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Evaluating Physical Climate Risk for Equity Funds with Quantitative Modelling

- How Exposed are Sustainable Funds?

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Abstract

Evaluating Physical Climate Risk for Equity Funds with Quantitative Modelling - How Exposed are Sustainable Funds?
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The climate system is undergoing rapid changes because of anthropogenic emissions of greenhouse gases. The effects from a warmer climate are already noticeable today with more frequent extreme weather events. These extreme weather events have financial consequences and pose risks to the financial system. This study evaluates such physical climate risks for the periods 2021-2025 and 2026-2030 by developing a quantitative model. Physical risks are here limited to heat waves, heavy precipitation events, drought and tropical cyclones. The model applies climate data from CMIP5 to evaluate hazard intensity at the location of a company. Vulnerability of the certain hazard is determined based on the sector. Physical risks from supply chain relations are also considered. The result is then aggregated on portfolio level. The model is applied to compare the exposure of physical climate risks on sustainable equity funds with the exposure on the general market and to determine what characteristics that contribute to low respectively high climate risks.

Generally, the total climate risk proves to be lower for the period 2021-2025 compared to 2026-2030 because of the natural variability in the climate system. Europe has the lowest climate risk, and the GICS-sector with the highest risk is Real Estate. No clear conclusion can be drawn in the comparison of physical risk exposure between sustainable funds and the market; however, the result indicates that sustainable funds select securities of lower risk within a specific investment universe. The average sustainable funds select equities with lower risk within regions, sectors and market cap sizes in almost all studied cases. Regional allocation proves to be important for the exposure to physical climate risks. This is also related to market cap size since larger companies are likely to have their assets distributed in several countries which contributes to diversification. On fund level, the strategy of carbon minimising is shown to have no significant impact on physical climate risks, neither positively nor negatively.

The awareness among investors on physical climate risks is currently low, and sustainability labels seems to offer no guarantee for minimising physical risk exposure. This study adds to the very small pool of studies on physical climate risks in investment management and provides a market wide overview. Hopefully, development of this research area can contribute to increase the awareness of investors and thereby drive capital towards a more resilient society.

Keywords: climate change, ESG, sustainable finance, sustainable investment.

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Referat

Utvärdering av fysiska klimatrisker för aktiefonder genom kvantitativ modellering - Hur utsatta är hållbara fonder?

Sofia Wiklund

Klimatet genomgår en snabb förändring på grund av antropogena utsläpp av växthusgaser. Effekterna av ett varmare klimat är redan kännbara idag med mer frekventa extremväderhändelser. De här extremväderhändelserna har finansiella konsekvenser och utgör en risk för det finansiella systemet. Den här studien utvärderar sådan fysisk klimatrisk för perioderna 2021-2025 och 2026-2030 genom att utveckla en kvantitativ modell. I begreppet fysiska klimatrisker innefattas här värmeböljor, kraftiga skyfall, torka och tropiska cykloner. Modellen använder sig av klimatdata från CMIP5 för att utvärdera intensiteten av naturfenomenet på den geografiska platsen för företagets tillgångar. Känslighet för naturfenomenet bestäms baserat på sektorn. Fysiska risker från värdekedjan inkluderas också. Resultatet är sedan aggregerat på portföljnivå. Modellen är applicerad för att jämföra fysiska klimatrisker för hållbarhetsfonder jämfört med den generella marknaden och för att bestämma vilka faktorer som bidrar till en hög respektive låg klimatrisk.

Generellt visades att den fysiska klimatrisken var lägre för perioden 2021-2025 jämfört med perioden 2026-2030 på grund av naturlig variabilitet i klimatsystemet. Europa hade den lägsta klimatrisken, och GICS-sektorn med högst risk var fastighetssektorn. Ingen tydlig slutsats kan dras i jämförelsen av klimatrisk för hållbarhetsfonder och marknaden, men resultatet indikerar att hållbarhetsfonder väljer aktier med lägre klimatrisk inom ett specifikt investeringsunivers. Den genomsnittliga hållbarhetsfonden väljer aktier med lägre risk inom regioner, sektorer och market-cap storlek i nästan alla studerade fall. Regional allokering visade sig vara en viktig faktor för exponering av klimatrisk. Det relaterar också till storlek av företaget eftersom större företag är mer troliga att ha tillgångarna fördelade i flera länder vilket bidrar till diversifiering. På fondnivå visades att strategin att minimera koldioxidintensitet inte påverkar klimatrisken signifikant, varken negativ eller positiv.

Medvetenheten om fysisk klimatrisk bland investerare är idag låg, och hållbarhetsmärkningar tycks inte innebära någon garanti för att minimera exponeringen till fysisk klimatrisk. Den här studien bidrar till den mycket lilla gruppen av studier inom fysisk klimatrisk i investeringar och erbjuder en överblick över hela marknaden. Förhoppningsvis kan utveckling av detta forskningsområde bidra till att öka medvetenheten hos investerare och därmed driva kapital mot ett mer resilient samhälle.

Nyckelord: ESG, hållbar finans, hållbar investering, klimatförändring.

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Preface

This study was conducted as a Master's thesis as part of the Master's Programme in Environmental and Water Engineering at Uppsala University and the Swedish University of Agricultural Sciences (SLU). The thesis supervisor was Professor Cecila Mark-Herbert at the Department of Forest Economics, SLU. The project was conducted at the Large Corporate and Financial Institution division of SEB. The thesis supervisor at SEB was Sofia Duvander.

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Populärvetenskaplig sammanfattning

Det råder stor osäkerhet om det framtida klimatet. Vart kommer världens insatser för att minska den globala uppvärmningen att leda? Kommer vi att nå målet om två graders uppvärmning? Något som dock är säkert är att oavsett dessa framtida insatser så kommer vi att se ett förändrat klimat som konsekvens av tidigare utsläpp av växthusgaser. Dessa förändringar kommer utgöra en risk för samhället och för det finansiella systemet. Extremväderhändelser kan orsaka kostsamma skador på infrastruktur och byggnader, en högre temperatur minskar effektiviteten av arbetskraft och förändrade nederbördsmönster påverkar inte minst skörden från jordbruk. Medvetenheten om sådana klimatrisker har varit och är fortfarande generellt sett låg hos finansiella aktörer. Det tongivande initiativet Task Force on Climate-related Financial Disclosures skrev år 2017 att klimatrisker är bland de ”mest betydande, men kanske mest missförstådda risker som organisationer står inför idag” (TCFD 2017, p. ii). Lagstiftning för att synliggöra klimatrisker börjar nu dock att komma ikapp, både inom EU och utanför. För investerare finns idag endast mycket vag vägledning för hur de ska hantera och minimera klimatrisker. Många investerare förlitar sig på samma indikatorer som i andra hållbarhetsfrågor - hållbarhetsmärkningar eller ett lågt koldioxidavtryck. Mycket lite forskning har gjorts på hur klimatrisk förhåller sig på marknaden där investerare navigerar.

Denna studie tar ett brett grepp på klimatrisker, genom kvantitativ modellering ges en översiktlig bild av hela marknaden för aktiefonder. Mer specifikt gäller studien fysiska klimatrisker, alltså klimatrisker som orsakas av de direkta fysiska förändringarna av klimatet, till exempel skada från extremväderhändelser. Fokus ligger på hållbara aktiefonder och att jämföra den fysiska klimatrisken för dessa fonder jämfört med den generella marknaden. De fyra klimatrisker som undersöktes var värmeböljor, kraftiga skyfall, torka och tropiska cykloner. Alla dessa väderhändelser förväntas öka i antingen frekvens eller intensitet i ett varmare klimat och deras påverkan är viktig ur ett globalt perspektiv.

Fysisk klimatrisk modellerades för varje innehav i en aktieportfölj som en produkt av två faktorer: intensiteten av väderhändelsen och känsligheten för den specifika händelsen. Intensiteten av väderhändelsen modellerades på den geografiska plats som företaget har sina tillgångar och beräknas som en skillnad jämfört med idag. Om värmeböljor kommer öka signifikant jämfört med idag klassades det som en hög intensitet av väderhändelsen. Känsligheten för den specifika händelsen beror av den sektor som företaget opererar inom. Hur känslig är sektorn för mer frekventa värmeböljor? Detta gjordes för vardera av de fyra valda väderhändelserna. I en allt mer globaliserad värld är det också viktigt att ta hänsyn till företags leverantörskedjor - om leverantörerna inte kan leverera påverkar det också företaget. Detta inkluderades därför också i modellen. Den fysiska klimatrisken modellerades för två perioder, 2021-2025 och 2026-2030.

Resultatet visade att klimatrisken var högst inom fastighetssektorn medan hälsa- sjukvård hade lägst risk. Den regionala fördelningen av risk visade att Europa hade lägst risk i båda studerade perioder, bland regionerna med högst risk var resultatet olika för de två perioderna. Nordamerika hade högst risk 2021-2025 medan Oceanien hade högst risk 2026-2030. Att resultatet skilde sig mellan de två perioderna beror troligen på att sammansättningen av risk varierar mellan de två olika perioderna. Under 2021-2025 dominerar risk från tropiska cykloner medan värmeböljor dominerar 2026-2030. Generellt är också risken lägre i den senare perioden 2026-2030 jämfört med 2021-2025. Detta kan tyckas vara kontraintuitivt, men kan förklaras med den naturliga variabilitet som finns i klimatsystemet. Fem år är en mycket kort period i klimatmått. Jämförelse med tidigare studier är svårt att göra, exempelvis bidrar troligen det kortare tidsperspektivet i denna studie till att skillnaden i risk mellan sektorer och regioner är mindre än i tidigare studier. Inkludering av risker från leverantörskedjan gör också att sektorer och regioner med lägst risk får högre risk, och vice versa. Vissa gemensamma trender kan dock urskiljas, till exempel att Europa generellt har låg risk.

Gällande jämförelsen av hållbara aktiefonder med den generella marknaden studerades tre grupper av fonder som klassificerats som hållbara enligt olika graderingar eller certifieringar på marknaden. Inga tydliga slutsatser kan dras gällande hur hållbara fonder förhåller sig till marknaden i fysisk risk, vilket i sig är ett viktigt resultat - att förlita sig på hållbarhetsmärkningar för att minimera fysisk risk som investerare är ingen säker metod. Det tycks dock som att hållbara fonder väljer företag med lägre risk inom ett givet universum, till exempel en region. Studien visar också att metoden att minimera koldioxidavtrycket hos fonden inte påverkar den fysiska klimatrisken, varken positivt eller negativt. Inte heller koldioxidavtryck är alltså en bra indikator för fysisk klimatrisk, men det är möjligt att konstruera en portfölj med både låg fysisk klimatrisk och lågt koldioxidavtryck. Valet av vilka regioner investeringen ska göras i är viktigt för fondens exponering för fysisk klimatrisk. Storleken av företagen är också viktigt, generellt skulle hållbarhetsfonderna gynnas ur ett klimatriskperspektiv av att välja större bolag. Detta kan bero på att stora företag ofta har tillgångar i flera länder och därmed sprider risken medan mindre företag snarare har alla ägg i samma korg - eller land.

Denna studie bidrar till en mycket liten grupp av kvantitativa modelleringsstudier av fysisk klimatrisk för investerare. Utveckling av det området kan akademiskt hjälpa forskare att hitta storskaliga mönster att studera djupare och operationellt hjälpa investerare att systematiskt undersöka ett större investeringsuniversum för att minska exponeringen för klimatrisk. Att hantera klimatrisk vid konstruktion av en portfölj kommer sannolikt bli allt viktigare, huruvida investerare lyckas med det eller inte kommer att speglas i den sista raden i resultaträkningen. Att investerare tar informerade beslut gällande klimatrisker är viktigt för samhällets förmåga att hantera klimatförändringarna då de styr det privata kapitalet. Om de investerar i företag som är motståndskraftiga kommer dessa företag gynnas och kan växa. Slutligen ska dock sägas att smarta placeringar endast lindrar symptomen av fysisk klimatrisk. För att på lång sikt minska den fysiska klimatrisken krävs aktiva åtgärder för att vi ska nå det där målet om maximalt två graders uppvärmning.

Table of Content

List of Figures

List of Abbreviations

ACWI	All Countries World Index
CAPEX	Capital expenditures
CRED	Centre for Research on the Epidemiology of Disasters
DICE	Dynamic Integrated Climate-Economy
ENSO	El Niño, La Niña and the Southern Oscillation
ESG	Environmental, social and governance
Eurosif	The European Sustainable Investment Forum
FUND	The Climate Framework for Uncertainty, Negotation and Distribution
GICS	Global Industry Classification Standard
IAM	Integrated assessment model
IFC	International Finance Corporation
IPCC	Intergovermental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
NAICS	North Atlantic Classification System
NOA	North Atlantic Oscillation
PAGE	Policy Analysis of the Greenhouse Effect
PRI	Principles for Responsible Investment
RCP	Representative Concentration Pathways
SRI	Socially responsible investment
SST	Sea surface temperature
TCFD	Task Force on Climate-related Financial Disclosures
TEG	Technical expert group
UNISDR	United Nations Office for Disaster Risk Reduction
WITCH	World Induced Technical Change Hybrid Model

List of Key Concepts

Attribution	An analysis tool, commonly applied to explain how excess performance was achieved for a portfolio compared to benchmark, but in this study applied to explain where physical risk stems from. Brinson Fachler attribution breaks down the difference between the portfolio and the benchmark into an asset allocation effect and a security selection effect.
Benchmark	An index selected by the fund manager to compare the fund's performance against.
Bottom-up	Fundamental analysis with focus on individual companies rather than macroeconomics.
CAPEX	Expenditures by a company to buy or maintain physical assets such as equipment, buildings or technology.
Clausius-Clapeyron equation	An equation in thermodynamics that describes the relation between pressure and temperature in a phase transition.
Climate risk	Risks stemming from adverse impact from climate change, including physical risks and transition risks.
Credit risk	The risk that a loan will not be returned.
Drought	A period of precipitation deficit and warm temperatures.
ENSO	Cycles of ocean-atmosphere interaction in the Pacific Ocean with warming and cooling periods that impact the climate globally. The cycles are approximately five years.
Equity	The ownership of a part of a company's business.
Equity portfolio	A pool of money that is invested primarily in equities.
Equity risk	The risk that the outcome will be lower than expected when investing into equities.
EU Taxonomy	A new regulation in the EU that will define what is sustainable in finance. The definition builds on the environmental objectives of EU, where climate mitigation and climate adaptation have been prioritised for the two first Taxonomies.
Heat wave	A period of higher temperatures than normally, measured relatively to the local meteorology.

Heavy precipitation	An intense precipitation event that for example can lead to flood or large run-off.
IAM	Integrated assessment models are cross-disciplinary models that link phenomenon in the biosphere and atmosphere with the economy.
Index	A basket of equities with weights that aims to replicate a piece of the market.
Investment universe	A set of equities that the investment manager can invest into.
Market cap or market capitalization	The total value of all the equities a company has on the market. Companies are commonly classified into large cap, mid cap and small cap. The exact definitions of these groups vary; however, here large cap represents companies with a market cap value above 10 billion USD and small cap represents companies with a market cap value below 2 billion USD. Mid cap are companies with a market cap value between 2 and 10 billion USD.
Physical climate risks	Climate risks related to the physical transformation of the climate such as extreme weather.
Sustainable fund	Currently, no common definition exists of what a sustainable fund is. Instead, there are several operational definitions. In this study the operational definitions of Morningstar, YourSRI (Lipper's classification) and Nordic Swan Ecolabel are applied.
Tipping point	A point where a small change leads to large, non-linear consequences for the climate system.
Transition climate risks	Climate risks related to the transition to a low-carbon society, including market risks, technology risks and regulatory risks.
Top-down	Analysis that focuses on the big-picture, such as macroeconomic trends and industry trends and apply them on individual companies.
Tropical cyclone	A low pressure area with circulating air mass, it is often associated with storm systems. Typhoons and hurricanes are other names for the same phenomenon.

1 Introduction

Human influence causes warming of the climate system. The average land and ocean surface temperature has increased by 0.85 degrees between 1880 and 2012 (IPCC 2014, p. 40). In recent decades, the impact from this warming has been observed on natural systems. The current rate of sea level rise is higher than in the previous two millennia. In some locations heavy precipitation events has increased, while there are signs of increased drought events in other locations (*ibid.*). Climate change leads to changes in intensity and frequency of extreme weather events (Seneviratne *et al.* 2012). Recent extreme weather events reveal significant vulnerability on many human systems to climate variability - food systems are disrupted, infrastructure is damaged and human well-being is affected (IPCC 2014). Extreme weather and climate change also pose risk on the financial market (TCFD 2017). The total economic losses from weather and climate extremes in member countries of the European Economic Area amounted to EUR 453 billion between 1980 and 2017 (EEA 2017, p. 12).

The awareness of climate risks in the financial sector has in general been limited and climate risks are currently not always taken sufficiently into account (The European Commission 2018). The Task Force on Climate-related Financial Disclosures (**TCFD**) states that risks related to climate change are among the "most significant, and perhaps most misunderstood" risks that organisations face today (TCFD 2017, p. ii). However, the high-level attention towards climate risks has recently increased. In the Global Risk Report of 2020, published by World Economic Forum (2020), all the top five risks in terms of likelihood are related to environmental aspects such as *Extreme weather* and *Climate action failure*. The European Union (**EU**) identifies the transition towards a low-carbon economy as necessary to safeguard long term competitiveness of the economy (The European Commission 2018).

Regulations are now also catching up to put requirements on financial actors to take climate risks into consideration in investment decisions and financial advisory. In 2018 EU launched an action plan on sustainable finance for integration of sustainability considerations into the financial policy framework. One of the key action was the incorporation of climate risks into financial decision-making (*ibid.*). From 2020, all signatories of Principles for Responsible Investment (**PRI**) must report climate risks according to the TCFD framework (PRI 2019). Disclosure of climate risks according to the TCFD framework was also a prerequisite for Canadian companies in order to receive monetary support from the government in the Covid-19 crisis (Department of Finance Canada 2020).

These changes of the landscape of sustainable finance are not happening in isolation. As part of the EU action plan on sustainable finance, a common taxonomy on what is sustainability in finance will also be introduced in the EU (TEG 2019). This will, at least within the EU, replace a scattered view on sustainability and is likely to lead to significant market changes where investors will need to rethink their strategies in building sustainable equity funds (*ibid.*). The taxonomy also introduces specific criteria for economic activities to significantly contribute to climate adaptation (TEG 2020). Meanwhile on the market side, the demand for sustainable products is increasing and exceeding the current supply in Europe (Eurosif 2018).

1.1 Problem Formulation

There is a growing body of research within sustainable finance. The main focus of the research has been on financial performance of sustainable products compared to non-sustainable products. Less focus has been given to climate risks (Ferreira *et al.* 2016; Groot *et al.* 2015), with a particular gap for physical climate risks in investing (Bender *et al.* 2019; Fang *et al.* 2018). Financial physical climate risks are here defined accordingly to TCFDs definition as "*risks related to the physical impacts of climate change*" (TCFD 2017, p. 5). Taking into consideration physical aspects of climate risks requires knowledge also in natural sciences, and these fully inter-disciplinary works are lacking (Linnenluecke *et al.* 2013). The increased focus on climate risks proven from financial participants in the Global Risk Report (World Economic Forum 2020) as well as from the regulatory side (PRI 2019; The European Commission 2018) in combination with the increasingly urgent evidence of a changing climate (IPCC 2014) indeed calls for more research in this area.

On the operational side, investor's methods for managing physical climate risks are currently very rudimentary (Clapp *et al.* 2017). A survey on CICERO Climate Finance Advisory Board, including many representatives from fund management, reveals that the investors often rely only on carbon intensity data from companies for assessing climate risks on portfolio level. Company data on physical risks is largely lacking. Carbon intensity does not provide information on how well the company is able to adapt to climate change (*ibid.*). Ralite *et al.* (2019) state that climate risks are not well compatible with traditional stress tests as traditional stress tests are non-sector specific and have a shorter time horizon than required for assessing climate risks (*ibid.*).

Another investment approach for managing climate risks is to target investments labelled as sustainable (Clapp *et al.* 2017). Among the many different sustainable investment strategies, incorporation of sustainability issues in investment decision is the fastest growing strategy in Europe (Eurosif 2018). It could be so that physical climate risks are included in these incorporated sustainability issues, but it is unclear how sustainable products on a larger scale relate to climate risks. In credit risk, where environmental issues has been included for much longer than in equity risk (Bender *et al.* 2019; Weber *et al.* 2008), research has shown that organisations with good environmental sustainability performance have lower credit risk (Höck *et al.* 2020; Weber *et al.* 2015). This has however not been related to better management of physical climate risks but rather to reputational risks and regulatory risks (Höck *et al.* 2020). The few studies conducted in the area of physical equity risk mainly cover climate risks on aggregated sectoral or regional level (among other: Clapp *et al.* 2017; Mercer 2015; Ralite *et al.* 2019; UNEP Finance Initiative 2019) rather than on portfolio level.

To gain a better understanding of the growing market of sustainable products, a structured analyze on physical climate risk exposure on sustainable equity funds compared to the general market is needed. From an operational perspective, this can guide investors in how to decrease exposure for physical climate equity risk and from an academic perspective this adds to an area where only little research has been performed. The study is conducted at the Skandinaviska Enskilda Banken AB (**SEB**).

1.2 Aim and Research Questions

The aim of this study is to quantitatively evaluate the physical climate risks of sustainable equity funds in comparison to the general market on a large scale. The research questions of the study are as follows:

- How does the physical climate risk exposure of sustainable equity funds compare to the physical climate risk exposure of the general market?
- What factors contribute to differences in climate risk exposure of funds?

1.3 Delimitations

Sustainable finance is an interdisciplinary research area (Linnenluecke *et al.* 2016), which should also be reflected in this study. Nevertheless, this study has its foundation in an environmental engineering perspective and hence leaves out the economic analysis on how companies' financial result and risk affects stock prices. No analysis or discounting for stocks is made, the results are presented on an ordinal scale instead of monetary quantification.

Climate related financial risks are commonly divided into two main categories, transition risks and physical risks (TCFD 2017). This study covers the physical risks that relate to the extreme weather events and new climatic conditions. Risks such as changed market preferences or regulatory risks are not considered. For some businesses climate change can bring opportunities of business significance (CDP 2019), such opportunities are however also outside the scope of this study. Any positive impact is simply treated as zero impact. Physical climate risk is a broad term spanning over all potential changes in the natural system that may affect the financial system (TCFD 2017). To limit the scope of this study, four natural hazards are selected as focus areas: heat waves, heavy precipitation events, droughts and tropical cyclones. See section 2.5 for a motivation of the selection.

This study takes a top-down approach where climate risks of portfolios are modelled based on quantitative data. The geographical scope is global and the coverage of the model includes all listed equities to provide a broad overview of the full market. However, this also comes with limitations in the level of detail that can be achieved. The model is not applicable for specific companies or for very local circumstances, but aims to give an estimate of risks on an aggregated portfolio level.

1.4 Outline

Chapter 2 introduces the theoretical background behind this study, basic financial theory, sustainable finance with climate risks and climate models. As this study targets readers from two separate research fields, finance and climate research, the reader may already be familiar with some of these topics. Chapter 2 also outlines the conceptual framework of this study. Chapter 3 provides the empirical background to the study, including previous studies. In chapter 4 the modelling methodology and framework for analysis are described. Chapter 5 presents the results of the study, first some general results and thereafter the results on comparisons of sustainable funds and certain characteristics. In chapter 6 the method is discussed, including the key assumptions and alternative model designs. Thereafter follows discussion of the relevance and interpretation of results. Finally, chapter 7 provides the conclusion of the study together with recommendations for further studies.

2 Theory

This chapter first gives an introduction to basic financial terms for the reader that is not familiar with finance. Thereafter follows a description of the area of sustainable finance, with specific focus on climate risks. Climate models are also introduced with their strengths and weaknesses. Finally, it is described how the theory presented in this section is assimilated and applied for the purpose of this study in the conceptual framework.

