Towards Greening Finance: Integration of Environmental Factors in Risk Management Impact of Climate Risks on Asset Portfolios

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2021

Towards Greening Finance: Integration of Environmental Factors in Risk Management & Impact of Climate Risks on Asset Portfolios[1]

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It is increasingly realized that financial-asset investors individually are not likely able to affect climate developments significantly, while the financial sector collectively cannot hedge all climate-related risks. Nevertheless, the financial sector could help channel savings into green projects through both equity and bond markets, and thus facilitate divestment from heavy carbon-footprint producers. This paper provides a novel framework for understanding climate-related adaptation, mitigation, and transition risks and outlines a method for valuing these risks in investors' portfolios. Our proposed comprehensive set up can serve as a call for action to longer-term institutional investors to obtain accurate information on climate-related risks, develop appropriate frameworks for understanding these risks, and regularly value them. We maintain that through improvements in the assessment of risks, financial stakeholders would be able to help better manage climate-related risks and facilitate an easier transition from brown to sustainable green finance.

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[4] We thank John Anagnostou, Adonis Kourtellis, Stelios Elia, Frederic Samama and Akis Souvaliotis for insightful comments and suggestions. The usual disclaimer applies.

I. Introduction

One of the aims of the 2015 Paris Climate Agreement is to make financial flows consistent with pathways towards low greenhouse gas emissions (GHGs) and climate-resilient economies (Farid et al., 2016). A growing body of research focusing on climate-related risks points to substantial physical, financial, and mitigation costs, amid the very limited progress the financial sector has since made in integrating climate-related risks in risk management practices and in transitioning to more climate-resilient balance sheets (Bolton et al., 2020, Engle III et al., 2019). In this context, we have observed that no study has so far examined ways that investors and asset managers could employ to make their portfolios resilient to climate-related mitigation and transition risks, while in the process assisting with the promotion of initiatives that could help avoid the most severe physical and financial costs of climate change and other global environmental challenges.

A central problem in dealing with climate-related risks is that individually investors are not likely able to affect the climate significantly, while collectively the financial sector cannot hedge all climate-related risks. However, investors could have a substantial effect on companies and other stakeholders in inducing them to reduce their greenhouse gas (GHG) emissions. Moreover, the financial sector could help channel savings into "green" projects through both equity and bond markets, and thus facilitate disinvestment from "heavy carbon footprint" (brown) producers and firms by environmentally-minded savers. Long-term investors considering climate-related risks in their portfolios need to use a comprehensive framework for incorporating these risks and integrate likelihoods of policy responses, such as carbon pricing and/or other forms of taxation, which could have a significant impact on both "brown" and "green" asset values. The transition to sustainable green finance entails investments into "green" assets and projects that promote the development of a more sustainable economy. These investment decisions have become more complex in light of the economic and financial implications of the Covid-19 pandemic (Hepburn et al., 2020, Awazu Pereira da Silva, 2020).

In this paper we analyze pertinent issues in making investors' portfolios resilient to climate-related risks and minimizing the substantial mitigation and transition costs involved. In particular, our study provides a conventional definition of climate-change-related risks and outlines some of their main determinants, while it makes a broad assessment of the impact on financial and physical costs if these risks materialize. Then, it discusses the possible weight of carbon and other emissions on climate-related risks, identifies the main polluting activities and polluters, and presents possible links between climate change and natural disasters. Given the deep and radical uncertainty involved in climate-related risks, traditional risk management practices using historical data cannot adequately capture their magnitude and impacts (BIS, 2020). Further, we provide a framework for guiding investors' decisions in making their portfolios resilient to climate change, which goes beyond traditional risk management by involving a qualitative and scenario approach to transition, mitigation and climate-related costs.

The rest of the paper is organized as follows: section II presents some scientific evidence regarding climate change, discusses definitions of climate change, and

analyzes determinants of climate-related risks; section III provides a framework for thinking comprehensively about climate-change, adaptation, and mitigation risks; section IV highlights a guide for understanding climate-related risks in portfolios and dilemmas regarding investments in green and brown finance and risk hedging; section V outlines a call for action to investors; and section VI offers concluding remarks and a guide for future work on a more rigorous background for analyzing climate-change effects and a broader framework for assessing economic and financial sector risks.

II. Climate-change evidence and determinants, climate-linked natural disasters and campaigns, policy responses and risks for investors

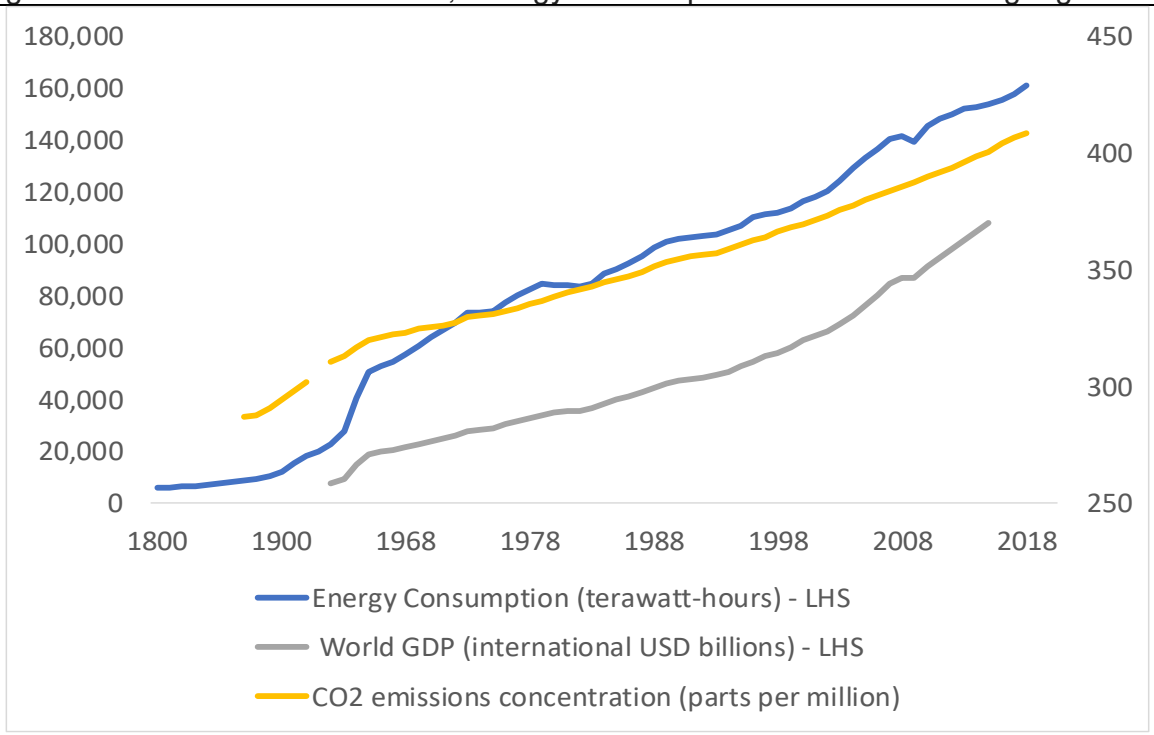
In recent years, studies have provided conclusive evidence supporting global warming and its relationship with GHG emissions. The 2014 Intergovernmental Panel on Climate Change (IPCC) report provides convincing evidence, on how growing CO_2 emissions produced by human activities, especially the burning of fossil fuels for energy production, are causing the acceleration in temperature increase. The sustained increase in global temperatures over the last two decades, i.e., the observed global warming phenomenon, constitutes a proof of climate change. The same report provides evidence that temperature increases could lead to further release of CO_2 into the earth's atmosphere, where, if not brought under control, the mutual reinforcing increase in temperatures and CO_2 concentrations could lead to a self-reinforcing cycle that has the potential to threaten the survival of humans on planet earth.

