Climate change, financial system and real economy: estimation of exposure of the Euro Area to climate change-related financial risks and gains

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Abstract

Policymakers, investors, and firms recognize the need to assess the financial impact of climate change and climate policy on the real economy and the financial system. It is debated, that the introduction of climate policies might lead to a reevaluation of a large portion of financial assets with implications for financial stability. However, currently, there are no consistent bottom-up monetary estimates of climate change-related financial gains and losses of the economy as well as of the current exposure of the economy's financial assets to climate change. To fill this gap, we develop a framework for the assessment of climate change-related financial gains and losses building on recent developments in climate policy assessment, climate stress-testing, and risk analysis. We apply this framework to macro-level and micro-level data of financial contracts (equity holdings, bonds, and loans) between firms worldwide, estimate climate policy risks for the Euro Area, and assess implications for financial stability. We find that direct exposure of the Euro Area through financial assets to fossil-fuel, utility and energy-intensive sectors is relatively small in monetary terms across equity holdings, bonds and loans. However, financial interconnectedness at the macro-level plays a crucial role in the assessment of climate change-related gains and losses, with noticeable consequences for insurance&pension funds sector of the Euro Area.

Key words: climate change, financial stability, networks, shock transmission channels, indirect effects, climate policy, low-carbon economy.

JEL codes: B40, C00, C81, C82, E61, G20, G11, G32.

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1 Introduction

The impact of climate change on economy and the financial system has been discussed by a number of studies (Carney, 2015; IPCC, 2014). Researchers and policy-makers agree on the fact that climate change and climate policies could potentially pose significant risks for the macroeconomic and financial stability (Carney, 2015; ESRB, 2016).

Climate change financial risks can generally be decomposed into two major categories: physical risks (e.g. caused by extreme wether events resulting in damages of the infrastructure) and policy risks (risks resulting from the climate policy regulations, e.g. imposing carbon tax or Emission Trading System (ETS), which could lead to re-evaluation of the financial assets of the market players). "While physical risks of climate change are hardly avoidable, climate policy risks can be evaluated and diminished if recognised early enough" (Battiston et al., 2016a). Therefore, an assessment of financial exposure of the real economy and financial system to climate policy risks could help to diminish these risks and turn them into opportunities for technological progress and green growth.

There is a wide debate on the fact that limiting GHG emissions and achieving the goals of the Paris Agreement would "require reallocation of financial capital from carbon-intensive to low-carbon economic sectors that would need not only market-based solutions but also economic policies for fostering the transition to a low-carbon economy" (Maxton and Randers, 2016; Stolbova et al., 2018). Economic costs of climate policies have been assessed in the literature in terms of GDP with Stock-Flow Consistent modelling approaches (e.g. Dafermos et al. (2017)) and Agent-Based Models (Lamperti et al., 2017). In addition, it was also shown that "the introduction of fiscal or monetary policies aimed at mitigation of climate change and supporting the low-carbon transition could result in win-win options" (Lamperti et al., 2016; Monasterolo and Raberto, 2016; Monasterolo et al., 2017).

It has also been discussed in the literature that the introduction of climate policies could pose risk for financial institutions that are locked-in into carbon-intensive investments (Carney, 2015). The estimation of part of this risk was performed by Leaton (2012) and Caldecott and McDaniels (2014), in terms of exposure to a loss of assets value resulting from "carbon stranded assets" . Dietz et al. (2016) estimated a first global climate "Value at Risk" (VaR) that takes into account "risks from climate-induced physical damages amounting to 24 trillion USD of lost financial asset". Battiston et al. (2016a), introduced a methodology for a climate stress-test of the financial system that allowed to estimate the exposure of listed equity portfolios of financial actors to climate-policy-relevant sectors (i.e. "sectors that are directly or indirectly responsible for greenhouse gases (GHG) emissions and thus more vulnerable in case of climate policies"). The results of this estimation showed that up to 40% of the equity portfolio of pension funds is potentially exposed to climate policy risks. This study also highlighted the fact that interconnectedness of the interbank market could amplify distress caused by the "too-late-too-sudden" introduction of climate policies with potential implications on systemic risk. It is, therefore, crucial to assess the impact of climate policies on the financial system and real economy.