2.1 Equity Funds

Equities and stocks are the ownership of a part of a company's business (Kumar 2014). When investors buy equities from a company, this gives them the right to a share of a company's assets. The investors have, in the case of liquidation of the company, residual claim on the company's assets. Listed equities are traded on the stock exchange. This is a platform for sellers and buyers. Equities play an important role for the growth of companies. Issuing equities gives funding of investments in the expansion of the company. The investors of common stocks are paid dividends regularly. The ownership of common stocks also gives voting rights in the election of the directors (*ibid.*).

A mutual equity fund, or stock fund, can be defined as a pool of money that is invested primarily in stocks (Sekhar 2017). The manager of the fund buys and sells equities from the money collected from the investors of the fund. The investors receive returns from the dividend on the investments. In turn, the fund manager earns a fee from the investors (*ibid.*).

In principle, there are two main types of equity funds: passive funds and active funds (Sekhar 2017). Passive funds follow a market index. An index is a basket of securities with weights that aim to replicate a piece of the market. For example, the Standard & Poor's 500 (S&P 500) is an index of 500 large companies traded in the US and is used as a proxy for the US stock market. The holdings and the weights of an index fund must have the same proportion as index. Active funds have more freedom in their investment decisions, but they must follow the stated objective of the fund. This is the objective that the investors have agreed to when investing in the fund. For example, there are funds that only invest in specific sectors or regions. To measure performance, active equity funds are often compared to a certain benchmark selected by the fund manager as a standard. Since active funds often have a higher fee than passive index funds they must outperform the benchmark or the market to present a rational option for investors (*ibid.*).

2.2 Financial Risk

A central concept in finance is risk. Different situations bring different types of risks. For example, credit risk is the risk when lending assets that the loan will not be returned (Hull 2006). Investment risk is the risk when investing into assets that the outcome or return will be lower than expected (Brealey *et al.* 1996). Investment risk of equity funds is the focus of this study. The volatility in prices of investments is commonly measured as the standard deviation from the expected return. In general, the higher risk the investor is exposed to, the higher is the potential return. The compensation for the risk exposure compared to a risk-free asset is referred to as the risk premium. Risk is therefore connected to the value of stocks and companies. Companies that manage to reduce their risk and provide stable growth are likely to enhance their market value (Olson *et al.* 2010). Risk-free assets are in theory deterministic with a standard deviation of 0 (Luenberger 1998). In practice, US Treasuries are among the investments that are the closest to be risk free assets (Brealey *et al.* 1996).

Financial risk is typically divided into two broad categories, systematic risk and unsystematic risk. The systematic risk affects an entire economic market. This causes an unison movement of all stocks on the market, either up or down (Hull 2006). Unsystematic risk is specific for the company or the stock and uncorrelated with the market. In contrast to systematic risks, unsystematic risks can be reduced by a diversification (Luenberger 1998). Unsystematic risks can derive from the inherent external environment of the company such as the industry of business or the internal environment with internal operational processes and resources (Olson *et al.* 2010). The risk when investing into equities can be further broken down into more granular categories. One categorisation of risk according to Investopedia (Chen 2020) groups risk into five main categories: business risk, country risk, financial risk, liquidity risk and exchange-rate risk. See Figure 1. Please note that also other categorisations and groupings of risk exist, for example Baker *et al.* (2015) that differentiates also for example governmental risk and behavioral risks.

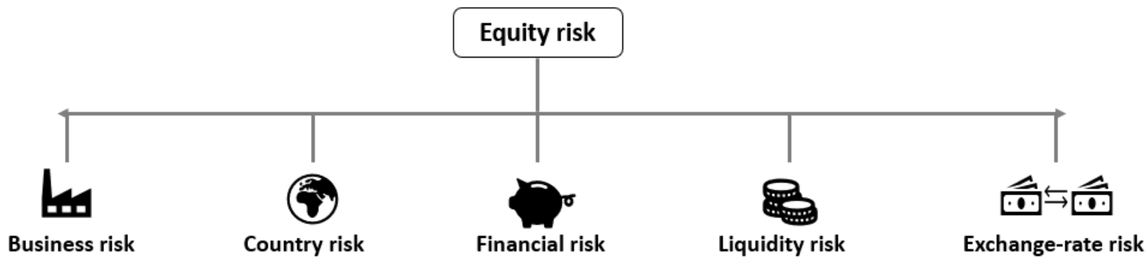

Figure 1: *The components of equity risk according to a classification by Investopedia (Chen 2020)*

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In the definition of Investopedia (Chen 2020), illustrated in Figure 1, business risk is associated with the company's operations and the inherent environment where it operates, for example sector specific characteristics. Country risk is specific for the region or country, this could for example include political risks. Financial risk is related to the company's capacity to finance its operations and pay its debts. Liquidity risk is the uncertainty when selling an asset, stocks with high liquidity can be sold easily while stocks with low liquidity can be costly or time-consuming to sell. Finally, exchange rate risk is the risk when investing in assets denominated in other currencies (*ibid.*).

For fund managers, maintaining risk on a certain level is an important part of achieving the fund objective. Common risk control measures applied on fund level are (Sekhar 2017):

- The investment objectives and restrictions
- Asset allocation
- Investment limits
- Positioning
- Benchmark index

The fund manager regularly monitors these control measures (Sekhar 2017). It is important for the fund to always follow the fund objective, it is a responsibility towards the investors. A common indicator for financial performance of a portfolio is tracking error. Tracking error is the standard deviation of the difference between the return on investment for the fund compared to benchmark. Deviations from the benchmark implies a risk for lower return than benchmark. Many active funds keep a low tracking error, that is follow the benchmark closely to minimize this risk (*ibid.*).

2.3 Sustainable Finance

In general terms, sustainable finance is the process of incorporating environmental, social and governance (**ESG**) considerations into investment decisions (Eurosif 2018; The European Commission 2018). Environmental considerations refer to mitigation of negative environmental impacts, adaptation to environmental changes and management of environmental risks. Social considerations refer to issues such as labour conditions, inequality, community and inclusiveness. Social and environmental aspects are often interconnected (The European Commission 2018). Sustainable finance has an important role to play in the strive towards a more sustainable society. Reorientation of capital can stimulate sustainable initiatives, while holding non-sustainable initiatives back (*ibid.*). Furthermore, investment and financing are directly present in decision making on projects and activities that promote the environment (Ferreira *et al.* 2016). The demand for sustainable products is growing on the financial market. Currently, the demand of sustainable products on the European market exceeds the supply (Eurosif 2018).

2.3.1 Sustainable Funds

No broadly accepted definition on what sustainable finance is exists today. This poses a challenge for investors to set up goals and choose sustainable investments (Eurosif 2018). In 2016, the board of The European Sustainable Investment Forum (**Eurosif**) reached consensus on how to define Socially Responsible Investment (**SRI**), which can represent the European common view:

> *Sustainable and responsible investment ("SRI") is a long term oriented investment approach which integrates ESG [Environmental, Social and Governance] factors in the research, analysis and selection process of securities within an investment portfolio. It combines fundamental analysis and engagement with an evaluation of ESG factors in order to better capture long term returns for investors, and to benefit society by influencing the behaviour of companies* (Eurosif 2018, p. 12).

The lack of a shared understanding of what sustainable investments is was one of the drivers for the EU Action Plan for Sustainable Finance. One of the pillars of the action plan is to provide clarity in this issue (The European Commission 2018). In March 2020 the final proposal for a common language - a Taxonomy - for sustainable activities was launched (TEG 2020). The Taxonomy contains a list of activities and corresponding thresholds for when these are regarded sustainable. The first Taxonomy covers EU environmental objectives for climate mitigation and climate adaptation, but also Taxonomies for the remaining environmental objectives are to be launched. Specifically, the Taxonomy for climate adaptation has specific criteria for what economic activities that significantly contribute to the adaptation to a changed climate (*ibid.*).

Sustainable equity funds should not be mixed up with non-commercial funds. Sustainable equity funds are expected to bring returns, and ESG integration and positive returns should go hand in hand (Eurosif 2018; PRI 2016). In the mission statement of PRI, they state that they believe that sustainability is necessary for long term value creation (PRI 2016). There is a broad range of sustainable investment strategies on the market today. These can be divided into seven categories, see Table 1.

Table 1: Sustainable investment strategies (Eurosif 2018; Scholtens 2014)

Strategy	Description
Exclusion	Exclusion of holdings (companies, sectors, countries) from the investment universe based on ESG criteria
Norm-based screening	Screening of investments according to international norms (UN Global Compact, OECD Guidelines for Multinational Enterprises, ILO Core Conventions etc.)
Engagement and voting on sustainability matters	Active ownership of stock holders and engagement to impact companies to improve in ESG aspects
Best-in-class investing selection	Investing in leading performance companies within their class based on ESG critera
Impact investing	Investing in companies with the intention to generate ESG impact, besides financial return
Sustainability themed investment	Selecting investments based on sustainability linked themes
Integration of ESG factors in financial analysis	Inclusion of ESG risk and opportunities into financial analysis

About half of the managed assets in the EU apply at least one of these strategies. Historically, sustainable investments have predominantly applied exclusion (Scholtens 2014). Exclusion is still the dominant strategy, but also other strategies involving pro-active positive screening and involvement are growing. According to questionnaire responses from 293 European SRI market participants (asset managers, banks and asset owners), integration of ESG factors in financial analysis is the fastest growing strategy. Integration of ESG factors in investment decisions can include, but is not limited to, consideration of climate risks. Exclusion is decreasing as a strategy, although still dominating. Common exclusion criteria are weapons, tobacco and gambling. Impact investment, Best-in-class investment and Sustainability themed investment remains small, but are growing strategies (Eurosif 2018).

Despite the lack of a theoretical definition of sustainability in finance, there are many operational definitions of sustainability. Many labels and certification schemes evaluate the sustainability of equity funds based on different criteria and priorities. Some example of providers of sustainability ratings are Morningstar, MSCI, Sustainalytic, BloombergESG, RobescoSAM and Nordic Swan Ecolabel. A study by Kumar *et al.* (2019) showed that the correlation between some of the main sustainability ratings on the market was poor. In pair-wise correlation tests between the ESG scores of MSCI, Sustainalytics, BloomberESG and RobescoSAM the correlation ranged between 0.46 and 0.76 (p. 2). There is also a challenge with transparency of the methodology applied for the different ratings (*ibid.*).

2.3.2 Climate Related Risk in Finance

Climate risks are commonly divided into two main categories, transitional risks and physical risks. Transitional risks include policy risk from changed regulations and litigation claims, technology risks from new innovations disrupting existing systems, market risks with changes in demand and supply and reputational risks. The focus of this study in only on physical risks. Physical risks include event driven and long term shifts in climate patterns that impact organisations financially (TCFD 2017). Incremental climate change can affect organisations' financial performance both from the cost- and revenue side. Costs can increase in operating costs (eg. higher price on water for cooling power plants), in capital costs (eg. damage to facilities), higher prices on raw material, increased insurance premiums, write-offs and early retirement of assets and negative impact on workforce. Revenue can decrease from lower productivity and lower sales (Clapp *et al.* 2017; TCFD 2017). Acute changes and extreme events can lead to damage of property value, lost production for fixed assets, operational downtime and risk to employee safety (Connell *et al.* 2018; TCFD 2017). Through global supply chains and multinational companies also companies not located in an affected area can be damaged through disrupted deliveries or sales (Clapp *et al.* 2017). See Figure 2 for a systematic overview on how physical risks impact financial risks. Adaptation to climate change can also present opportunities for early movers. Developing risk-resilient technologies can give advantages in competition (Clapp *et al.* 2017; TCFD 2017).

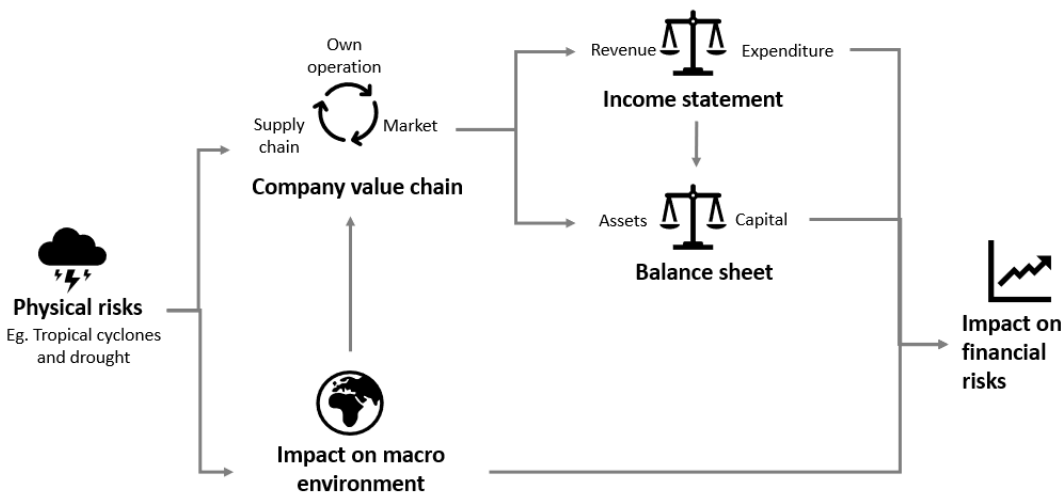


Figure 2: *A systematic view on how physical climate risks impact financial risk. Based on Ralite et al. (2019), p. 19.*

The attention to climate risks and environmental risks has increased in recent years. In the Global Risk Report 2020 all the top five risks in terms of likelihood, and three of five top risks in terms of impact, were related to environmental aspects. The Global Risk Report is an annual study published by World Economic Forum and reflects a multi-stakeholder view of risk. Sources include experts and major insurance companies. When studying the progress of listed risks the last ten years, there is a clear trend towards more and more focus on environmental risks. The report of 2020 was the first ever where all the top five risk came from the same risk category (*Environment*) (World Economic Forum 2020).

In June 2017 TCFD released its "Recommendations of the Task Force on Climate-related Financial Disclosures" to develop voluntary and consistent financial disclosures that allow investors to assess climate risks. TCFD developed four main recommendations for financial reporting on climate related aspects (TCFD 2017). The four recommendations relate to disclosure of governance, strategy, risk and targets for climate risks. When describing the potential impact of climate risks on the business strategy, it is recommended to apply a scenario-based approach (*ibid.*). These recommendations have been adopted by many organisations (PwC n.d.). From 2020 and onwards all PRI signatories must report their climate risks according to TCFD's recommendations (PRI 2019). The recommendations apply across sectors, but the financial sector is mentioned as particularly important (TCFD 2017).

In EU's action plan for sustainable finance, one of the key objectives was the incorporation of climate risks into financial decision-making (The European Commission 2018). One of the main tools for achieving this is Regulation (EU) 2019/2088 on sustainability-related disclosures in the financial services sector that entered into force in 2020, and that will be applied in 2021. Article 6 states the following:

> *Financial market participants shall include descriptions of the following in pre-contractual disclosures (a) the manner in which sustainability risks are integrated into their investment decisions; and (b) the results of the assessment of the likely impacts of sustainability risks on the returns of the financial products they make available.*

2.4 Climate Models

Climate models are fundamental research tools for understanding past and future climate (Rummukainen 2010). In its simplest form, a climate model is derived from physical laws which are subjected to physical approximations for the large scale climate system, and further approximated with mathematical discretisation. Computational power constraints the resolution that is possible in discretisation of equations in climate models (IPCC 2007). Global climate models have a high resolution for simulating phenomena on the level of the general atmospheric circulation or sub-continental precipitation patterns. The real resolution is of the order of 1,000 km (Feser *et al.* 2011, p. 83). With a coarse grid resolution extremes may be averaged out since the grid represent a larger area. Certain local phenomenon may therefore not be registered (Feser *et al.* 2011; Rummukainen 2010).

The starting point for numerical models, the initial conditions, are based on observed values. Uncertainty in the choice of initial conditions is most relevant for short term predictions. In general, the climate system is highly complex and a model cannot include all processes. Many models exist, with different parametrisations and choices of what to describe and what to neglect. The uncertainty that stems from model choices is structural. To reduce such uncertainty, an ensemble of models is often applied. Multi-model ensembles are sets of model simulations from models with different structures (Tebaldi *et al.* 2007). Generally, multi-model ensembles are found to better forecast climate (Rozante *et al.* 2014; Tebaldi *et al.* 2007). Some characteristics of the climate are however still hard to reflect in climate models.

One such characteristic is tipping points. Tipping points are critical thresholds where the climate shifts abruptly from one stable state to another stable state. The change may be irreversible. The risk for tipping points is moderate in a warming of 0-1° but steeply increases under further warming (IPCC 2014).

To predict future climate, the Intergovernmental Panel on Climate Change (**IPCC**) uses the Representative Concentration Pathways (**RCP**) as a standard, see Figure 3. The RCPs describe four scenarios for atmospheric greenhouse gas concentrations in the 21st century (IPCC 2014) . The scenarios represents, and are labelled after, a radiative forcing of 2.6 W/m^2 to 8.5 W/m^2 in 2100 (Vuuren *et al.* 2011).

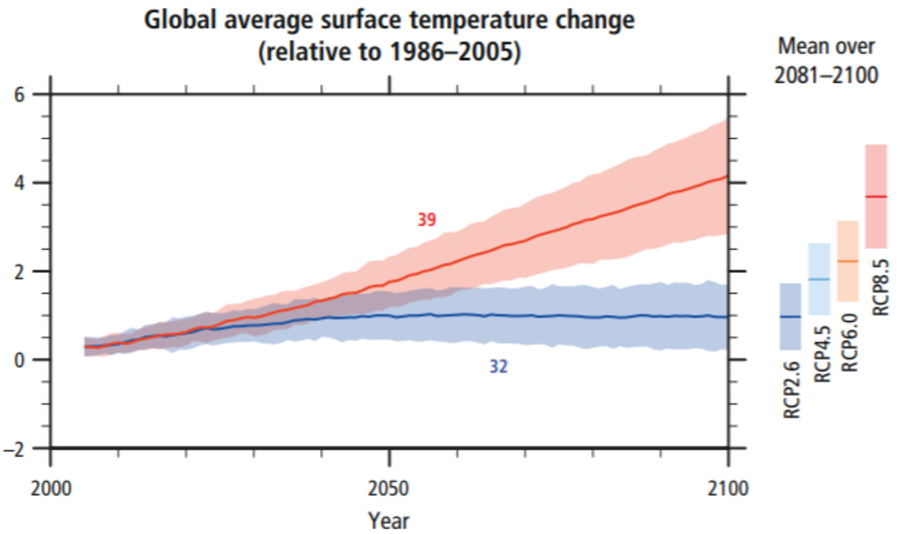


Figure 3: *Illustration of IPCC's Representative Concentration Pathways and the corresponding average surface temperature change (IPCC 2014, figure SPM.6 p. 11).*

RCP2.6 in Figure 3 is a mitigation scenario that likely keeps the global warming below 2°C compared to pre-industrial levels. For RCP6.0 and RCP8.5 is the warming likely to exceed 2°C, and for RCP4.5 the warming is more likely than not to exceed 2°C (IPCC 2014, p. 10). Business as usual leads to pathways between RCP6.0 and RCP8.5 (*ibid.*).

2.5 Conceptual Framework

Physical climate risk is a relatively new concept in investment finance. The traditional financial risk analysis does not explicitly include climate risks, see Figure 1. However, the assumption of this study is that physical climate risks can be incorporated into this more traditional financial framework. For example, the changes of hazard probability in a warmer climate can be incorporated under country risks as they are region specific. The framework by Ralite *et al.* (2019) in Figure 2 further shows touch-points of climate risks onto the financial system. These two frameworks, the more traditional view on equity risk and the illustration of impact from physical climate risks, are joined together for the purpose of this interdisciplinary study. Because of the focus on equity funds in this study, the risk control measures on fund level according to (Sekhar 2017) are also added as a second level of factors that impact risk. Together this makes the conceptual framework of this study, see Figure 4. The fund manager selects from equities that all have their specific underlying risk. The selection is made within investment restrictions, for example a specific region. The selection of equities can be affected by ESG considerations.

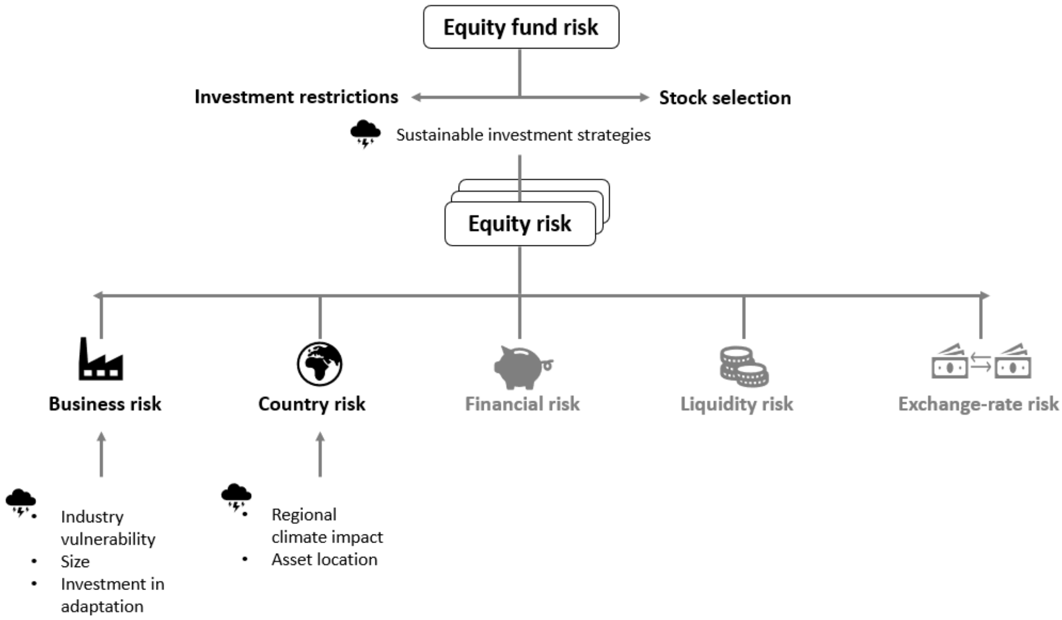


Figure 4: *The conceptual framework of this study merges a traditional financial view on equity risk with a view on how physical risks impact financial risk. Because of the focus of this study on mutual equity funds, a second level for factors that impact risk on fund level is also added.*

The thundercloud in Figure 4 marks factors that are hypothesized to have first and second order impact on physical risks, in other words the risk of damage to the company's own operations or the operations of the supply chain. Effects beyond second order are not included in the analysis of this study and are therefore marked with grey in 4. Effects beyond second order could for example be the effect from natural hazards on political decisions, the market or behaviour. Such effects are rather part of transition climate risks (TCFD 2017) and therefore left outside the scope of this study.

The scope of this study is global and the factors impacting physical risks are therefore selected because of their global relevance. Similarly, the limitation of natural hazards to heat waves, heavy precipitation events, drought and tropical cyclones was also made because of their global relevance on a 5-10 year horizon. According to a survey of almost 7,000 global companies the three most commonly identified physical risks were extreme weather events, changes to precipitation patterns and rising temperature (CDP 2019). Data for natural disasters 1998-2017 from CRED and UNISDR (2018) show that the selected natural hazards were among the top six most frequent hazards and the top six hazards with largest economic losses. The selected natural hazards also corresponds well to previous studies on physical climate risks (see section 3.3). The study acknowledges that locally or in specific sectors the selected natural hazards or studied factors may not be the most relevant. For example in agriculture in the Nordic countries, ice injury can cause significant economic damages in a warmer climate (Ericson 2018).

Other potential physical risks are left out of the scope. Outside scope are "unknown-unknowns" that may be of equal importance as selected risks, but because of current lacking knowledge are not included. Potential tipping points are not regarded. The relatively short time horizon also leaves the majority of the future climate risks outside the scope, particularly if the level of greenhouse gases continue to increase the risk will only to grow bigger beyond the 5-10 year horizon studied here (IPCC 2014). Similar to unknown climate risks, there may also be technological development for climate adaptation that is unknown of today. This is also outside the scope of this study.