Below, Figures 1 and 2 show that the increase of CO2 concentration is positively associated with the increase in global temperature, as well as with the increase in world energy (mainly fossil fuel) consumption, the world GDP growth, and the increase in world population, consistent with the findings of the IPCC (2014) report.[5] These trends clearly show that higher world income levels and consequent consumption have led to increased burning of fossil fuels and higher CO2 emissions, indicating that there were no sufficient and timely deployment of technological advancements to curtail the emission of CO2 per unit of energy produced. This implies that technological innovations should aim at (i) reducing CO2 emissions per unit of energy production and (ii) identifying and eliminating the already existing CO2 in the atmosphere. If the private sector does not undertake such initiatives on an urgent basis, the state(s)

[5] Greenhouse Gas (GHG) emissions to the earth's atmosphere consist of carbon dioxide (CO2), methane (CH4), nitrous oxide (N2), and fluorinated gases emissions, Each gas' effect on climate change depends on (i) how much is in the atmosphere, measured by its concentration, (ii) how long do they stay in the atmosphere, and (iii) how strongly do they impact the atmosphere, with some gases being more effective than others at making the planet warmer and "thickening the Earth's blanket." CO2 emissions stem from the burning of fossil fuels, including CO2 produced during consumption of solid, liquid, and gas fuels, per time period (flow concept), while CO2 concentration is the cumulative amount of CO2 gas by volume in the air (stock concept), e.g., 100ppm (parts per million) of CO2 means 100 gas molecules of carbon dioxide per million gas molecules at a particular point in time.

should then intervene with appropriate regulations and mechanisms to price the social cost of CO2 concentration and impose commensurate taxation.

Figure 1. CO_2 Gas Concentration, Energy consumption and GDP trending higher



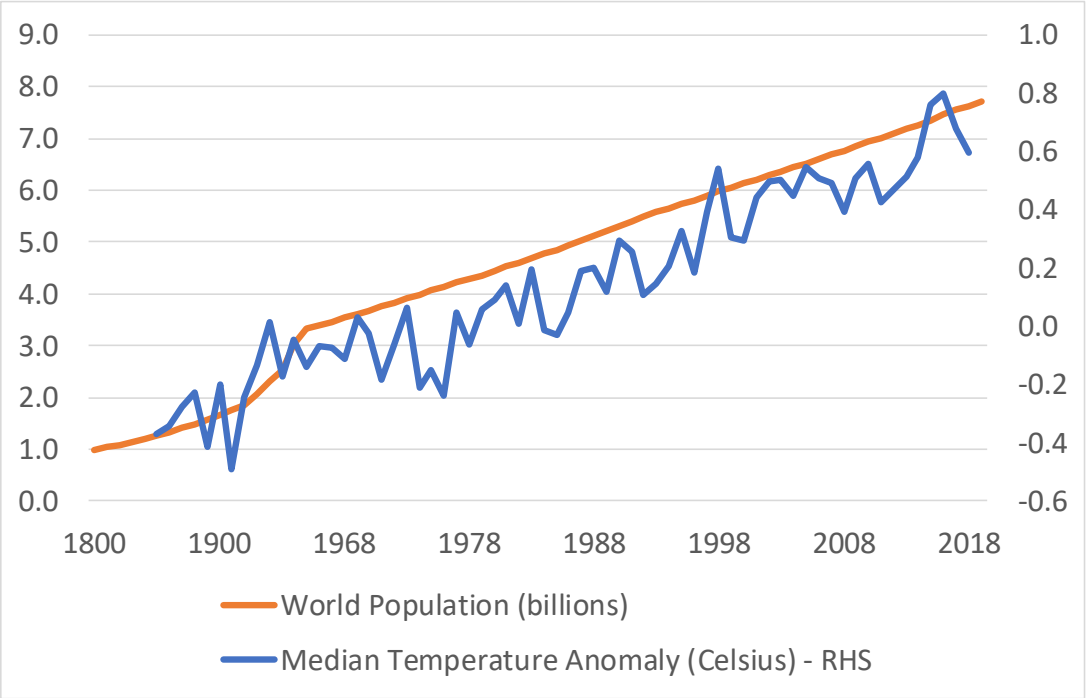
Sources:[6] New Maddison Project Database,World Bank, Bereiter et al. 2015, and OurWorldinData

A simple Granger causality test supports the scientific contention that higher energy consumption leads to higher CO_2 concentrations. The Granger causality test examines whether there is causal relationship between energy consumption and CO_2. The test confirms that energy consumption since 1965 Granger causes higher CO_2 concentrations (Figure 1). This further supports the scientific findings that higher energy consumption in the past years contributes to the increased CO_2 particles in the atmosphere.[7] Despite the Covid-19 pandemic, and the consequent virus-containment measures, CO_2 emission concentration are not expected, as of yet, to fall substantially without further policy actions, even though energy consumption has been reduced dramatically.

[6] HYDE aggregated estimates published in earlier publications. See Appendix on data sources for more information.

[7] See Granger C. J (1969).

Figure 2. World population and median temperature are trending higher



Sources:[8] Met Office Hadley Centre, McEvedy and Jones (1978), OurWorldinData

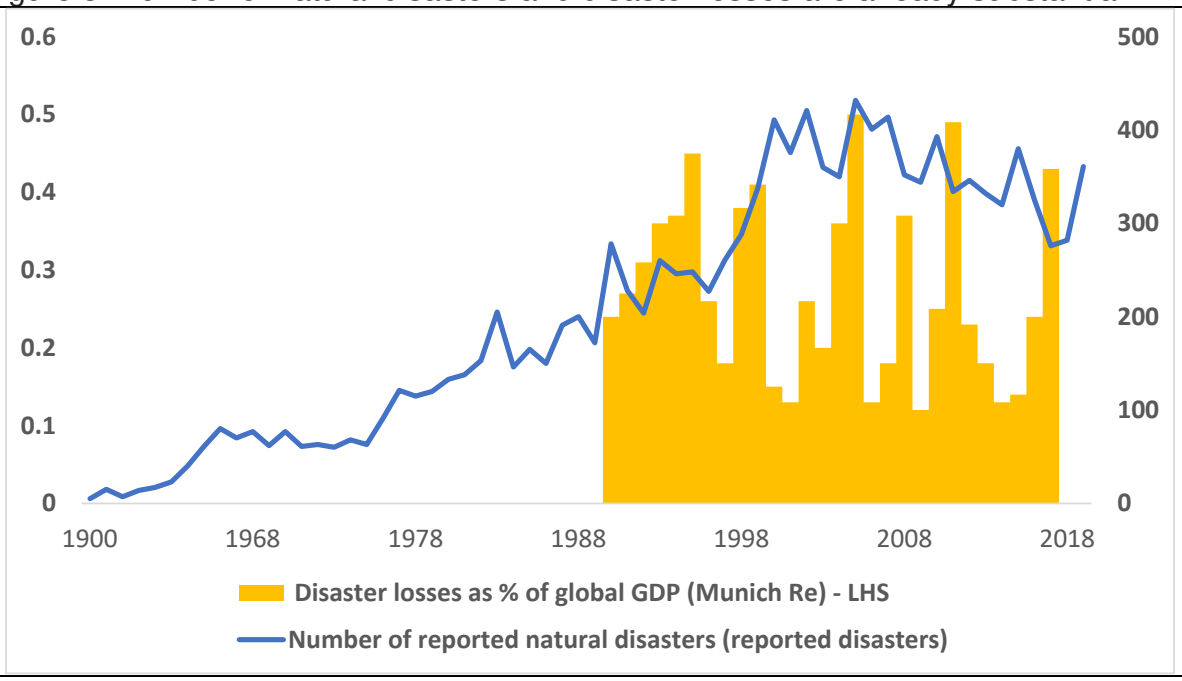
A consensus has recently emerged that GHG emissions pose risks to financial markets and stranded assets could lead to significant losses for investors. CO_2 atmospheric concentration has risen over 40 percent since the early stage of industrial revolution, around 412 parts per million (ppm) in 2018, which is contributing to global warming. In order to contain global warming, the temperature increase should be kept within 2 degrees Celsius by 2050, according to the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations 2009 Copenhagen Accord on Climate Change. This is interpreted as maintaining atmospheric CO_2 level to less than 450 ppm by 2050. If the world's major fossil fuel producers were to dig out all their effective reserve and sold them into the market, according to Leaton (2012), atmospheric CO_2 could be five times above the safe level, specified by the UN. The baseline prediction, according to the Climate Action Tracker, is that global temperatures will increase by 4.1 to 4.8 degrees Celsius by 2100, with GHG emissions reaching 150 $GtCO_2e$ per year (Climate Action Tracker, December 2019).[9] Hence, the large amount of "unburnable" carbon reserves could significantly affect firms with large carbon reserves, if markets

[8] See Appendix on data sources for more information.