The aim of this paper is to assess the magnitude of the exposure of the financial system and real economy to climate policies and climate policy announcements. In order to do so, it is crucial to identify not only how climate policy shock[1] would affect institutional sectors directly, but also how it could propagate and reverberate through the financial interlinkages among the market players and sectors of the economy, resulting in indirect exposure of institutional sectors to climate policy shocks. In this respect, we base our work on literature addressing the propagation of distress in financial networks (Battiston et al., 2016d; Cimini et al., 2015) to analyze climate policy shock propagation through the economy at the macro-level. By financial networks, one usually understands a number of financial or non-financial firms linked through financial contracts that they establish with each other (e.g. equity holdings, loans, bonds, etc.). (Bardoscia et al., 2016) described the existing mechanism through which negative shocks on equity values of firms result in changes in the equities values of the other firms holding their debt obligations thus leading to the propagation of a negative shock through financial contracts in the financial network, which takes place in a mark-to-market accounting environment. This mechanism of shock propagation could lead to significant amplification of the initial shock on the assets and has implications for the financial stability (Barucca et al., 2016). In this paper, we extend this methodology for the assessment of exposures to climate-sensitive sectors through several financial instruments and apply it on the macro-level. One of the first studies analyzing the shock propagation at the macro-level was done by Castrén and Rancan (2014), where a concept of macro-networks was introduced to describe the set of financial linkages within the economy aggregated at the level of institutional sectors. In this paper, this concept was extended and applied to estimate shock propagation through the financial interlinkages of institutional sectors in the context of climate policy shocks – shocks resulted from the "too-late-too-sudden" introduction of climate policies. Here, we estimate the direct and indirect effects of climate policies at the sector level, considering shock propagation and amplification from the financial sector to the real economy.

From the perspective of financial industry, many financial institutions become concerned with potentially relevant risks of decarbonization of the economy and start to perform an "in-house" climate stress-tests. In particular, many development banks started to introduce climate risk assessment of their projects' portfolio. In addition, there is a sizable movement of institutional investors towards "green" or low-carbon investments. The size of the climate finance – financial resources allocated to support green-growth technologies – is rapidly increasing: in 2014, 292 USD bn was invested in low-carbon and climate-resilient growth, and these numbers are growing. Despite the growing interest in climate finance, and significant achievements in climate negotiations highlighted by the Paris Agreement [2], there is a fear among the investors and policy makers that

[1] in case of "too-late-too-sudden" climate policy introduction.

[2] signed by 195 countries committing to reduce global GHG emissions

"climate change deal is bad for business" [3]. However, it is important to highlight, that shocks imposed on the investors and financial system due to climate policy risks are not necessarily negative, they can also be positive and could boost the economy. Therefore, financial institutions are interested in finding their best portfolio of the assets allocation in the transition to a low-carbon economy. Despite the growing interest in the affect of the climate change on the financial system and economy, there is a lack of methodological framework which would allow to estimate the costs of transition to a low-carbon economy (Bloomberg's FSB task force, 2degrees investing, G20 enquire). Existing literature so far is mostly focused on stranded assets (financial assets that can not me used in the future if satisfying the climate regulations) from fossil fuels and unburnable carbon (IADB, Carbon Tracker Initiative, Oxford's stranded assets initiative).

Due to the lack of disclosure of detailed information on portfolios of financial institutions and non-financial companies, today it is difficult to fully assess climate change related risks for the whole economy bottom up: from a company level to institutional sectors level. However, the combination of the microlevel ownership data, data on bonds and loans issuance, and data on financial interdependencies between the financial actors through various financial instruments can shed the light on the estimation of climate related exposures of institutional sectors of the economy. Recently, a methodology of the climate stress-test has been proposed by (Battiston et al., 2016a) which allows to estimate the climate policy risks on several levels starting from individual firm, household or bank and finishing with the whole economy. In addition, in Stolbova et al. (2018), it was shown that economic shocks arising from the "too-late-and-too-sudden" introduction of climate policies (ESRB, 2016) can be amplified through feedback loops of chains of financial exposures in the economy, and the methodology to assess these shocks was proposed.