3 Background Empirics

This chapter gives an empirical background to this study. First the selected natural hazards are introduced with their driving forces and expected changes in a warmer climate. Thereafter, previous studies in the area of physical climate risks are presented.

3.1 Climate Change - Natural Variability and Anthropogenic Impact

The climate is constantly changing (Hartmann 2016), both driven by natural and anthropogenic factors. The natural drivers of the climate cause significant variation over the timescales. In timescales of tens of thousands of years and hundreds of thousands year, the axial tilt, obliquity, of the Earth and the eccentricity of the Earth's rotation around the sun impact the climate on Earth. This variability is responsible for ice-ages. In the timescale of a hundred years, cycles in the solar luminosity impacts the climate. The activity of sunspots varies which gives colder periods when the sunspots are frequent and warmer periods when less frequent. In the timescale of years, volcanic eruptions and ocean-atmosphere interactions impact the climate. Volcanic eruptions inject aerosols to the atmosphere that can remain in the atmosphere for months up to years. By reflecting the radiation of the sun, these aerosols contribute to lower temperatures. Aerosols can also have other sources than volcanic eruptions, for example meteoritic debris and forest fires (*ibid.*). One of the more important cycles of ocean-atmosphere interaction is El Niño, La Niño and the Southern Oscilliation (**ENSO**). ENSO events occur approximately every fifth year in the Indian Ocean and Pacific Ocean (Bartlein 2013). Normally, the westward trade winds cause upwelling of cold water along the Peruvian coast (Kayano *et al.* 2005). Under El Niño event, the westward winds slacken and give rise to higher sea surface temperatures which have an impact on the climate globally. La Niña event is the opposite phenomenon, when the westward winds are stronger than normally (*ibid.*). The ENSO phenomenon is not the only oscillation that have major impacts on the climate. Other examples are the North Atlantic Oscillation (**NOA**) that impacts the climate predominantly in the North Atlantic region (Wanner *et al.* 2001) and the Madden-Julian Oscillation that impacts the tropical areas and monsoons (Woolnough *et al.* 2007). In addition to this variability, there is also a large interannual variability of the climate, because of the stochastic nature of the climate system (Bartlein 2013).

Today the anthropogenic influence is also an important driver for change of the climate. This change is happening rapidly. Increased anthropogenic emissions of greenhouse gases leads to an enhanced greenhouse effect where more energy is absorbed in the atmosphere (Rohli *et al.* 2013). The sun's shortwave ultraviolet radiation heats the Earth surface which emits longwave infrared radiation. Greenhouse gases can absorb the infrared radiation and emit it back to the Earth surface. During ordinary circumstances, this mechanism is essential for keeping the Earth at liveable temperatures. However, when anthropogenic activity increases the level of greenhouse gas in the atmosphere this leads to more energy being absorbed and hence a warmer climate (*ibid.*).

3.2 Effects and Consequences of Climate Change

Impacts of the global warming can already be observed today. Snow and ice have diminished, and the rate of sea level rise is faster than in previous two millennia. Change has also been observed in precipitations patterns and extreme weather events. With continued emissions, the warming will further increase and these changes will be further amplified. The extent of the future warming will depend on both past emissions, future emissions and natural climate variability. However, temperature change in the close future 2016-2035 will be less affected by future emission scenarios because of inertia of the climate system (IPCC 2014). Below follows a description of the four natural hazards in scope and how they may be affected in a changed climate. For each natural hazards, it is also described what financial impact it can have. Any other humanitarian impact is acknowledged but left outside of this study.

3.2.1 Heat Wave

Between 1800-2012, the average land and ocean temperature increased by 0.85°C (IPCC 2014, p. 40). The increase in average surface temperature 2016-2035 is likely to be between 0.3°C and 0.7°C (*ibid.*, p.58). For regional temperature maximums over land, the increase is expected to be even greater (IPCC 2014; Seneviratne *et al.* 2016). The most rapid warming will occur in the Arctic region which is often explained by feedback effects such as a changed surface albedo when ice melts, and less longwave radiation back to space compared to lower latitudes (Stuecker *et al.* 2018).

Heat waves are likely to become more frequent and more intense in the future climate (IPCC 2014; Meehl *et al.* 2004). There is no universal definition of heat waves, but they are related to periods of abnormally high temperatures. Heat waves are measured relative to a specific location's meteorology - what is considered a heat wave in one place may be normal weather in another place (McGregor *et al.* 2015). Besides the general warming of the climate, increased temperature variability in the future climate will also contribute to more common heat waves (Fischer *et al.* 2009). The driving processes for increased variability of the climate are related to reduction of cloudiness, changes in atmospheric circulation, depletion of soil moisture, changed interactions between land and atmosphere and increased variability of net surface radiation (*ibid.*).

For the agricultural sector, heat waves can impact yields negatively (Smoyer-Tomic *et al.* 2003). Crops have a tolerance temperature range where they can adapt through for example reduced number of stomata or by extending root system. The adaptation capacity is different between species, but outside this range high temperature will lead to damage and ultimately death. Heat conditions often correlate with drought and water stress, and on a longer time perspective this is what causes the major damage to crops. However, initially heat stress is more damaging (*ibid.*). A heat wave in the US 2012 contributed to a 13% decrease of corn production compared to the previous year (Chung *et al.* 2014, p. 68). Modelling has shown that extreme heat stress can double the losses of maize yields and spring wheat yields in 2080 under RCP8.5 (Deryng *et al.* 2014). Heat waves also have a negative effect on livestock production. A study in Italy showed that mortality among diary cows was higher during periods of heat waves (Vitali *et al.* 2015).

Heat wave is also one of the main contributors to wildfires, for example a study in Portugal showed that 97% of their wildfires between 1981 and 2010 occurred during heat wave events (Parente *et al.* 2018, p. 539).

Besides yield and production losses in the agriculture sector, heat waves also lead to economic losses from decreased labour productivity. In higher temperature, workers must take more or longer breaks and sometimes limit working hours. The International Labour Organisation (**ILO**) estimates that in 2030 an average of 2.2% of total working hours globally will be lost due to high temperatures (ILO 2019). The agricultural sector will be the worst affected by lower labour productivity because of its physical nature and location in more heat affected regions (ILO 2019; Xia *et al.* 2018). The agricultural sector is expected to be followed by the construction and mining sector in terms of lost working hours (Xia *et al.* 2018).

Other economic impacts from heat waves are less efficiency in cooling processes and disturbances in the transportation system (Vliet *et al.* 2016). The electricity sector depends on the availability of cold water for dissipating excess heat from thermoelectric power production. This includes nuclear power, fossil fuel power, biomass fuel power and geothermal power. Heat waves therefore are therefore harmful for energy production (*ibid.*). Finally, transportation is affected by lower engine performance and thermal shrinking of rail roads (Smoyer-Tomic *et al.* 2003). The lower density of warm air compared to colder air impacts the lift of aircrafts. Current aircrafts are not designed for temperatures above 50°C (*ibid.*).

3.2.2 Intense precipitation

The hydrological cycle is driven by energy from the sun. The radiation heats the ocean and land which causes water to evaporate into the atmosphere. When dew point is reached, the vapour condenses and falls as precipitation (Trenberth 2011). Precipitation patterns in a future climate are harder to predict than temperature because of the large yearly variability in regional and local precipitation (Dai *et al.* 2018). Natural variability, for example caused by ENSO events and Interdecadal Pacific Oscillation (**IPO**) can still dominate climate change effects in some regions in the mid-late twenty first century (*ibid.*). However, researchers seem to agree on that a warmer climate will shift the balance in the hydrological cycle and extreme precipitation events will become more common (Allen *et al.* 2002; Asadieh *et al.* 2015; Dai *et al.* 2018; IPCC 2014; Trenberth 2011; Westra *et al.* 2014). Extreme precipitation is often local and develops over a short time scale (Trenberth 2011), extreme precipitation can therefore be classified as an acute climate risk. When discussing effects of precipitation events it is not only the total amount of precipitation that is of importance (*ibid.*). Characteristics such as intensity, frequency and time can be as important, or even more important. Steady, moderate rain can soak into the soil and benefit vegetation while the same amount but under a short period may cause flooding and runoff which leaves the soil drier than before (*ibid.*).

The capacity of the air to hold water vapour increases with temperature. This means that the atmosphere can hold more water in a warmer climate. According to the well established Clausius Clapeyron equation, the water holding capacity increases with 7 % per 1 K increase of air-temperature (Trenberth 2011, p. 124; Asadieh *et al.* 2015, p. 878). Provided that water is available, global warming hence causes an increase of evaporation

(Allan *et al.* 2008; Asadieh *et al.* 2015; Trenberth 2011). Consequently, the precipitation must also increase to maintain the hydrological balance (Trenberth 1998). While evaporation from oceans is continuous, precipitation only falls 5-10% of the time (*ibid.*). This means that most precipitation systems mainly feed on converged moisture. Moisture can be carried with atmospheric winds over extensive regions to where storms thrive. Increased moisture in the atmosphere will therefore increase convergence of moisture and thereby lead to more intense precipitation (*ibid.*). Referring again to the Clausius Clapeyron equation, the intensity of rainfall would therefore increase with 7% per 1 K (Westra *et al.* 2014). Observations confirm the trend of increased intensity of precipitation with increased moisture (Asadieh *et al.* 2015); however, the degree of intensification varies between studies and location. Other atmospheric processes such as circulation patters and availability of moisture covary with temperature which complicates the analyse (Westra *et al.* 2014).

On a larger scale the same increase of precipitation is not expected. The overall mean precipitation is not only controlled by moisture, but also by energy (Allen *et al.* 2002; Chou *et al.* 2009). Generally, global precipitation patterns depend on the general atmospheric circulation (Trenberth 2011) that transports energy from the equator to the poles which, in combination with the circulation of the Earth, creates circulation cells with areas of convergence and divergence (Rohli *et al.* 2013). The atmospheric circulation is expected to be prone to changes in a warmer climate (Trenberth 2011). It is expected that dry regions will get drier and we regions get wetter. In regions with convergence the increased moisture will lead to increased precipitation, while in areas with divergence the precipitation will decrease (Asadieh *et al.* 2015; Chou *et al.* 2009; Trenberth 2011). Precipitation is expected to increase in tropical Africa, extratropical North America and most of Eurasia, while decreasing in the Mediterranean area, southwestern North America, parts of South America, southern Africa and most of Australia (Dai *et al.* 2018).

For the tropics and for mid latitudes Pacific rim countries, ENSO events are also important for the distribution and timing of floods and droughts (Trenberth 2011). An increased sea surface temperature has been suggested to change the characteristics of ENSO, but it remains uncertain how these changes will be projected (Chen *et al.* 2016; Lian *et al.* 2018).

Extreme precipitation acts as a trigger for further natural hazards, so-called secondary hazards. Among these secondary hazards are floods, debris flows, landslides and snow avalanches (Schauwecker *et al.* 2019). Extreme precipitation cannot itself explain the variance of flood damage (Pielke *et al.* 2000), but there is a strong relation between extreme precipitation and flood damages (Oubennaceur *et al.* 2019; Pielke *et al.* 2000). Floods can cause significant and costly damage on infrastructure and buildings (Oubennaceur *et al.* 2019; Pielke *et al.* 2000; Poussin *et al.* 2015). Besides potential damages on property, floods can lead to productivity losses and business close downs. An empirical study of the manufacturing industry in China showed that flood events reduce labor productivity (financial output per employee) in average by 28 % (Hu *et al.* 2019, p. 10). System effects and propagating costs through supply chain was shown to be of great importance for the degree of damage (*ibid.*). Extreme precipitation also damages crop production. In addition to direct flood impacts, excess moisture of soils contributes in damaging crops because of anoxic conditions, increased risk of insect infestations and plant diseases (Rosenzweig *et al.* 2002).

3.2.3 Drought

Drought is associated with precipitation deficit and warm temperatures (Dai *et al.* 2018). Drought develops over longer time scales (months or years) (Dai *et al.* 2018; Trenberth 2011) and can therefore be classified as an incremental climate risk. Droughts are often related to high pressure with anomalous atmospheric circulation that suppresses cloud formation or a shift in rainbelt. Droughts are self-reinforced by less water being evaporated which leads to lower relative humidity and higher temperature (Dai *et al.* 2018). In subtropical areas, near convective areas, the upper-ante mechanism can explain a decreased precipitation (Neelin *et al.* 2003). Upper-ante means that low level moisture required for convection increases in the warmer climate. Areas that have a strong inflow from subsidence areas cannot compete for convection under these circumstances which results in reduced precipitation (*ibid.*). A shift towards lower frequency of precipitation events and heavier rainfalls, potentially causing flash droughts, also contribute to an increased risk for droughts (Dai *et al.* 2018).

The economic impact of droughts is harder to measure compared to the one of many other natural hazards (Ding *et al.* 2011). It is not always clear what economic damage that can be assigned to drought because of its longer development over a non finite period. The most clear economic impact from droughts is on the agricultural sector, this is also the most well covered sector in literature on economic impact from droughts (*ibid.*). For example, during the first years of the millennium drought in Australia, the yield of summer-bearing oranges was 32% lower than in previous years (Dijk *et al.* 2013, p. 1051). Agriculture consumes the majority of water globally (Berrittella *et al.* 2007). Drought causes lower yield because of water shortage to plants, but also because pests sometimes thrive better in a dry environment (Wheaton *et al.* 2008). Drought is also, just like heat waves, an important contributor to wildfires (Gudmundsson *et al.* 2014). A study by Gudmundsson *et al.* (2014) showed that meteorological drought was a significant predictor for above normal wildfire activity.

Many other sectors, besides agriculture, suffer economic damage from droughts. Water is a basic supply in human society. In the tourism sector, many activities are water related and therefore harmed in times of drought (Dijk *et al.* 2013). Electricity generation can also be negatively affected by droughts from lower availability of cooling water for thermoelectric power. Streamflow droughts also affect hydropower generation with lower utilisation rates (Vliet *et al.* 2016). For non-agriculture sectors the negative effect on GDP growth from droughts comes later than for agriculture, often in the years after the event (Fomby *et al.* 2013).

3.2.4 Tropical Cyclone

A cyclone is an area of low pressure (Rohli *et al.* 2013). If the low pressure occurs near the surface, it causes convergence of winds towards the center which results in a rising motion. The rising air is cooled down and at dew point clouds form. Cyclones with low pressure near surface are therefore associated with storm systems. The interplay between the pressure gradient force and the Coriolis effect gives rise to a circulation air mass around the low-pressure center. At the northern hemisphere, the air circulates counterclockwise and at the southern hemisphere the circulation is clockwise (*ibid.*). Tropical cyclones emerge over tropical oceans, the water temperature must be above 26°C (Emanuel 2003, p. 78). The primary energy source driving the tropical cyclone is heat transfer from the ocean (*ibid.*). After development, they can then move out to higher latitudes. Tropical cyclones with wind speeds of 33 m/s or greater are also referred to as hurricanes in the eastern North Pacific and the western North Atlantic regions and as typhoons in the western North Pacific regions (Emanuel 2003, p. 76-78). Here, the term tropical cyclones is used to describe this phenomena.

There are great challenges in observing historical trends in tropical cyclone activity, mainly because of the natural variability and uncertainties in historical data (Seneviratne *et al.* 2012). IPCC states that it is "virtually certain" that the tropical cyclone activity has increased since 1970 in the North Atlantic basin. However, it is "low confidence" that the long term changes in cyclone activity are robust (IPCC 2014, p. 53). The main view from projections of future tropical cyclones is that intensity of tropical cyclones will increase with climate change (Cheal *et al.* 2017; Chen *et al.* 2020; Knutson *et al.* 2019; Seneviratne *et al.* 2012; Walsh *et al.* 2016). The view on how the frequency of tropical cyclones will change is more divided, one hypothesis is that the frequency of tropical cyclones in general decreases while the frequency of very intense tropical cyclones increases (Cheal *et al.* 2017; Knutson *et al.* 2019; Seneviratne *et al.* 2012; Walsh *et al.* 2016). Rainfall rates in tropical cyclones are expected to increase in a warmer climate by 7% per degree according to the Clausius Clapeyron equation as described in section 3.2.2 (Knutson *et al.* 2019). These changes are not homogeneously distributed globally but model results are more uncertain for individual basins (Walsh *et al.* 2016).

A warmer climate leads to increased tropical sea surface temperature (**SST**) (Chen *et al.* 2020). Observations show that potential tropical cyclone intensity positively correlates with SST (Seneviratne *et al.* 2012), this is supported by the theory that a warmer ocean provides more heat flux to the cyclone formation (Chen *et al.* 2020). However, the threshold for tropical cyclone formation is not only dependent on SST but also on atmospheric stability (Chen *et al.* 2020; Seneviratne *et al.* 2012). Tropical cyclones are also tied to ENSO variations. Changes in the ENSO pattern in a warmer world would hence also affect tropical cyclones' formation and tracks. If and how these changes would project is currently unclear. A warmer climate will also lead to sea level rise mainly because of thermal expansion of water mass and glacier mass loss. The total sea level rise in the 21st century is likely to be in the range 0.25-0.8 m, depending of pathway (IPCC 2014, p. 13). Sea level rise will increase the level of storm surges for the tropical cyclones that occur, which increases potential damage from tropical cyclones (Chen *et al.* 2016; Knutson *et al.* 2019; Walsh *et al.* 2016).

Tropical cyclones can be very lethal and expensive disasters (Bertinelli *et al.* 2013; Hallegatte 2008; Hsiang 2010; Lenzen *et al.* 2019), the majority of the damage is caused by storm surge and flooding from extreme precipitation. The most intense tropical cyclones are rare, but correspond to the majority of damage caused by tropical cyclones (Seneviratne *et al.* 2012). Economic damage from tropical cyclones include both direct and indirect effects. Direct effects is for example infrastructural damage. Damage and destruction of for example bridges, airports, roads, water and wastewater plants damage can reach values of billions of dollars (Lenzen *et al.* 2019, p. 140). Indirect effects are for example when damage of capital goods and infrastructure lead to business interruption and production losses during reparations (Hallegatte 2008; Lenzen *et al.* 2019). Because of the interconnection between businesses and sectors, these indirect effects travel through the supply chain (Lenzen *et al.* 2019). An analysis of the cyclone Debbie that hit Australia in 2017 showed that around 4,800 jobs were lost in industries directly hit, while almost 3,700 jobs were lost in industries upstream the supply chain (*ibid.*). Hsiang (2010) state that industries where location is central in the production are particularly severely damaged by cyclones. Examples are agriculture and tourism. Other sectors may not choose to locate in high risk areas as an adaptive strategy (*ibid.*). For tourism, it is not only the effect of damaged infrastructure and property that contributes to the economic losses. Disasters such as cyclones also impacts the perceived safety of tourists and bring a negative tourism image (Tsai *et al.* 2016).

3.3 Previous Studies

The main focus of research within the growing area of sustainable finance has been on financial performance of sustainable products compared to non-sustainable products (Ferreira *et al.* 2016; Groot *et al.* 2015). Although a range of outcomes, the main conclusion has been that there is no significant difference in financial performance for sustainable products compared to non-sustainable products (Groot *et al.* 2015). Less focus has been given to climate risks (Ferreira *et al.* 2016; Groot *et al.* 2015). A major challenge in quantifying climate risks compared to other risks is the long time horizon with impacts decades into the future. There is also a scarcity of reliable data (Fang *et al.* 2018). Particularly in the area of physical equity risk has research been very scarce (Bender *et al.* 2019; Fang *et al.* 2018). This section starts with a review of methods and results from research on climate credit risk, as that is a more mature area (Bender *et al.* 2019). Thereafter follows a review on climate related equity risk. Previous studies on climate related equity risk are summarised in table 2.

3.3.1 Climate Related Credit Risk

Credit risk reflects the potential risk that a borrower fails to fulfill their agreed obligations (Basel Committee on Banking Supervision 2000). For banks, the largest source of credit risk is loans, but also financial products such as options and bonds involve credit risk. Banks must maintain the credit risk exposure within acceptable limits. The specific practices to manage credit risk varies between banks and supervisors, but the Basel regulations set out general principles on how banks credit risk management system should be evaluated (*ibid.*). According to theory developed by Altman (1968), bankruptcy of a counterpart can be predicted by financial indicators related to the debtor. More recent research include not only quantitative financial indicators, but also qualitative factors such as management and sustainability indicators (Weber *et al.* 2015). Environmental aspects have been considered by European and American banks in credit risk management since the 1990s (Weber *et al.* 2008). In 1998, the World Bank and the International Finance Corporation (**IFC**) published guidelines on how to incorporate environmental assessments into credit risk assessments (IFC 1998).

The theory for applying environmental, or sustainability, indicators when assessing credit risk is that a good sustainability performance decreases risks associated with negative environmental and social impact and regulations (Weber *et al.* 2015). More specifically, Höck *et al.* (2020) state that lower credit risk for sustainable companies is associated with four interconnected risk mitigation channels. First, good environmental performance implies a better adaptation to new regulations, and decreased risk of being fined for violating environmental regulations. For example, the polluter pays principle in the EU make companies financially liable for the environmental damage they cause (Höck *et al.* 2020). The cost of clean-ups of contaminated sites and producer responsibility schemes was one of the first reasons that drew the attention to environmental aspects among banks (Weber *et al.* 2008). Second, better environmental performance decreases reputational risk. This is becoming increasingly important with an increased public attention towards sustainability issues. Third, when investors integrate sustainability criteria in their investment processes more capital will be directed towards sustainable companies which decreases the financial risk among these companies. Last, less sustainable companies have a higher risk for events such as dam bursts (Höck *et al.* 2020). This channel is closely connected also to reputational risk since stakeholder relations and trust can be severely damaged from major incidents (Henisz *et al.* 2019). Several studies have empirically proven the correlation between incorporation of environmental sustainability criteria and lower credit risk (among other: Graham *et al.* 2006; Henisz *et al.* 2019; Höck *et al.* 2020; Schneider 2011). Weber *et al.* (2015) have shown that this correlation holds also for companies in countries with less developed environmental regulations. They performed a study on 57 commercial loans from seven Bangladeshi banks. By dividing the loans into two groups, one where the agreements were fulfilled and one where agreements were not or only partly fulfilled, they could then perform correlation tests to sustainability indicators. The result indicated that the sustainability indicators were useful in predicting credit losses (*ibid.*).

Physical risks also seem to impact the risk perceived by banks. Do *et al.* (2020) investigated how the credit rating and risk premium of corporate borrowers correlated with drought risk. They studied private bank loans from the period 1984–2016 in the US and compared the loan spread to a drought index. The results showed, particularly significantly for the food industry, that drought affected borrowers payed a higher loan spread. The result was consistent both when comparing loans at the time of dry periods with loans at less dry periods, and when comparing loans in the top five dry states with loans in bottom five least dry states. The difference between the loan spread was significant at the 1% level (*ibid.*).

How to integrate environmental risks into credit management processes is however still a challenge since the risks depend local conditions and sub-sector characteristics (Cojoianu *et al.* 2017). Cojoianu *et al.* (2017) suggest a framework to guide banks to a bottom-up evaluation of environmental risk for smaller scale bank loans. The study focuses on wheat farming in Australia, but suggests that the same approach could be applied to develop frameworks also for other sub-sectors and geographies. The approach follows three steps. First, a broad picture of relevant risks for the main sector is painted. Second, materiality of these risks are evaluated based on the specific requirements of the sub-sector. Third, material risks are further investigated and summarized under three titles: an overview of the risk, how the risk can be mitigated and information requirements for lenders. Cojoianu *et al.* (2017) admits that also this approach poses some challenges. Many risks are multidimensional and the impact does not only depend on intensity but also on timing and interconnection to other risks. The approach also requires extensive work for specific sub-sectors. Zeidan *et al.* (2015) proposes another approach for evaluation of sustainability risks. They suggest a six step process for a Sustainability Credit Score System.