[9] Note that tCO2e refers to Green House Gasses, measured as CO2 equivalent (thus "e"), with this figure including methane emissions, e.g., around 1 tone of CH4-methane, corresponds to 17 T of CO2 in GHG potential.

begin to take it into account in their valuation. Therefore, carbon stranded assets (brown) are considered to pose a significant threat to long run investors.[10]

Figure 3. Number of natural disasters and disaster losses are already substantial



Sources:[11] Munich Re, Bereiter et al. 2015, Leuven, and OurWorldinData

Carbon pricing and policy changes related to global warming could also pose risks for investors. In the short run it is less likely that there will be global coordination or an agreement for the introduction of binding and comprehensive policies on limiting global GHG emissions or levying heavy taxes on GHG emission, but as global warming and its adverse climate and physical consequences become more severe, politicians and policymakers are expected to be under increasing pressure to implement fiscal measures, such as carbon taxes. These policies are likely to have a negative impact on stock and bond returns of heavy GHG emission firms. Although, stranded assets and carbon taxes problems have only recently been discussed by policy makers and financial market participants, their implications have not been widely recognized by the investment community, especially with regard to portfolio risk management. Several studies have shown that climate-related risks and the associated financial risk have not been

[10] However, if Carbon Capture and Storage options become financially viable, then stranded assets could become "unstranded."

[11] See Appendix on data sources for more information.

appropriately priced into asset prices (Bolton et al., 2020; Bennani et al., 2018; UNEPFI, 2017).[12]

The first comprehensive global reaction to climate change risks was the 2015 Paris Agreement. The Paris agreement set goals to contain global average temperature to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the increase to 1.5 degrees Celsius, in order to substantially reduce the risks and impacts of climate change. Countries committed to contain temperature increases, aim to increase their ability to adapt to the adverse impacts of climate change and make "finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development." However, the agreement was not based principally on systematic scientific analysis of the links among global carbon emissions, climate change and experienced weather-related hazards, but rather on general contentions about the likely impacts of man-made air pollution. Also, goals without programs of action hardly ever guarantee progress. To attain the agreement's goals, investing in programs that aim at building effective transformations and transitions from brown to green economy were required. In the absence of such programs, the end-dates for the envisaged climate change-related performance seem to remain elusive.

Since then, it has been increasingly accepted that in tandem with increased levels of gas emissions, global warming and phenomena of climate change deteriorate. As carbon emissions have heightened and global temperatures are increasing, the effects on the climate are cascading with sea ice melting and oceans rising at the fastest rate we have ever seen and extreme weather phenomena having intensified, including high-strength hurricanes becoming more frequent and record heat waves thawing Siberia's permafrost. The US Environmental Protection Agency estimates that carbon dioxide emissions have increased by about 90 percent since the 1970s, while NASA reports that the average global temperature on earth has increased by about 1.4 degrees Fahrenheit since 1880. Further, global average temperatures over the next 5 years are forecast to increase between 1.15 and 1.46 degrees Celsius above that of the pre-industrial era. In comparison, the average for 2015-2019, the hottest period on record, reached 1.09 degrees Celsius. The 2015 Paris Agreement set targets for the increase in climate temperature to 2 degrees Celsius, and ideally to 1.5 degrees, until 2100, in relation to the pre-industrial age. This mandates a drastic and immediate reduction in gas emissions that create the greenhouse phenomenon from human activity. Further, according to the UK Meteorological Office, there is a small risk (about 10 percent probability) that the limit of 1.5 degrees Celsius will be exceeded in one of the years between 2020 and 2024.

[12] The importance of appropriate pricing of climate-related risks is highlighted by the lawsuit brought by New York State's attorney-general claiming that Exxon Mobil engaged in dodgy climate-change accounting opened in court, reported on October 24, 2019. The suit accused the oil company of defrauding investors by disclosing a public proxy cost of carbon emissions to account for the possibility of climate regulations, while using a separate, lower estimate for carbon costs in its internal planning. The attorney-general maintains that this meant investors could not properly account for the risk posed by climate regulations. The company has denied wrongdoing.

Nevertheless, some events after the signing of the Paris Agreement raise concerns and cast further doubts about the achievement of its goals. In particular, the inability of participating states in the December 2018 UN COP 24 to enhance the required Paris Agreement actions to contain global warming and deal with climate change and the official withdrawal of the United States from the Agreement on November 4, 2020 were major disappointments. Specifically, they were unable to agree on the rules to implement the agreement relating to (i) financial help for poorer countries, (ii) a trading scheme for emission cuts, and (iii) how those emissions should be measured. Also, the social unrest and protests to the approach of French President Emmanuel Macron's fuel tax increases in January 2019 to wean France off fossil fuels point to the difficulties of devising plans and designing programs to combat gas emissions. Nevertheless, a positive development should also be recognized relating to the emerging global consensus for the need to establish a climate-friendly financial system. To avoid the disastrous effects of further climate change, policymakers appear to increasingly realize the need to urgently ensure that both public and private financial flows align with the climate agenda and that the right conditions should be created to make the global financial sector the facilitator of, rather than a barrier to, a low-carbon future. Further, it remains to be seen whether the coronavirus pandemic would act as a catalyst for an acceleration of these endeavors or it would distract policymakers from the actions likely needed to avoid the most disastrous effects of climate change.

However, social movements and campaigns against polluters and their financial backers have begun to pose different and additional challenges to investors. Environmental activists and campaigns against climate change urging for immediate and stronger action to address climate risks, such as Fridays for Future and coordinated multi-city/country protests, could push policymakers to take more drastic action against polluters and nudge consumers and investors into abandoning polluting or unresponsive firms to climate-related risks. The campaign to adopt lifestyle choices in order to reduce individual carbon footprint, such as giving up air travel, not eating meat and reducing the use of plastic, could affect the financial valuation of firms beyond the fossil fuel and energy industries. On February 3, 2020 protesters in Germany increased the pressure on the largest asset manager in the world, BlackRock, by staging a demonstration, warning that its assets are on fire and urging divestment from brown projects.

Substantial losses from natural disasters over time could further induce policy and social actions against polluters and their financial backers, which may disrupt asset markets. AON reports that at least 207 natural disasters were recorded globally in the first six months of 2020, which was above the 21st century average (2000-2019) of 185 disasters. The wildfires in California in 2019 and 2020 and in Australia early in 2020, the hurricane Dorian in The Bahamas, and the cyclones Idai and Kenneth that hit Southern Africa, are some of the natural disaster events that have been linked to climate change. Again, the Sendai Framework states that "disasters, many of which are exacerbated by climate change and which are increasing in frequency and intensity, many of which are exacerbated by climate change and which are increasing in frequency and intensity." The increase in the occurrence and intensity of such events pose risks for financial firms such as insurers and banks and increase the probability of the introduction

of policies to limit and perhaps "price" the cost of GHG emissions with implications for both "green" and "brown" assets in investors' portfolios.

Policy makers and companies appear to gradually understand the need to stop the acceleration of global temperatures that pose significant risks to society and to the economic and financial systems. Although it is not always clear what climate policies will be adopted and how quickly, many governments and businesses have now pledged to take various measures to avert the disastrous impacts of climate change. In particular, many companies have announced ambitious objectives, e.g., to lower their GHG emissions to net zero by 2050 or earlier, or to not only go carbon negative (reducing more GHG than they add to the environment) but also remove all the emissions that the companies have ever produced (Microsoft). Also, some major financial institutions have pledged to take steps to minimize carbon-heavy investments in their portfolios, or others to cut by more than 50 percent the carbon emissions generated by the projects they finance by 2030 (Lloyds), or to place climate change at the center of their investment strategies (BlackRock). Further, other companies have pledged to develop a core set of common metrics to track sustainability factors, including environmental and social responsibility, such as willingness to measure carbon footprints and plans to address them. In this regard, Norway's Government Pension Fund Global, the world's largest sovereign wealth fund, will divest from companies involved in fossil fuels based on set exclusion criteria.