In this manuscript, building on the previous literature we address three following main questions: i) What is the magnitude of total financial exposure of the Euro Area economy to climate change risks? ii) What could be potential financial gains and losses of economic actors on the way to decarbonization? ii) Which economic actors could be against decarbonization of the economy and how to convince them to change their minds?

This manuscript is organised as follows. First, we perform a review of the available data sets and conduct a data sets consolidation from a number of sources including the Bureau Van Dijk Orbis database, Thomson Reuters, and ECB Data Warehouse. Second, we describe the methodology. Third, we provide a monetary estimates for the mutual interdependencies between the financial sector of the Euro Area and the real economy through the main financial instruments: equity holdings, bonds (tradable debt obligations) and loans (non-tradable debt obligations). Then, we provide estimated of full exposure of the Euro Area institutional sectors to climate policy risks and discuss policy implications.

[3] https://www.bbc.com/news/election-us-2016-36401174

2 Data

2.1 Macrolevel data

Data on financial exposures at the sectoral level have been obtained from the ECB Data Warehouse [4]. Equity holdings exposures are presented as listed shares and investment fund-shares, and unlisted shares (that correspond up to 64% of the equity holdings in the Euro Area). Bond holdings data are presented as short-term bonds (with maturity less than a year) and long-term bonds (with maturity more than a year). For the loans exposures, we combine the data on short-term loans, long-term loans and deposits. Since insurance&pension scheme guarantees represent a significant portion of the balance sheet of households of the Euro Area (around 30%), we also include them in the analysis.

Despite the fact that ECB Data Warehouse provides the data on mutual exposures between the institutional sectors of the Euro Area, it only allows to identify the mutual exposures within the Euro Area and the amount of equity, bonds and loans connecting the Euro Area institutional sectors with the rest of the world. However, the information about institutional allocation of the exposures of the rest of the world is not identified. In order to fill this gap in the reconstruction of the financial exposure allocation outside of the Euro Area, in this manuscript we use microlevel firm data.

2.2 Microlevel data

2.2.1 Listed equity

We were able to obtain the data on individual equity holdings through the Bureau Van Dijk Orbis database. First, we analyzed listed equity by researching all publicly listed companies with at least one shareholder in the Euro Area for the last available year – 2017. As a result of a search, we found all active publicly listed companies worldwide with at least one shareholder in Euro Area with shares from 0.01% to 100% with market capitalization of at least 1000 euros. The search resulted in 11,182 companies [5],[6].

Characteristics of companies in the search include: Company Name, BvD ID number, Country ISO Code, Country, NACE Rev. 2 Core code (4 digits), Operating revenue (turnover), market capitalization 2017, book value per share 2017, total company assets, number of outstanding shares, number of employees, listing status, NACE Rev. 2 Primary code=NACE Re. 2 Core code (4 digits), NACE Rev. 2 main section (1 letter NACE Code), NAICS 2017 Core code (4 digits), NAICS 2017 Primary code.

For the shareholders of these companies we collected the following data: Shareholder Name, Shareholder BvD ID, Country ISO code, NACE code (4 digits), Type of Share-

[4] `http://sdw.ecb.europa.eu/`

[5] Date of search: December 4th, 2018.

[6] In comparison, the fool universe of publicly listed companies at that date available in the database was 65,000.

holder (Banks, Financial companies, Hedge funds, Corporate companies, Insurance companies), Direct percentage of share in a given company, Total percentage share in a given company (when direct was not available, total was used[7]), Shareholder Total assets.

Then, we cleaned the data, specifying climate-sensitive sectors [8] as fossil-fuel, utility, energy-intensive, transport, housing, finance, other (as defined in Battiston et al. (2016a)) and allocating 4 digit NACE code for companies to one of the previously mention sectors.

2.2.2 Unlisted equity

Similarly to listed companies, we collected a global sample of all active unlisted companies with at least one shareholder in Euro Area with shares from 0.01% to 100% with operating revenue of at least 1000 euros. The result of the search described above is 687,840 companies [9].