This approach is bottom-up as well, but more high-level than the approach of Cojoianu *et al.* (2017) . The approach includes an analysis of the industry and firm according to three paths of different time horizons. Then, relevant variables in six different areas are defined. The six areas are economic growth, environmental protection, social progress, socioeconomic development, eco-efficiency, and socio-environmental development. Based on the information, the material issues for vulnerability and opportunities are selected. The combined information is used to obtain questions for the credit score system, and the result is analysed and weighted together. Zeidan *et al.* (*ibid.*) suggest that their Sustainability Credit Score System can be used in practise by sending out questionnaires to by branch and account managers with specific knowledge in the firms of the industry studied.

The method of questionnaires has the disadvantage of being very resource intensive and it requires high competence among respondents (Georgopoulou *et al.* 2015). To address this need, Georgopoulou *et al.* (2015) developed a top-down approach to physical and regulatory risks. They identified the most material sectors based on industry classification codes. Materiality was assessed considering potential climate impact and exposure of loans to the specific sector. The sub-sectors were then grouped into units based on their characteristics, for example based on geographic location, the crop cultivated, the raw material used or the crop cultivated. Input and output from this unit were calculated as weighted averages. The assessment for physical risk for each unit was made with regional climate models. Georgopoulou *et al.* (2015) used a regional climate model with daily frequency to predict the future climate 2021-2050. The model was applied on Greek banks. Among the sub-sectors relevant for these banks the greatest physical risk was identified for growing of vegetables and for the hotel industry. The agricultural sector was affected by rising temperatures and changes in precipitation patterns. Within manufacturing, the risk was higher for manufacturer that processes agricultural raw materials, when the raw material used depended on other raw material (i.e. meat production where livestock is fed on agricultural products) and when the consumption of its products was impacted on climatic conditions (i.e. ice-cream). The impact on the tourism sector could be derived from two main reasons, first the perceived attractiveness of the area connected to climatic conditions and second increased energy consumption for cooling in the summer that result in higher operational costs (*ibid.*).

3.3.2 Climate Related Equity Risk

Less research has focused on physical climate risks for equities compared to credits (Bender *et al.* 2019; Fang *et al.* 2018). Although growing (Bender *et al.* 2019), the academic literature has a very scarce starting point in terms of quantity. In 2017 Diaz-Rainey *et al.* 2017 surveyed 20,725 articles from 21 leading finance journals but found only 12 articles related to climate finance. A major contribution to the literature on climate risks instead comes from institutional investors, research institutes and consultancy firms (see for example Clapp *et al.* 2017; Mercer 2015; S&P Global 2015; Schroders 2020. These often take on a more high-level perspective with a broader perspective of several sectors and regions; however, their disclosure of methodology is naturally less detailed.
From an inside perspective of the firms, around 50% of firms identified that they faced substantive climate risks or opportunities. This was shown in a survey study of almost 7,000 companies made by (CDP 2019, p. 10) in 2018. Among the top 500 largest companies in the world (whereof 366 were included in the survey), a larger share (82%) reported

substantive climate risks. The majority of companies reporting climate risks identified both physical and transition risks. More than 70% of the physical risks were identified in the direct operations, around 20% in supply chain and the rest on the customer side (CDP 2019, p. 12). The main financial driver for physical risks was decreased production capacity, followed by increasing operating costs, increased capital costs and reduced revenue from lower sales or output (*ibid.*).

From an investor perspective, different approaches have been taken to understand physical climate risks, see Table 2 for some examples. A bottom-up approach is to collect information on firms from sources such as sustainability reports. Nikolaou *et al.* (2014) applies this approach in addressing how water risks can be incorporated into investment decisions. The authors acknowledge the challenge in evaluating water risks because of the lack of a widely accepted method to measure risk among firms. Their methodology is therefore based on a scoring method borrowed from environmental accounting where information from sustainability reports is scored from 0-5. A score of 5 indicates the most mature state where water risks are taken into consideration and the company is exposed to a relatively low risk. Limitations with this method is that sustainability reports are not written with the purpose of solely disclosing water risks (*ibid.*).

Among the top-down approaches to measure physical risks from an investor perspective are three main groups: Scoring based on greenhouse gas emissions, evaluation based on historical data and simulations with models. Scoring based on carbon intensity was applied by Andersson *et al.* (2016) to estimate climate risk, including physical climate risks. They developed an index to hedge climate risk based on companies' carbon intensity. Bender *et al.* (2019) acknowledged that climate adaptation commonly refers to resilience of physical changes due to climate change; however, they expanded the definition to focus rather on adaptation to a low-carbon society. Their assessment of adaptation was hence, just like (Andersson *et al.* 2016), focused on greenhouse gas emissions. By applying a rating based on the company's current position in climate change and their emission reduction plan they performed an assessment on climate adaptation (Bender *et al.* 2019).

Another approach is to estimate economic losses of physical climate risks from historical data. This was applied by Addoum *et al.* (2020). They applied historical data on temperature shocks in the US and studied the causal impact on corporate performance. They first calculated indicators for extreme temperature (such as days above the 90th percentile of temperature) for certain areas and fiscal periods. Thereafter, they run running panel regressions to sales results for firms. Burke *et al.* (2019) applied a similar method, but for GDP of districts instead of company performance. Their study also had a wider scope of 37 countries and temperature was measured as an average over the area and time period. The effect of temperature was then isolated to decide a non-linear relationship between temperature and economic performance (*ibid.*). The research of Burke *et al.* (2019) lays the foundation of the analysis of Schroders (2020). S&P Global (2015) and Ralite *et al.* (2019) applied a mix of historical data and future looking data for assessing physical climate risks for GDP. Damage on GDP was then correlated with share prices. The historical data constitutes of economic losses from previous natural hazards.

The future looking data was leveraged from S&P Global (2015) that evaluated sovereign ratings by estimating once in a 250-year floods and tropical cyclones with the model Climada. Climada combines hazard, vulnerability and exposure to calculate economic risk from natural hazards.

This brings the third approach to estimate physical risks top-down, by modelling climate risks. A common type of models is Integrated assessment models (**IAMs**). An IAM is a cross-disciplinary model that links together phenomenon in the biosphere and atmosphere with economy. IAMs are simplifications of reality and often neglect non-quantitative forces, but can take a lot of different inputs (Fang *et al.* 2018). Fang *et al.* (2018) state that IAMs better reflect the comprehensiveness of physical risks compared to carbon footprint, which is also confirmed by Mercer (2015). Fang *et al.* (2018) applied the World Induced Technical Change Hybrid Model (**WITCH**) to generate climate scenarios. The two proxies for climate impact were radiative forcing and global mean temperature change. The scenario pathways were then multiplied with sector specific weights based on sensitivity (*ibid.*). This approach is very similar to the one of Mercer (2015) and Clapp *et al.* (2017), although Clapp *et al.* (2017) do not detail how the scenario pathways were calculated. In Mercer (2015) a combination of IAMs was applied: The Climate Framework for Uncertainty, Negotiation and Distribution (**FUND**), Dynamic Integrated Climate-Economy (**DICE**), Policy Analysis of the Greenhouse Effect (**PAGE**) and WITCH. Another common model type for evaluating climate risk is Computable General Models (GCM), their focus is on the relation between different economic actors via productive activities and trade flows. GCM models better illustrate the effect on different sectors and regions, but do not cover non-market impacts well (OECD 2015). OECD (2015) apply a GCM for evaluating climate risks until 2060, and an IAM beyond 2060. Many different climate impacts are considered, including changed crop yields, damages from tropical cyclones, energy demand for cooling and health care costs and labour productivity losses from heat waves. These results were then leveraged by Ralite *et al.* (2019) to study sectoral losses from incremental climate change.

Table 2: *Summarising table of examples of methods to approach physical equity risk on corporate level*

Methodology type	**Study**	**Description**
Bottom-up		
Scoring of sustainability reports	Nikolaou et al. (2014)	Scoring of maturity in water risk management based on sustainability reports.
Top-down		
Risk based on greenhouse gas emissions	Andersson et al. (2016)	Development of an index to hedge climate risk based on the company's carbon footprint.
	Bender et al. (2019)	Rating based on the company's current position and emission reduction plan.
Historical data	Addoum et al. (2020)	Sturdy of the causal relation between temperature shocks and corporate performance in the US.
	Burke et al. (2019)	Study of the causal relation between temperature shocks and GDP in countries.
	Ralite & Thomä (2019)	Regional study partly based on historical data for natural hazards and economic impact.
Modelling	Clapp et al. (2017)	Application of IAMs, unclear what IAMs, coupled with sector vulnerability.
	Fang et al. (2018)	Application of WITCH to generate scenario pathways that is coupled with sector vulnerability.
	Mercer (2015)	Application of a combination of IAMs coupled with sector vulnerability.
	Ralite & Thomä (2019)	Sectoral study based on GCM models from OECD (2015).

With the broad range of methodologies, and what is considered within the scope of physical risks, there is also a broad range of output results. When comparing the risks between the different countries and regions, the study by Ralite *et al.* (2019) on impact on share prices 1 year after the event of once in 250 year flood, storm, drought and wildfire showed the highest risk for Asia. The risk was mainly driven by flood risk. Second highest risk was evaluated for Americas, where storm risk dominates. Europe had the lowest risk. Of the countries studied in Schroders (2020) the most negative impact on equities from rising temperatures was evaluated for Singapore and Indonesia, but note that the study only included a subset of all countries. European countries such as Switzerland and the UK had low risk, but also the North American countries Canada and the US had low risks. Regarding also studies on country level rather than equity price level, the study by S&P Global (2015) found that Latin-America and the Caribbean, followed by Asia-Pacific were the regions most impacted by climate change (defined as floods and tropical cyclones) in 2050. In the study by OECD (2015) Africa and Asia were the most negatively affected regions from climate damages, with many economies that do not have high capacity to manage negative impact and hence are very vulnerable. The large economies of the OECD countries were less negatively affected (*ibid.*). According to the survey among the largest companies globally conducted by CDP (2019), the largest physical climate risk was reported among European companies. Companies in the US, report significantly lower physical risks and China reports almost no physical risks (*ibid.*).

When comparing the results on a sector level, the largest physical risk due to incremental changes (year 2025 and 2060) was found in the agriculture sector according to the study by Ralite *et al.* (2019). The second largest risk was found in the energy and extraction sector (Ralite *et al.* 2019) . Agriculture was not included in the sector comparison of climate risks by Mercer (2015), but the energy and extraction sector were identified as high risk sectors (note that this includes both physical risks and transition risks). Since the study by OECD (2015) was based on countries and GDP it brings a different perspective. Given the size of the service sector many countries, it was found to largely contribute to the negative impact on regional GDP even though it may not be the most severely hit sector. Generally, losses in crop yield and labour productivity were evaluated as the most significant drivers for global GDP decrease from climate change (*ibid.*). In the perception of large companies, the financial sector reported the by far largest physical risks in terms of financial impact (CDP 2019). The financial sector was followed by infrastructure, transportation and fossil fuels, although these report significantly lower physical risk (*ibid.*).

4 Method

This study was performed as a top-down, quantitative analysis where the potential climate was modelled and evaluated as risk based on sector vulnerability. The model was then applied on three groups of sustainable equity funds and a proxy for the general market. This chapter first describes how the model was constructed, and then how the output was analysed.

4.1 Model Construction

To be able to assess global equity funds in large scale, climate risks were in this study evaluated by top-down quantitative modelling. The input to the model are ISIN-codes and weights of the holdings in an equity portfolio. The output is the aggregated physical climate risk of the portfolio per studied risk event (heat wave, heavy precipitation, drought and tropical cyclones) on an ordinal scale. The theoretical minimum total risk is 0 and the theoretical maximum risk is 100.

The physical risks were assessed on two periods, 2021-2025 and 2026-2030. This equals a five respective ten year time horizon which are relevant time frames for many investors. For the companies' perspective, the survey by CDP (2019) showed that the range of definitions of long term and medium term was very large; nevertheless, five years roughly corresponded to medium term and ten years to long term. A common standard for measuring climate normals is 30 years (Arguez *et al.* 2010) because of the natural variability such as ENSO events in the system. The time periods in this study were substantially shorter, only five years. However, the purpose of this study is to measure the total physical risk, whether this risk stems from fluctuations or more permanent changes is therefore not of interest. Neither does this study try to determine what changes that can be deferred to anthropogenic impact or natural variability. In this relatively short time span, previous studies (among other: Clapp *et al.* 2017) have shown that the choice of RCP scenario is not significant. The selection of scenario in this study was therefore rather based on data availability whereof RCP4.5 was chosen. The short time span also means that transitional risks will be close to independent from physical risks (*ibid.*), which justifies modelling of physical risks separately. On a longer time horizon physical climate risks are connected to transitional risks, stricter policies will likely lead to less severe impacts for example (UNEP Finance Initiative 2019).

Olson *et al.* (2010) state that the value at risk from natural hazards for a company is a function of hazard and vulnerability. Similarly to Clapp *et al.* (2017), Fang *et al.* (2018) and Mercer (2015) physical risks were here calculated as a product between hazard intensity and vulnerability. The hazard intensity is related to the location of the company and its supply chain and how the climate is assumed to change there, while vulnerability is related to the sector(s) the company operates in. On an aggregated portfolio level the weight of the holdings is also considered. This gives an expression for portfolio risk as in Equation 1.

$$Risk\,per\,portfolio = \sum_{i=1}^{j} w_i \left(\sum_{h=1}^{k} w_m(H_{i,n}v_{i,n}) + w_s(h_{i,n}v_{i,n}) \right) \quad (1)$$

Where i represents a company with weight w_i in the portfolio of j companies. $H_{i,n}$ represents the intensity of hazard n at the location of assets for company i. $v_{i,n}$ represents the vulnerability for hazard n for company i, including vulnerability of the supply chain. $h_{i,n}$ represents the intensity of hazard n at the location of suppliers. The risk of the main company is weighted with w_m and the risk of the suppliers is weighted with w_s. k is the number of natural hazards studied, in this study $k = 4$ (heat waves, heavy precipitation, drought and tropical cyclones).

The following sub-sections describe how hazard intensity and sector vulnerability were determined.

4.1.1 Hazard Intensity

Hazard intensity is dependent on how the climate will change locally where the company operates. According to Fang *et al.* (2018) and Mercer (2015), IAM is the best approach to describe physical hazards. In this study, the determination of hazard intensity was also based on modelling of climate, but not on models that integrate socio-economic aspects. IAMs take into consideration many aspects which reflects the complexity of the ecological, as well as societal system (*ibid.*). However, modelling climate separately brings more freedom in designing the parameters of analysis and increase transparency.

The data applied for the climate scenarios in the model was collected from the database Earth System Grid Federation (**ESGF**). ESGF is a world wide platform for sharing of climate data. ESGF collects data from various institutes, research groups and projects (ESGF-CoG n.d.). In this study, data from the Coupled Model Intercomparison Project Phase 5 (**CMIP5**) was applied. CMIP is a project that involves many research groups globally. By following the same formats and standards data can be compared and analysed collectively. CMIP data is extensively used for climate research, notably the Fifth assessment report from IPCC (IPCC 2014) relied to a large extent on data from CMIP5 (World Climate Research Programme n.d.). This study applied model data from four different models in CMIP5, see Table 3 for a description of the institutes behind the models and their respective resolutions. For all models data from ensemble number r1i1p1 was applied.

Table 3: Data from the following four data models were applied in this study. When two numbers are given for resolution, the resolution is not constant. The first number is the resolution by the equator and the second that by the poles

Model	**Institute**	**Resolution (atmosphere)**		**Resolution (ocean)**	
		Lat	Lon	Lat	Lon
CanESM2	Canadian Centre for Climate Modelling and Analysis	2.791°	2.813°	0.930°, 1.141°	1.406°
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation/ Queensland Climate Change Centre of Excellence	1.865°	1.875°	0.933°, 0.946°	1.875°
HadGEM2-AO	National Institute of Meteorological Research of Korea Meteorological Administration	1.25°	1.875°	0.3396°, 1°	1°
MIROC-ESM-CHEM	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	2.790°	2.813°	0.558°, 1.711°	1.406°

Based on climate data from the models in Table 3, hazard intensity for the four natural hazards in scope was measured as deviations from today's climate. Model results of today were hence compared with model results of 2021-2025 respectively 2026-2030. This is based on the assumption that the market is already calibrated for the existing risks, and only the additional risk is of interest for future valuations. As described above, natural yearly variability was not excluded from the study but to receive stable values the climate was defined as a five year average where today's climate was defined as the average of 2016-2020, the climate in five years was defined as the average of 2021-2025 and climate in ten years was defined as the average of 2026-2030.

The indicators and corresponding data variables that were used for measuring the intensity of hazards are summarized in Table 4. For heat waves and heavy precipitation daily data for near-surface temperature respectively precipitation was applied. Clapp *et al.* (2017) defined heat events and extreme precipitations as the frequency of days that exceed the 90th percentile of daily maximum temperature. The relative measure captures that heat waves and heavy precipitation are not defined in absolute numbers but relative the local conditions of a certain area (McGregor *et al.* 2015; Pielke *et al.* 2000). For floods, Pielke *et al.* (2000) evaluated measures for precipitation and found that the number of wet days followed by the number of 2-day heavy precipitation events most closely relate to flood damage. A shortage of the indicator used by Clapp *et al.* (2017) is that it does not take into consideration the level of temperature or the amount of precipitation for the days that exceed the 90th percentile. This means the severity of the events is not considered and the information in the tail is not leveraged. This study therefore applies the financial risk measure expected shortfall, introduced by Artzner *et al.* (1999), to capture hazard intensity. In this specific setting this means that the risk of heat waves and heavy precipitation were measured as the integral of temperature/precipitation for the days that exceed the current 90th percentile, see Equation 2 for heat waves. The risk for heavy precipitation events was defined identically, except integration over precipitation amount instead of temperature. Temperature and precipitation were measured as close as the resolution allowed to the location of the capital of the country. This value was applied for all companies with assets in the country since no data of better detail on asset location was available.

$$Hazard\,intensity(T) = \int_{t_\alpha}^{\infty} T dt \tag{2}$$

Where T represents daily temperature in Kelvin and t time measured in days. t_α is the day of the 90th percentile in temperature in today's climate.

The indicator for drought risk was defined similarly as the ones for heat waves and heavy precipitation events, except the frequency of data was monthly and the 10th percentile was applied instead of the 90th since it is the absence of rain that is the risk rather than the abundance, see Table 4. The rational for using monthly data instead of daily data is that drought develops over longer periods with a time scale of months or years (Dai *et al.* 2018; Trenberth 2011).

Table 4: *Indicators applied to measure hazards intensity*

Natural hazard	Data variable	Indicator
Heat wave	Future near surface air-temperature (daily)	The integral of future daily temperature beyond 90th percentile of daily temperature in today's climate.
Heavy precipitation	Future precipitation (daily)	The integral of future daily precipitation amounts beyond 90th percentile of daily precipitation in today's climate.
Drought	Future precipitation (monthly)	The integral of future monthly precipitation events within the 10th percentile of monthly precipitation in today's climate.
Tropical cyclone	Future and historical sea surface temperature (monthly)	The increase in intensity of tropical cyclones calculated based on monthly mean sea surface temperature increase since pre-industrial times.

In the future climate, both the intensity and the frequency of tropical cyclones might change (Knutson *et al.* 2019). However, there is no majority consensus on how the frequency will change. While there is a tilt towards the perception on an overall decrease of tropical cyclones, there is a tilt towards the perception of an increase of the biggest, most destructive cyclones (Knutson *et al.* 2019). Because of this uncertainty, change of frequency was not regarded in this study. Taking into account the short time perspective studies, this is considered as a fair simplification. The change of intensity for tropical cyclones is also very complex to predict with many variables interacting, but a simplified expression for how the intensity of tropical cyclones change with the climate could be derived from an equation that is used in IAM FUND Model 3.9 (applied by among other Mercer (2015)), see Table 4. The original equation describes the economic damage on GDP from tropical cyclones based on intensity, here only the factor that describes how the cyclone intensity depends on sea surface temperature was used to indicate hazard intensity. The difference in temperature is measured compared to pre-industrial times. See Equation 3.

$$Intensity = (1 + \delta T_{t,r})^{\gamma} - 1 \tag{3}$$

Where δ represents a constant for increase in wind speed per degree warming. According to WMO (2006) δ is approximately 0.04/K. $T_{t,r}$ represents the warming in region r at time t. γ represents the power of the wind from its speed and is a constant of 3.

When IPCC compares temperature increase to the pre-industrial they define pre-industrial times as 1850-1900 (IPCC 2014). Here, the difference in sea surface temperature was therefore calculated with the temperature of 1871-1875 as a baseline. The temperature increase was calculated monthly. The mean temperature difference was applied in Equation 3 and the intensity of the future was calculated. The intensity was calculated per tropical cyclone basin. The oceans are often divided into seven tropical cyclone basins (NOAA - PhOD n.d.). Based on research on tropical cyclone tracks by Goni *et al.* (2009) the the sea surface temperature was collected at 2-4 coordinated per basin where tropical genesis is likely. The total risk was calculated as an average risk for these measurement points. The seven basins were then mapped to countries that are likely to be hit by a cyclone from that specific basin. The mapping was based on the cyclone maps in NOAA - PhOD (n.d.) and Goni *et al.* (2009), complemented by a check at the web-based tool *ThinkHazard!* by GFDRR (2017). *ThinkHazard!* is supported by, among other, the World Bank Group. These sources are based on historical data rather than future predictions which is an uncertainty since tropical cyclone patterns may change. Kossin *et al.* (2014) shows that tropical cyclones have been moving polewards, on both hemispheres, the past 30 years. However, with the short time horizon studied here this uncertainty should not be too large.

For all risks, the calculated indicators were compared with the value of today. The standard deviation of the difference between the indicators of today and the future was calculated. The risk was assessed on a scale 0-5 based on the standard deviation, see Table 5. Note that decreased risks were assessed as 0 since opportunities are neglected in this study.

Table 5: *Scoring of hazard intensity 0-5 based on standard deviations of difference between today and the future, i represents an indicator for a natural hazard*

Difference ($\Delta_i = i_{today} - i_{future}$)	**Intensity score**	**Description**
$\Delta_i > 2\sigma$	5	Relatively very large intensity
$2\sigma \geq \Delta_i > 1.5\sigma$	4	Relatively large intensity
$1.5\sigma \geq \Delta_i > \sigma$	3	Relatively moderately large intensity
$\sigma \geq \Delta_i > 0.5\sigma$	2	Relatively moderately little intensity
$0.5\sigma \geq \Delta_i > 0$	1	Relatively little intensity
$0 \geq \Delta_i$	0	No, or negligible intensity

A significant share of risk for companies is related to supply chain relations. For example, a flood in Thailand in 2011 severely affected the Japanese company Toyota as Thailand is an important hub for automobile production. Toyota lost the production of 240,000 cars (Haraguchi *et al.* 2015, p. 261). With globalisation, risks related to supply chain are increasingly important. Because of incomplete data for supply chain relations, ”standard suppliers” were here constructed according to a similar method as Georgopoulou *et al.* (2015) applied to evaluate sector risks. From a large universe of companies, Georgopoulou *et al.* (*ibid.*) formed sub-groups based on common characteristics. Evaluation was then made for a typical unit of each sub-group which is applied for all companies in the sub-group. In this study, the companies were divided into 3-digits sub-sectors according to the North Atlantic Classification system (**NAICS**). This divides the universe in approximately 100 sub-sectors. For each sub-sector, the five largest companies in terms of revenue were selected. The common asset location of their three largest suppliers was summed up per country. If data was available for all five companies and suppliers, this gave an asset location sum of fifteen companies. Based on these sums, the five majority countries in terms of assets were selected and the asset split re-balanced to 100%. The result was a standard supplier per sub-sector group with an asset split on five countries. Hazard intensity was calculated for this standard supplier according to the same process as described above for the direct operations of the main company. The total hazard intensity was calculated as a weighted sum of the standard supplier and the direct operations.