Corporates are increasingly sensitized to climate-related risks following the incurred large damages and costs so far. The extreme weather events experienced last year, such as the California wildfires that are estimated to have caused US$25.4 billion in damage and to have pushed Pacific Gas and Electric, the largest energy producer in the state of California, to file for bankruptcy, as well as the severe floodings in the United States that led to the temporary closing of many major companies' stores (e.g., Ikea) and hotel chains (e.g., Marriott), have caused many of these companies' executives to come forward and express their dismay over the impact of fires and storms on their operations. These calamities, along with growing concerns about tangible risks that could affect the bottom line, including the possibility of ratings agencies factoring in climate risk, pressure from climate-sensitive employees, changing consumer preferences, and new government regulations, e.g., a carbon tax, are likely motivating companies to become actively involved in the effort to fight climate change.

The business community's efforts to address rising GHG emissions, decarbonize investments, and solve the climate crisis should be accommodated and reinforced by the official sector in a consistent private-public sector CO2-emission cutting framework. The official sector does not only have to coordinate its actions with the private sector, but it has also to be actively involved through cutting fossil-fuel subsidies and investments for ensuring a change. In addition, the official sector efforts would be easier realized if investors implement drastic changes. The real evidence of change would come when investors start exiting carbon-heavy companies, especially those with no transition plan. Such change will follow the absolute realization of the ensuing climate-related risks by investors and their consequent decisions to direct their capital to non-carbon emitting

companies. However, the pace of fossil-fuel divestment needs close attention so that remaining carbon budget considerations and resulting financial stability implications are balanced.

Unless climate change is effectively dealt with, it could have serious global financial stability implications. Bolton et al. (2020) maintain that climate change could cause the next financial crisis. Also, Mark Carney, who has stressed that companies need to examine and disclose their strategies and timelines for lowering their carbon footprints, highlights the need for central banks to carry out stress tests assessing climate impacts on every sector in an effort to tame financial stability risks (Bank of England, 2019).[13] As this entails a transition for the whole economy, companies that lag will face retribution. Despite these endeavors and initiatives to contain climate-related risks, few companies and investors have so far provided adequate information on how they would transition away from an economy based on fossil fuels. Reportedly, only few global companies currently disclose the financial risks posed by climate change and even a smaller number have set their own targets and timetables to reduce total GHG emissions by half over the next decade, as is widely proposed in order to keep climate-related impacts under control. In this regard, it is important to note that, while global investment in renewable energy reached US$289 billion in 2018, far exceeding the investment in new fossil fuel power, wind and solar remain a small portion of total energy production (UNEP, 2019).

III. A novel framework for climate change, adaptation, mitigation, and transition risks

No organization has yet provided a comprehensive analysis of climate-related risks. Therefore, we aim to provide a systematic framework for thinking about these risks. Given the deep and radical uncertainty of climate-related risks, traditional backward-looking risk management methods do not provide a comprehensive method for evaluating costs. The role of the financial sector in helping reduce climate change risks, mitigate its impact, and adapt to the consequences of climate change is critical. All countries and investors are vulnerable to the effects of climate change, however, some have a lower capacity to prepare and cope, given weak institutional capacity, limited access to the tools and data, and the mandates to deal with climate-related risks in order to mitigate the adverse effects of climate change and the transition costs to a sustainable green finance. However, the financial sector can play an important role in reducing climate change risk, mitigating its impact, and adapting to the consequences of climate change. The transition from brown (i.e., financing fossil-fuel projects) to sustainable green finance requires an evaluation of the risks and costs of reducing climate-related risks, mitigation and adaption.

a. Reducing climate change risk

[13] Further, the Network of Central Banks and Supervisors for Greening the Financial System, currently consisting of 66 members, aims to promote the understanding and the analysis of macroeconomic and financial stability risks associated with climate change.

Financial sector policies can play a catalyzing role and contribute to the mitigation or reduction of climate change risk. It could help channel capital into the development of green technology and the construction of "green" projects, as well as provide incentives for companies to reduce their greenhouse gas (GHG) emission. Recent studies, e.g., IFC and Mercer, 2015 and 2011, show that climate change poses serious risks for investors and that integrating climate risks into investment strategies can improve the resilience of an investment portfolio and help return outcomes.

In this context, the financial sector can help channel savings into "green" projects through both equity and bond markets. In equity markets, various green stock indices, which include only green technology companies, have been constructed, along with investment vehicles that closely track these indices. For instance, the WilderHill Clean Energy Index (ECO) includes firms which could benefit from the introduction of carbon pricing and firms which are leading players in renewable energy industries, such as solar and wind. Another example is the PowerShares Cleantech Index, which includes publicly traded firms representing the global clean tech industry. These "green" indices have facilitated environmentally-minded investors to invest in green-technology companies by reducing firm-idiosyncratic risk and trading cost, thereby broadening the investor base of these companies and reducing their funding cost accordingly.

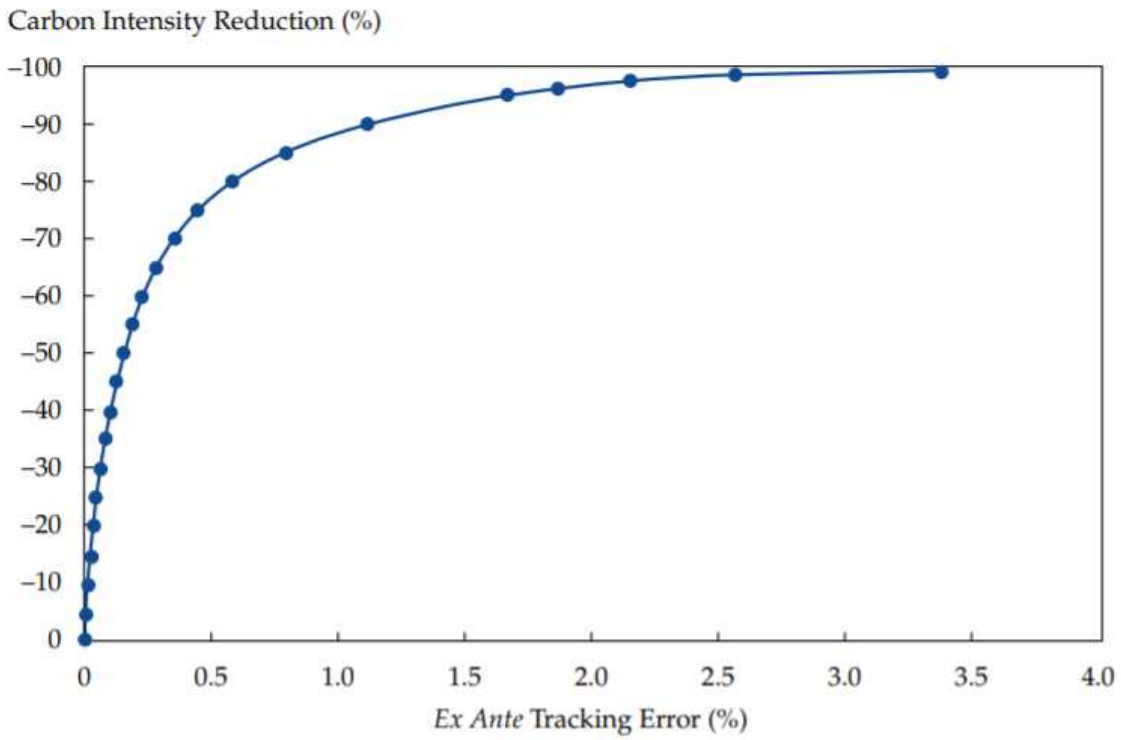
In bond markets, the rapid development of "green" bonds has also offered investors the opportunity to participate in the financing of 'green' projects.[14] At the same time, issuers (including sovereign countries, municipalities, and companies) can tap into long-term, low-cost financing for projects aiming at reducing GHG emission. The recent substantial drop in global oil prices could spur investors to allocate a higher percentage of their portfolios to "green" investments, including in the equity and fixed-income asset classes.