Characteristics of companies in the search include: Company Name, BvD ID number, Country ISO Code, Country, NACE Rev. 2 Core code (4 digits), Operating revenue (turnover), Current Ratio, Shareholder Funds, Profit Margin, Net Income, Total company assets, number of employees, listing status, NACE Rev. 2 Primary code=NACE Re. 2 Core code (4 digits), NACE Rev. 2 main section (1 letter NACE Code), NAICS 2017 Core code (4 digits), NAICS 2017 Primary code.

For the shareholders – we collected the following data: Shareholder name, Shareholder BvD ID, Country ISO code, NACE code (4 digits), Type of shareholder (Banks, Financial companies, Hedge funds, Corporate companies, Insurance companies), Direct percentage of share in a given company, Total percentage share in a given company (when direct was not available, total was used[10]), Shareholder Total assets.

Due to the fact that unlisted companies do not have corresponding market capitalization, we apply different methods of valuation of the shares of these companies. In particular, we used a widely known methods of valuation: i) through estimation of shareholders' equity via current ratio and total assets, ii) through profit margin and operating revenue, iii) through shareholders' funds. When method i) was not possible, we used estimations from method ii), and in all other cases we used estimation from the method iii). Taking into account that all these methods provide a lower bound estimate of the value of the company, with this analysis we provide a lower-bound estimate of exposure of Euro Area institutional sectors to climate-sensitive sectors of the economy. However, as there is no publicly available data on valuation of unlisted companies, we consider that the described above approach provides us with a reasonable estimate of these exposures.

[7]It is not always possible to determine the direct share of a shareholder. In order to overcome this obstacle we used information on the total share provided by the Bureau Van Dijk Orbis database.

[8]see Appendix for classification of the climate-sensitive sectors

[9]Date of search: December 20th, 2018

[10]It is not always possible to determine the direct share of a shareholder. In order to overcome this obstacle we used information on the total share provided by the Bureau Van Dijk Orbis database.

After the data cleaning, we end up with 186,163 unlisted companies located globally and 694,480 shareholders located in the Euro Area 19.

For the mapping of the 4-digit NACE code into climate-relevant sectors we used classification proposed in Battiston et al. (2016a)[11].

2.3 Bonds and loans

While there is lack of available data on bonds and loans holdings (e.g. who holds which bond)[12] at the micro or firm-level, we use available data on issuance of bonds from Thomson Reuters and loans from Bureau Van Dijk Orbis database. The information on the issuer (ID of the issuer and NACE code) combined with information on the amount of bonds and loans allowed us to investigate the sectoral breakdown of bonds and loans issuance in the Euro Area. For the analysis of the bond holdings in the climate-sensitive institutional sectors, we use available data on issuance of bonds from Thomson Reuters. Taking into account the lack of availability of individual bond holdings data, we analyze bond issuance in the Euro Area and based on this assume that Euro Area institutional sectors invest in bonds with the same proportion as these bonds are issued in the Euro Area. This can be viewed as a reasonable assumption considering the fact the on the macro-level institutional sectors of the Euro Area can be considered diversified in their bond holdings and the fact that the most of the EA bond holdings are domestic [13] For the search we use the universe of government and corporate bonds taking in to account only active bonds [14]. Issuer type include only corporate bonds, while governmental-, agency-, non-US Mus. and other Gov/Supra-type issuers are not included in this analysis. Bonds of all grades are analysed, including investment grade, high yield and not rated, and Sukuks are excluded from the analysis. In terms of bond types, we only consider bonds, without analysing certificates of deposit and commercial paper - as due to their short maturities (up to 1 year), these instruments are considered to be highly liquid and will unlikely be impacted by the types of shock we consider in our analysis, in addition, they represent only a small portion of the balance sheets of the institutional investors of the Euro Area, thus, can be excluded from this analysis without having much of an impact. For the purpose of the analysis we focus only on bonds issued in 19 Euro Area countries. As unlike with equities, with the bonds we can not analyse the full /close to full universe of holdings of the EA shareholders, in the case of bonds we use microdata to determine the shares of bonds issued by issuers in climate-sensitive sectors and use this data to obtain the estimates of the overall bonds exposure of EA institutional investors to climate-sensitive sectors of the economy. For each bond issue, we identify the issuer,

[11]see Appendix for details

[12]To our knowledge, currently there is no publicly available information on the holders of these bonds and loans.