According to a study on economic losses from heat waves in China by Xia *et al.* (2018) (p. 817) the share of economic losses in a natural disaster from supply chain respectively from direct operations varies per sector. In the manufacturing sector, indirect losses accounted for 88% of the total economic loss. In agriculture and mining the relation was almost the opposite, in these sectors indirect losses accounted for 26%. According to the survey by CDP (2019) (p. 12) companies in general identified roughly 70% of the total physical risk to derive from direct operations, 20% from supply chain and 10% from customer. The assumption in this study is that supply chain accounts for 30% of the total risk and direct operations 70%, regardless of sector. Because of the very wide range of numbers in the literature, this assumption is uncertain. To test the assumption the model was also run with other weights for supply chain risk. It should however be noted that also the scenario of no weight to supply chain includes a supply chain perspective since the sector vulnerability includes vulnerability from supply chain, see section 4.1.2.

4.1.2 Sector Vulnerability

Sector vulnerability was assessed specifically for each of the four natural hazards in scope on a scale 0-5 based on potential economic impact. The sectors were classified according to the industry classification system NAICS and the assessment was made on two digit level. Both vulnerability from the direct operations and from supply chain were included in the assessment. No regards were taken to future adaptive capacity of the sector, the analysis was based mainly on historical data and models.

Although previous studies have applied similar methods of assessing sector vulnerability (see for example Clapp *et al.* (2017), Fang *et al.* (2018), and Mercer (2015) their methodology of evaluation is poorly described and does not have the desired level of detail in terms of specific hazards or nuance. Both Mercer (2015) and Fang *et al.* (2018) assessed sector vulnerability on a scale -1 to +1 (where positive numbers represent an opportunity) for sectors according to the Global Industry Classification Standard (**GICS**). The risk was assessed as total physical risk, in other words there was no differentiation between risks from for example cyclones and heat waves. There are significant deviations between the assessments of the two studies. A more detailed assessment on sub-sector level and per climate risk can be found in the final report from the Technical Expert Group (**TEG**) on the Taxonomy (TEG 2020). However, the assessment is only made on a binary scale (Y/N). An company perspective of vulnerability to physical risks can be leveraged from the survey of around 2,500 companies in the CDP 2016 Company Reports, summarized by Clapp *et al.* (2017). The companies reported perceived risk to cyclones, change in precipitation extremes and change in temperature extremes.

To complete these vulnerability assessments, a literature study of qualitative and quantitative descriptions of economic damage from the four natural hazards was made, see Table 6 for a summary of the main studies applied. For heavy precipitation the bulk of the available studies on economic damage on sectors focused on floods. Heavy precipitation does not in itself lead to flood, but because of the strong relation between the two (Oubennaceur *et al.* 2019; Pielke *et al.* 2000), this data was still considered relevant. As mentioned above, the economic impact of droughts is more difficult to measure than many other natural hazards because of more incremental characteristics (Ding *et al.* 2011). To complement the available data and gain a broader spread of sectors, statistics of water use per sector in Europe was also applied (EEA 2019). It is important to note that data for water use does not cover drought vulnerability such as the one for hydropower where water is not consumed. Europe is neither representative of water consumption globally, but is assumed to be fairly representative for the universe that most investors focus on.

Table 6: *Studies used for data to base assessment on sector vulnerability on*

Natural hazard	Study	Description
Heat wave	Xia *et al.* (2018)	Case study of productivity losses during heat waves in Nanjing, China
	ILO (2019)	Estimates by ILO on what sectors that will be most affected by labour productivity losses from heat waves in 2030
	Smoyer-Tomic *et al.* (2003)	Empirical study of Caribbean and Central American countries on economic output and heat waves
Heavy precipitation	(Haque *et al.* 2015)	Calculation based on floods in Bangladesh in 2004 and 2007
	(Jonkman *et al.* 2008)	Modelling of a flood in the Netherlands
Drought	Horridge *et al.* (2005)	Modelling based on the Australian drought 2002–2003
	Kamber *et al.* (2013)	Modelling based on drought in New Zealand
	EEA (2019)	Statistics of water use in Europe
Tropical cyclone	Lenzen *et al.* (2019)	Study of value loss in sectors caused by Debbie in Australia
	Hallegatte (2008)	Empirical study of sector growth rates in Louisiana after hit by Katrina compared to nation-wide growth rates
	Smoyer-Tomic *et al.* (2003)	Study of economic output and tropical cyclones in Caribbean and Central American countries

The data from the studies mentioned above and in Table 6 were compiled and translated to the NAICS industry classification system. For studies that categorised sectors as ”service” and ”industry”, service was defined as Professional, Scientific, and Technical Services (54), Administrative and Support and Waste Management and Remediation Services (56), Arts, Entertainment, and Recreation (71), Accommodation and Food Services (72) and Other Services (except Public Administration) (81). Industry was defined in line with the definition in ILO (2019) as Mining, Quarrying, and Oil and Gas Extraction (21), Utilities (22), Construction (23) and Manufacturing (31-33). For sectors classifications that translated to several NAICS-codes, the damage was divided equally between the different sectors if measured in absolute numbers (for example cost). If the economic impact was estimated to be positive (an opportunity) it was set to 0 since opportunities are outside the scope of this study.

The compiled data measured economic damage from hazards in different measures and scales, it varied between USD, volume water and unitless sensitivity scores. To be able to compare the different data sets, three steps were performed. The first step was to standardize the data with a normalized value (z-score), see Equation 4. No standardisation was made on the binary data sets because it would give extreme values. A physical risk for binary data was instead defined as -1 in the standardized score. This was considered reasonable in comparison to the output from the standardisation of the other data sets.

$$z = \frac{x - \bar{x}}{S} \tag{4}$$

Where $\bar{x}$ represents the mean of the sample and S represents the standard deviation of the sample.

In the second step, an average of the standardized score was calculated for each of the four natural hazards. The average was based on the sector specific data sets (binary and non-binary) and the two data-sets from Mercer (2015) and Fang *et al.* (2018) for total vulnerability to physical risks. Lastly, the averages were transformed to the scale 0-5 according to Table 7.

Table 7: *Scoring system for sector vulnerability, the standardized score is an average of standardized data from previous studies*

Standardized score	**Vulnerability**	**Description**
$x \geq \mu + 1.5\sigma$	5	Very strong vulnerability
$\mu + 1.5\sigma > x \geq \mu + 0.75\sigma$	4	Strong vulnerability
$\mu + 0.75\sigma > x \geq 0$	3	Moderately strong vulnerability
$0 > x \geq \mu - 0.75\sigma$	2	Moderately weak vulnerability
$\mu - 0.75\sigma > x \geq \mu - 1.5\sigma$	1	Weak vulnerability
$\mu - 1.5\sigma <$ x	0	No, or negligible vulnerability

The sector vulnerability score in this study describes the sector's vulnerability of a specific natural hazard relative the other sectors. Each risk was treated separately. The methodology does therefore not capture how severe the natural hazards are relative each other within the sector. A weighted sum for the risk of the different hazards (in Equation 1) would relate the hazards to each other. However, assigning such weights would introduce another level of uncertainty and the model would lose transparency. It was therefore decided to perform the analysis of sustainable funds with a model without such weights. To try alternative approaches, it was however tested to run the model also with a weighted sum. The weights were based on global numbers from Centre for Research on the Epidemiology of Disasters (**CRED**) and United Nations Office for Disaster Risk Reduction (**UNISDR**) (2018, p. 10) for economic losses 1998-2017 per natural hazard type, see Table 8.

Table 8: *Data on economic losses from natural hazards 1998-2017 was used for assigning weights for the different hazards in an alternative model version*

Natural hazard	Share of total economic loss from natural hazards 1998-2017	Weight	Note
Heat wave	2%	0.1	
Heavy precipitation	23%	0.3	Numbers for floods in CRED and UNISDR.
Drought	4%	0.2	
Tropical Cyclone	46%	0.4	Numbers for storms in CRED and UNISDR

The most economic damaging natural hazard according to the data in Table 8 is tropical cyclones (here described aggregated as storms) followed by floods. The losses of heat waves and droughts are smaller (CRED and UNISDR 2018). The data does not separate tropical cyclones from other storms and heavy precipitation does not have its own category. The weights are therefore re-balanced where tropical cyclones are assumed to stand for 2/3 of the economic losses from storms and heavy precipitation receives a comparably lower weight. The relation between drought and heat waves is maintained.

4.2 Method of Analysis

4.2.1 Method for Comparing Sustainable Funds with the Market

To answer the first research question, whether sustainable funds have lower physical climate risk than the market in general, poses two challenges: first how to define the market and second how to define sustainable funds. The market was here defined as the global equity index MSCI All Country World Index (**ACWI**), representing mid and large cap companies in global markets. It covers around 3,000 equities from all sectors. The index constituents are of March 2020. By applying a global index as comparison to sustainable funds, it is assumed that all deviations from the market are active choices. In other words, both investment restrictions (for example a specific region) and security selection within the restrictions are regarded as active choices of the sustainable fund.

As described in section 2.3, no common definition of sustainable funds exists. To avoid limiting the study to one of the operative definitions of sustainability, funds from three different ratings/certifications of sustainability were analysed: funds from the Morningstar ESG rating, funds classified as sustainable according to YourSRI and funds certified with the Nordic Swan Ecolabel. These were selected as they build on well known providers of sustainability classifications that are important on the market. The Nordic Swan Ecolabel provided a regional perspective and the aspect of a certification rather than a rating. Furthermore, it was possible to receive representative samples from these groups. See Table 9 for a summary of the characteristics of the groups.

Table 9: Selected sustainability ratings and a summary of features for the samples

Sustainability certification/rating	ESG methodology	Features of sample	Size of sample
Morningstar ESG rating	Relative ESG performance based on Sustainalytics' ESG risk rating of material risks and risk management.	Highest ESG score, global and regional focus, non-thematic, available to Swedish investors	101 (randomized sample based on 1,519 funds)
YourSRI sustainability classification	Based on Lipper's classification of ethical fund, made by review of investment objective for incorporation of sustainability criteria.	Global focus, non-thematic, available to Swedish investors	105 (full universe)
Nordic Swan Ecolabel	Multiple criteria regarding, among other, exclusion of extraction of fossil fuels, norm-based screening and incorporation of ESG analysis.	Global focus, non-thematic, available to Swedish investors	19 (full universe)

The Morningstar Sustainability Rating is based on ESG research from Sustainalytics on company level (Morningstar 2019). Portfolios are scored from 1-5 based on their relative ESG performance compared to peers. ESG performance is calculated as the weighted sum of the ESG Risk Rating from Sustainalytics for the companies in the portfolio (*ibid.*). In this study, only funds of the highest score are included as sustainable funds. The ESG Risk Rating from Sustainalytics is based on a materiality analysis of ESG related issues based on the sub-sector of the company; included ESG issues are for example diversity and employee health and safety. The score is then evaluated as a measure of unmanaged risks stemming from the material issues, unexpected risks and corporate governance (Sustainalytics 2019). YourSRI is based on Lipper's classification of ethical funds. An ethical fund is by the analyst team defined as a fund that bases investment decisions on criteria such as inclusive employee policies, environmental issues or religious beliefs. To classify a fund, the analyst team reviews the investment objective of the fund. The Nordic Swan Ecolabel is a certification scheme for funds within the Nordic countries. To qualify for the label, the fund must exclude for example extraction of fossil fuels, it must adhere to international norms and conventions, 90% of the holdings must have undergone an ESG analysis to demonstrate that issues in all ESG areas are covered and the majority of the holdings must have strong ESG practises (Nordic Ecolabelling 2019).

All analysed funds are mutual equity funds that are available to Swedish investors. The funds from YourSRI have a global focus, the two other groups are a mix of global and regional funds. The funds are non-thematic, which is evaluated based on the name of the fund. As an example, the fund *Guinness Sustainable Energy* is excluded as it appears to heavily focus on the energy sector. The universe from Morningstar is a randomized sample of 101 funds, extracted from 1,519 funds that fulfilled the criteria. The universe from YourSRI consists of 105 funds and represents the full universe that fulfilled the criteria. The universe from the Nordic Swan Ecolabel also represents the full universe of funds that fulfilled the criteria, but because of its smaller coverage, this universe is significantly smaller than the two other groups (19 funds).

4.2.2 Method for Analysing Characteristics of Funds

Based on the conceptual framework described in Figure 4, the physical risks of funds can be impacted by characteristics on the fund level or on the equity level. On the fund level, it was investigated how different sustainable investment strategies (see Table 1) impact physical risks. Proxies were used for testing the strategies because of the challenge with large scale data on what sustainable investment strategies different funds apply. It was not possible to test the strategies in isolation since many funds in practise apply a mix of several strategies. However, since this is the reality on the market it is not regarded as a limitation, instead it increases the relevance of the study.

First, the three groups of sustainable fund ratings put focus on different sustainable investment strategies. The Morningstar rating appears to have a strong focus on the integration of ESG factors in financial analysis to consider ESG risks. For YourSRI it is not specified what strategy that should be applied to incorporate ESG criteria in investment decisions and the stragey can hence vary from fund to fund. However, it seems to be a focus on exclusion and integration of ESG factors, perhaps also on sustainability themed investing. The Nordic Swan Ecolabel requires a mix of several investment strategies: Norm-based screeening, Engagement and ESG integration. The results for these three different groups were compared with each other and with index. Second, to test another example of a strong Norm-based screening strategy and Engagement the National Pension Funds of Sweden (the AP funds) were also run through the model to compare their physical risk with the market. In 2019 it was decided that the National Pension Funds must contribute to sustainable development (AP-fonderna n.d.). Investment decisions should be based on international conventions ratified by Sweden and Sweden's environmental quality objectives. Advocacy of sustainable practices to the holdings is also an important tool in contributing to sustainability (*ibid.*). Although the National Pension Funds are not limited to the two strategies Norm-based Screening and Engagement, these are dominant in the description of their strategy. Third, the correlation between carbon intensity and physical risk was tested. Carbon intensity was measured quantitatively based on reported and estimated data. Carbon intensity can serve as an ESG criteria for exclusion, best-in-class investments or when incorporating ESG factors in financial analysis. According to Ralite *et al.* (2019) many investors rely on low carbon intensity as an indicator for sustainable funds as that is one of few fairly reliable data points that companies report within sustainability.

On the equity level, four characteristics that potentially impact physical risk were studied. These were sector allocation, regional allocation, market cap size and capital expenditures (**CAPEX**). Sector and region are both mentioned by several previous studies as factors that impact physical risk (Clapp *et al.* 2017; Fang *et al.* 2018; Mercer 2015; Ralite *et al.*

2019). Market cap size may be related to regional allocation as larger companies could have a broader regional exposure. To study the impact from these three characteristics, Brinson Fachler attribution was applied. Attribution is an analytical tool to explain differences between a portfolio and benchmark. Commonly, attribution is applied on performance but here it is instead applied on physical risk. CAPEX includes the investments of the company, maintenance and improvement on physical assets. Investments in climate adaptation could hence be included as part of CAPEX. As the CAPEX-data is not historical, it would not be expected that companies with high CAPEX have lower physical risk. Instead, CAPEX could serve as an indicator on whether the companies with largest physical risks are preparing through adaptation measures. To neutralize for size of the company, CAPEX was measured as percentage of revenue.

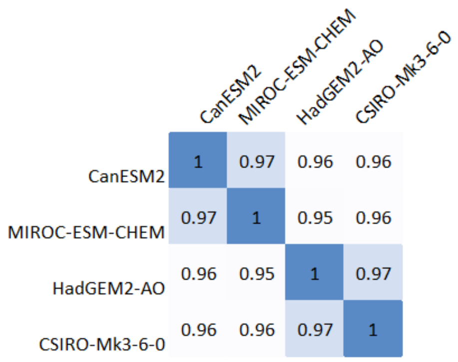
5 Results

This chapter provides the results of the study. First, some general results for the full universe are presented to give an understanding of the data. Results for alternative model parameters are also presented. Thereafter follows the results on sustainable funds and certain factors impacting risk. These results are structured according to the conceptual framework in Figure 4.

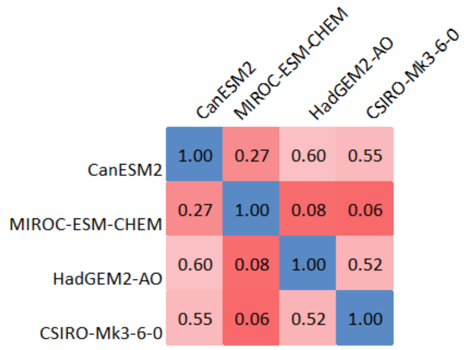
5.1 Underlying Universe

5.1.1 Climate Model Data

As described in section 2.4, climate models have different choice of initial conditions, parametrisations and priorities. The four climate models used to evaluate hazard intensity in this study therefore all have their unique output. The mean values of the output for the risk in 2021-2025 are in general well correlated, see for example the correlation matrix for mean air surface temperature 2021-2025 in Figure 5a.



(a) Mean temperature 2021-2025.



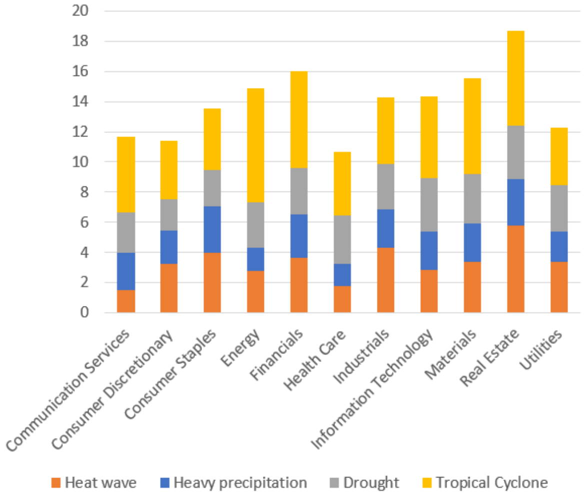
(b) The indicator for heat wave 2021-2025.

Figure 5: *Correlation matrixes between the selected climate models.*

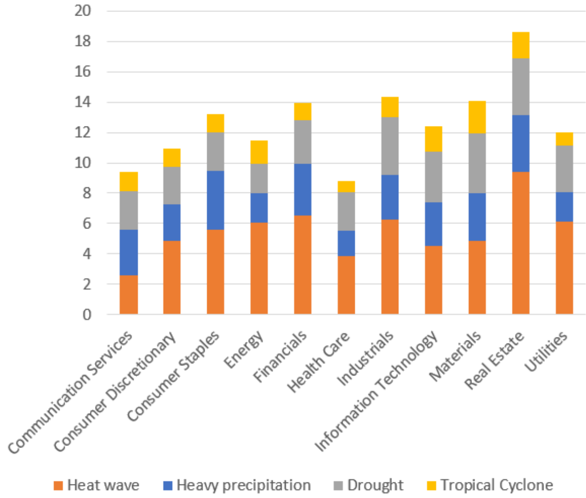
The tails do however not have as strong correlation. Figure 5b shows the correlation matrix for the indicator of heat waves, the integral of temperatures above the 90th percentile of today. The indicator generally has a significantly lower correlation than the mean value.

5.1.2 Description of the Full Universe

To get a picture of the wider market, the full universe of all listed companies was run through the model. The risk score of a single company ranged between 1 and 45. The result shows that all sectors face a climate risk for both periods studied, see Figure 6a and 6b. Note here that the results are shown based on sector classification on company level instead of activity level. Companies often operate in several sub-sectors, the sector classification on company level is therefore not always a clear-cut. No regard is taken to the size of the company, all companies are weighted equally.



(a) Sector risk in 2021-2025.



(b) Sector risk in 2026-2030.

Figure 6: *Risk per sector, based on all listed companies. All companies are weighted equally.*

The highest risk is in the Real Estate sector for both studied periods. In 2021-2025 the risk is dominated by tropical cyclones while in 2026-2030 the risk for tropical cyclones is lower. Instead, the risk of heat waves is higher. Health Care has the lowest risk.

A full universe-view on countries show that companies registered in countries of emerging markets are in general exposed to a higher risk than companies registered in developed markets, see Figure 7 and 8. It should be noted that the results are presented by country of registration on company level, which must not necessarily be the same as the location of their assets.

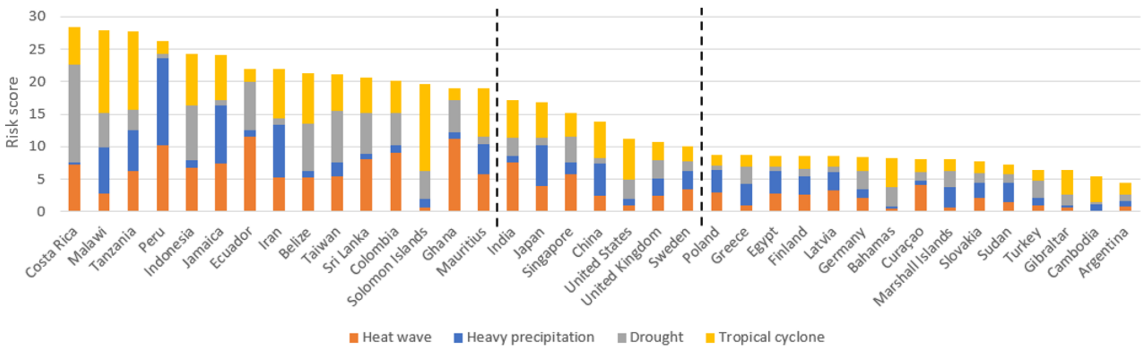


Figure 7: *Risk per country based on all listed companies in 2021-2025, including top 15 highest, and lowest risk countries and some countries of special economical or geographical interest. All companies are weighted equally.*

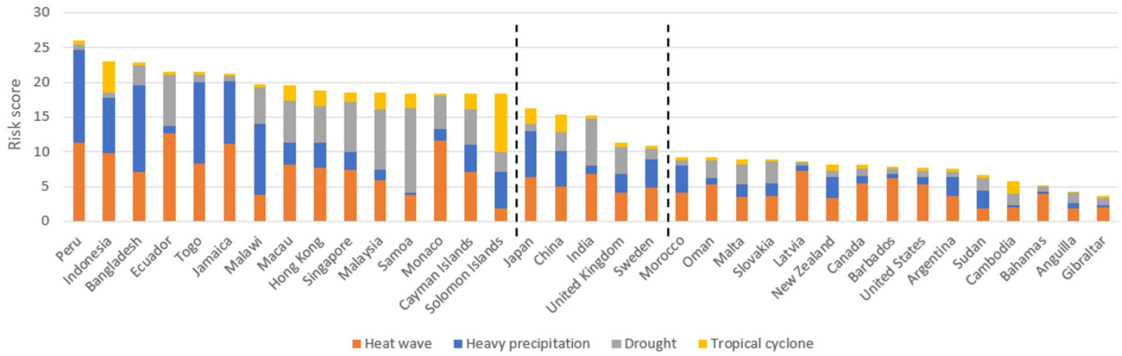


Figure 8: *Risk per country based on all listed companies in 2026-2030, including top 15 highest, and lowest risk countries and some countries of special economical or geographical interest. All companies are weighted equally.*

In the period 2021-2025, Costa Rica (number of companies $n = 1$), Malawi ($n = 5$) and Tanzania ($n = 13$) are the countries most exposed to physical risk, see Figure 7. Many European countries are among the 15 countries with lowest risk; however, the country with the lowest risk is Argentina ($n = 41$). No consideration is taken to how many companies that are registered in the country. A few companies will hence have a very high weight on small country markets, for example in Costa Rica, Cambodia and Gibraltar only one listed company is registered and can be measured. Some of the top 15 countries with highest risk in 2021-2025 are recognized also among the top risk countries in 2026-2030, for example Peru ($n = 57$) and Indonesia ($n = 389$), see Figure 8. The economically important markets Singapore ($n = 547$) and Hong Kong ($n = 1{,}564$) are also among the top 15 countries with the highest risk in 2026-2030. The US ($n = 5{,}079$) on the other hand is among the 15 companies of lowest risk. When comparing Figure 7 and 8, it is also here clear that the risk of tropical cyclones is most important in 2021-2025 and that the risk of heat waves is more dominating in 2026-2030.