The financial sector can facilitate divestment from "heavy carbon footprint" products and firms by environmentally-minded savers. Therefore, financial markets can provide incentives for firms with heavy carbon footprints to reduce their GHG emissions. The aim is to enable pension funds, insurance pools, sovereign wealth funds (SWFs), and other investors to replace high carbon-footprint equities with low carbon-footprint investments that offer solid long-term payoffs in a world of increasingly stringent preventative measures. This requires conveying accurate long-term information to savers and investors and encouraging investors to look beyond current policies and pricing and factor in their investment decisions policies that would mitigate climate change. Instruments to achieve this could be guided or voluntary, including encouragement of investors to disclose carbon footprints of investments along with their risk-return characteristics; construction of green indexes; and decarbonization of investor portfolios (analyzing the policies, parameters, time horizon, and financial consequences of different decarbonization scenarios and publicizing through flagships).

[14] "Green" bonds are addressing environmentally-sensitive bond-investors interests, with admittedly limited green-bond return and default information to compare with ordinary bonds.

Among the decarbonization initiatives, the recent development of low-tracking error (Low-TE) indexes aim at reducing portfolio carbon footprints by taking out heavily pollutant companies from a benchmark market index (such as the S&P500), while still closely tracking the performance of the benchmark index through appropriate portfolio design, provides a good example.[15] By construction, a Low-TE index has a much lower exposure than the benchmark S&P500 index to carbon trace, leading to much less climate change risk (Figure 4). This characteristic makes a Low-TE index very attractive to passive long-term investors, such as the pension funds, insurance companies and SWFs. A Low-TE index, therefore, provides an incentive mechanism for companies to reduce their GHG emission, so as to be included in the index, which helps reduce the cost of combating global warming.[16]

Figure 4. Carbon Frontier on the MSCI Europe Index



Sources: Andersson, Bolton, and Samama (2016) from Amundi (30 June 2015).

[15] Several index providers, e.g., MSCI, FTSE Russell, State Street, issue their own methodologies and benchmarks that apply a carbon minimization within a TE tolerance limit. Further, sometimes they do not exclude some heavily pollutant companies from an index, but rather tilt weights in the index to reward or "punish" companies in the two extremes.

[16] The implicit assumption here is that companies are interested in being included in an index. However, there may be companies that are not.

Meanwhile, investors should continuously be educated about the evolution of climate change risk and the related regulation risk.[17] This is especially relevant for long-term investors, such as pension funds and insurance companies, whose long-term holdings are directly exposed to such kind of risk. As long as long term investors realize and start calculating the environmental risk, thereby shifting their investment from heavy carbon trace companies to "green" companies, the financial market will play the role of information aggregation on long-term environmental and regulatory costs and risks, and therefore help direct fixed capital formation to where it will offer a high long-term return given climate change. Active investors can engage with firms directly to urge for lowering their carbon footprint. Passive investors can approach index compilers and discuss the exit from indices of heavy polluters to enable divestment of passive investors from 'heavy carbon footprint' assets and thus enable a smoother transition to green finance.[18]

b. Mitigating the impact of climate change

Absence of well-developed financial markets and instruments for hedging, or limited access to such markets and instruments, undermines the ability of countries to insure and reinsure against risks associated with climate change. Evidence from SwissRe shows that in 2013, insurance covered less than 20 percent of total disaster losses in developing countries, on average, compared to about 60 percent in North America (World Development Report, 2014). Financial market disruptions, due to the coronavirus pandemic, are likely to make it more difficult to develop specific markets for climate change hedging and climate insurance products.

A well-developed financial sector could help countries better manage climate change risks through intra-temporal insurance and financing for reconstruction. Access to credit and market insurance (e.g., disaster or life insurance), self-insurance through bank deposits, and self-protection through safe and efficient payments can help businesses and households mitigate the impact and reduce the cost of climate change-related risks. Similarly, availability of disaster risk insurance, and related hedging instruments help protect countries from the potential economic burden of disasters associated with climate change and thus increase the state's financial capacity to respond to emergencies.

Given the rising frequency and costliness of weather-related disasters, there is increasing emphasis on taking priority actions to reduce disaster losses (Hyogo Framework Action for disaster risk management). A key activity under this priority action is the promotion of developing financial risk-sharing mechanisms that provide efficient means for countries to financially protect themselves from natural disasters and

[17] For example, EIOPA incorporates ESG criteria in their stress testing specifications: https://www.eiopa.europa.eu/content/eiopa-publishes-results-2019-occupational-pensions-stress-test_en

[18] Arguably, when divesting from heavy polluters, the transition would be difficult to be smooth. Divestment would be more disruptive than diverting new flows into green(er) projects.

reduce the associated economic and fiscal burden. Specific strategies include developing instruments such as catastrophe bonds that mitigate natural disaster risks by transferring the risk of a disaster to financial market participants and have them sharing the climate risks by allowing the issuer to forgo repayment of the bond principal if a major disaster occurs (see World Bank Group, 2011, and Cummins and Mahul, 2010). Weather hedges based on an underlying weather index are another example of a tool that transfers the risk to financial markets, as payments are triggered by prespecified adverse weather events (e.g., levels of rainfall, seasonal temperatures, etc.).

Another important role that a well-functioning financial market should play is to help in financing the reconstruction process after disasters. There is often a surging demand for fixed asset investment after a major natural disaster. Although government funding is important, the private sector funding through a well functioned financial market is also essential for the infrastructure to be rebuilt, migrants to be relocated and public services to be restored. In the ideal situation, the financial market can significantly accelerate the recovery. The recent coronavirus pandemic, could spur policymakers and investors to institutionalized markets that help to finance the reconstruction process after disasters including climate change.

c. Adapting to the consequences of climate change

Adapting to climate change risk entails the undertaking of appropriate action to prevent or minimize the adverse effects of climate change. Prevention and mitigation of climate change risk have to go hand in hand with adaptation to reduce climate change damages, with well planned, early adaptation action capable of saving resources and lives when risks materialize. Examples of adaptation measures include the adaptation of building codes to future climate conditions and extreme weather events; building of flood defenses and raising the levels of dykes; development of drought-tolerant crops; choosing tree species and forestry practices less vulnerable to storms and fires; and setting aside land corridors to help species migrate.

The financial sector plays an important role by providing access to funding for these adaptation efforts. Financial markets are already an important source of climate finance, with multilateral and bilateral development banks issuing generic bonds as a means of raising private finance from capital markets to support projects that facilitate adaptation to the consequences of climate change. The financial sector could play a further role in generating new finance and providing risk management tools, including insurance.

As concentrations of carbon dioxide in the atmosphere hit records recently and the world as a whole is burning through what is called the carbon budget, which is the cumulative amount of carbon dioxide that can amass in the atmosphere over a period of time to keep temperatures within certain thresholds, calls for taking action to stop investing in fossil fuel companies and to divest out of fossil-fuel assets have increased. During the recent Davos World Economic Forum of January 21-24, 2020, many corporate executives and investors who attended the conference reportedly expressed concerns for the first time about climate change-related risks and

the threats that accelerating global warming poses to society and to their company profits, as well as the need to address these risks by curbing the emissions of global-warming gases and avert the adverse effects of climate change. However, few reported details on exactly how and how quickly they would transition away from a global economy based on fossil fuels. In this spirit, Larry Fink, CEO of BlackRock, had reportedly said recently that it would place climate change at the center of the world's largest institutional investor's investment strategy.

d. Transitioning to lower emission and sustainable green finance

Facilitating the transition to a green socioeconomic environment and to sustainable green portfolios becomes imperative, but this transition is unlikely to happen without some costs. Given that there are no well-established ESG investment theories or blueprints yet, and backward-looking risk management practices are unlikely to offer precise guidance given the uncertainty relating to climate change, general good practices are likely to offer valuable guidance to investors. Forward looking and scenario-based analyses could help to gauge transition risks to a more sustainable green finance. Particularly during transition, the asset returns of affected non-ESG companies, industries and markets, and of ESG ones should be carefully analyzed, while at the same time investors' reactions should be monitored on an ongoing basis. Under a quicker- or slower-than-anticipated transition to a sustainable green finance, a substantial disruption in asset prices could be expected as the transition from non-ESG to ESG assets pushes relative asset prices up (or down) and poses substantial risks to financial stability.

