The Impact of Stranded Fossil Fuel Assets on International Financial Institutions: A financial exposure analysis and implications for European central banks and financial regulators

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C-EENRG Working Papers, 2020

November 2020

UNIVERSITY OF CAMBRIDGE

CEENRG
Cambridge Centre for Enviroment, Energy and Natural Resource Governance

Please cite this paper as:

M.T. Baer. "The Impact of Stranded Fossil Fuel Assets on International Financial Institutions: A financial exposure analysis and implications for European central banks and financial regulators". C-EENRG Working Papers, 2020-2. pp.1-38. Cambridge Centre for Environment, Energy and Natural Resource Governance, University of Cambridge.

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The Impact of Stranded Fossil Fuel Assets on International Financial Institutions: A financial exposure analysis and implications for European central banks and financial regulators

Moritz Baer

ABSTRACT

This paper presents a comprehensive exposure analysis of international financial institutions (FIs) to stranded fossil fuel assets (SFFA) across 68 countries. The analysis disaggregates a 2.81 trillion US$ exposure of 6,510 FIs to the 26 largest publicly traded oil and gas companies (IOCs) and captures the SFFA-exposure not only through the equity but also through the bond channel. I present granular empirical insights on the composition and level of SFFA-exposure on the individual FI-level, the financial sectorial level, and the jurisdiction and international level. The results highlight the importance of bonds in the financial analysis because outstanding bonds account for almost 60% of the direct SFFA-exposure of the insurance sector alone. The paper draws on a new comparative framework of Risk-Levels for financial sectors that captures the financial risk and its diversification across different FIs. This uncovers financial stress and portfolio vulnerability of financial sectors and the respective country jurisdictions. The analysis reflects the highest Risk-Levels for pension funds and sovereign wealth funds in Norway, banks in France and the US, and insurance companies in the US and UK. With a focus on Europe, I stress the need to enhance prudential reforms by financial regulators. I argue that climate-related disclosure requirements alone are not sufficient to mitigate the far-reaching consequences of a high SFFA exposure of FIs. I discuss several measures for an intensified role of European central banks and financial regulators. These measures contribute to building a climate-resilient financial system.

Keywords: Stranded assets, climate-related financial risk, central banks and financial regulators, exposure analysis, low-carbon transition.

1. INTRODUCTION

The urgent need for mitigating climate change is calling for a fundamental transition towards a low-carbon economy. This entails a substantial reallocation of capital from the fossil fuel industry towards sustainable investments and gives rise to 'climate-related transition risks' (IPCC, 2018; NGFS, 2019). More specifically, stringent climate change policies and innovations in technology could induce a disruptive reassessment of the value of financial assets and create credit exposure as opportunities and costs associated with such climate-related risks become apparent (Bank of England, 2017; PRI, 2018). Among international cooperative initiatives, such as the Network for Greening the Financial System (NGFS), there has been an increasing awareness of such transition risks and the associated implications for financial stability (NGFS, 2019; Regelink and Reinders, 2017).

To achieve the goals of the Paris Agreement and limit global warming to 1.5°C with a probability of 50%, it is required to stay within the remaining carbon budget of 580 $GtCO_2$ (IPCC, 2018). Yet, the carbon potential of the total reserves of fossil fuels is estimated at around 2,750 $GtCO_2$ (Rogelj et al., 2016). This would result in the 'stranding' of global fossil fuel reserves and the associated extraction infrastructure, that would 'prior to the end of their economic life, no longer be able to earn an economic return' (IEA, 2019). A significant share of the total physical fossil fuel supply infrastructure that is at risk of 'stranding' is controlled by international oil and gas firms (IOCs). These firms represent 62% of oil and gas upstream assets, such as oil and gas wells, and 26% of downstream assets, such as refineries and pipelines (Carbon Tracker, 2020).

International financial institutions (FIs) are exposed to such 'stranded fossil fuel assets' (SFFA) through a direct financial exposure. False expectations about the valuation of the associated fossil fuel firm and their extraction infrastructure, leaves FIs vulnerable to a transition-induced reassessment and potential deterioration of their financial positions. SFFA-exposed FIs are at risk of significant financial loss with systemic consequences for the stability of financial systems and their macroeconomic performance (ESRB, 2016; Finansinspektionen, 2016).

A comprehensive understanding of the impact of SFFAs on the financial system is therefore exceptionally relevant in building up a climate-resilient financial system and in supporting a non-disruptive low-carbon transition (NGFS, 2019). In particular, efforts to safeguard financial stability from climate-related transition risks, require a granular analysis of the direct exposure of financial institutions to SFFAs. An internationally comprehensive and disaggregated analysis of the exposure of the financial system to these IOCs, incorporating the *asset* and *credit* exposure would therefore be highly valuable to understand the financial impacts of SFFAs.

The purpose of this paper is to provide such a disaggregated empirical analysis, by assessing the direct financial exposure of international FIs to the 26 largest IOCs. These 26 companies

represent a total market capitalisation of 58.13% of the wider publicly traded international oil and gas sector[1]. I utilise a newly created and unique dataset that incorporates on a granular asset-level the direct *equity* and *bond (credit)*[2] exposure of international FIs and their respective country jurisdictions. I perform an analytical analysis of financial stress and portfolio vulnerability by employing a comparative framework of financial sector-specific 'Risk-Levels' that captures the financial risk of the identified SFFA-exposure, relative to international peers. These insights are then discussed to derive the role of European central banks and financial regulators in building up a climate-resilient financial system (NGFS, 2019; PRI, 2018).

The structure of this paper is organised as follows. In section 2, I present a literature review on the interlinkages and mechanisms of climate-transition risks, specifically stranded fossil fuel assets (SFFA), with the financial system and feedback effects to the macroeconomy. In section 3, I prepare the quantitative research stage by presenting the data, the methodology of the exposure analysis and Risk-Levels, followed by a discussion of the scope and limitations of this paper. In section 4, I present the quantitative research results. I discuss the results of the direct SFFA-exposure for individual FIs and country jurisdictions. I highlight the necessity to incorporate the bond channel to comprehensively assess the exposure, especially in the international insurance sector. Further, I analyse the relative SFFA-exposure for individual FIs in the European banking and insurance sector. This serves as the basis to assess the vulnerability of FIs and the risk of such institutions to slide into financial distress. I then present financial sector-specific Risk-Levels for the most exposed countries and the G8 to identify countries that reflect less diversified exposures and hence are faced with a greater risk of an abrupt readjustment of financial assets. In section 5, I build upon the empirical insights and discuss the role of European central banks and financial regulators in minimising climate-related financial risk. I identify that current efforts undertaken by these actors dominantly focus on prudential financial initiatives, such as climate-related disclosure requirements. However, limitations of such prudential initiatives coupled with the presented empirical insights, suggest, that these initiatives are likely to be insufficient to mitigate the risk of a disruptive readjustment of SFFAs. I argue in favour of more pro-active financial initiatives and an intensified role of the European Central Bank (ECB). These initiatives would contribute to building a climate-resilient financial system.

[1] For the purpose of this paper I use the term 'SFFA-exposure', while acknowledging that the international IOCs in my sample only represent a subsample of the wider fossil fuel sector.

[2] The loan and bond channels combined represent the 'credit' channel - due to the lack of granular loan data for banks or FI's, I focus in my empirical analysis only on the bond channel to assess the credit exposure

2. CLIMATE-RELATED TRANSITION RISK AND THE FINANCIAL SYSTEM

This section aims at conveying the mechanisms and channels through which climate-related transition risks impact the financial system. The relevant theoretical concepts are visualised in *Figure 1* (see page 8) and are substantiated with a critical discussion of the sustainable finance and macroeconomic literature. In the first section, I discuss SFFAs and the direct effect on the real economy. The second section incorporates the exposure of FIs to highlight how the wider financial system has the potential to aggravate the financial loss stemming from SFFAs.