[13]Based ECB DataWarehouse.

[14]as of December 9th, 2019

the amount issued in USD, the type of the bond, instrument type, country of issue, maturity of the issue and issue date, domicile, TRBC sector, sector of the issuer (we assume the the sector of the issuer coincides with the sector of the issue). Table 1 below shows the mapping that we propose from sectors in TR to climate-sensitive sectors (defined in Battiston et al. (2016a)).

TR Sector	**Sectors**
Oil and Gas, Gas Utility- Pipelines, Oilfield Machinery and Services	Fossil-fuel
Gas Utility - Local Distrib, Utility - Other	Utilities
Building Products, Chemicals, Consumer Products, Electronics, Industrials - Other, Machinery, Metals/Mining, Pharmaceuticals, Vehicle Parts, Automotive Manufacturer, Textile/Apparel/Shoes	Energy-intensive
Aerospace, Airline, Transportation - Other, Railroads	Transport
Home Builders, Real Estate Investment Trust, Mortgage Banking, Lodging, Property and Casualty Insurance	Housing
Banking, Financial - Other, Securities, Life Insurance	Finance
Beverage/Bottling, Cable/Media, Conglomerate/Diversified Mfg, Containers, Food Processors, Gaming, Health Care Facilities, Health Care Supply, Information/Data Technology, Leasing, Leisure, Publishing, Restaurants, Retail Stores - Food/Drug, Retail Stores - Other, Service - Other, Telecommunications	Other

Table 1: Mapping of sectors from Thomson Reuters sector classification to classification in climate-policy-relevant sectors as defined in Battiston et al. (2016a).

The selection of bonds from the universe of the corporate active bonds was done based on TRBC Sectors that include: Financials (excluding Banking services - as this activity related to lending via loans, not bonds), Telecommunications Services, Utilities, Industrials, Consumer Cyclicals, Technology, Healthcare, Basic Materials, Consumer Non-Cyclicals, Energy.

In order to estimate the exposure of the Euro Area institutional sectors to climate-sensitive sectors we combine the macrolevel data on the amount of bonds and loans held by institutional sectors from ECB DataWarehouse with microlevel data on bond and loan issuance. We also assume that institutional sectors (e.g. banks, insurance companies and etc.) have diversified portfolios in respect with sectors of the economy and, therefore, hold bonds and loans proportionally to the bonds and loans issued. This assumption allows us to estimate the exposure of Euro Area institutional sectors to climate-relevant economic sectors[16] through bonds and loans.

[16] see Appendix for details.