IV. Understanding climate-related risks in portfolios -- dilemmas

Despite recent progress, internationally comparable data on the carbon footprint of firms and projects are scarce, presenting serious challenges to sound empirical analysis. Reliable data on 'green finance' and on carbon footprint that are comparable across countries and over time are not available at the moment.[19] [20]This is due partly to the lack of specificity of what exactly constitutes 'green' and 'brown' finance, and the absence of international cooperation to set minimum standards and a framework for gauging carbon footprints, in the spirit of the bank capital in the Basel framework. Moreover, green finance is a broader concept that includes not only the financing of

[19] The GHG Protocol Corporate Standard categorizes GHG emissions into three scopes. Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain. of the reporting company, including both upstream and downstream emissions.

[20] The GHG Protocol provides 15 categories in scope 3 to provide companies with a systematic framework to measure, manage, and reduce emissions across a corporate value chain. The categories are designed to be mutually exclusive to avoid a company double-counting emissions among categories. See https://ghgprotocol.org/sites/default/files/standards_supporting/Intro_GHGP_Tech.pdf

mitigation, adaptation, transition and sustainable firms and projects but also the financing of new technologies that do not have carbon emissions as by-products.

Also, green finance relates to the maintenance of biodiversity, sustainable water treatment and the preservation of natural habitats and the earth's poles, among other things. Since definitions of green finance vary substantially from country to country, global cooperation in the format of the Basel bank capital framework could be helpful to set minimum standards and provides definitions of what constitutes green finance. Our focus would be on providing a framework for understanding climate change, adaptation, mitigation, and transition risks in investors' portfolios and the dilemmas investors face when making decisions regarding their portfolio allocations given the lack of data.

Given the lack of comparable data, investors should enhance their understanding of their current exposures to climate-related risks by taking stock of their brown investment exposures. The way to measure these exposures is to start by classifying exposures according to their carbon footprint.[21] Priority should be given to further assessing high carbon footprint exposures because of the likelihood that these firms/projects could have high shares of stranded assets that might be unable to be recovered, and hence have a higher probability that in the future discount rates for these assets could be increased and the valuation of these exposures might be lowered. A good starting point for assessing whether firms are disclosing their current and thorough estimation of their carbon footprint and exposures to climate change would be whether they subscribe to the recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD). The TCFD has offered recommendation to companies for structuring their disclosures about identifying and sharing both risks and opportunities they face as a result of climate change. These recommendations are voluntary but constitute an

[21] British Petroleum has set out a plan to cut its carbon footprint to net zero by 2050, while major mining companies are devising strategies on coal to reduce carbon emissions and thus to respond to climate change. For example, while Rio Tinto sold its last coal mines in 2018, Glencore, the biggest producer of thermal coal burnt in power plants, is limiting production of coal to 150 million tons a year and has promised to provide detailed projections for tackling emissions in its annual report on its climate-change objectives, BHP targets net-zero carbon from its own emissions by 2050 and has indicated it will sell off interests in thermal coal mined in Colombia and Australia, and Anglo American has said that it will quit thermal coal mining. In this context, BlackRock has stated that it will sell its stakes in companies that derive more than 25 percent of their sales from coal – it should be noted that many mining companies fall below this limit, e.g., Glencore makes 6 percent of its revenues from coal. However, spinning off coal mining will not end concerns about climate change because, although the listed companies are not exposed to it, the coal is going to get burnt.

important starting point for producing comparable data for climate-related exposures and risks.[22]

Investors should further enhance their understanding of their current exposures to climate-related risks by taking stock of their green investment exposures. After investors take stock of their brown investment exposures, they should also take stock of their green investment exposures because of the likelihood that these firms/projects could provide in the future a higher return than brown assets. This is due to their ability to provide the mitigation, transition, adaptation, and sustainable and technological solutions necessary for turning brown to green finance, thus having a higher probability that in the future discount rates for these assets could be reduced and the valuation of these exposures might increase.[23] With regard to brown asset investment, a good starting point for assessing whether these green firms are disclosing their current and thorough estimation of their carbon footprint and exposures to climate change would be whether they subscribe to the recommendations of the TCFD.

After taking stock of their brown and green exposures, investors need to assess the adequacy of reporting, the accuracy of the data, and if data reported by firms/projects are appropriate for a thorough cataloguing of the climate-related exposures in investors' portfolios. A thorough review of how accurate data collected and provided by firms/projects and providers would be needed, in order to assess the reliability of the carbon footprint stock taking. The best data would be internationally agreed, unified and comparable. Unfortunately, these data do not exist yet, but efforts are underway to produce them, and investors should encourage firms to report more extensively their exposures to climate change. Given the uncertainties of incomplete and non-comparable data, a thorough cataloguing of climate-related exposures should be succeeded by an analysis of risks that is forward looking and by scenario analyses that are conducted under stress conditions.

By taking stock of current exposures to brown and green investments, investors can gauge the volume of emissions and measure the carbon footprint of their investments and start pricing climate-related risks in their portfolios. Once the stocktaking exercise has been performed, investors need to gauge the costs and price the damages that could arise from climate change, and mitigation, transition and adaptation efforts. Given the radical uncertainty in pricing risks emanating from climate change, stress scenarios need to be calibrated. Making gross calculations using forward looking indicators could be the appropriate way of pricing risks in investors' portfolios. By pricing climate-related risks, a clearer understanding would be achieved on how to

[22] As of February 2020, it was reported that more than 1,000 issuers and investors worldwide, representing a combined market capitalization of almost USD 12 trillion (with 473 financial firms managing combined assets of USD 138.8 trillion), supported the TCFD initiative.

[23] See FTSE Russell Green Revenues: https://www.ftserussell.com/data/sustainability-and-esg-data/green-revenues-data-model

manage these risks. A plan for managing climate-related risks should be drawn, which could include divestments, adding to green exposures, and further diversifying climate-related risks.

It is necessary to continuously track the exposures to brown and green investments, and make adjustments if necessary, while being mindful of new research and estimates for climate change, policy initiatives and changes in the carbon footprint of firms/projects. Tracking of developments in emissions and change in the carbon footprint of their investments is going to be necessary in order to assess changes in the volume of emission in investors' portfolios. Continuously tracking the carbon footprint of portfolios would enable investors to observe changes in climate-related risks in their portfolios. Moreover, by dynamically tracking changes in the carbon footprint and the prices of their assets, investors could identify assets that are vulnerable to changes in policies related to climate change. Additionally, by dynamically tracking the carbon footprint and prices of assets to changes in policies, investors could identify assets vulnerable to changes in the pace of climate change and technological developments related to climate change.

Solutions provided by taxes and emission trading schemes would also need to be monitored closely regarding their efficacy in halting climate change, their costs and efficacy regarding mitigation, adaptation and transition and their impact on portfolios. Policy changes[24] are unlikely to completely halt climate change in the short run, but policies could become more effective as the impact of climate change is more visible and policymakers respond to stakeholder pressure. As the social and political pressure on firms to respond to climate change becomes higher, they might adopt solutions that change their valuations and perspectives. Therefore, investors need to closely monitor changes in policies and link policies with their prices of their assets that are vulnerable to policy changes.

All these policy changes and measurement improvements are unlikely to provide a comprehensive solution for climate related risks and investors are likely to need to resort to hedging that would move risks to those who are more able to bare them; however, this is likely to be costly and incomplete. Even if data become better these might not be enough to induce divestment from brown assets. Pricing of risks is unlikely to be good enough to enable an accurate assessment of climate-related risks and shift away from brown investment through pricing of assets. Because there has been no implementation of a systematic and comprehensive pricing of costs, and no effective nor sufficient taxation of carbon emissions has been employed, an emission trading scheme that sufficiently reduces climate risks could be way off in the future. If climate-related risks cannot be assessed correctly, then we should assume that risk assessments are providing incorrect signals for financial markets. Still, hedging could be necessary but costly, and some work has been done on the costs of hedging by Engle, Giglio et al. 2020 (Hedging Climate Change News).

[24] Regarding regulations, such as emission rates, energy efficiency, and renewables standards.