2.1 Stranded Fossil Fuel Assets (SFFA)

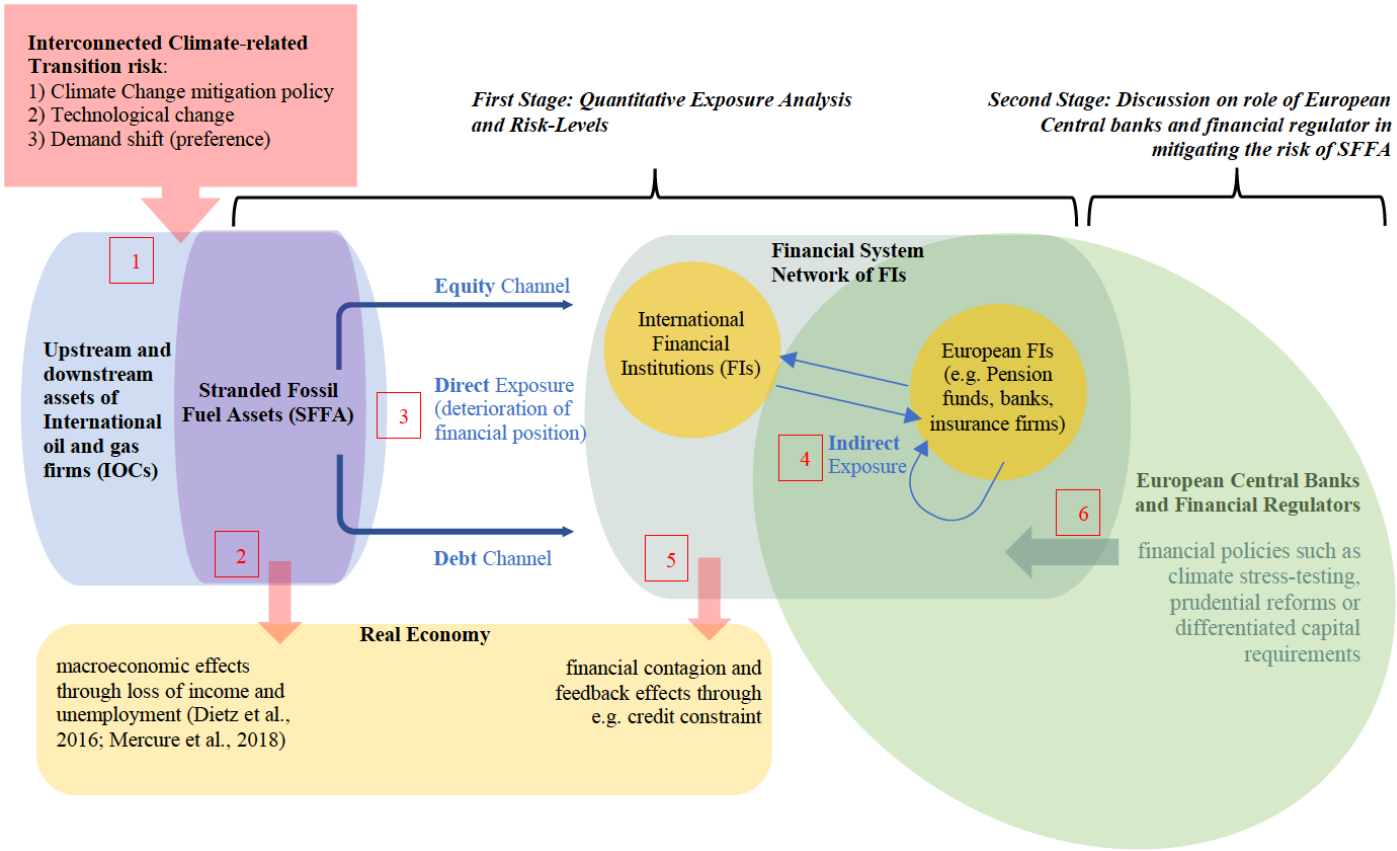
Following the Bank of England (2018), the drivers of climate-related transition risk can be categorised into three interconnected dimensions (*Figure 1*, *Box 1*). First, the fossil fuel industry is affected by climate change mitigation policies or changes to regulatory structures. As Rogelj et al. (2016)'s review article shows, the carbon potential of the total reserves of fossil fuels is estimated at around 2,750 $GtCO_2$. To achieve the goals of the Paris Agreement and stay within 1.5°C warming, relative to pre-industrial levels, it is required to stay within the remaining carbon budget of 580 $GtCO_2$ (IPCC, 2018).[3] This may result in the 'stranding' of up to 79% of the fossil fuel reserves.[4] The ESRB (2016) highlights that under a more stringent policy scenario, oil, gas and coal companies could lose up to 28 trillion US$ in revenue in the next twenty years, relative to baseline projections, representing a 22% decrease in sales for the fossil fuel industry. Second, technological change, such as the decreasing cost of renewables based on their levelised cost of energy causes profound disruptions in the wider fossil fuel energy system (BNEF, 2020). Third, a change in consumer preferences or economic downturns, as evident in the COVID-19 crisis, have a profound market impact, forwarding peak demand for fossil fuels (Carbon Tracker, 2020). All three dimensions are strongly interconnected and might materliase at the same time.

These drivers of climate-related transition risk may result in the stranding of upstream and downstream assets of IOCs. This confronts economies with the risk of a declining industry and macroeconomic effects through loss of income and unemployment *(Figure 1, Box 2).* Based on a top-down integrated assessment model (IAM), Mercure et al. (2018) suggest a discounted wealth loss of 1-4 trillion US$ from SFFAs. However, such an analysis neglects the direct exposure of FIs to vulnerable oil and gas firms and the interdependencies within the financial system that have the

[3] Assuming a 50% probability to stay below the 1.5°C target
[4] This is the authors' own calculation, which is based on the estimates of (IPCC, 2018; Joeri Rogelj et al., 2016).

potential to aggravate the financial loss stemming from SFFAs (Roncoroni et al., 2019). By employing a financial exposure analysis, this paper aims to overcome exactly this limitation.

Figure 1: Conceptual Map of research area on the impact of transition risk on the financial system



2.2 Exposure of the Financial System

To understand the risk that arises from SFFAs, it is crucial to conceptually understand how the financial system is linked and exposed to IOCs *(Figure 1, Box 3).* SFFA-exposure may affect the financial systems through a direct exposure of two[5] financial instruments. First, FIs are exposed through equity holdings, such as tradable ownership shares on stock markets. A highly exposed fossil fuel firm could be obliged to write-down its stranded assets, leading to a sudden devaluation of the

[5] due to the lack of granular loan data for banks or FI's, I focus in my empirical analysis only on the bond channel to assess the debt exposure

equities held by FIs.[6] Second, financial actors hold bonds, such as tradable debt securities and credits, that in the event of SFFAs are devalued due to a decreased creditworthiness of the fossil fuel firm (Daniëls et al., 2017; Stolbova et al., 2018). The Bank of England (2018) suggests that banks and FIs may have a significant credit exposure to IOCs because they face a higher risk of reduced corporate earnings and business disruption, leaving them unable to meet their debt obligations. And as costs and opportunities associated with the adjustment process of a low-carbon transition become apparent, the value of these financial instruments could abruptly be reassessed (PRA, 2018).

The expectation of high future profitability combined with an underestimation of climate-related transition risks results in an overvaluation of IOCs on financial markets. While the literature is consistent that such a mispricing is evident, there is no clear evidence on the extent of the mispricing of transition risks and whether this is giving rise to a systemic 'carbon bubble' (Campiglio et al., 2018; Sussams and Leaton, 2017). However, the literature identifies several factors that suggest a systematic underestimation of the risk from SFFAs.

First, short-termism of financial actors and their incentive structure suggest a subjective underestimation of long-term risk. This myopia results in a 'blindness' to climate-related financial risk (Silver, 2017; Thomä and Chenet, 2017). Second, the perceived political and technological uncertainty around the stringency of climate policies creates uncertainties around the degree of policy induced-transition risk (Quahe, 2018; Rietig, 2019). Third, undynamic financial risk models that inform financial decisions are unable to incorporate the uncertainty and fat-tailed distributed risk of irreversible climate catastrophes (Thomä and Chenet, 2017; Weitzman, 2009). This evidence suggests that financial markets misprice climate-related financial risk.

This mispricing of SFFAs on financial markets is further reinforced by current investments in the fossil fuel production and extraction infrastructure. The Carbon Tracker (2020) suggests, that around 1 trillion US$ is annually spent in the form of capital expenditures on expanding the supply of the fossil fuel industry. What is more, 3-4 trillion US$ of financial capital flows to expand the fossil fuel demand infrastructure yearly. Trends show a 4% rise in upstream oil and gas spending and significant investment in fossil fuel ventures, such as oil and gas wells (IEA, 2019). Such operations are partially financed through the issuing of new debt on financial markets, further reinforcing the exposure of FIs to the oil and gas industry. For instance, independent US shale companies rely heavily on new debt by selling *equity* and *bonds* on capital markets (IEA, 2019b). These investment levels, combined with the reinforced exposure of financial markets, suggest severe negative effects on unaware financial investors who are locked into fossil fuel investments (Caldecott, 2018; Scott et al., 2017).

[6] See e.g. BP writing off up to 17.5 billion US$ after cutting the energy price outlook. https://on.ft.com/3fp3UO7. (accessed 13.07.2020)

Such a direct SFFA-exposure then results in first-round losses. If such losses outweigh the overall equity of FIs for their leveraged positions, it is then transferred to their counterparties through indirect exposure across the financial network *(Figure 1, Box 4)*. This causes indirect second-round-losses which pose a risk to the financial stability (Roncoroni et al., 2019), and give rise to potential feedback effects to entire macroeconomies (Clerc et al., 2014). For instance, a significant financial loss from SFFAs could negatively affect the banks' lending decision and lead to substantial credit constraints *(Figure 1, Box 5)*. However, these feedback loops are less properly understood in the literature (NGFS, 2019).

For Central banks and financial regulators, a deep understanding and comprehensive empirical evidence of the impacts of SFFAs on the financial system are exceptionally relevant in building a climate-resilient financial system (BIS, 2020; NGFS, 2019). A granular analysis of the direct exposure of FIs could inform the design of prudential financial policies or climate-stress tests that are aimed at identifying and mitigating the risk from SFFAs *(Figure 1, Box 6).*

However, an internationally comprehensive and disaggregated analysis of the exposure of the financial system to IOCs, incorporating both, the *equity* and the *bond* channel, is still lacking. Partial exposure analyses with a focus on the equity channel have been undertaken. An example of this is Battiston et al. (2017) who identify a significant equity portfolio exposure of all European FIs, but neglect the debt network of *bonds* to SFFAs. Other exposure analyses, such as by Weyzig et al. (2014) or Carbon Tracker (2020) merely focus on aggregated sector exposures and thus lack the granularity that is provided in this paper. The only comprehensive study, undertaken by Vermeulen et al. (2019), that incorporates the exposure through the *equity* and *bond* channels on a granular firm-level is limited in its geographical scope, with a focus on the Dutch financial system.