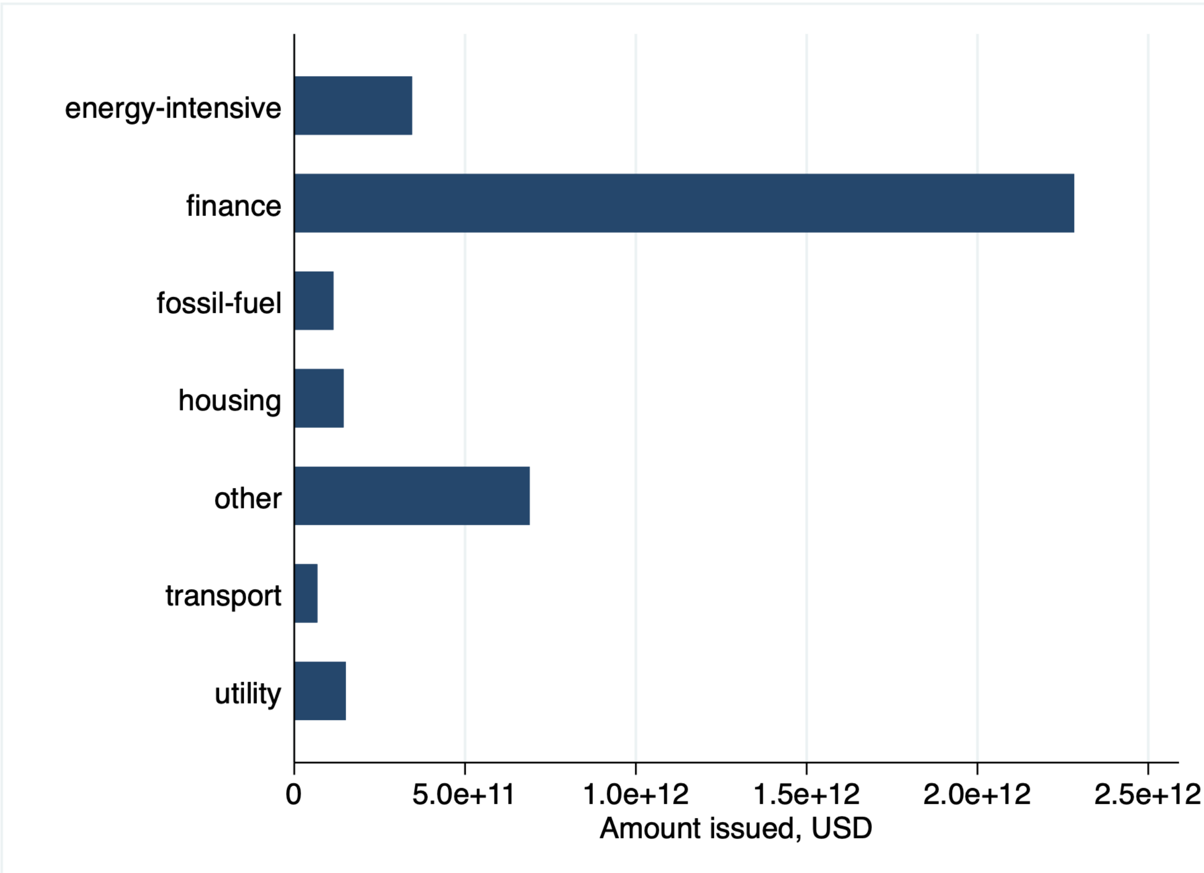


Figure 1: Bonds issued by Euro Area firms by climate-sensitive sector.[15]

3 Methodology

3.1 Financial system and real economy: from microlevel to macrolevel

At the microeconomic level, economic actors (e.g. firms, banks, households, pension funds, insurance companies) are connected with each other via various financial contacts (e.g. loans, equity, bonds, and insurance&pension schemes guarantees). Depending on the financial instrument used for the contract, economic actors experience different repercussions as a result of economic or financial shock affecting their counterparties. For example, in case of an equity investment, a bank invested in the firm could experience financial gain on its asset if the shares of the aforementioned firm have risen in value, and a loss, in the opposite case. Instead, if the same bank would buy a bond issued by this firm, normally, it can not receive a gain higher than the bond value [17], it can experience

[17]However, if it bought the bond when the company was doing bad, the bond can rise in value and the banks would have received a gain