5.1.3 Universe of Studied Funds

To be able to analyse the three groups of sustainable funds (funds of Morningstar, YourSRI and the Nordic Swan Ecolabel), it is important to understand their underlying characteristics. The sector allocation of the funds according to GICS compared to the market (MSCI ACWI) is shown in Figure 9.

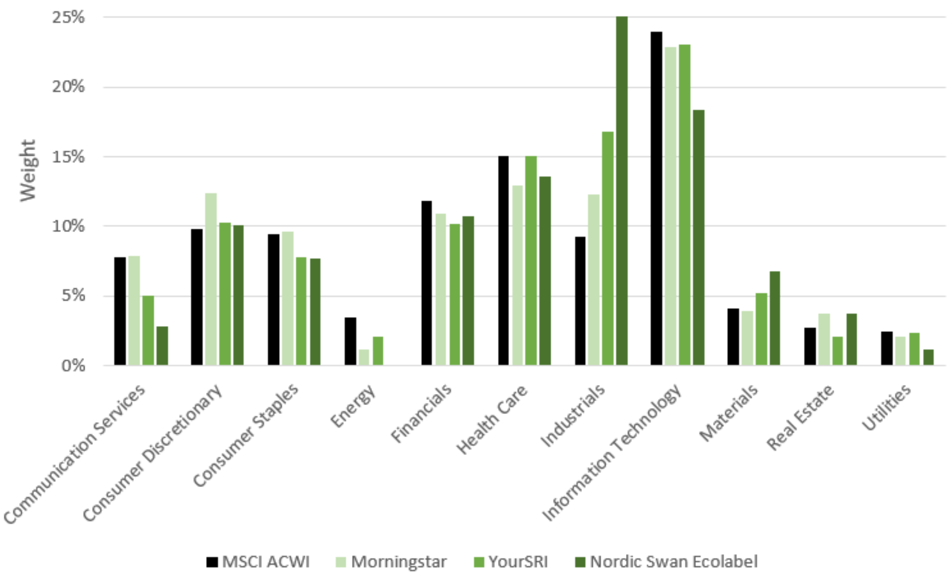


Figure 9: *Sector allocation of the three groups of sustainable funds compared to the market.*

The sector allocation of the sustainable funds is in general similar to the market. What stands out is however a higher weight in Industrials for sustainable funds compared to the market. Industrials include Capital Goods, Commercial and Professional Services and Transportation. Notably, the funds of the Nordic Swan Ecolabel do not have any weight in Energy. This is probably because of the exclusion of fossil fuels as Energy in GICS only include oil, gas and coal. For the regional allocation there are larger deviations from the market, see Figure 10.

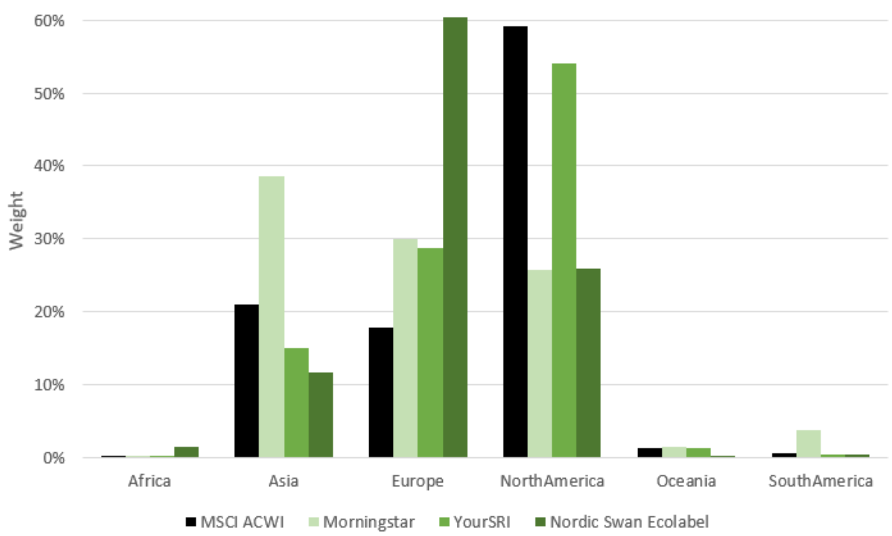


Figure 10: *Regional allocation of the three groups of sustainable funds compared to the market.*

The sustainable funds of Morningstar have a considerable tilt towards Asia and from North America compared to the market. The difference between MSCI ACWI and the funds of Morningstar in allocation to North America is 33 percentage points. The group of funds certified with the Nordic Swan Ecolabel also deviates from the market in regional allocation with a significantly higher weight in Europe. Sweden has the highest weight of all countries with a weight of 7.7%. The weight in North America is 33 percentage points lower than MSCI ACWI. The sustainable funds of YourSRI have a regional allocation more similar to the market. The funds of YourSRI is the only fund group where only global funds (no regional funds) are included. It can also be noted that the funds and the market in general have relatively low exposure to Africa, Oceania and South America.

5.1.4 Test of Alternative Model parameters

A central assumption in the model was the weighting of risk from supply chain compared to risk from the direct operations of the main company. In the standard model, supply chain accounted for 30% of the total risk. To test this assumption, the full universe of all listed companies was run with alternative weights of supply chain, ranging from 0% up to 70%. The result per sector in 2021-2025 for the scenarios of altered supply chain weight can be seen in Figure 11.

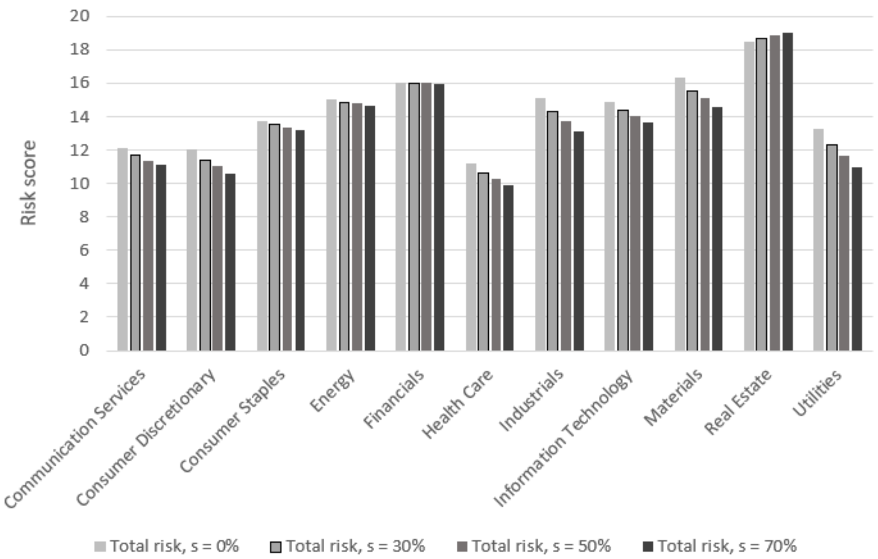


Figure 11: *Total risk in 2021-2025 per sector with different weights for supply chain, denoted by s and a percentage in the legend. For example, s = 30% means that the risk from supply chain has weight 30% and risk from direct operations has weight 70%. A supply chain weight of 30% is the standard model and that scenario is therefore marked with black borders.*

For most sectors, the difference in results with altered supply chain weights is not very large in absolute risk score. The relative risk compared to each other changes with sector weights but not drastically, the overall order from the sector with the highest to the lowest risk is maintained. The largest difference in total risk 2021-2025 is for Utilities, the risk is 17% lower when supply chain is weighted the highest (70%) compared to when supply chain has no weight. For all sectors except Real Estate, the total risk decreases with increased supply chain weight. The type of risk also changes with the weight of supply chain. In 2021-2025 the risks for heat and drought generally decrease with supply chain weight, while the risks for heavy precipitation and tropical cyclones increase. The risk of drought in 2026-2030 decreases with supply chain weight for all sectors, particularly for Real Estate. The risk of heavy precipitation generally increases with supply chain weight in 2026-2030. Figure 12 show the results for the scenarios of altered supply chain weight per region.

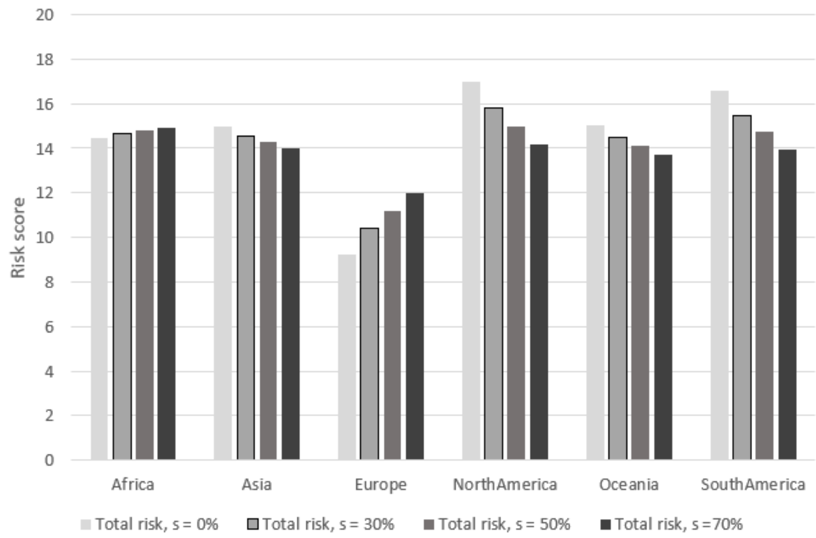
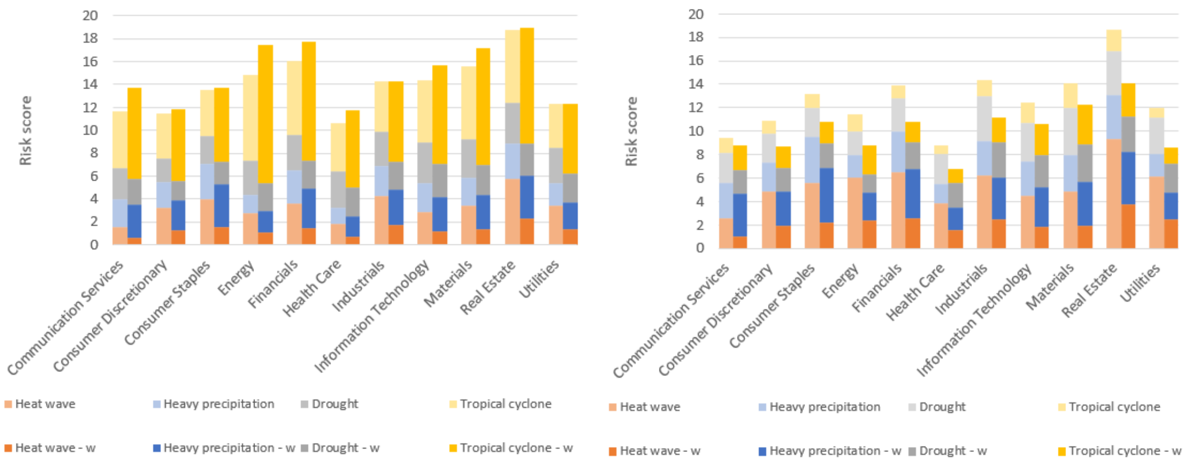


Figure 12: *Total risk in 2021-2025 per region with different weights for supply chain, denoted by s and a percentage in the legend. For example, s = 30% means that the risk from supply chain has weight 30% and risk from direct operations has weight 70%. A supply chain weight of 30% is the standard model and that scenario is therefore marked with black borders.*

In the period 2021-2025, North America and Europe are the most affected by a changed weight for supply chain. The risk in North America decreases by 2.8 risk points when supply chain is weighted 70% compared to no weight, while the risk in Europe increases between the same scenarios by 2.8 risk points. The changes in risk score create a new order between the region of the lowest risk and the highest risk. Africa climbs to a higher relative risk position. Africa is the only region besides Europe where the risk increases with increasing supply chain weight. In the other regions the risk decreases. The trend is similar for 2026-2030, except the differences between the highest weight scenario and the lowest weight scenario for Europe and North America are smaller, only 1.2 respectively 0.5 risk points. The effect on individual countries from a changed supply chain weight is significant. For example, in 2021-2025 Tanzania ($n = 13$) has a risk score of 18 in the scenario with 70% supply chain weight but 36 in the scenario with no supply chain weight. The risk in Argentina ($n = 41$) in 2021-2025 increases by 636% in the scenario with the highest supply chain weight compared to no weight. For the US ($n =$ 5,079), the risk in 2021-2025 increases by 22% and the risk in 2026-2030 by 68% with a higher supply chain weight. The risk increases also for Sweden ($n = 440$), by 35% in 2021-2025 and 8% in 2026-2030. Generally, countries that have low risk when supply chain is weighted low the risk increases when supply chain is weighted higher and vice versa. The Pearson correlation between the risk in the scenario where supply chain has no weight and the percentage change in risk when comparing to the supply chain weight of 70% is -0.59 for risk in 2021-2025 and -0.85 for risk in 2026-2030.

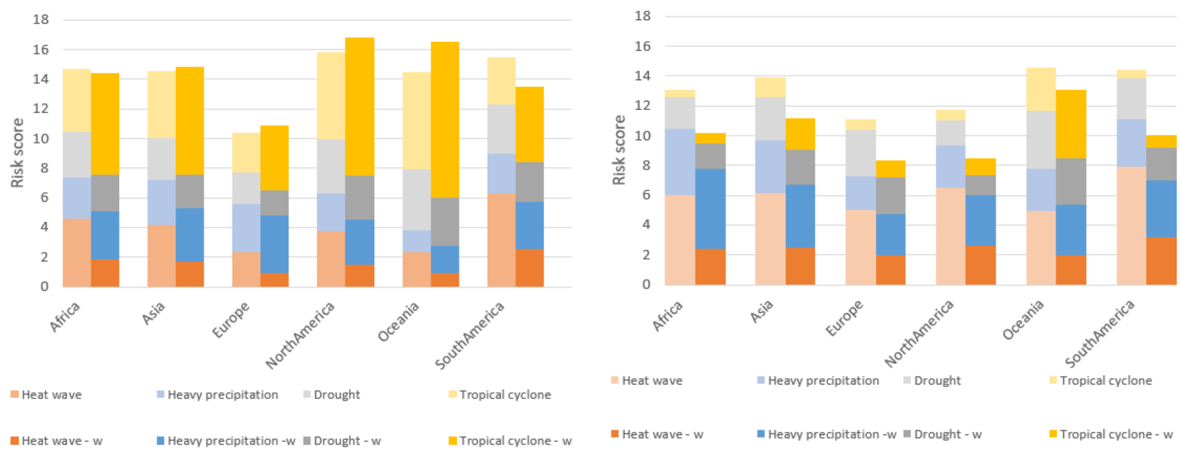
Another assumption of model parameters was that risks from all natural hazards were weighted equally. To test this assumption, the model was also run with the modified weights in Table 8, based on empirical data for global economic losses from natural hazards. Based on this data, tropical cyclone was given the highest weight while heat waves was given the lowest weight. The results on sector output show that the total risk for the sectors changes when applying the new weights, in general it increases for the risk in 2021-2025 and decreases for the risk in 2026-2030, see Figure 13a and 13b.



(a) Sector risk 2021-2025. *(b) Sector risk 2026-2030.*

Figure 13: *Comparison of sector risk for the original model with all natural hazards weighted equally in the left pale bar, and modified weights (marked with w) in the right bar.*

The order between the sector with the lowest risk and the highest risk remained about the same when changing the weights. In the period 2021-2025, Consumer Staples received a relatively lower risk compared to the other sectors while Communication Services received a relatively higher risk. The relative risk for Communication Services also increased in the period 2026-2030 with the altered weights of the natural hazards. Utilities received a relatively lower risk in 2026-2030. Regarding the regional risk when altering the weights, the results do not change much in terms of absolute risk score, see Figure 14a and 14b.



(a) Regional risk 2021-2025. *(b) Regional risk 2026-2030.*

Figure 14: *Comparison of regional risk for the original model with all natural hazards weighted equally in the left pale bar, and the model with modified weights (marked with w) in the right bar.*

The order between the region of the lowest risk and the highest risk do however change. In 2021-2025, Oceania climbs to a higher relative risk position while South America falls. South America also falls in relative risk in 2026-2030 compared to the other regions. For specific countries, the risk profile changes significantly. The risk in 2021-2025 for the

US (n = 5,079) increases by 25% with the altered weights. In Brazil (n = 329), on the other hand, the risk in 2021-2025 increases by 21%. For Sweden (n = 440), the risk also decreases with altered weights, both in 2021-2025 and 2026-2030. The risk 2026-2030 also decreases significantly for Mexico (n = 85) by 40%.

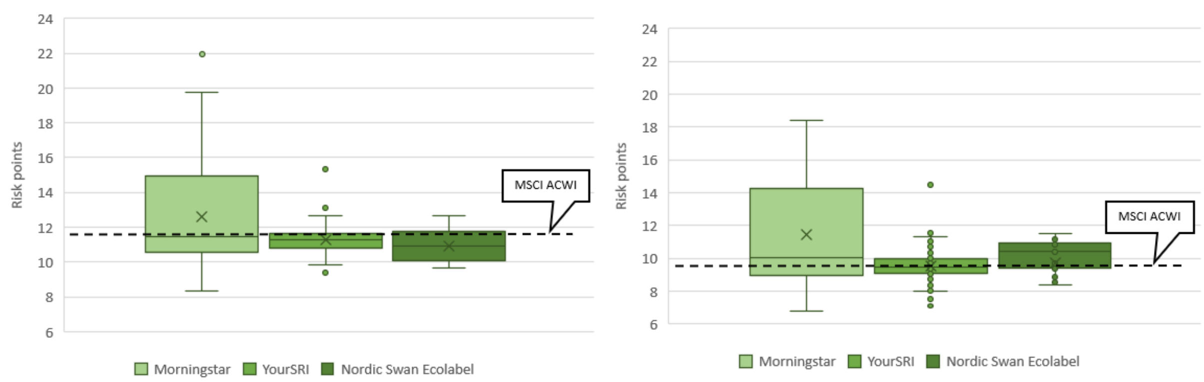
5.2 Comparison of Sustainable Funds and the Market

The mean physical climate risk score for the market (MSCI ACWI) is 11.8 in 2021-2025, and 9.9 in 2026-2030. In 2021-2025, the sustainable funds of YourSRI and the Nordic Swan Ecolabel have a significantly lower risk than the market on a 95% confidence level, see Table 10. In 2026-2030 only the sustainable funds of YourSRI have a significantly lower risk than the market. The sustainable funds of Morningstar have a significantly higher risk than the market in both periods studied. The sustainable funds of Nordic Swan Ecolabel have neither a significantly higher nor lower risk than the market in 2026-2030.

Table 10: *Average risk score with 95% confidence interval for the market and the three groups of sustainable funds*

	5 year	10 year
Market (MSCI ACWI)	11.8	9.9
Morningstar	12.6 $[12.0, 13.1]_{95\%}$	11.4 $[10.8, 12.0]_{95\%}$
YourSRI	11.3 $[11.1, 11.5]_{95\%}$	9.6 $[9.4, 9.8]_{95\%}$
Nordic Swan Ecolabel	10.9 $[10.5, 11.4]_{95\%}$	10.2 $[9.8, 10.6]_{95\%}$

As shown in Figure 15a and 15b, the spread of risk scores is broader among the sustainable funds of Morningstar compared to the two other groups of sustainable funds.



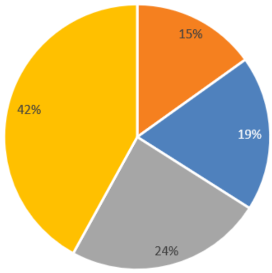
(a) Physical risk 2021-2025.

(b) Physical risk 2026-2030.

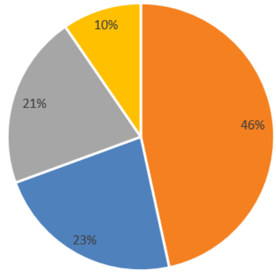
Figure 15: *Risk of the three groups of sustainable funds compared to the market.*

The group of sustainable funds certified with the Nordic Swan Ecolabel is a smaller universe which is probably the explanation for the more narrow distribution; however, the universe of YourSRI is of similar size as the one of Morningstar and has a significantly more narrow distribution. The highest risk score of any sustainable fund in any period is 22, this is a sustainable fund of Morningstar in 2021-2025. Also the fund that has the lowest risk score is as fund of Morningstar, it has a risk score of 6.8 in 2026-2030. In general, the risk scores are lower in 2026-2030 than in 2021-2025.

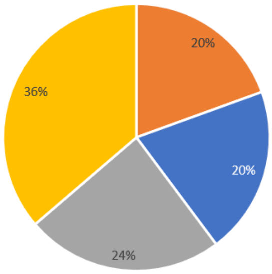
Regarding the type of risk that the funds are exposed to, the sustainable funds are very similar to the market, see Figure 16.



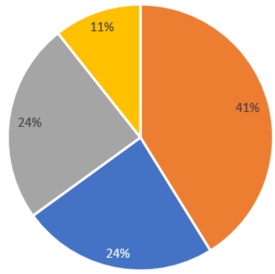
(a) The market (MSCI ACWI), 2021-2025.



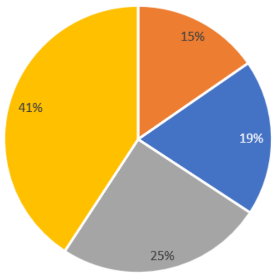
(b) The market (MSCI ACWI), 2026-2030.



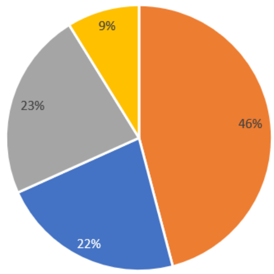
(c) Sustainable funds of Morningstar, 2021-2025.



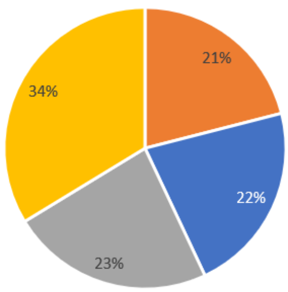
(d) Sustainable funds of Morningstar, 2026-2030.



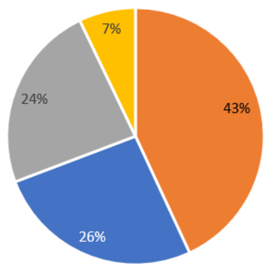
(e) Sustainable funds of YourSRI, 2021-2025.



(f) Sustainable funds of YourSRI, 2026-2030.



(g) Sustainable funds of Nordic Swan Ecolabel, 2021-2025.



(h) Sustainable funds of Nordic Swan Ecolabel, 2026-2030.

■ Heat wave ■ Heavy precipitation ■ Drought ■ Tropical cyclone

Figure 16: *Share of total risk derived from the different types of risk for the market and the sustainable funds. The pie charts in the left column show the risk in 2021-2025, and the right column show the risk in 2026-2030.*

In 2021-2025, the dominating risk type is risk from tropical cyclones. Tropical cyclones stand for 34-41% of the total risk among the sustainable funds. Risk from tropical cyclones is followed by risk from drought in terms of importance. The risk of heat waves and the risk of heavy precipitation are about equal. In 2026-2030 the risk profile looks very different. Risk from tropical cyclones is then the smallest risk for all sustainable funds. Instead, the largest risk is from heat waves (ranging from 41-46% among the sustainable funds).

5.3 Characteristics that Possibly Impact Climate Risk

The results on what fund characteristics that contribute to a low respective high physical risk is structured accordingly to the conceptual framework. First are the results on characteristics on fund level described. Thereafter are the results on characteristics on equity level presented: sector allocation, regional allocation, market cap size and CAPEX.