The quantitative first stage analysis of the *equity* and *bond* exposure of FIs to IOCs aims to fill this gap in the literature. Moreover, my analysis has an international scope of 68 countries that captures the exposure not only within but also across financial markets and allows for a comparison of individual FI exposure on a firm-level, as well as sector-specific exposures across country jurisdictions in the Risk-Level framework.

3. METHODOLOGY OF QUANTITATIVE ANALYSIS

In this section, I present the dataset and the methodology of the empirical exposure analysis in section 3.1. Then the Risk-Level framework is presented in more detail (sections 3.2), followed by a discussion of the scope and limitations of the analysis in section 3.3.

3.1 Data and Empirical Analysis

My empirical analysis employs a newly created dataset that contains all outstanding equity and bond holdings on the 26 largest publicly traded IOCs by market capitalisation as of the third quarter of 2018. The sample of IOCs represent an absolute market capitalisation of 2.62 trillion US$ or 58.13% of the wider international oil and gas sector. The dataset was comprised from two separate datasets, gathered independently from *Bloomberg*, namely the equity data and the bond data, resulting in 1,865 unique FIs that hold direct exposure through the bond channel and 5,134 unique FIs that hold direct equity exposure across 68 country jurisdictions. Additionally, the dataset comprises individual information on the overall equity portfolio of the FI that is used to compute the individual portfolio share of the exposure, the country of origin of the respective FI, and the financial institution type.

In the empirical approach, I distinguish between three levels of analysis, namely the individual FI level, the financial sectorial level, and the country level.

First, I estimate the direct absolute exposure on an individual FI-level based on the sum of all outstanding *equity* and *bond* holdings to the 26 international oil and gas companies (IOCs). For all FIs *f*, and the set of all IOCs $\mathbb{S}$, the total exposure, E_f, is given by the monetary values of the exposure to the *equity* and *bond* instruments to all i ∈ S, δ_{fi}^{Equity} and δ_{fi}^{Bond}, respectively. Finally, δ_{fi}^{Misc} represents the unmeasured exposure for instruments such as loans that are not considered in this empirical analysis due to data limitations. The absolute SFFA-exposure can thus be measured as follows:

$$E_f = \sum_{i \in \mathbb{S}} \left(\delta_{fi}^{Equity} + \delta_{fi}^{Bond} + \delta_{fi}^{Misc} \right) \qquad \text{(Eq. 1)}$$

This individual FI exposure is termed ***absolute SFFA-exposure.***

I further construct the individual FI's equity portfolio P_f^{Equity} and compute the share of the direct absolute equity exposure E_f^{Equity} to this overall portfolio. This is termed ***relative SFFA-exposure*** and can be measured as follows:

$$RE_f = \sum_{i \in \mathbb{S}} \left(\frac{E_{fi}^{Equity}}{P_{fi}^{Equity}} \right) \quad \text{(Eq. 2)}$$

RE_f represents the portfolio diversification of FIs. Note, that due to data limitations, this diversification is only based on the overall *equity* portfolio and does not incorporate the share of *bond* exposure to the overall *bond* portfolio.

Second, I analyse this *absolute* and *relative SFFA-exposure* on a financial sectorial level. This represents the set of FIs that are the same types of financial institutions, e.g. pension funds, banks or insurance firms. I derive the aggregated absolute SFFA exposure AE_s based on the set of FIs within a financial sector *s*:

$$AE_s = \sum_{f \in F_s} E_f \quad \text{(Eq. 3)}$$

Further, I compute the relative SFFA exposure RE_s by constructing the overall sectorial equity portfolio. This is the mean of the relative equity SFFA-exposure for the set of FIs in the same financial sector. This is done for each financial sector within a given country.

Third, I estimate the aggregated *absolute SFFA-exposure* AE_c on a country level. I derive this exposure by combining the total exposure of the FIs within the same country of origin c, based on *Bloomberg data.* The rationale behind this is that the country of origin is ultimately responsible for the FIs and is confronted with the financial risk to their economy. More formally:

$$AE_c = \sum_{f \in F_c} E_f \quad \text{(Eq. 4)}$$

I further estimate the global aggregate exposure AE_g by summing the country exposure:

$$AE_g = \sum_{c \in C} \sum_{f \in F_c} E_f \quad \text{(Eq. 5)}$$

The empirical estimates from the analysis on the financial sectorial level and the country level serve as input for the computation of the Risk-Levels. This aims at uncovering financial stress and portfolio vulnerability of financial sectors and the respective country jurisdictions.

Summary Table of Aggregation:

$\mathrm{E_f}$	absolute SFFA-exposure for individual FI
$\mathrm{RE_f}$	relative *equity* SFFA-exposure for individual FI
$\mathrm{AE_s}$	aggregated absolute SFFA exposure for financial sector s
$\mathrm{AE_c}$	aggregated absolute SFFA exposure for country c
AE_g	aggregated global absolute SFFA exposure

3.2 Risk-Levels

The Risk-Level framework presents a comparative approach to assessing the risk associated with the SFFA-exposure of a set of FIs within a national jurisdiction. This framework has two levels. First, the Risk-Levels rank each country's absolute SFFA-exposure AE_c relative to the global aggregated exposure AE_g. I focus on the most exposed and G8 countries[7]. Second, on a more granular level, I derive the Risk-Levels of each financial sector within a host country by comparing the sectorial SFFA-exposure AE_s of country c relative to the overall sectorial exposure globally. Furthermore, I integrate into the framework the diversification of such an exposure to derive relevant risk implications. The intuition behind this is that the more the exposure is diversified across different FIs, the less vulnerable a sector or country is to systemic risk that arises due to a disruptive adjustment of financial assets. This is due to the systemic risk implications, i.e. contagion and second-round effects such as fire-sales, that arise when a large share of FIs within a particular financial sector are exposed to the materlialisation of common climate-related risks.

[7] i.e., the United Kingdom, Saudi Arabia, Germany, China, Norway, Canada, the United States, Russia, the Netherlands, Cyprus, Italy, Japan, France, and additionally on the EU27

The following Risk-Levels are computed based on the quantile distribution of the aggregated SFFA-exposure AE :

Risk-Levels

Very Low	*Low*	*Medium*	*High*	*Very High*
$(-\infty, x_{[20]}]$	$(x_{[20]}, x_{[40]}]$	$(x_{[40]}, x_{[60]}]$	$(x_{[60]}, x_{[80]}]$	$(x_{[80]}, +\infty)$

More specifically, AE_s is normalised to derive the five categories based on the quantiles to rank the set of financial sectors across countries. This results in the above-mentioned risk categories, ranging from Level *one* 'Very Low' to the highest Level *five* 'Very High'.

Moreover, I apply a weight w_f to the SFFA-exposure AE_s that represents the diversification D_f of the financial sector, i.e. the number of individual FIs by which the absolute SFFA-exposure is spread among. The rationale for applying a weight w_f (see equation 6) is twofold. First, it serves as a proxy to account for the relative financial market activity of the respective country. For instance, the United States and the Czech Republic are exposed to IOCs and hence present a positive AE_c value. However, as the US represents the largest financial market activity in the world, the aggregated exposure in the US is larger, in absolute terms, than the SFFA-exposure in the Czech Republic. In order to compare such heterogenous countries, we are interested in the SFFA-exposure in relative terms, corrected by a weight that accounts for the relative financial market activity, namely the diversification factor D_f. This results in a weight of 12.03 for the US, based on the largest diversification in the sample with the SFFA exposure spread across 4183 FIs, and a weight of 1.0 for the Czech Republic with a diversification value of only two. This allows for an unbiased comparison of the exposure among countries with a heterogenous financial market size, e.g. the US and the Czech Republic.

Second, in addition to serving as a proxy for the *'financial market activity',* the weight w_f also incorporates relevant risk implications into the computation of the Risk-Levels. As the diversification factor D_f also represents the number of FIs by which the potential financial loss stemming from an exposure to IOCs, is spread among. For instance, despite a sector having a low level of SFFA exposure on average, the risk stemming from such an exposure could be substantial if a disproportionate exposure is accumulated in a small number of institutions. Intuitively, a larger diversification value, not only represents a larger financial market activity of the FIs host country, but also decreases the individual and systemic risk vulnerability to SFFA. In other words, the more the exposure is spread among heterogenous FIs, the more diversified is the risk and the less vulnerable the country is to the associated financial and economic risk.

Note that I compute the weight based on a logarithmic function of the diversification value D_f, as it is assumed that the marginal benefit of diversifying the SFFA exposure is decreasing.

$$w_f = \log_2(D_f) \quad \text{(Eq. 6)}$$

This is intuitive. When the SFFA-exposure E_f is kept constant, moving from a low diversification level of two FIs to four FIs is decreasing the associated risk to a greater extent, then moving from a high diversification level of 100 FIs to 102 FIs, which only decreases the associated risk marginally. Note that the analysis may be sensitive to the specification of the functional form of the weight w_f. I have performed therefore a sensitivity analysis for a variety of functional forms and identify with a Wald-test that the resulting rankings of the sector-specific Risk-Levels are not significantly different.