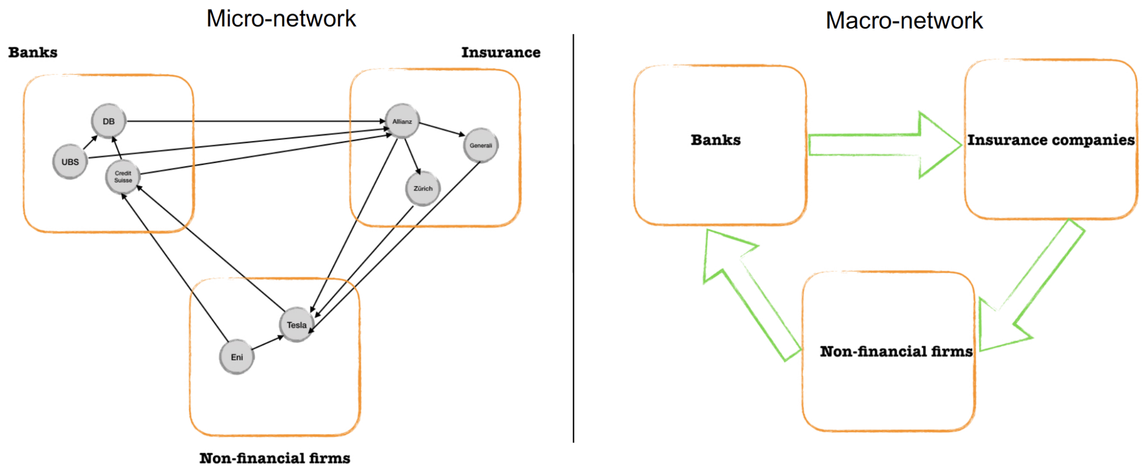


Figure 2: Illustration of transition from microeconomic financial networks to macronetworks.

financial loss if the firm will not be able to repay the bond in full. Taking into account the complexity of the financial system and financial interlinkages among the economic actors, it can also happen that a shock on one actor could propagate through the chain of financial interlinckages to another actor, which was not its counterparty in financial contracts, and, therefore, did not anticipate this shock. This mechanism of shock propagation through the financial system was named as a major cause of the last financial crisis. There are also cases, when the shock affecting am economic actor could not only propagate through the chain of financial interlickages but also come back to this actor amplified through the feedback loop of financial exposures as was shown in Stolbova et al. (2018). As a result, in certain cases economic actors cannot be assumed to fully anticipate shocks arising from certain shocks, such as e.g. climate change and associated policies. This leads to the fact that under certain conditions (information asymmetry and not fully collateralised financial contracts) there are potential cases of systematic mispricing of assets affected by these shocks. In Stolbova et al. (2018) it was shown that the propagation of distress through the macronetwork of financial exposures between the sectors is the result of the aggregation of shocks propagated through the financial contracts between individual firms. Thus, the shock propagation through the macronetwork reflects the aggregated shock propagation through the micronetwork of financial contracts. In order to assess the exposure of the financial system and the real economy to shocks associated either with climate change or climate policy, and to estimate the risks related to the transition to a low-carbon economy, here we apply financial macronetwork approach at sectoral level.

3.2 The financial macronetwork approach

Here, we build on the previous literature that considers the economy from the perspective of financial macronetwork including the work of Castrén and Rancan (2014),Stolbova et al. (2018). We reconstruct and analyze a multilayer financial macronetwork of institutional sectors [18], where links represent aggregate exposures among pairs of sectors along a specific type of financial instruments (i.e. equity, bonds, loans or insurance&pension schemes guarantees). The weight of a link represents the monetary value of the financial exposure (relative to total assets of the sector that bears the exposure) along a given instrument. Overall, since financial contracts vary in size across various instruments (i.e. loans, equity, bonds, and insurance&pension schemes guarantees), the economy on a macrolevel can be represented as a multilayer weighted and directed network. In this study, the direction of the link is specified from the sector which holds the asset to the sector which issues the asset.

The balance sheet of institutional sector i (e.g. non-financial firms, banks, investment funds, other financial institutions, government, households, insurance&pension funds) at a given time t is described as follows:

$$A_i(t) = \sum_{j,k} A_{ij}^k(t) + S_i(t), \tag{1}$$

where A_i is the value of total assets of an institutional sector i, A_{ij}^k is the exposure of an institutional i to institutional sector j through instrument k, and S_i is the rest of the assets (i.e. the total assets excluding equity shares, bond holdings, loans and deposits holdings, and holdings of insurance and pension schemes guarantees). In this paper we consider the following institutional sectors (i,j): non-financial firms, banks, investment funds, other financial institutions, government, households, insurance&pension funds. The institutional sectors are linked through the following instruments (k): equity, bonds, loans, insurance&pension schemes guarantees.