5.3.1 Sustainable Investment Strategies

The three groups of sustainable funds represent focus on different sustainable investment strategies. When comparing the three groups, the funds of YourSRI have the lowest risk exposure while the funds of Morningstar have the highest. However, because of differences in other important characteristics these results can not be attributed to their sustainable investment strategies. When comparing the funds of Morningstar and YourSRI in attribution based on region, the selection of regions (the regional allocation) is a much more important explanatory factor for the difference between the two groups compared to security selection within regions, see Figure 17.

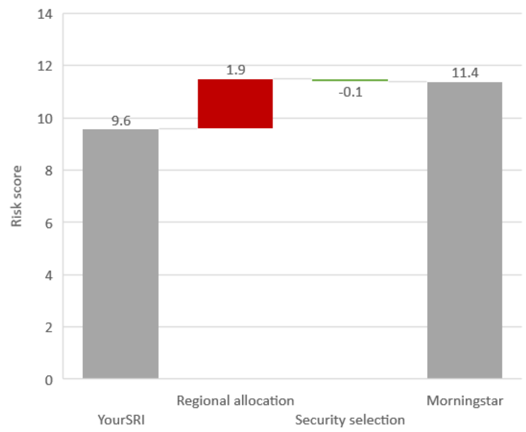


Figure 17: *Attribution based on region comparing the funds of Morningstar with the funds of YourSRI in 2026-2030. Red colour marks contributions to an increased risk score, and green marks contributions to a decreased risk score.*

The National Pension Funds of Sweden were also tested for physical risk exposure as an example of a group of funds with a clear exclusion and engagement strategy, see Figure 18.

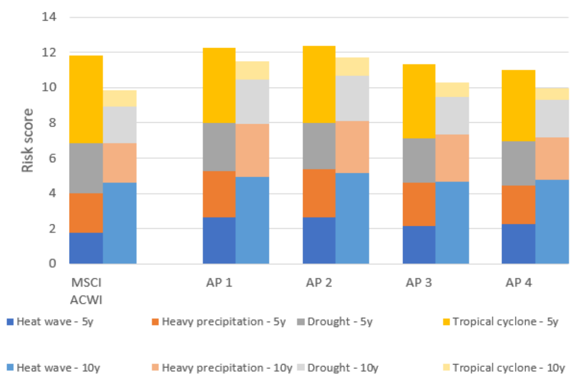
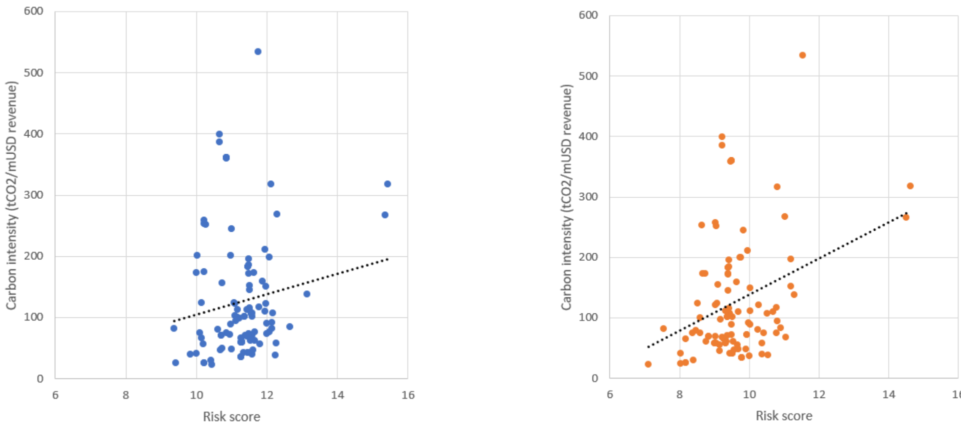


Figure 18: *Comparison of physical risk between the National Pension Funds of Sweden in the left bright bar and the market in the right pale bar.*

The risk score of AP1-AP2 ranged between 11.0 and 12.4 in 2021-2025 and between 10.0 and 11.7 in 2026-2030. Two of the funds had higher risk in 2021-2025 than the market, the other two had lower risk. In 2026-2030, all AP funds had higher risk than the market. The final characteristic on fund level that was tested for its relation to physical risk was the strategy of minimising carbon intensity, see Figure 19a and 19b.



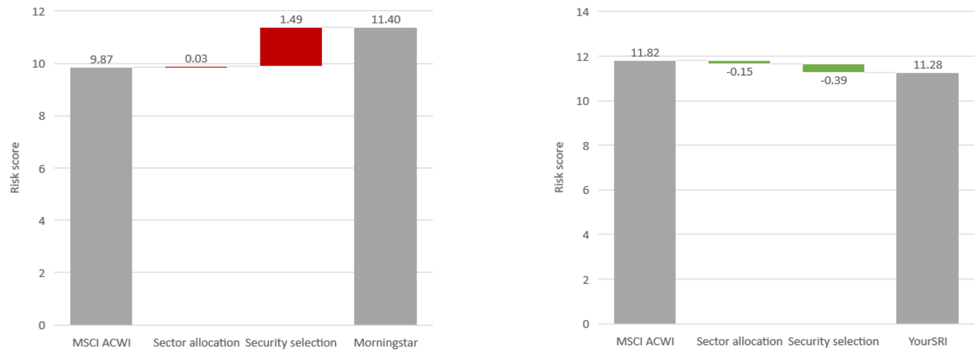
(a) Sustainable funds of YourSRI in 2021-2025. *(b) Sustainable funds of YourSRI 2026-2030.*

Figure 19: *Relation between carbon intensity and risk.*

The average carbon intensity of the funds was 127 tCO2/mUSD with a broad range from 23 tCO2/mUSD to 534 tCO2/mUSD. The carbon footprint on MSCI ACWI was 195 tCO2/mUSD. No correlation was found between carbon intensity and the risk in 2021-2025 or in 2016-2030 for the sustainable funds of YourSRI, see Figure 19a and 19b. The Pearson correlation coefficients was 0.15 for the risk in 2021-2025 respective 0.32 for the risk in 2026-2030.

5.3.2 Sector Allocation

Attribution for physical risk based on sectors shows that for all funds and periods (except Nordic Swan Ecolabel in 2026-2030), the selection of companies within sectors is more important than the sector allocation to explain differences in risk. This is particularly true for the sustainable funds of Morningstar. For the funds of Morningstar in 2021-2025, the increased risk due to security selection within sectors is larger than the total difference in risk score. For the funds of Morningstar in 2026-2030, almost 98% of the difference in risk is derived from disadvantageous security selection within sectors, see Figure 20a. For the sustainable funds of YourSRI the selection of companies within sectors instead is an important contributor to lower physical risk compared to the market in 2021-2025. Around 70% of the difference in risk compared to the market can be attributed to better selection within sectors, see Figure 20b.



(a) Sustainable funds of Morningstar compared to the market in 2026-2030.

(b) Sustainable funds of YourSRI compared to the market in 2021-2025.

Figure 20: *Attribution based on sectors comparing two groups of sustainable fund with the market. Red colour marks contributions to an increased risk score, and green marks contributions to a decreased risk score.*

Figure 21 shows a more detailed view of the sector attribution for the sustainable funds of YourSRI in 2021-2025.

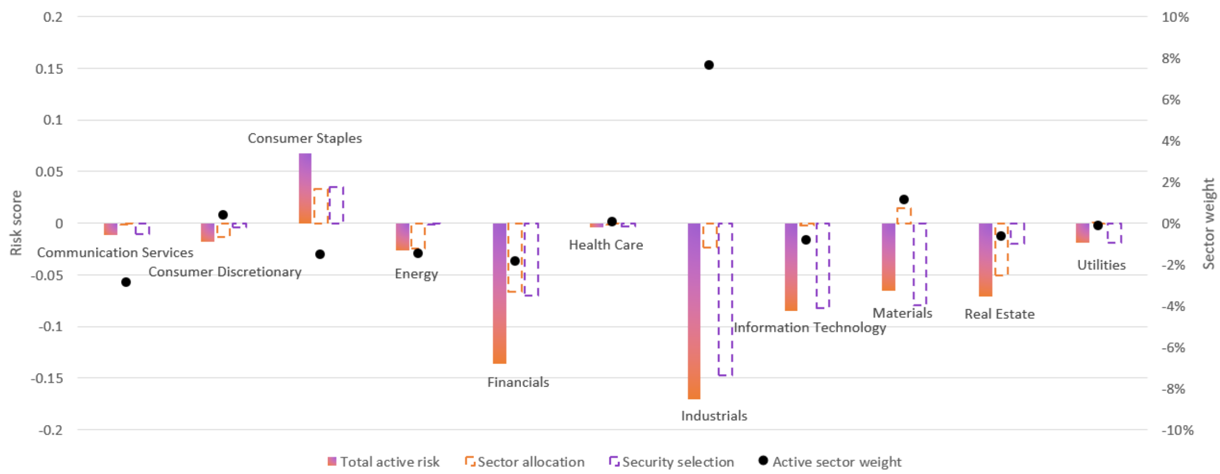
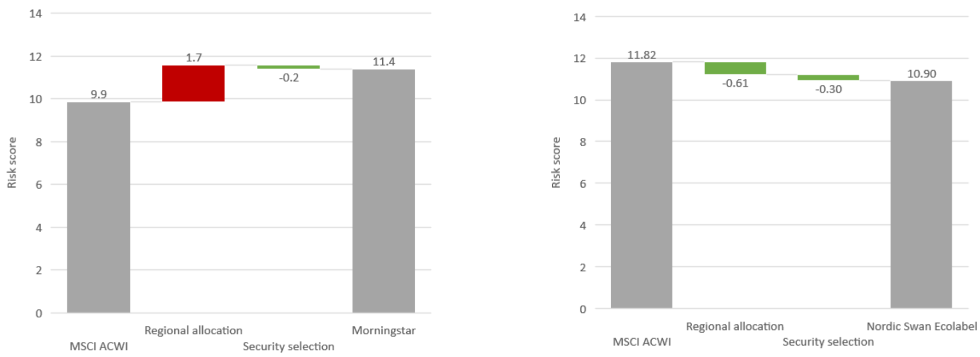


Figure 21: *Detailed view of the sector attribution for the sustainable funds of YourSRI in 2021-2025. Active sector weight is the sector weight compared to MSCI ACWI. A negative contribution represents decreased risk.*

The major difference in risk compared to the market for the funds of YourSRI in 2021-2025 comes from Industrials where the sustainable funds select better companies. Note that this does not say anything about the absolute risk contribution since the sector weights are not taken into account. Industrials include for example renewable energy companies. The funds of YourSRI also benefit from having a higher weight in Industrials compared to the market (MSCI ACWI). The overweight in Consumer Staples is disadvantageous from a physical risk perspective. The funds of YourSRI also select disadvantageous companies within this sector which contributes to a higher risk.

5.3.3 Regional Allocation

Attribution based on regions show that the regional allocation is an important explanatory factor for the higher physical risk for the sustainable funds of Morningstar compared to the market. If the sustainable funds of Morningstar would have a regional allocation as the market (MSCI ACWI), their physical risk would be 1 risk point lower in 2021-2025 and 1.7 risk points lower in 2026-2030, see Figure 22a. The regional allocation is also an important explanatory factor for the lower physical risk for sustainable funds of Nordic Swan Ecolabel compared to the market. Two thirds of the total difference of 0.9 risk points can be explained by advantageous regional allocation, see Figure 22b.



(a) Sustainable funds of Morningstar compared to the market in 2026-2030.

(b) Sustainable funds of Nordic Swan Ecolabel compared to the market in 2021-2030.

Figure 22: *Attribution based on region comparing two groups of the sustainable funds with the market. Red colour marks contributions to an increased risk score, and green marks contributions to a decreased risk score.*

A more detailed view of the regional allocation of the sustainable funds of Morningstar show how the regional tilt towards Asia and from North America contributes to a higher physical risk, see Figure 23. Both the overweight in Asia and the underweight in North America is disadvantageous from a risk perspective compared to the market.

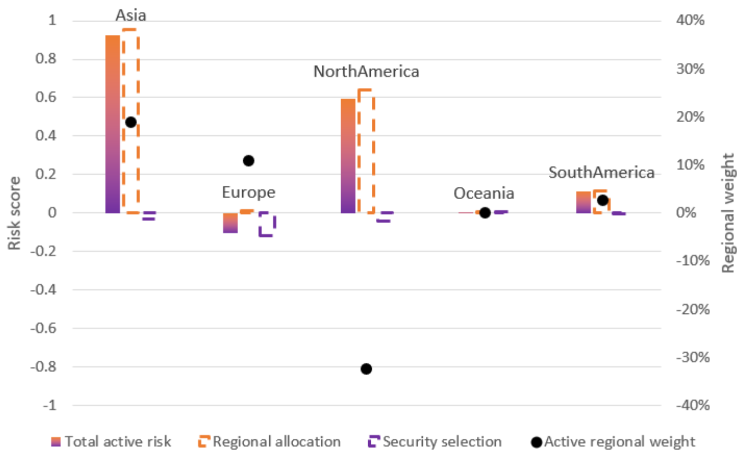


Figure 23: *Detailed view of the region attribution for the sustainable funds of Morningstar in 2026-2030. Active regional weight is the regional weight compared to MSCI ACWI. A negative contribution represents decreased risk.*

Within the regions, almost all sustainable funds for all periods (except Nordic Swan Ecolabel in 2026-2030) select better companies than the market. In other words, they decrease their physical risk compared to the market by a better security selection within regions.

5.3.4 Market Cap Size

MSCI ACWI is an index of only mid and large cap companies. The sustainable funds include also small cap companies. Attribution analysis shows that allocation to small cap companies is disadvantageous from a physical risk perspective compared to the market (MSCI ACWI) for all sustainable funds, see for example the sustainable funds of YourSRI in 2026-2030 in Figure 24. The trend is stronger for all funds in 2026-2030 than 2021-2025.

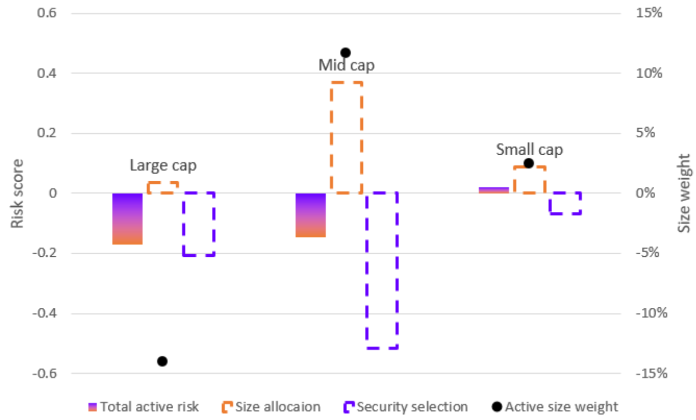
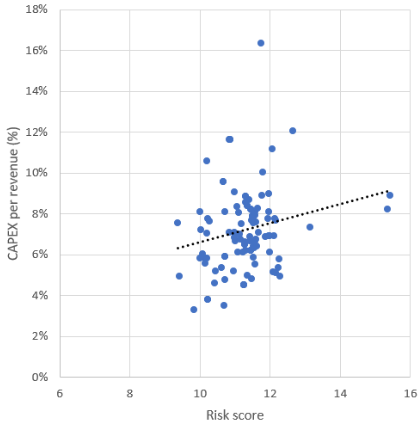


Figure 24: *Detailed view of the market cap size attribution for the sustainable funds of YourSRI in 2026-2030. Active size weight is the size weight compared to MSCI ACWI. A negative contribution represents decreased risk.*

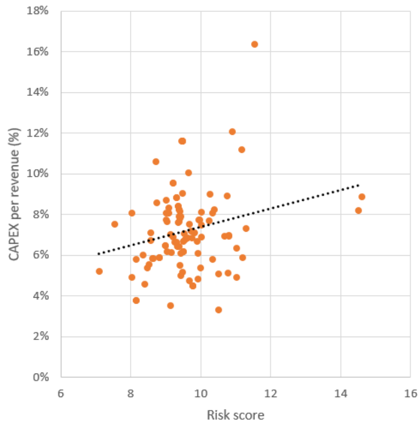
All sustainable funds also show a disadvantageous overweight in mid cap companies compared to the market. The total market cap size allocation is hence disadvantageous for all sustainable funds compared to the market. The sustainable funds of YourSRI and Nordic Swan Ecolabel do however, fully or partly, compensate by a better selection of companies within the market cap group. For example, for the funds of YourSRI in 2026-2030 the selection of companies within mid cap contributes to a total risk contribution from mid cap companies that is negative (decreases the total risk), see Figure 24.

5.3.5 CAPEX

The correlation between physical risk and CAPEX is non-existent or very weak, see Figure 25a and 25b.



(a) Sustainable funds of YourSRI in 2021-2025.



(b) Sustainable funds of YourSRI in 2026-2030.

Figure 25: *Relation between CAPEX and risks.*

The Pearson correlation coefficient between CAPEX per revenue and the risk in 2021-2025 is 0.20. The correlation coefficient to the risk in 2026-2030 is 0.24. The average CAPEX per revenue (in percent) for the sustainable funds of YourSRI is 7.2%, which is lower than the market average of 8.7%.

6 Discussion

This chapter provides the discussion of the study. First, the method and the assumptions made in the study are discussed. Thereafter follows the discussion of the relevance of the results. Finally, the meaning of the results for the market of sustainable funds and portfolio construction is interpreted.

6.1 Discussion of Method

In this study, the top-down method of quantitative modelling was selected to approach the evaluation of physical risks. From a philosophy of science perspective, models can be described as "an interpretative description of a phenomenon that facilitates access to that phenomenon." (Bailer-Jones 2009, p. 1-2). In other words, a model is an approximation of real world phenomenon that are complex or difficult to describe directly. Models strive to be close to reality, but they are always approximations (*ibid.*). Quantitative modelling offers objective computations with comparable results - all funds are evaluated according to the exact same process. An important contribution of top-down quantitative modelling is to provide large scale analysis and screening for trends or characteristics. The results are of interest on aggregated level, but cannot provide insights on specific details. Models are today important tools both in finance and climate research (Ravindran *et al.* 2014; Rummukainen 2010). Two key factors for the reliability and validity of the model output are the underlying data and the assumptions made to simplify the reality. These factors are discussed in this section. Furthermore, the alternative model parameters are discussed for improvement of future models. Finally, the method of analysis of the model output is discussed.

6.1.1 The Challenge with Tail Volatility in the Underlying Climate Data

The main underlying data of this model are climate and company data. As described in section 2.4, each climate model has its specific assumptions and priorities with strengths and weaknesses. A common method to minimize potential errors in individual models is to couple several models (Tebaldi *et al.* 2007). In this study, four different models were therefore applied. This strengthens the reliability of the model as the coupling of models increases the likelihood that also other climate models would give the same result. The models show strong correlations for average temperature over a five year period, see Figure 5a. However, the correlation is significantly weaker in the tails of the models, see Figure 5a. Volatility in the tails is a general problem for modelled data, the precision is often better around the mean value (Castillo *et al.* 1997). When studying acute physical risks, the interest is in the extreme values in the tail - the most extreme events that are likely to be the most costly occur in the tails. Tail volatility is therefore a challenge in this study as well as in other studies on acute climate risks (Cooley 2009; Katz 1999; Towler *et al.* 2010). The challenge does not occur when studying incremental physical risks. Another challenge with global climate data is the limitation in resolution (Feser *et al.* 2011). The resolution of the selected climate models varies between 0.34 and 2.79 degrees latitude and between 1 and 2.81 degrees longitude, see Table 3. The largest grid box is approximately 31 km × 31 km. The result is a mean value of the climate within this box, which can leave out important extreme values. Furthermore, the coordinates of the capital can therefore not be measured exactly. As an example, the largest deviation between the real coordinates and the coordinates in the data for heat waves is 1.39 degrees longitude and 1.4 degrees latitude. This is equal to a deviation of around 15 km longitude and latitude.

Regarding the data on company details, it is reported by the companies in annual reports or similar and translated to a standard format by the data provider. In this translation process, data can get lost. It is for example common that companies report a region as asset location instead of a country. Not all companies have complete data sets. From the original full universe of almost 52,000 companies, around 26,000 companies can be evaluated. Companies that lack complete data are for example companies that no longer are listed, but there is also a reporting bias. However, larger companies that are common in portfolios are more likely to have complete data and on aggregated fund level this bias should therefore not have a large impact on the results.

6.1.2 Transparency on Assumptions to Ensure Reliability

Besides the underlying data, the assumptions and approximations of the model are also important for the quality of the output for the model. It lies in the nature of models that they must rely on certain assumptions. It is likely that other models for physical climate risk to some extent would have different priorities and assumptions which could give a different output. To increase reliability of the study, transparency of these assumptions is important. Many of the assumptions have already been described in the methodology. Here follows a discussion of some of the critical assumptions in more detail.

When measuring the hazard intensity for a company, the coordinates of the capital of the country of reported asset location is applied. As climate change will not have a uniform effect, this assumption comes with limitations. The assumption is more valid in smaller countries and in certain sectors, for example Real Estate and Accommodation and Food Services are likely to be centered in the capital while Agriculture and Mining, Quarrying, and Oil and Gas Extraction are not. Many of the common countries to invest in are larger countries and this is therefore a simplification that affects the validity of the model. However, as no large scale data for the exact location of company's assets was available this was regarded the best viable option. To calculate an average of the country is not desired since it is the extreme values that are of interest. It should also be noted that only the change in hazard indicator impacts the result; therefore, it does not matter if a country has warm and cold areas if the relative change is the same.

Sector vulnerability is here evaluated on sector level. NAICS divides the universe into 24 sectors which is not a very granular grouping of companies. It is for example likely that agriculture will be affected differently depending on the type of crop cultivated. This assumption therefore impacts the validity of the study. Going into sub-sector level would however have implied a trade-off between uncertainty and detail. As of knowledge, there is no comprehensive study that compares sub-sector vulnerability of natural hazards. Most studies, for example Lenzen *et al.* (2019), Xia *et al.* (2018), Hallegatte (2008), are made on sector level. Previous studies on physical climate risks have also applied vulnerability scores on sector level (see Mercer (2015) and Fang *et al.* (2018)). No reliable data could hence be leveraged for sub-sector level evaluation. An evaluation on sub-sector would therefore have needed to rely mainly on assumptions which would have increased the uncertainty.

The selection of hazard indicators (see Table 4) is critical to the output of the study. Because of their significance for the result, it was considered to apply several indicators and calculate an average. However, as averages even out extreme values this was not made. The fact that indicators are calculated only on five year averages is another challenge. Time horizon is generally a challenge in the intersection between climatology and finance where climatology have longer time horizons than finance (Ralite *et al.* 2019). As the climate is defined for 30-year periods, no conclusions about future climate trends can be made based on five year data. However, for the interest of investments of this time spectra, it is of less importance if the change will be sustained or if it is a temporary fluctuation.

The management of supply chain in this study has the assumption that companies within the same sub-sector will have similar suppliers in terms of where they are located. Because of the fact that the location data is based on the suppliers of the largest companies, it is likely that there will be a tilt towards the larger economies. Indeed, the US is the top most common asset location for the standard suppliers. However, also Vietnam and Italy are common locations. Since the companies with larger revenue also are likely to be more present in common portfolios this is considered a fair assumption that reflects reality. Although it would be desirable with large-scale, quality data for supply chain relations, this approach has the advantage of better reflecting the market of available suppliers. This is of relevance since a company may change supplier if its supplier is frequently damaged by natural disasters. It should be noted that in some sectors very few companies had data for supply chain relations which limited the representativeness of the standard supplier.

A limitation of this model is that no company or country specific features are regarded; one such feature that is important is the ability to adapt to climate change. OECD (2015) state that the regions' ability to adapt by changing technologies, consumer behaviour and trade patterns will be important for what magnitude of damage climate change will cause. Although no correlation was shown between climate risk and CAPEX, see Figure 25a and 25b, investment in adaptation measures can mitigate the effect of certain natural hazards. Examples of adaptive measures from the final Taxonomy report by TEG (2020) are use of early warning systems for wildfire, construction of irrigation systems and strengthening of dams. Countries also have different vulnerability for climate change, for example different standards of infrastructure. It is also likely that countries that today are on the edge of managing climate relate challenges may be more sensitive than countries with a larger marginal. The assumption here is that the market is effective and has included such sensitivity in the valuation. It can however be questioned how well informed the market is on these issues, for example based on the survey referred to by Clapp *et al.* (2017) where investors state that guidance on how to manage physical climate risks is lacking.