Note that the proposed framework faces some limitations. While the Risk-Levels provided in this paper reflect the combined *equity* and *bond* exposure, as well as the diversification among FIs, it is not yet incorporating the relative SFFA-exposure of the individual FIs portfolio. This is because currently available data on the relative SFFA-exposure is only based on the overall *equity* portfolio and does not incorporate the share of *bond* exposure to the overall *bond* portfolio. Nevertheless, I present the relative SFFA-exposure RE separately with the Risk-Levels to interpret the Risk-Levels in conjunction with the partially available relative equity portfolio of financial sectors in section 4.4.

3.3 Scope and Limitations of the Analysis

My data is just representative of a subsample of the wider fossil fuel industry. Further, I do not incorporate firms in the coal industry due to data limitations. This is justified, as coal assets only account for 12% of the total value for all fossil fuel supply infrastructure. By contrast, oil and gas upstream assets (oil and gas wells) account for 62% and oil and gas downstream assets (refineries and pipelines) for 26% (Carbon Tracker, 2020). Overall, 53%[8] of the physical infrastructure that is at risk of 'stranding' is represented in the financial holdings of the largest international oil and gas firms in my sample.

Moreover, a limitation to the external validity arises because a large share of the world's reserves of oil and natural gas are controlled by unlisted national oil corporations (NOCs), for which only limited data is available. However, I incorporated NOCs that are listed on financial markets, such as OMV, CNOOC, ENI, Gazprom, Petrobras, SINOPEC, Rosneft, and Saudi Aramco. These represent 60.38% of the market capitalisation in my sample. This allows me to account for the increasing dominance of NOC relative to IOCs. I do not differentiate between those oil and gas firms in my sample and group *publicly listed* NOCs together with IOCs under the term IOC.

[8] 88% of the fossil fuel supply infrastructure is held by IOCs, of which 58% are represented in my sample. My sample therefore represents around 53% of the fossil fuel supply infrastructure

In general, my empirical analysis aims to estimate the direct *equity* and *bond* exposure of international FIs to the international oil and gas firms itself and its granular composition. It does not consider the exposure to firms that are only indirectly related to stranded fossil fuel assets through a disruption in the supply chain. Following the Carbon Tracker (2020), the integration of such firms in the industries *oil and gas equipment*, *service*, *construction* and *engineering* would add another significant exposure of 3,989 trillion US$. However, due to data limitations of the vulnerability of individual firms to stranded assets within such sectors, only an aggregated exposure analysis is currently feasible.[9]

The exposure estimates in my financial analysis therefore just represent a fraction of the total SFFA and climate-related exposure of international FIs and should be considered as lower bound estimates. However, note that the aim of this paper is not to provide an aggregated exposure estimate but rather to generate relevant insights on the composition of the exposure and the relative exposure to the overall portfolio of FIs. This is shown in the next section.

[9] For such an analysis, see the latest report by Carbon Tracker (2020).

4. FINANCIAL EXPOSURE ANALYSIS

In this section, I present the results of the direct exposure of FIs to stranded fossil fuel assets (SFFAs). Doing so contributes to the literature with disaggregated empirical results on the *absolute* and *relative* SFFA-exposure. I focus the discussion of the results from my analysis on two areas that I identify as relevant in informing European central banks and financial regulators.

First, in section 4.1, I show that the incorporation of the bond-channel is necessary to comprehensively assess the SFFA-exposure of FIs in climate-stress tests and effectively decide on efficient prudential reforms. My analysis underlines that the direct *bond* exposure of international FIs to SFFAs alone amounts to 210.03 billion US$. In the insurance sector alone, the bond exposure amounts to 58.31% of the overall combined SFFA-exposure.

Second, in section 4.2, I analyse the relative SFFA-exposure for individual FIs in the European banking and insurance sector (the EU27 and the UK). This is important to assess the vulnerability of FIs and the risk of such institutions to slide into financial distress. If an FI's portfolio is insufficiently diversified, substantial first-round losses due to a deterioration of the FI's financial position could then be transferred to their counterparties within the financial network. This results in indirect second-round-losses and poses a risk to the financial stability (Roncoroni et al., 2019). I hence present empirical evidence on the portfolio diversification and relative SFFA-exposure on highly vulnerable FIs in Europe. This is aimed at informing relevant European actors about the severity of the risk of SFFAs in some particular instances. Furthermore, I want to utilise such cases to conceptually analyse the chain of factors that determine the overall financial loss and risk to economies.

Such a conceptual financial loss and risk analysis is then undertaken in section 4.3. The aim is to give a complete conceptual picture of the risk of SFFAs and the potential amplification and second-round losses, substantiated with empirical evidence where necessary. This advances the understanding of the far-reaching risk implications stemming from SFFA. Lastly, in section 4.4, I present the results from the comparative framework of Risk-Levels that partially captures such risk implications, to inform financial and supervisory actors, as well as jurisdictions about the degree of risk their economies are facing.

4.1 The Bond-Exposure

As shown in *Table 1,* my analysis suggests a significant financial exposure through the *bond* channel for several types of FIs *(highlighted in red).* For international banks, outstanding bonds to IOCs account, on average, for 14.52% of the overall SFFA-exposure. For investment advisors and hedge funds the share of bond exposure amounts to 16.66% and 14.76%, respectively. The largest share

of bond exposure is present in the international insurance sector where the overall SFFA sectorial exposure amounts to 58.31%. These numbers show that previous studies which did not incorporate the *bond*-channel have missed a significant part of the overall exposure of insurance firms, investment advisors, banks, and hedge funds.

Table 1: Disaggregated overall SFFA-Exposure to IOCs by share of Bond and Equity Exposure for financial sector.

Financial Sector	***Direct overall Exposure in US$ billion***	***Bond Exposure in US$ billion (share of total)***	***Equity Exposure in US$ billion (share of total)***
Bank	131.62	19.11 (14.52%)	112.52 (85.48%)
Corporation	33.54	1.39 (4.14%)	32.15 (95.86%)
Government	1811.85	1.99 (0.11%)	1809.86 (99.89%)
Insurance Company	113.92	66.43 (58.31%)	47.49 (41.69%)
Investment Advisor	617.00	102.79 (16.66%)	514.21 (83.33%)
Pension Fund	13.71	2.22 (1.18%)	11.49 (98.82%)
Sovereign Wealth Fund	37.50	0.04 (0.10%)	37.46 (99.90%)
Hedge Fund	9.68	1.43 (14.76%)	8.25 (85.24%)
Others	44.41	3.52 (7.92%)	40.89 (92.18%)
Combined SFFA-Exposure	**2811.68**	**210.03** (7.47%)	**2601.65** (92.53%)

In my sample, the bond-exposure accounts for 7.47% of the overall exposure of FIs to IOCs. Note that this estimate is highly sensitive to an equity holding *outlier* of the Kingdom of Saudi Arabi to Aramco Oil. This significantly distorts the relative share of bonds. If this outlier is not considered in the analysis, then the overall share of the bond-exposure to the aggregated global SFFA-exposure rises to 16.73%. In total, the direct *bond* exposure of international FIs to SFFAs amounts to 210.03 billion US$.

This has important implications on the climate-stress testing efforts and prudential reforms by financial regulators, such as the European Insurance and Occupational Pensions Authority (EIOPA). For the insurance sector, the financial exposure might amount to more than twice the previous exposure estimates in the literature that are based only on a partial *equity*-analysis, such as undertaken by Battiston et al. (2017). This shows that previous studies that did not incorporate the bond-channel may have missed a significant part of the picture.

Furthermore, the insurance sector is also increasingly vulnerable to climate-related physical risk, leading to increased financial damage from droughts and storms (NGFS, 2019; Scott et al., 2017). These interconnected physical risks may further exacerbate the impact of climate-related transition risks, such as the risk of SFFA. In the next section, I turn to an analysis of the relative SFFA-exposure for European insurance firms and banks to determine the risk of SFFA.

4.2 The Relative SFFA-Exposure

The *equity* and *bond* exposure analysed above is important to derive the potential first-round losses due to a deterioration of the financial position of the respective FIs. However, to determine the overall financial risk, including the second-round financial losses, it is more important to measure the level of exposure relative to the overall portfolio of the FIs.

For these reasons, I now present the relative SFFA-exposure estimates for financial sectors with a focus on the EU27 and the UK. As shown in *Table 2* below (page 19), the relative SFFA-exposure RE_S represent 3.59% for the banking sector and 1.73% for the insurance sector. Focusing on a more granular level, I identify particularly high exposed banks such as the *Consorbank* with a relative exposure RE_f of 32.38% or the Caixa Bank S. A with 28.82%. For the insurance sector, among the most SFFA-exposed FIs relative to their overall portfolio, I identify *La Mondiale Partenaire* with 23.57% and the *Swiss Re AG* with 23.32%.