However, climate-related risks are unhedgeable for the financial industry as a whole. Despite the ability of investors to hedge part of their portfolios, the industry as a whole will not be able to hedge all the risks related to climate change and the costs of hedging are likely to be significant. Disaster-risk insurance and related weather hedging instruments transfer climate damage risks to those more willing to bear it has been employed since at least the mid-1990s but there are obstacles to wider private investor involvement in these and related instruments (IMF, 2016). Therefore, investors face dilemmas with regard to which parts of their portfolio to hedge, how much to divest from brown assets and what their exposure should be towards sustainable and green finance. Green indexes, such as the S&P U.S. Carbon Efficient, could offer opportunities for investors to shift their portfolios away from brown assets, and provide some guidance on pricing the risks of portfolios that have high concentrations of brown assets.

The formulas for quantifying the carbon footprint in investors' portfolios are straightforward[25] but because data are not comparable and consistent, there is a large degree of uncertainty. The following equations determine the total carbon footprint of an investor's portfolio:[26]

$$(1)\ Carbon\ Footprint_i = Carbon\ Footprint\ of\ security\ i$$

$$(2)\ \omega_i = weight\ of\ security\ i\ in\ portfolio$$

$$(3)\ Total\ Carbon\ Footprint = \sum_{securities}^{\infty} \omega_i\ .\ Carbon\ Footprint_i$$

Then we determine the contribution of each security to the total carbon footprint of the portfolio. By dividing the carbon footprint of each security by the total carbon footprint of the portfolio, we find the contribution of each security to the total carbon footprint as:

$$(4)\ \text{contribution}_i = \frac{\omega_i\ Carbon\ Footprint_i}{Total\ Carbon\ Footprint}$$

The contribution of each security to the total carbon footprint provides a way for tracking the securities that pose the largest climate-related risk on the portfolio. The quantification of the largest climate-related risks in the portfolio provides a guidance for divestment, re-allocation, and hedging as part of a portfolio-wide climate-related risk management strategy.[27]

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[25] See Russell Investments "Portfolio Decarbonization Strategy (2016)"

[26] See also https://www.msci.com/documents/10199/2043ba37-c8e1-4773-8672-fae43e9e3fd0

[27] Several considerations to the above simple carbon-footprint measure as a proxy of the climate-related risk to the portfolio could be brought forward: (i) carbon footprint alone may be inadequate. Instead, some standardized carbon footprint could be more appropriate, e.g., for a large airline that has a larger footprint than a smaller regional one, the carbon footprint could be weighted by miles or mile-passengers flown. Or, more generally, the carbon footprint could be expressed as carbon footprint per USD of revenue; (ii) the risk could be different, e.g., two companies may have the same carbon footprint but different potential to change, such as a cement factory will always emit CO2 while an airline could switch to a renewable liquid fuel; (iii) similarly to (ii), incorporation of a time element to the measure may be important, e.g., the metric should account for a company that has a high footprint today but has declared that it will change, while

A portfolio-wide climate-related risk management and mitigation strategy involves several implementation stages. Managing climate-related risks as part of a comprehensive strategy for divestment, re-allocation, hedging and engagement with stakeholders to induce a reduction in the firms' carbon footprint and investment in clean energy and renewable technology assets entails:

Managing climate-related risks as part of a divestment step. Depending on the risk tolerance and the investment horizon of the investor, among other considerations, it might be necessary to remove the heaviest carbon-footprint sectors, in order to reduce the overall carbon footprint of the portfolio. An abrupt divestment of the heaviest carbon footprint sectors provides an immediate reduction in the carbon-footprint of the portfolio, but it could result in a significant change in the portfolio shares and sector exposures, which would lead to deviations from the benchmark indices.

Managing climate-related risks as part of a re-allocation step. Also, depending on the risk tolerance and the investment horizon of the investor, among other considerations, it might be necessary to divest from the heaviest carbon-footprint securities in the sector and invest in lower carbon-footprint securities within the same sector,[28] aiming to reduce the overall carbon footprint of the portfolio. This will require active re-allocation within the sector and constant monitoring of firms and securities' carbon footprint, which could result in the reduction of the total portfolio carbon footprint.

Managing climate-related risks as part of a hedging step. Depending on the risk tolerance and the investment horizon of the investor, among other considerations, it might be necessary to hedge some of the exposure to heavy carbon-footprint securities. Hedging would entail costs and might be of limited time-horizon and less than the exposure to heavy carbon-footprint firms. However, the strategy could involve not only purchasing catastrophe insurance and/or hedging default risks, but also investments in competitors with lower or negative carbon-footprint and renewable energy technologies. This will require active management of hedging and entail costs of monitoring carbon-footprint size and finding new firms and projects with green energy technologies and renewable development. Constant monitoring of firms and securities carbon footprint would be needed but hedging could lower the risk profile of heavy carbon-footprint investments and reduce the total portfolio carbon footprint.

Managing climate-related risks as part of an engagement with stakeholders. Again, depending on the risk tolerance and the investment horizon of the investor, among other

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another has a smaller footprint but is not willing to change; (iv) the risk not to be measured by the carbon footprint (or a normalized version) but by the cost for reducing the footprint by a unit, i.e., if a company can reduce its footprint by 1 arbitrary unit with a cost of 1 million, it will assume a much lower risk than a competitor that needs 10 million, even if the competitor has lower carbon to start with; and (v) the metric may not be appropriate for investments with potentially negative carbon footprint, e.g., in case of carbon sequestration.

[28] This also applies to sectors that are by definition heavily "brown," e.g., transportation, utilities, energy, automobiles.

considerations, it will be necessary to engage stakeholders, including corporate boards, to encourage and promote reduction in substantial carbon-footprint activities, and research, innovation and investment in green technologies. Active engagement with stakeholders, provides an avenue for investors to elevate the topic of carbon emission and climate change, and to point out the risks of not doing enough to reduce firms' carbon footprint and not investing in green technologies. This will require active engagement of investors and their agents and will require avenues and goals for firms to meet but help to lower the risk profile of heavy carbon-footprint investments and reduce the total portfolio carbon footprint.[29]

Managing climate-related risks as part of an investment in clean-and-renewable energy-technologies step. Investment in new and green technologies would be an important way investors and asset managers could employ to make their portfolios resilient to climate-related mitigation and transition risks, while in the process assisting with the promotion of initiatives that could help avoid the most severe physical and financial costs of climate change and other global environmental challenges.[30] However, caution is warranted as many new "green" technologies entail risks as they are unproven.

V. A call to action for investors

A call for a concerted environmental policy action has become an immediate world policy priority as a response to observed extreme climate-related phenomena and increased global awareness. The warnings and fears expressed in past years about the adverse effects of climate change are now unfolding in front of us and become reality. The extreme weather phenomena manifested by the very warm temperatures, droughts and ferocious fires or by biblical storms, massive outpours and flooding of rivers and cities have intensified nowadays and fundamentally impacted economic activity, cultural traditions, the quality of life and personal lifestyles at the local and global levels. As such, we have witnessed changes in the cultivation of certain crops, e.g., rice and cotton, forced evacuations, increased anxiety and sicknesses in affected areas, and changes in work, leisure and transportation habits.

The adverse climate-related impacts clearly indicate that the current world modus operandi is unsustainable. As a result, economic structures, government organizations, societal norms and daily operations will have to adapt, either voluntarily by reconsidering operations that consume carbon-emitting energy and promoting technological innovations that mitigate climate-risks or through government intervention and building of appropriate regulation that prohibits or limits the use of carbon-generating activities. Thus, to insulate the economy from the negative implications of climate change and avoid an

[29] See http://www.climateaction100.org; https://www.unglobalcompact.org/what-is-gc/mission/principles; https://www.unpri.org/pri/an-introduction-to-responsible-investment/what-are -the-principles-for-responsible-investment

[30] An extra benefit of directly investing in green technologies is that the transactions costs of divestment, re-allocation etc. are minimized.

irreversible environmental catastrophe, a drastic shift away from fossil-fuel energy sources and carbon-pollutant industries has to be advocated and implemented by governments, the private sector and the public on an emergency basis.