6.1.3 The Importance of a Supply Chain Perspective

The importance of a supply chain perspective has become evident during Covid-19. For example, when China shut down production of pharmaceutical ingredients to limit the spread of the virus, this largely impacted the industry as China produces 70% of these ingredients globally. Events in one country affect also other countries through interconnected supply chains (Oxford Business Group 2020). Previous studies also highlight the importance of a supply chain perspective for natural hazards, for example the study by Xia *et al.* (2018) and (Haraguchi *et al.* 2015). The test of the model with alternative weights for supply chain risk did not show very large changes on aggregated sector or region level in absolute risk score. However, the changes are not insignificant and at a closer look also the results of this study strengthen the need of a supply chain perspective when studying climate risks. For both regions and sectors the relative risk between the groups changed. Generally when weighting supply chain the highest, the risk decreased for the regions with highest risk and increased for the region with the lowest risk. The larger changes do however occur at country level. The fact that the risk increases with increases supply chain weight for countries with low risk, such as Sweden, is perhaps not surprising but illustrates that climate change is a common risk globally that no country can escape. The characteristics of the risk per sector also changes when considering supply chain. In this study, the risk profile probably becomes more similar to the one of the larger economies as they dominate for the standard suppliers. This reflects that the climate risk in main export countries will have a larger impact on the economy as a whole.

Regarding the other alternative model parameter - weighting of the natural hazards - it is also shown to impact the results, particularly on country level. The aggregated risk on region and sector level is less affected. As the estimations of weights for the natural hazards was quite rough in this experiment, the results rather serve as an indication that further research would need to be done on natural hazards relative importance to each other in order to refine the model and find optimal weights. No other, more specific conclusions should be drawn from the result.

6.1.4 The Challenge to Define Sustainable Funds

Regarding the analysis of the output of the results, the challenge of defining sustainable funds was very present in this study. This is a well know challenge discussed by many parties, notably Eurosif (2018) and The European Commission (2018). The increasing demand for sustainable products on the financial market (Eurosif 2018) could be a contributing factor the the width of sustainability offerings which could very well be regarded positive, but at the same time it makes it difficult for investors to navigate sustainability in investment management. The need of a common definition of sustainability that hopefully will be brought by the EU Taxonomy is clear. The EU Taxonomy will also make it clear why the company or fund is regarded sustainable, for example because of sustainable management of climate risks (TEG 2020). The selection of three different sustainability certifications/ratings decreases the impact of the challenge to define sustainable funds; however, the samples showed to not be fully comparable. Most importantly, the regional tilt for the funds of Morningstar is not regarded as representative since Morningstar does not have a specific profile of Asian companies. The sample of equity funds certified with the Nordic Swan Ecolabel is also fairly small, and with a significant sector tilt towards Europe compared to MSCI ACWI.

6.2 Relevance of Results

6.2.1 Natural Variability is Important on a Short Time Scale

At first glance on the results, it may seem unintuitive that the total risk is higher in 2021-2025 than in 2026-2030. It may also be surprising that the type of risk changes so drastically between the two periods studied. However, as described in section 3.1 the natural variability of the climate is large and five years is a short period in climatology.

Particularly, interannual variability is prominent on this time scale (Bartlein 2013). Dai *et al.* (2018) state that natural variability, such as ENSO events, can dominate anthropogenic impact on heavy precipitation in the mid to late twenty first century. The change of the climate that can be attributed to human activities will increase beyond five or ten years into the future according to IPCC (2014), particularly if greenhouse gas emissions continue to increase. The insight of lower risk in many countries in 2026-2030 compared 2021-2025 could potentially give rise to investment opportunities.

The risk that decreases the most in 2026-2030 compared to 2021-2025 is the risk for tropical cyclones. Temporary decreased risk of tropical cyclones could be explain by variability of ocean currents such as ENSO events. The motion of ocean currents is also a plausible explanation for why the risk of heat waves and tropical cyclones do not correlate. Although a high air temperature contributes to heating the oceans, ocean currents also have an important impact on sea surface temperature (Kayano *et al.* 2005). It should also be remembered that tropical cyclone genesis occur in a limited area close to the equator while heat waves can occur globally. For drought and precipitation events it is expected that they follow each other since the total amount of precipitation will not change significantly globally (Trenberth 1998).

6.2.2 Difficult to Compare Previous Studies of Sector Risk

Because of the scarce offering of previous, global studies in this area, there are not many studies that the results of this study can be compared to. For sector distribution, only the study by Ralite *et al.* (2019) can be used for comparison and also that comparison is problematic. Ralite *et al.* (2019) study only incremental climate effects on sector level, while this study includes both incremental and acute effects. The study by (Georgopoulou *et al.* 2015) can be used as an indicator for comparison but since they only cover Greece the results are not necessarily translatable to a global context.

When comparing the results on sector risk of this study in Figure 6a and 6b by the results from Ralite *et al.* (2019), the risk for agriculture is high in Ralite *et al.* (2019) which is not reflected in this study. Georgopoulou *et al.* (2015) also show high risk for the agriculture sector. The sector classification for comparing sector risk is in this study is made according to GICS where food and other agricultural products are classified within the larger category Consumer Staples. Consumer Staples also include the sale of food, which according to Georgopoulou *et al.* (2015) has significantly lower risk. When looking at the sector vulnerability of this study (made in NAICS), Agriculture has about the same sector vulnerability as Real Estate, the sector with the highest risk according to this study. The sales of food (Retail); however, has very low vulnerability. Another sector with high risk according to Ralite *et al.* (2019) is energy and extraction. Materials, which includes products from extraction, do indeed have a high risk also in this study. Energy (which includes oil and gas) and Industrials (which includes renewable energy) have high risk in one period each, Energy is the fourth sector of most risk in 2021-2025 while scoring among the sectors of lower risk in 2026-2030. Industrials is in the middle in terms of risk in 2021-2025, but the second sector with most risk in 2026-2030. A final observation when comparing the results of this study with the results of Georgopoulou *et al.* (2015) is that the hotel business have high risk in their study. Hotel business is in the GICS system included in Consumer Discretionary. Again, this category includes also other economic activities which makes comparison more difficult. Nevertheless, Food and Accommodation Services in this study have low vulnerability which indicates that there would be a difference compared to Georgopoulou *et al.* (2015) regardless of industry classification system. The comparison do however raise the question on whether the GICS system is the most suitable industry classification system when evaluating risk since key sectors are not very distinguished.

Neither the study by Ralite *et al.* (2019) or Georgopoulou *et al.* (2015) cover the Real Estate or Financial sector, the relevance of the high risk for these sectors can therefore not be commented based on previous studies. However, both these sectors have a high sector vulnerability assessed based on previous studies (empirical as well as theoretical studies), the high risk is therefore not surprising. When comparing the sector risk to the results in the survey on large companies by CDP (2019), the financial sector also identifies the by far largest physical risk. Furthermore, CDP do not separate Real Estate (that has the highest risk in this study), and the risk of Real Estate may at least partly fall into Financials in their sector classification.

6.2.3 Regional Risk Findings Resemble Previous Studies

For regional risk, the study by Ralite *et al.* (2019) and Schroders (2020) offer comparison. The study by S&P Global (2015) and OECD (2015) can also provide some comparison; however, since these are based on countries or regions rather than equities the comparison has to be made with caution.

The study by Ralite *et al.* (2019) show the largest impact on share prices from once in 250-year events for Asia. Asia does not have a low risk according to the results of this study, but it is not in the top. However, America has the second lowest risk which corresponds better to the results of this study, especially for the five year risk. Europe has the lowest risk in both this study, the study by Ralite *et al.* (2019) and the study by S&P Global (2015). The difference in risk between the regions is significantly larger in the study by Ralite *et al.* (2019) than in this study. This is probably explained by a longer time horizon. The fact that Ralite *et al.* (2019) base their results on correlation with GDP could also contribute. Such an approach does not take into account for example supply chain effects and the results of this study show that considering supply chain risks decreases the spread between regions and sectors. The study by Schroders (2020) evaluates physical risk based on temperature shocks. Their results are therefore expected to be most similar to the results for risk in 2026-2030 as heat waves then are more prominent. Indeed, among the countries in their sample with the most negative impact on equities from physical risk are Singapore, Indonesia and Hong Kong that also are among the top 15 countries with the most risk in 2026-2030. The United States and Canada are among the 15 countries with the lowest risk which is also reflected in Schroders (*ibid.*).

The study by S&P Global (2015) includes only the risk of flood and tropical cyclones. Their result should therefore be most similar to the risk in 2021-2025 when tropical cyclones dominate, and the similarity is expected to increase when weighting the natural hazards, as tropical cyclones and floods both have high weights. When comparing the results for the regions included in S&P Global (2015), South America indeed has the highest risk both according to their results and 2021-2025 in this study. When weighting the natural hazards; however, South America receives a lower risk in this study. Perhaps this trend is because S&P Global (2015) only study in total 38 countries, and the selection may have a bias towards countries where tropical cyclones and floods are more common as these events probably are better documented there. The study by OECD (2015) has a slightly different perspective as it focuses more on economic relations, it therefore provides an interesting comparison. The regions with most risk are Africa and Asia, party because of their smaller capacity to manage risks. The capacity to manage risks is not included in this model, and the difference between the results further emphasizes the discussion in section 6.1.2 that this is an important factor.

Regarding the companies' own view on physical risk for regions, it deviates clearly both from the results of this study and other studies. European large companies report the highest physical risk according to the survey by CDP (2019). This may reflect that self-reported physical risk is also an issue of awareness.

In summary, the model results of this study do not directly correspond to the results of previous studies, but considering the different approaches of these studies the deviations are not alarmingly large. Many of the general trends in sector an regional risk are common for this study and previous studies.

6.3 Interpretation of Results

6.3.1 Sustainable Funds Select Companies with Lower Risk in a Given Universe

Sustainable funds are not a homogeneous group when it comes to physical risk. Figure 15a and 15b show a spread in physical risk within sustainable funds. This is despite the restrictions on the samples of sustainable funds, such as a non-thematic focus and availability to Swedish investors. Because of the large variability among sustainable funds, no clear conclusions on how sustainable funds as a group compare to the general market in terms of physical risk can be drawn. Nevertheless, the results indicate that sustainable funds could have a lower physical risk than the market. The sample of 105 sustainable funds of YourSRI has significantly lower physical risk than the general market in both periods studied. The risk of the sustainable funds of Morningstar is significantly higher than the market in both periods; however, this can to a large extent be explained by the regional tilt in the sample. If the funds of Morningstar would have the same regional allocation as MSCI ACWI they would actually have a lower physical risk than the market in both periods, see Figure 22a. Investment restrictions, including regional restrictions, were here assumed to be active choices but the large regional tilt that the funds of Morningstar have is not considered, as discussed above, a representative sample. The funds of the Nordic Swan Ecolabel is a significantly smaller sample than the other two and has a regional tilt towards Europe. It is therefore more uncertain to draw conclusions from. The result of the funds of YourSRI is regarded the most representative, but considering the poor correlation between different sustainability ratings shown by (Kumar *et al.* 2019) only indicative conclusions can be drawn for the whole market of sustainable funds. Furthermore, the difference between the funds of YourSRI and the market in physical risk was not large. The funds of YourSRI are global and many are probably measured against benchmarks similar to MSCI ACWI. To reduce tracking error, they stay close to index.

While no unambiguous conclusions can be drawn regarding the physical risk of sustainable funds compared to the market, there is stronger evidence that sustainable funds select equities with lower physical risk within investment restrictions. For almost all studied periods and sustainable fund groups, the security selection within the category contribute to a decreased physical risk. Advantageous security selection is made within sectors, regions and market cap size, see for example Figure 20b, 22a and 22b. A notable exception from this is the sustainable funds of Morningstar for selection within sectors, which likely can be explained by the disadvantageous regional tilt. It is mainly in the security selection where the sustainable funds have room to make choices because of other considerations, such as diversification and tracking error. The assumption in this study is that all deviations from index, investment restrictions as well as security selection within restrictions, are active choices. It is possible that if only security selection would have been regarded as an active choice the result would have been different. In such a study the approximation of the market must instead of a global index be the actual benchmark of the fund. For example, a sustainable fund with a Nordic focus would be compared to a Nordic benchmark. The preferences in assumptions is here more of a philosophical question. Should sustainability be measured relatively to a group of comparable peers (i.e. only security selection is an active choice) or should sustainability be measured more absolute (i.e. also investment restrictions are active choices)? From an equality perspective it could be argued that all regions, sectors and sizes should have a fair chance to reach sustainability in a best-in-class system. Investments are needed also in countries of high climate risk, but these can be made more or less sustainable. On the other hand, an absolute definition of sustainability makes it more transparent for the investors to understand what a sustainable investment represents. It could also be argued that there must be a minimum level of protection for physical risks for an investment to be called sustainable to not dilute the concept.

6.3.2 The Question of Fortunate Coincidence or Active Choice

It cannot be concluded from this study whether the selection of securities of lower risk is a result of active choice and awareness of physical risks, or if it just a fortunate side effect of security selections motivated with other reasons. Lower physical risk could for example coincidence with other sustainability considerations. As described in previous studies, companies regarded as environmentally sustainable have in general lower credit risk (among other: Graham *et al.* 2006; Henisz *et al.* 2019; Höck *et al.* 2020; Schneider 2011; Weber *et al.* 2015), however, this is not connected to physical risk specifically. Neither this study can show what these sustainability factors could be. Because of large differences in other characteristics between the groups of sustainable funds, no conclusions can be drawn on sustainable investment strategies for the samples. The differences in risk between the groups are more likely to be explained by other factors than strategies. See for example Figure 17 where regional allocation is shown to be the major explanatory factor of the difference between the physical risk of Morningstar compared to YourSRI. Neither do the Norm-based screening and Engagement of the National Pension Funds prove to be an advantage or disadvantage from a physical risk perspective, no clear trend on the risk of the National Pension Funds can be distinguished. The only sustainable strategy that clearly can be shown to have almost no impact of physical risk is minimising of carbon intensity of a portfolio, see Figure 19a and 19b. This is an important result since carbon intensity is a common sustainability measure of funds; the result is also in line with previous studies by Clapp *et al.* (2017). Many investors rely on carbon intensity for evaluating sustainability in general, including physical risk, according to Clapp *et al.* (2017).

It is also important to note that there does not seem to be a conflict between the objective to minimize carbon intensity and minimising physical risks. The result hence indicates that it is possible to construct a portfolio with a low carbon intensity and a low physical climate risk exposure.

6.3.3 Region and Size are Important Characteristics for Physical Risk

When studying the factors that potentially could impact physical risk on equity level (see Figure 4), it seems like regional and size allocation are important. For many funds, the selection of regions is more important than the selection of securities within the region in the comparison of physical risk to the market. Funds that overweight European stocks compared to the market had an advantage from a physical risk perspectives because of the relative low risk in the region. Furthermore, there are large differences between countries within regions. The allocation of size is also an important contributor to physical risk when comparing to the market. Larger companies do in general have lower risk. This strengthens the theory that larger companies have a more diversified physical risk because of their wider spread over several regions and countries.

Sector allocation and CAPEX seems to be less important predictors for physical risk. The selection of securities within the sector is more important than the selection of sectors when comparing sustainable funds to the market. However, some sectors prove to have significantly lower risk than other. The risk of Health Care is less than half of the risk of Real Estate in 2026-2030. Average CAPEX of the fund is shown to have no correlation with physical risk. There is hence no indication of that funds with high average CAPEX would hold companies that are aware of a high risk and therefore investing in adaptation measures. The estimate of average CAPEX per revenue on fund level is however a quite rudimentary proxy on adaptation measures, particularly since adaptation measures are not likely to represent a large part of total CAPEX for most companies today.

6.3.4 The Creation of a Portfolio of Low Physical Risk

If applying these conclusions in the creation of an equity fund with minimized physical risk, it is likely that this fund would be a sustainable fund. It is however unclear what type of sustainable investment strategies that it would apply, or what sustainability ratings or certifications that are most plausible. An important focus of the fund would be large companies registered in Europe. The sector allocation would come as a second priority, but a tilt towards Health Care, Retail and Utilities is desirable while reducing Real Estate, and Financials. No considerations would be made towards carbon intensity or average CAPEX. Now, this is of course very speculative and this fund is undesirable from many other aspects. The reasoning does however illustrate that physical risk cannot be treated separately. Both from a financial perspective and a sustainability perspective the construction of a portfolio must take also many other considerations into account. From a climate justice perspective, investments must be made outside Europe and large companies. Countries of the developed markets have generally contributed the most to the changed climate, while countries of emerging markets generally are the ones that will be worst affected by the consequences of climate change (Kanbur *et al.* 2018). Companies and countries with the highest physical risk are likely to have to make investments into adaptation measures in the future, and equities is one of the possible sources of liquidity for this. In a longer time horizon of physical risks, it is also important to steer capital towards the transition towards a low-carbon economy to mitigate climate change. Managing the effects of physical climate risks is just a relaxation of the symptoms, it does not treat the root cause of the problem.

Although physical risk is not the only factor that can be considered when constructing a portfolio, the awareness of physical risks contributes to an informed investment decision. Clapp *et al.* (2017) have previously shown that the maturity of investors' knowledge on physical risks is low. The comparison of this study's results with the understanding of physical risks regionally among companies (CDP 2019) further highlights that also the awareness of physical risks among many companies is poor.

7 Conclusions

7.1 Implications

The aim of this study was to investigate the physical climate risks of sustainable funds in comparison to the market, and to evaluate which characteristics that contribute to a high respectively low physical risk. The study did not give a clear answer on how sustainable funds in average compare to the general market for climate risks, perhaps because sustainable funds is a broad group with different characteristics. However, the results indicated that sustainable funds select better equities within specific investment restrictions such as regions and sectors. It is therefore possible that the result would be different if comparing the sustainable funds with their own benchmarks with more similar investment universe. In the comparison between global and non-thematic sustainable funds from YourSRI and the market represented by the global index MSCI ACWI, the sustainable funds proved to have a significantly lower risk in both periods studied. The sustainable funds of Morningstar had a heavy regional tilt which significantly impacted their physical risk. If the sustainable funds of Morningstar would have had the same regional allocation as MSCI ACWI, they would have had a lower physical risk than MSCI ACWI.

This study could not give an answer on what sustainable investment strategies that impact climate risk, it did however show that minimising carbon intensity of a fund has almost no impact on physical climate risk, neither positive nor negative. Previous studies have shown that investors in general do not know how to manage climate risks in their investment decisions, the awareness is low (Clapp *et al.* 2017). The results of this study further emphasize the challenge of low awareness of physical risks among investors. Although there is an indication that investing into sustainable funds may result in a lower physical risk exposure compared to peers, investing in sustainable funds is certainly not a guarantee for low exposure to physical climate risks. Furthermore, this study proves, in line with previous studies (*ibid.*), that the common sustainability indicator carbon intensity does not provide guidance for investors on physical climate risks. There is, at the time of writing, no simple guidance for investors on how to minimize physical risk exposure. Because of the complexity of physical climate risks, this puts a heavy burden on investors. The new EU Taxonomy will hopefully offer guidance on climate risks and adaptation for investors, particularly once the disclosure obligation for large companies enters into force (TEG 2020).

In the academic sphere, the physical climate risks for equity portfolios is still only briefly covered, and many of the studies that do exist are rudimentary and not regarding the different types of risks or drawing simplistic correlations to predict future performance. Physical climate risk is a complex research area because of its interdisciplinary character with one leg in climate research and one leg in finance. In comparison to transitiona risks, it requires deeper knowledge in the natural sciences which is not always well represented in the finance sphere. This study has however shown that physical climate risks can be integrated into more traditional financial analysis. The analysis of the study was structured according to a framework that merged a traditional financial view on equity risk and the impacts from physical risks. This framework has shown to be useful for the analysis of physical climate risks.

The main contribution of this study is nevertheless a quantitative modelling framework for physical risks. Few studies before have modelled physical risks large scale, and none of these have systematically described the modelling methodology and the output. No study before this one has included supply chain implications, from the understanding of the disclosed methodology. The analysis in this study emphasizes what previous studies (for example Xia *et al.* 2018 and Haraguchi *et al.* 2015) also have stated about the importance of a supply chain perspective when evaluating physical climate risks. A quantitative top-down approach to physical climate risks provides investors with an overview of the potential investment universe and outlines the context of physical risks for academia. Models can be used for finding patterns and screening out interesting cases in a larger universe. Such analysis is very time consuming and resource intensive if made with bottom-up methods, for example the methods of Nikolaou *et al.* (2014). Cojoianu *et al.* (2017) and (Zeidan *et al.* 2015) where sustainability reports must be scanned, sub-sector analysis performed or questionnaires sent out. Top-down analysis with quantitative models therefore serves as an important complement to bottom-up studies, where bottom-up studies can analyse company by company in depth. Other natural hazards than the ones selected in this model such as wildfires, pandemics and pests could also be included in a similar framework of quantitative modelling. However, the more parameters that impact the hazard the more complex becomes the modelling.

Investing is a game of information and many sources, not least the Global Risk Report (World Economic Forum 2020) indicate that the information of physical climate risks will become increasingly important for investors in the future. Investors that are aware of physical climate risks will have an advantage in this game of information. In a larger perspective, investor awareness can also benefit the economy as a whole. Investment capital is an important driving force for the direction that society will take (The European Commission 2018). Investors as a group have the power to steer capital away from businesses that are particularly susceptible to climate change into more resilient alternatives. Investors that are aware of physical risks can thereby contribute to reducing the economic damages from climate change.

7.2 Further Studies

The need for further studies within the area of physical climate risks in investments is evident. The model developed in this study can be applied to answer many more research questions. An interesting next step of this study would be to compare the physical risk of sustainable funds with the physical risk of their specific benchmark, instead of a general global benchmark as applied here. Such a study would contribute to further investigate the indication from this study that sustainable funds select lower risk securities within a given investment universe. A longitudinal study could also evaluate the development of regions with high risk for certain natural hazards. Will companies of high vulnerability move away from these regions?

To strengthen the research area of large scale analysis of physical climate risks, more models must also be developed. Climate models are often coupled to increase precision and gain a majority view of priorities (Tebaldi *et al.* 2007). Similarly, the model developed in this study would need to be coupled with other models. Other models may for example make different evaluations regarding sector vulnerability or apply alternative indicators for hazard intensity. Three key areas where potential improvements are identified are adaptive capacity, nuances in hazard indicators and detail level for sector vulnerability. First of all, in this model all companies in the same sector and at the same location are evaluated to have the same risk. No company-specific characteristics such as adaptive capacity are considered. When the disclosure obligations of the EU Taxonomy for climate adaptation enters into force, the availability of such data will increase and can be incorporated as a factor in the model. Secondly, the hazard indicators could be refined by considering seasons and interrelations. Droughts should for example be more critical for the agricultural sector in the growth season than in the winter season, and rain deficits more severe if happening at the same time as a heat wave. Lastly, the evaluation of sector vulnerability would need further level of detail. This is an example when bottom-up research and quantitative modeling can complement each other. A bottom-up research study could for example evaluate vulnerability for representative companies of clusters of sub-sectors. Case studies of previous natural hazards on sub-sector level could also contribute to a more nuanced vulnerability evaluation.

There is a lot of uncertainty on the future climate with complex feedback mechanisms and potential tipping points. Where will the world's action for mitigating climate change lead? Will the Paris agreement of limiting warming to below two degrees be achieved? However, what is certain is that the impacts of a changing climate are and will be noticeable today and in the future. To manage these effects, frameworks for understanding climate risks are needed. Academic research on physical climate risks can play an important role in informing investors on physical risks and thereby contribute to increased resiliency of society.

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