Table 2: Disaggregated relative SFFA-exposure by financial sectors and selection of firms with lowest portfolio diversification

Financial Sector	*Relative SFFA-exposure (in %)*	*Country*
Bank	**3.59**	**-**
Consorbank	32.38	Germany
ING DiBa AG/Austria	30.55	Austria
Caixa Bank S.A.	28.82	Spain
Corporation	**23.69**	-
Government	**8.36**	-
Insurance Company	**1.73**	-
La Mondiale Partenaire	23.57	France
Swiss RE AG	23.32	United Kingdom
Livforsakringsbolaget Skandia OFB	10.79	Sweden
Investment Advisor	**1.81**	-
Pension Fund	**5.47**	-
Sovereign Wealth Fund	**2.76**	-

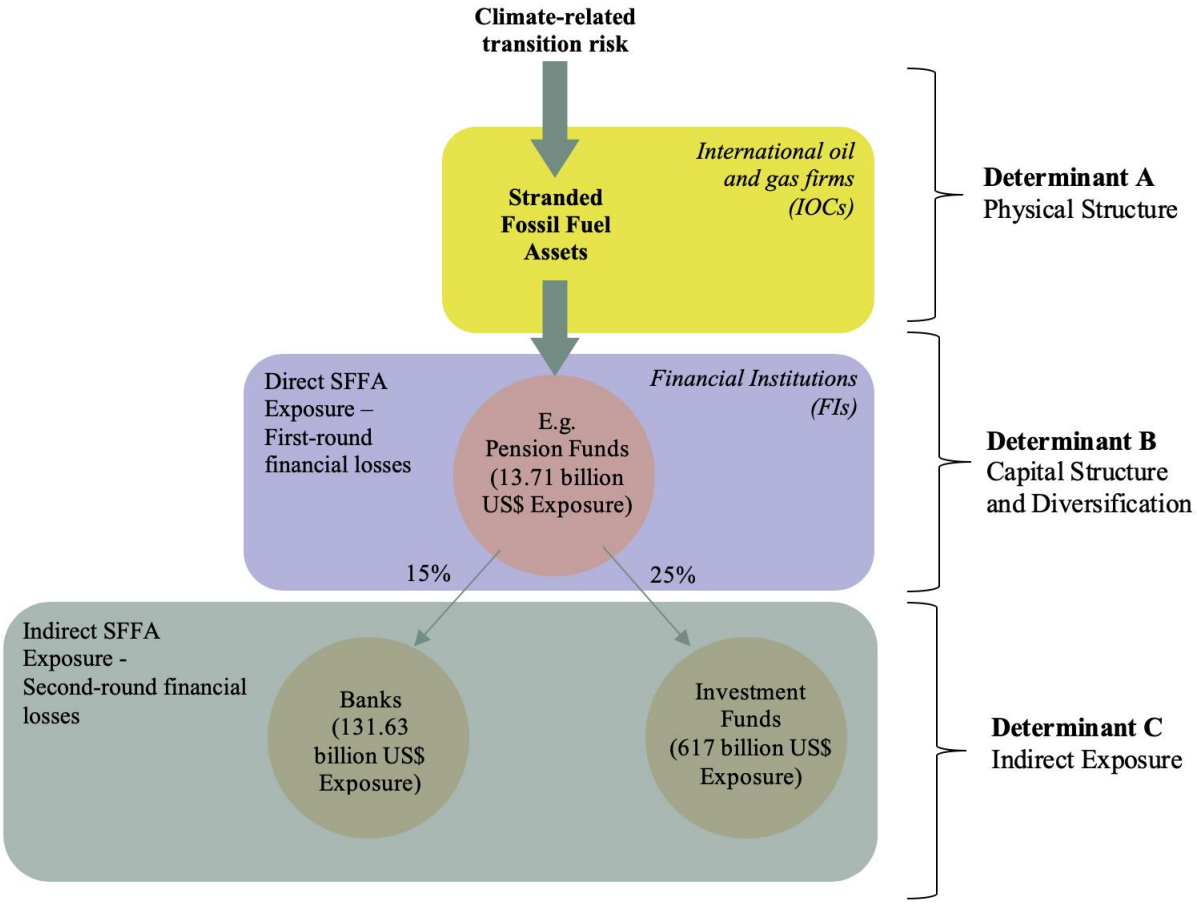
These results suggest that a significant share of the respective FI portfolios is exposed to IOCs. Such FIs are then disproportionally more vulnerable to a disruptive readjustment of financial asset values. In the event of an insufficiently diversified portfolio, these losses may lead to a solvency risk and could be transferred to their counterparties within the financial network. I further explain such implications in an analysis of risk and financial loss in the next section.

4.3 Risk and Financial Loss

In this section, I derive the magnitude of risk and potential financial loss stemming from SFFAs. To this end, I first propose three interconnected risk determinants (see figure 2, page 21). A risk determinant is part of a chain of factors that transfer risk from the initial SFFAs in the IOC industry, over FIs, to the wider financial system. *Determinant A* captures the physical structure of the oil and gas firms (IOCs), such as the vulnerability and composition of the associated extraction infrastructure. *Determinant B* captures the capital structure of the financial institution (FIs) and the respective portfolio diversification. *Determinant C* captures the indirect exposure of FIs among the financial network. I build upon the results of the previous section, by considering the relative SFFA-exposure to FIs. This substantiates *Determinant B* and *C* with relevant empirical insights.

The discussion answers how financial institutions are affected by the risk stemming from SFFA-exposure. A further aim of this section is to provide a clear understanding of the mechanisms through which the SFFA risk is materializing. Note that I do not give an *exhaustive* account of the risk implications within a financial network. Instead, my discussion provides an avenue for further research to qualitatively assess in a case by case study highly exposed FIs to determine potential weak links in the financial network.

Figure 2: Chain of SFFA risk determinants that capture the degree of risk and financial loss



The **first** factor in the chain of determinants relates to the composition and vulnerability of the physical infrastructure to climate-related risk drivers (Determinant A). This determines to what extent IOCs are affected by stringent climate policy, technological innovation, or a demand change for fossil fuels. The institutional context of the respective IOC therefore matters. This includes the underlying tax regime or the competition from the market penetration of renewables. In other words, this determines which fraction of the IOCs' assets and associated extraction infrastructure are becoming 'stranded'. For instance, in my sample the IOC *'Anadarko Petroleum'* is highly vulnerable to a policy-induced demand shock due to its unprofitable extraction methods. The firm operates mostly with relatively expensive shale oil that leaves the IOC with high variable costs. In contrast to IOCs with conventional low-cost oil extraction methods, a demand-driven decrease in the global oil price would leave firms such as *Anadarko* most vulnerable. Generally, their relatively uncompetitive extraction methods are sensitive to disruptions to corporate earnings and further highly dependent on subsidised government programs. Following the vulnerability matrix by the

Carbon Tracker (2020), new assets such as gas turbines and oil drilling infrastructure face the highest risk of becoming stranded in the near future.

Second, the extent to which the risk of SFFAs is then transferred to exposed FIs is determined by the capital structure and diversification of the respective FI (Determinant B). FIs with a high diversification in their portfolios (low RE_f) are – irrespective of their absolute exposure E_f – less vulnerable to a disruptive devaluation of SFFAs. By contrast, less diversified FIs with a significant share of their portfolio exposed to IOCs, are less capable to absorb the potential first-round losses that result from an abrupt readjustment of SFFA. Fender et al. (2019) show that, for instance, increasing green bonds in the portfolio is necessary for the diversification and resilience of the portfolio to safeguard financial institutions through the transition process.

However, my empirical analysis of the relative equity SFFA exposure to the overall portfolio shows that the *practice* looks different. I identify FIs with a low diversification. Various Banks in Europe are holding a significant share of their portfolios in equities issued by the IOCs, leaving a large share of their overall equity portfolio highly exposed to SFFAs. For instance, I identified *Consorbank* in Germany, *ING DiBa AG* in Austria, or *Caixa Bank S.A* in Spain with a low diversification in their portfolios. Their SFFA equity exposure relative to the overall portfolio ranges from 28.82% to 32.38%. Put differently, around one-third of their total equity holdings (that also serve as capital buffer) is invested in the IOCs in my sample and is thus at risk of SFFAs. A disruptive adjustment of SFFA-valuation poses a significant solvency risk to such banks.

Third, and finally, the indirect exposure of such FIs to other financial institutions among the financial network is highly relevant. As Battiston et al. (2017) show conceptually, financial actors' exposure to the financial sector itself via equity-shares range from 13% to 25.8%. As an illustration, consider pension funds that hold a direct *equity* and *bond* exposure to SFFAs of 13.71 billion US$ and a diversification level with an average relative exposure to their overall portfolios of 5.47% (see empirical results of previous section).

In addition to this significant direct exposure and unfavourable diversification in their portfolios, Battiston et al. (2017) also demonstrate that pension funds hold 25% of their total assets in equity shares of investment funds. However, based on my estimates, investment funds themselves hold a significant direct SFFA exposure of 617 billion US$. Even though the diversification level of investment funds is moderate at 1.87% relative to their overall portfolio, this link in the financial network represents a significant indirect exposure of international pension funds. What is more, pension funds hold another 15% of total assets in bonds and loans to banks. Additionally, they are directly exposed with 131.63 billion US$ and a relatively unfavourable exposure diversification of 3.59 % to their overall portfolio.

Taken together, these considerations imply that climate-related transition risks, such as SFFAs, impact pension funds not only through the absorbed first-round loss, but also through their

indirect exposure among other FIs in the financial network (Figure 2). If the first-round financial losses from the direct exposure (represented by a combination of Determinant A and B) outweigh the overall equity of FIs, such losses are transferred to their counterparties within the financial network (Roncoroni et al., 2019) and thus give rise to amplification effects. This results in financial frictions and uncertainties about the counterparties' liquidity and ability to repay debt obligations. Estimates for the interbank market by Roncoroni et al. (2019) suggest that such second round losses create financial contagion and might be of similar size than losses from the direct exposure.