The private sector is decarbonizing its investment portfolios on a voluntary basis, but the lack of a wide adoption of standards such as those proposed by the TCFD and the lack of consistent standards for measuring footprints hinder progress towards a sustainable green finance. Initiatives such as the TCFD help in promoting more consistent standards for carbon related footprint disclosures and the Portfolio Decarbonization Coalition has garnered the commitment of a group of long-term institutional investors to shift institutional investments to low-carbon-exposure firms (IMF, 2016). However, a wider adoption and more thorough data regarding carbon footprints are necessary to assess the climate-related risks in investors' portfolios. Moreover, the commitments to shift assets towards low-carbon-exposure firms remain small compared to the amount of assets controlled by long term investors. If future mitigation policies are adopted faster than investors expect, fire sales and precipitous asset price declines could ensue, which could affect even seemingly unrelated institutions and asset classes, aggravating investors' fears, and could lead to large market fluctuations and substantial asset portfolio losses (IMF, 2016).

Given the risks involved and the limited progress made towards decarbonizing portfolios, active investors will need to collaboratively engage with companies in their portfolios to find ways to pursue a transition to lower GHG emissions and to sustainable companies.[31] Active investors should engage with companies in their portfolios to encourage disclosure of climate-related risks and carbon footprints, the adoption of a framework for mitigation, adaption and transition of the firms' business models. Continuous engagement with portfolio firms would help signal that climate-related risks must be incorporated in a holistic framework for the firms' business models and assist in the transition to a sustainable and green finance.

As major asset managers, e.g., BlackRock, have set environmental sustainability as a core goal, targeted investing should be one direct route to begin forcing change on carbon-emitting companies. While ultimately hedging against climate change risk should involve portfolios comprising long green and short brown (e.g., energy) companies, in an intermediate (transition) period investing may target some of the investments going into companies with high carbon footprints but with a strategy to move toward a more sustainable business model or into companies with a low carbon emissions to earnings ratio (based on current or future carbon emissions and earnings). In this vein, Engle III et al. (2019) maintain that creating the optimal portfolio to mitigate climate change requires investors to invest into green strategies but also into existing, non-green companies (most exposed to climate change). In effect, this approach implies a stance that the economic consequences of cutting carbon too quickly will overweight the short-term benefits to the environment. However, investors with a green focus may challenge this longer-term approach and advocate that a more immediate climate change

[31] See also UBS (2020) introduction of a Climate Aware framework for supporting investors to reach their climate goals https://www.ubs.com/global/en/media/display-page-ndp//en-20200120-wef.html

investing strategy, e.g., investing in companies with a green score higher than 90 out of 100, should be adopted.

Further, passive investors should collaboratively engage with index compilers, while the passive investors' stakeholders will have to engage with them to introduce additional investment goals for reducing climate-related risks. Passive investors should engage with index compilers to find ways to limit the inclusion of heavy carbon footprint companies that are not preparing for a transition to a sustainable and green future. Stakeholders of passive investors should engage with the passive investors to introduce additional investment goals for reducing climate-related risks in their portfolios (see Andersson et al. 2016). The shift will require more comprehensive information on carbon footprints and how these might respond in the future, but stakeholders should encourage the boards of passive asset managers to compel managers of funds to become sensitive to climate-relate risks and disclose the carbon content of portfolios.

Even the full implementation of these actions by active and passive investors will unlikely be enough to a speedy move from brown to a sustainable green-finance economy. These steps would be the beginning of a long process of encouraging firms to disclose more of their climate-related risks and carbon footprints, setting widely adopted standards for disclosure, including climate-related risks in firms' business models, understanding the volume of carbon and climate-related risks in investors' portfolios, and starting a transition from brown to a sustainable green finance. A comprehensive framework for pricing climate-related risks will also need to be developed and appropriate policy actions, both nationally and internationally, will need to be taken to reduce risks of climate change, including for adaptation, mitigation and transition to a sustainable and green economy.

Further, if actions by environmentally-concerned investors and voluntary reporting of carbon footprint by companies prove inadequate to stave off carbon emissions, stricter global measures should be considered. These measures may include: (i) a requirement that all companies mandatorily report their carbon footprint via a qualified agency (same as they are required to submit accounting reports), (ii) the establishment of an environmental-risk rating system for companies (similar to credit rating systems), and (iii) a mandate that environmental ratings be explicitly included in companies' credit ratings so as investors are better informed and efforts to move towards green finance are expedited.

Green finance could have several benefits. It can facilitate the 'green transformation' of the global economy by ensuring environmental sustainability and long-term growth. Green finance could help facilitate policies to promote green investments, mitigate the impact of climate change, and positively affect economic growth, saving and investment levels, capital flows, and exchange rates by ensuring environmental sustainability. The channels, through which green finance can help the transformation to a green economy, alleviate and prevent environmental disasters, and ensure environmental sustainability and long-term growth, need to be explored further.

Green finance can help shift employment to the green economy and increase overall employment. Investment in green technologies could help shift employment away from polluting and toward green industries. The overall effect on employment depends on the elasticity of substitution between labor and capital in different sectors. There are important challenges related to retraining, skill enhancement, and potential relocation. Policies may be needed to facilitate the shift to the green economy.

Green finance can help economies diversify and expand growth away from 'brown' into 'green' technologies. Green technologies can increase growth through innovations that would boost productivity, employment, and related demand. Moreover, green finance can be important for growth and employment in local economies in particular in cases of polluted cities that are cleaned and become more attractive to live and work, and thus become more conducive to attracting talent/innovation. The overall impact will partly depend on the ability of green technologies to obtain financing, which should be a focal point of this analysis.

VI. Conclusion and future work – scientific background and economic for financial sector

This paper provides a novel framework for evaluating climate change, adaptation, mitigation, and transition risks. We provide a method for valuing climate-related risks in investors' portfolios. Through improvements in the assessment of risks, financial stakeholders would be able to help manage climate-related risks and assist in the transition from brown to sustainable green finance.

We cast a call for action by investors in appropriately valuing climate-related risks, obtaining accurate information and developing adequate frameworks for understanding climate-related risks. A central problem in dealing with climate-related risks is that, individually, investors are not likely able to affect the climate significantly, while collectively the financial sector cannot hedge all climate-related risks. The financial sector could help channel savings into green projects through both equity and bond markets, and thus facilitate divestment from heavy carbon footprint producers.

Nevertheless, the prospects of portfolio decarbonization over the next decade are not favorable and appropriate global regulation would be advisable in the near-term. Investors, therefore, are advised to take stock of their portfolios in relation to climate-related risks, build forward-looking risk management, examine scenarios and case studies, make portfolios climate-risk resilient, understand the limitations of methodologies, and facilitate the transition to a green socioeconomic environment.

Future analytical work could focus on providing better quantitative information on the impact of the reduction of climate-related risks, including mitigation, adaptation and transition from brown to green finance, on firms, projects, and investors' portfolios. A more comprehensive framework for analyzing and quantifying climate-related risks is necessary to assess these risks and price their impact on investors'

portfolios. The costs of not doing enough to transition from brown to a sustainable green finance would also need to be evaluated and price these risks in investors' portfolios. The impact on the cost of capital and capital allocation efficiency from private green finance mobilization and the impact of the transition from 'brown' to 'green' firms and projects should be essential elements of such evaluation (G20 GFSG, 2016).

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Data Sources for OurWorldinData

Long-term global average atmospheric concentrations of CO_2 have been combined using several sources, all available at the NOAA/ESRL Global Monitoring Division.
Very long-term data from ice cores – specifically the Dome C core – has been made available from the NOAA here: https://www.ncdc.noaa.gov/paleo-search/study/17975. In this original dataset, some years had multiple measurements (taken at different points of the year). To normalize this to a single year, where several measurements were available, we took the average of these concentration values.

The original source of this research is:
Bernhard Bereiter, Sarah Eggleston, Jochen Schmitt, Christoph Nehrbass-Ahles, Thomas F. Stocker, Hubertus Fischer, Sepp Kipfstuhl and Jerome Chappellaz. 2015. Revision of the EPICA Dome C CO2 record from 800 to 600 kyr before present. Geophysical Research Letters. doi: 10.1002/2014GL061957.

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