This analysis provides the context for the interpretation of the Risk-Levels in the next section and demonstrates how the empirical estimates of the direct exposure analysis are translated into financial loss. This further demonstrates how this could pose a risk for the stability of the financial system.

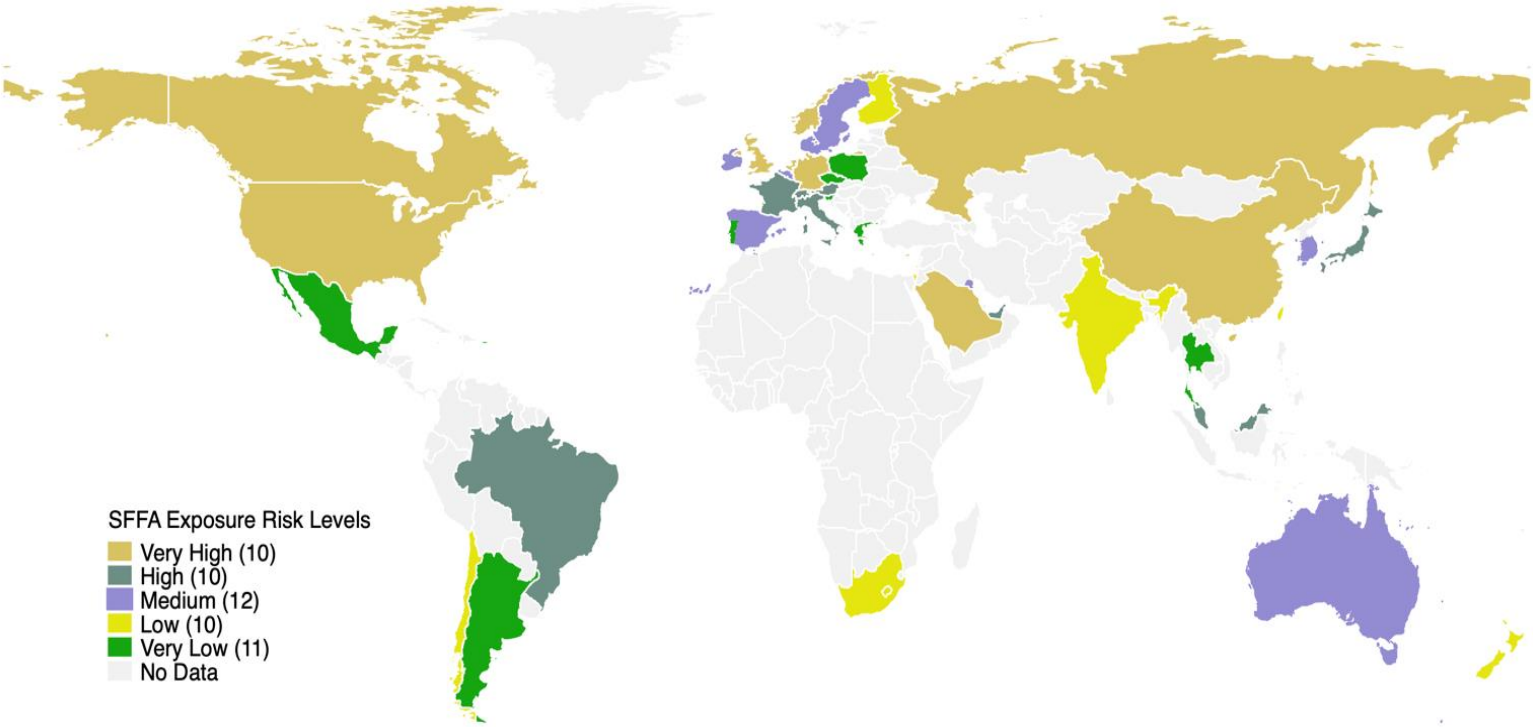
4.4 Risk-Levels for Country Jurisidictions and Financial Sectors

This section discusses the results of the Risk-Levels for country jurisdictions and financial sectors. These Risk-Levels reflect a comparative approach that is based on the combined *equity* and *bond* exposure, as well as the diversification among FIs that controls for the overall financial market activity *(see methodology section 3.2).* Recall, that the framework is not yet incorporating the relative SFFA-exposure of the individual FIs or sectorial portfolio. Instead, I present the relative equity SFFA-exposure separately to interpret the Risk-Levels in conjunction with the respective sectorial portfolio diversification. As identified in the analysis of risk and financial loss (see section 4.3), highly exposed and undiversified sectors are at a higher risk of second-round losses that pose a threat to financial stability.

This section is structured along the three levels of my analysis. First, I discuss the results on an aggregated country level. Second, I discuss the Risk-Levels on a more granular level, focusing on the financial sector within a country jurisdiction. Where necessary, I substantiate the discussion with empirical results on the individual FI-level.

Figure 3 shows the Risk-Levels for all geographical areas on a country level. I identify the highest Risk-Level for Saudi Arabia, reflecting a total SFFA-exposure of 1.65 trillion US$, the United States with an exposure of 627.54 billion US$ spread among 4,183 FIs, and the United Kingdom with 67.44 billion US$ spread across 195 FIs.

Figure 3: Risk-Levels for countries based on exposure diversification and combined SFFA equity and bond exposure, relative to international peers



Among the most exposed countries, Norway and the Netherlands are the least diversified with the total SFFA-exposure to IOCs of 51.67 billion US$ and 42.49 billion US$ spread across only 21 and 34 FIs, respectively. China, Russia, Canada, Germany, and Cyprus also fall within the highest Risk-Level. While France, with 28.88 billion US$, has a similar exposure as Germany, it only represents the Risk-Level 'High' due to a relatively higher diversification level among 112 FIs, as opposed to 57 FIs in Germany. Additionally, for Europe, my analysis suggests a direct exposure of 344.87 billion US$, including the United Kingdom, the EU27, Norway, and Switzerland.

Further, the right column in *Figure 4* (see page 26) presents the relative SFFA-exposure of these jurisdictions to their respective GDP. I identify a substantial relative exposure of Saudi Arabia with 83.15% of GDP and Cyprus with 30.54% of GDP. The Saudi Arabia estimate is mainly driven by a single equity holding of the government to the IOC *Aramco Oil*. Cyprus' exposure is largely explained by an unclassified holding of an individual to the IOC *Lukoil*.

I further identify FIs in Norway and the Netherlands as highly vulnerable with a combined SFFA exposure of 12.04% of GDP and 4.08% of GDP, respectively. For the Netherlands this exposure

is mainly driven by the *FI Euroclear Netherlands*, *APG Asset Management*, as well as the insurance company *NN Group* and the *Aegon Group*. The exposure in Norway is primarily explained by the *Kingdom of Norway Ministry of Petroleum & Energy*, the *Norges Bank*, *and Folketrygdfondet*.

Taken together, the G8 countries represent a combined relative SFFA-exposure to the IOCs in my sample that amounts to 1.29% of the GDP, or 1.03 trillion US$ in absolute terms. Overall, the direct *equity* and *bond* exposure of international FIs to international oil and gas firms (IOCs) amounts to 2.81 trillion US$, representing 1.88% of global GDP.

This significant exposure and subsequently high Risk-Levels reflect a high degree of risk and vulnerability of FIs to a disruptive readjustment of financial assets. This confronts the host country, which is ultimately responsible for these financial actors, with a substantial risk to their economies. For a more detailed understanding of the SFFA-exposure composition, I analyse these highly exposed jurisdictions, together with the remaining G8 countries, on a more granular financial sector level. My aim here is to present a detailed account on the sector-specific composition and associated risks of high exposure-levels to SFFA. These results then inform my discussion in the next section on the role of European Central banks and financial supervisors in designing and implementing sector-specific and systemic financial policies to monitor and mitigate the risk stemming from SFFA.

Figure 4: Risk-Levels on financial sector level for most exposed jurisdictions and G8 countries, and in brackets the sectorial relative SFFA-exposure RE_s in percent)

Most Exposed	*Bank*	*Corporation*	*Government*	*Insurance Company*	*Investment Advisor*	*Pension Fund*	*Sovereign Wealth Fund*	*Exposure/GDP in % (absolute Exposure E_c)*
Saudi Arabia	-	-	**Very High** *(4.80%)*	-	-	-	-	**83.15** *(1645.12)*
Cyprus	-	**Very High** *(100%)*	-	-	-	-	-	**30.54** *(11.62)*
Norway	**Low** *(1.95%)*	**Low** *(61.57%)*	**High** *(100%)*	**Very Low** *(22.92%)*	**Very Low** *(3.50%)*	**Very High** *(11.77%)*	**Very High** *(2.19%)*	**12.04** *(51.67)*
Netherlands	**Very Low** *(2.13%)*	**Low** *(1.16%)*	-	**Medium** *(0.91%)*	**Very High** *(7.87%)*	**Very Low** *(4.24%)*	-	**4.08** *(42.49)*
Russia	**Very Low** *(23.91%)*	**Very Low** *(1.92%)*	**High** *(73.94%)*	-	**Very Low** *(14.56%)*	-	-	**1.23** *(55.56)*
G8 Countries								**1.29** *(1029.49)*
United States	**Very High** *(2.30%)*	**Medium** *(12.96%)*	**Low** *(1.14%)*	**Very High** *(1.67%)*	**Very High** *(1.49%)*	**High** *(4.22%)*	**Medium** *(2.33%)*	**2.81** *(627.54)*
Canada	**High** *(1.41%)*	**Very Low** *(81.96%)*	**Very Low** *(21.96%)*	**Medium** *(1.04%)*	**Medium** *(0.87%)*	**Medium** *(2.71%)*	**Low** *(1.62%)*	**2.10** *(41.41)*
United Kingdom	**Medium** *(18.92%)*	**High** *(19.34%)*	**Very Low** *(9.04%)*	**Very High** *(6.28%)*	**High** *(2.20%)*	**Low** *(12.62%)*	-	**2.09** *(67.74)*
France	**Very High** *(2.03%)*	**Medium** *(12.70%)*	-	**Low** *(6.54%)*	**Medium** *(1.46%)*	-	-	**0.91** *(28,88)*
EU27	**High** *(1.65%)*	**Very High** *(37.93%)*	**Low** *(15.52%)*	**High** *(2.81%)*	**High** *(1.92%)*	**Very Low** *(2.28%)*	-	**0.86** *(203.06)*
Italy	**Very Low** *(0.81%)*	**Medium** *(25.82%)*	**Medium** *(29.87%)*	**Low** *(0.85%)*	**Very Low** *(2.86%)*	-	-	**0.72** *(17.94)*
Germany	**Medium** *(6.95%)*	-	-	**High** *(0.18%)*	**Low** *(0.74%)*	-	-	**0.55** *(25.12)*
Japan	**Low** *(1.37%)*	**Very Low** *(0.12%)*	-	**Very Low** *(0.13%)*	**Low** *(0.60%)*	-	**High** *(1.31%)*	**0.30** *(17.80)*

Figure 4 shows the results on a financial sector level within jurisdictions. My analysis attributes a Very High Risk-Level to pension funds and sovereign wealth funds in Norway. Here a disproportionate exposure is accumulated in individual financial institutions. The *Norges Bank* as a sovereign wealth fund alone represents a significant SFFA-exposure of 16.68 billion US$. The pension fund *Folketrygdfondet* represents a 15.19 billion US$ exposure. Such a substantial exposure that rests upon a single FI without any diversification poses a risk of second-round losses among the financial network if their capital structure represents a low capability to absorb the potential first-round losses from SFFA. In the case of *Folketrygdfondet,* a substantial share of 11.77% of the overall

portfolio is exposed to the IOCs in my sample. Such an undiversified portfolio poses a Very High risk among the financial network, suggesting a significant vulnerability to SFFAs.

I also identify a Very High Risk-Level for the banking, insurance, and investment advisor sector in the United States. While these sectors are highly diversified across 3.895 FIs, they still represent a greater risk of financial loss stemming from SFFAs because their exposure is disproportionally higher than peer sectors in other countries. However, the insurance and investment advisor sectors have diversified portfolios, with the exposure to IOCs in my sample amounting to only 1.67% and 1.49% of the overall sectorial equity portfolios respectively. This implies that FIs in the US, due to their diversified capital structure, are at a lower risk of sliding into financial distress from the initial first-round losses.

For the United Kingdom, I identify a Very High Risk-Level for the insurance companies, based on a high absolute SFFA exposure that is accumulated in only six FIs. And while UK banks only represent a Medium Risk-Level due to a low absolute SFFA-exposure, the insurance sector presents a significant vulnerability to second-round financial losses. This is due to the relatively undiversified portfolio compared to its international peers. 6.28% of the total assets in the sector-portfolio are exposed to the IOCs in my sample. Initial first-round losses due to a disruptive adjustment of the financial value of these SFFA may outweigh the overall equity of insurance companies. This gives rise to second-round losses among the indirectly exposed financial network, as losses are transferred to their counterparties. Especially increased defaults on the outstanding debt to UK and international banks may give rise substantial amplification effects.

This is problematic as banks and insurance companies in the EU27 themselves represent a High Risk-Level based on the absolute SFFA-exposure and the diversification among 65 European banks and 22 European insurance companies. However, as opposed to the UK, the share of SFFAs in the overall sectorial equity portfolios remains moderately low at 1.65% for banks and 2.81% for insurance companies. But within the EU27, the French banking sector present a Very High Risk-Level. This is because the absolute *equity* and *bond* exposure is only diversified across four banks, a fact that is driven by a significant exposure of the *Credit Agricole Group* with 13.80 billion US$, followed by *Natixis SA* and *Societe Generale SA*.

Interestingly, the Risk-Levels further point to limitations in the transparency of data on FIs portfolios. As shown in the methodological section 3.3, the relative SFFA-exposure that represents the diversification within the sectorial portfolio is only based on the overall *equity* portfolio and does not incorporate the share of *bond* exposure to the overall *bond* portfolio. My findings thus have interesting implications on current disclosure practices. The insufficient transparency around the climate-related disclosure of relevant information of the overall *bond* portfolio of FIs has to be overcome to equip financial regulators with the tools necessary to accurately assess the vulnerability of financial distress and second-round effects. This is especially relevant for the

European Insurance and Occupational Pensions Authority (EIOPA) which is tasked with the prudential oversight of highly *bond* exposed European insurance firms.

In the next section, I discuss the financial policy implications of such a limitation and more broadly discuss the role of European actors in enhancing their supervisory ability to monitor and identify the risk associated with SFFAs.

5. THE ROLE OF EUROPEAN BANKS AND REGULATORS

This section builds on the empirical insights and limitations of the financial SFFA-exposure analysis and the Risk-Levels. With a European focus, I critically discuss the current political economy and sustainable finance literature.

This section is structured as follows. In the first section, I specifically focus on the role of EIOPA in identifying the SFFA-risk for highly exposed European insurance firms. I suggest that enhancing the disclosure on bond-portfolios of FIs is a pre-requisite to better assess and monitor such risk. Such financial policy initiatives are in the realm of a risk-focused prudential role of European actors. In the second section, I present the limitations of such prudential measures. I argue that while enhanced disclosure requirements increase the supervisory ability, their reluctance on the market prevents such measures from effectively mitigating the risk of SFFAs. In the third section, I then discuss the role of the European Central Bank (ECB) in mitigating the high Risk-Level for European banks. I argue, in light of vulnerable European banks and the limitations of prudential measures, for a more promotional role to actively mitigate the risk of financial distress and to safeguard financial stability.

5.1 Prudential Role of Enhancing Disclosure

As evident in the limitations of the Risk-Levels, the transparency and disclosure around the overall *bond* portfolio of FIs is currently insufficient. Such transparency is, however, crucial to accurately identify and monitor the vulnerability of financial distress and second-round effects (see section 4.3). This is especially relevant for the role of EIOPA, which is tasked with the prudential oversight of highly *bond* exposed European insurance firms. As shown in section 4.1, 58.12% of the overall SFFA-exposure is due to the bond-channel. Further, I identified highly exposed insurance firms such as *La Mondiale Partenaire* or *Swiss Re AG* that reflect highly undiversified equity portfolios with a RE_f of up to 23%, meaning that their portfolios are heavily invested in the IOCs in my sample. As my analysis does not include the relative bond portfolio exposure to SFFA, these RE_f estimates could be severely underestimated. Hereby, this paper aims to provide a first initial step in the direction of a reliable climate-stress test by uncovering the relevance of the bond channel and the associated limitations that arise in this context.

Neglecting the bond channel in the tools that inform prudential regulation leads to a substantial underestimation of the risks associated with SFFA. More specifically, an extensive disclosure of the overall bond portfolio of European insurance firms is necessary to accurately identify the systemic risk implications that arise due to second-round losses. I therefore stress the

need for enhancing climate-related disclosure requirements in this area. This could substantially increase EIOPA's supervisory abilities.

Such insights could be included in EIOPAs technical advice to the European Commission on potential amendments acts under Directive 2009/138/EC (Solvency II Directive) with regard to the integration of climate-change risks. Recent developments go in the right direction. First steps are being undertaken by assessing the exposure of European insurance firms to sovereign bonds (Battiston et al., 2019; Stolbova et al., 2018). However, corporate bonds, that are the subject of the analysis in this paper, are still neglected. For the UK, the Prudential Regulatory Authority acknowledges its role of enhancing the resilience of the UK financial system by supporting a non-disruptive market transition towards a low-carbon economy (PRA, 2018). An example of this is the integration of climate-related risks in its prudential supervision. This includes deepening activities in the insurance sector, with the PRA joining a group of insurance regulators in 2016 to establish the Sustainable Insurance Forum.

5.2 Limitations of Prudential Role

While such developments represent a promising and, more importantly, a necessary avenue, these initiatives and climate-related disclosure requirements are dominantly in the realm of prudential policies. These policies are aimed at enhancing the transparency of market information associated with the risk of SFFAs but remain subject to accurately identifying and monitoring the risk (Lautenschlaeger, 2018). Enhancing data around the bond portfolio of FIs, or requiring financial actors to disclose climate-related risk are hereby aimed to better inform risk management procedures, investment decisions, and longer-term strategies of FIs (BIS, 2020). This is based on a market-fixing approach that requires the implementation of such disclosed information through a voluntary market-discipline (Kattel et al., 2018; Ryan-Collins, 2019).

However, it remains unclear whether this is sufficient to actually mitigate the risk of SFFAs. Undoubtably, enhanced prudential measures significantly increase the supervisory ability of European actors to monitor and identify risk. Yet, the mitigation of such risk, through the incorporation into investment decisions, is left to financial actors on a voluntary basis. In other words, the mitigating effect of climate-related disclosure requirements rely on efficient markets to incorporate such information into risk management procedures (Ryan-Collins, 2019). But recent evidence suggests that a voluntary approach to e.g. risk disclosure may not be sufficient to generate a step change in investment behaviour (Christophers, 2017). Further problems arise when considering the fossil fuel firm behaviour. As Bebbington et al. (2020) show, the absence of mandatory requirements results in these firms to insufficiently reflect climate-related risks in their reports and strategies.

What is more, the short-term incentives and behavioural biases by market participants are likely to prevent these measures to effectively translating into sufficient market action. The short-term bias on financial markets may prevent financial actors to integrate long-term perspectives and insights generated from climate-related disclosure in their investment decisions (Caldecott et al., 2016; European Commission, 2019; Griffin et al., 2015). Furthermore, as argued in the previous section, improving the awareness of investors on climate-related risks requires extensive datasets and standardised methodologies that are currently unavailable *(e.g. data on bonds or portfolio diversification)*. In the light of this, mitigating and minimising the exposure of FIs to substantial second-round losses among the financial network, may require a more promotional role of European actors.

5.3 The Need for a More Promotional Role

Insufficient transparency around the diversification of *bond* portfolios, coupled with the general limitations of a prudential approach, suggest that current initiatives may be insufficient to mitigate the risk of SFFAs. I hence turn to a discussion of two more promotional measures, namely *differentiated capital requirements* and *the incorporation of climate risks into portfolio decisions.*

First, I discuss *'differentiated capital requirements'* that would alter the value of-risk weighted assets (RWA) for highly exposed banks in determining their capital ratio (EU, 2013a, 2013b). This so called 'brown penalising factor' (BPF) (D'orazio and Popoyan, 2019) would require banks to hold more capital for regulatory purposes when credit is allocated to carbon-intensive oil and gas firms. In other words, European banks would be incentivised through their financing conditions to actively steer credit towards more longer-term, sustainable investments. A BPF would hence be utilised to respond to development strategies or a wider public purpose by steering financial flows to sustainable sectors, irrespective of their implied risk. This follows a market-shaping approach, rooted in the precautionary principle, that favours development strategies, e.g. the transition towards a decarbonised economy, over risk considerations (Kattel et al., 2018; Mazzucato, 2016).

The results from my exposure analysis support a more promotional role of European central banks. As is evident in the Risk-Levels, the banking sector in the EU27 and especially in France is highly exposed to the IOCs that pose a threat to the financial stability due to a low risk diversification. A large share of the SFFA-exposure and the associated risk is spread only among very few banks in the Eurozone. Further, in section 4.2, I identified individual banking institutions such as *Consorbank* that hold a highly undiversified relative SFFA-exposure of up to 32.38%. Such banks are particularly vulnerability of sliding into financial distress as a result of a disruptive devaluation of stranded fossil fuel assets in their portfolios.

Given such High Risk-Levels for the European banking sector, the ECB, being responsible for banks in the Eurozone (Andenas, 2016), should consider incorporating these climate-related risks in

their calculation of capital requirements and their adequacy (BIS, 2020). This way, capital requirements would reflect the financial risk of undiversified bank portfolios or when credit is allocated to climate-intensive oil and gas firms. This is especially relevant in the light of, financially distressed banks that may transfer financial loss from SFFAs to their counterparties within the financial network. This could negatively affect the banks' lending decisions and lead to substantial credit constraints, which in turn have negative feedback effects to the macroeconomy (Clerc et al., 2014; NGFS, 2019)

Second, I stress the need for a more pro-active role of the ECB to *incorporate climate-risks into their own portfolio decisions*. The ECB should be aware of its own SFFA-exposure and its associated risk of substantial financial loss due to a deteriorated creditworthiness of international oil and gas firms. The ECB could follow recent developments of other European central banks, such as the Swedish central bank that has decided to reject issuers with a 'large climate footprint' (Flodén, 2019), or the Banque de France and the Dutch central bank who have adopted a Responsible Investment Charter for the management of own funds. And the European Investment Bank announced to stop financing fossil fuel energy projects by 2021 (EIB, 2019). These developments may provide a significant step change towards a more promotional engagement of the ECB (BIS, 2020).

To summarise, mitigating the significant risks that stem from a high SFFA exposure of European FIs to IOCs, may require two differentiated roles of European actors. First, enhancing climate-related disclosure, specifically around data on the *bond* portfolio, is crucial to better assess and identify the risk. Such financial policy initiatives are in the realm of a risk-focused prudential role of European supervisors. Second, a more promotional role of European central banks may be necessary to actively mitigate the risk of financial distress and to safeguard financial stability.

6. CONCLUSION

Among international cooperative initiatives there has been an increasing awareness of climate-related financial challenges associated with SFFAs. In particular, efforts to safeguard financial stability from such climate-related transition risks, require a granular analysis of the direct exposure of financial institutions to stranded fossil fuel assets. The purpose of this paper was to provide exactly such a disaggregated empirical analysis, that assesses a 2.81 trillion US$ exposure of 6,510 unique FIs across 68 jurisdictions to the 26 largest publicly traded oil and gas companies (IOCs). Utilising a unique dataset, my analysis is the first attempt to measure comprehensively the SFFA-exposure not only through the *equity* but also through the *bond* channel with an international scale. My analysis further draws on a new comparative framework of Risk-Levels that captures the financial risk of SFFA-exposure and analyses the financial stress and portfolio vulnerability on a reliable and detailed firm and financial asset-level.

This paper serves as a step towards a more comprehensive understanding of the exposure and risk associated with stranded fossil fuel assets and contributes with the following insights.

First, I empirically assessed the current level and composition of international FIs' direct equity and bond exposure to SFFAs. The global absolute SFFA-exposure amounts to 1.88% of the world's GDP. The G8 countries represent a combined relative SFFA-exposure to the IOCs that amounts to 1.29% of the GDP. Among the most exposed countries are Norway and the Netherlands with a relative exposure to GDP of 12.04% and 4.08%, respectively. Further, the share of bonds to the overall portfolio amounts to 58.31% in the international insurance sector. Overall, the direct *bond* exposure of international FIs to SFFAs amounts to 210.03 billion US$, representing 7.47% of the overall SFFA-exposure globally. With a focus on Europe, I identified particularly high exposed and undiversified banks such as the *Consorbank* with a relative exposure of 32.38% or the Caixa Bank S.A with a relative exposure of 28.82%. For the insurance sector, among the most SFFA-exposed FIs relative to their overall portfolio, I identify *La Mondiale Partenaire* with 23.57% and the *Swiss Re AG* with 23.32%.

Second, I demonstrated how these FIs and respective jurisdictions are affected by the risk stemming from the SFFA-exposure. For this, I proposed three interconnected risk determinants that transfer risk from the initial SFFAs in the IOC industry, over FIs, to the wider financial system. I showed that a vulnerable extraction infrastructure of the IOC *(Determinant A),* coupled with an undiversified portfolio diversification and a high indirect exposure among the financial network of the FI *(Determinant B and C)* results in a higher risk of SFFA. Substantiated with empirical insights, I showed that in such an instance, FIs and jurisdictions are disproportionally more vulnerable to a disruptive readjustment of financial asset values. This may result in financial frictions and second-round losses that pose a threat to financial stability. This conceptual understanding further served as the context for the interpretation of the financial sector-specific Risk-Levels. I established the

highest Risk-Levels for pension funds and sovereign wealth funds in Norway, banks in France and the US, and insurance companies in the US and UK. Moreover, I identified a high Risk-Level for insurance firms and banks in the EU27. With these results, I presented the relative SFFA-exposure to interpret the Risk-Levels in conjunction with the respective sectorial portfolio diversification.

Third, I discussed the role of European central banks and financial regulators in minimising such risk and building a climate-resilient financial system**.** I argued, that in order to mitigate the significant climate-related risks, two differentiated roles of European actors are necessary. First, an enhanced prudential role is necessary to accurately monitor and identify the risk of SFFAs. More specifically, based on the limitations around the transparency of the bond portfolio of FIs identified in the Risk-Level framework, I argued for enhanced disclosure requirements in this realm. This is relevant for EIOPA in identifying the SFFA-risk for highly *bond* exposed European insurance firms. Second, a more promotional role of the ECB may be required. I discussed two such measures and argued in favour of them. Based on the limitations of solely prudential measures, and in the light of my empirical evidence on vulnerable European banks, such measures may be necessary to mitigate the risk of financial distress and to safeguard financial stability.

Overall, this paper generated disaggregated empirical insights on the composition and level of SFFA-exposure on the individual FI-level, the financial sectorial level, and the jurisdiction and international level. However, this is not an exhaustive account of the empirical insights that could be generated from the dataset that was created. Future research could use the dataset to: i) identify in a case-by case study highly exposed FIs that present a weak link in the financial network; ii) focus on different financial sectors and jurisdictions; or iii) expand the Risk-Levels with the incorporation of the indirect SFFA-exposure.

ACKNOWLEDGEMENTS

M.T. Baer would like to thank Dr. Pablo Salas for his continuous support throughout this work and Professor Laura Diaz Anadon for providing useful comments to this mansucript. Two anonymous reviewers are also acknowledged. Any views expressed are solely those of the author.

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