Taking into account that the exposure of the institutional sector i to institutional sector j is defined as $A_{ij} = \sum_k A_{ij}^k$ (since we consider a fixed time snapshot, we omit t), while the relative exposure of the sector i to the sector j is defined as $w_{ij} = \frac{A_{ij}}{A_i}$. We apply this methodology to ECB DataWarehouse in order to analyze the mutual exposures among the institutional sectors through various financial instruments (please see Empirical Results).

3.3 Shock propagation methodology

Shock transmission between the institutional sectors is realized through financial security re-evaluation. The shock propagation between the sectors of the economy (e.g. financial

[18] see Appendix - for the detailed description of sectors

system and the real economy) is taken from (Stolbova et al., 2018) and can be described as follows. Let us consider a simple scenario of two institutional sectors with assets A_i and A_j with exposure of a sector i to a sector j as A_{ij}. Then, in case of an initial shock $\Delta A_i(t_0)$ to a sector i (where the shock - $\Delta A_i(t_0)$ - shows changes in assets of the sector i), the shock will propagate to the sector j and will cause changes in assets of the sector j:

$$\Delta A_j(t_1) = A_{ji} \cdot \frac{\Delta A_i(t_0)}{A_i}. \tag{2}$$

Therefore, $\Delta A_j(t_1)$ – is a shock to sector j as a result of a shock to its counterparty's sector i. It serves as an example of an indirect shock to the sector j: even if sector j is not exposed directly to the aforementioned shock (e.g. does not have assets exposed to this shock), it could still be affected by the shock indirectly.

In case of chain of financial exposures between several sectors, under the condition that shock affects sector i and there are several sectors in between i and j (e.g. $A_i \leftarrow A_m \leftarrow A_f \ldots \leftarrow A_n \leftarrow A_j$, where arrows are in the direction of exposure and the shock propagates in the opposite direction of the arrows), the resulted shock of sector j could be described as:

$$\Delta A_i(T) = \Delta A_i(t_0) \cdot w_{mi} \cdot w_{fm} \ldots \cdot w_{jn} = \Delta A_i(t_0) \prod_{m,k \subset s} w_{mk}. \tag{3}$$

where w_{ij} is the relative exposure of the sector i to the sector j, T – time when an initial shock reaches the sector under consideration.

A number of studies consider the shock propagation through the financial system using the mechanism described above – through exposures between the economic actors. However, it is not always the case in practical applications. Several studies point out that there is another, more realistic scenario of shocks' transfer from borrowers to lenders (Battiston et al., 2016; D'Errico et al., 2017). This mechanism takes into account balance sheet identities of economic actors and the fact that in a case of a shock, some of the assets could lose their value [19], thus, reducing the leverage[20] of the actor and increasing its probability of default (Bardoscia et al., 2015). As a result, all the counterparties of this actor should take into account that they should adjust the valuation of assets that they have from this economic actor. This, in turn, can lead to re-adjustment of their own leverage, therefore, causing the chain of assets reevaluation. In the requirements of mark-to-market valuation of financial assets, this re-evaluation should be performed by all market participants. Taking this fact into account and applying it to the macronetwork of institutional sectors, shock propagation from one sector to another is not proportional to the exposure between the sectors but to their *leverage*, i.e. the ratio of the sector's equity, calculated as the difference between assets and liabilities, to its assets.

[19] that corrensponds to so-called case of "recovery rate less than one", meaning that after the shock even in case of collaterilized securities, their value after the shock could be less than their initial value.

[20] a measure describing relation between assets and liabilities of the actor.

In particular, financial shocks could be transmitted through the net leverage matrix defined in Battiston et al.,2016, and applied to the institutional sectors in Stolbova et al., 2018:

$$\lambda_{ij} = \frac{\Delta A_{ij}}{E_i} = \frac{A_{ij}(1-r)}{E_i}, \tag{4}$$

where A_{ij} is the exposure of an institutional sector i to a sector j, E_i is equity of a sector i (computed as a difference between assets and liabilities of the sector), and r is a recovery coefficient rate or *recovery rate*, i.e. a portion of assets of the institutional sector i that is recovered after a shock due to assets re-evaluation. Therefore, leverage can be interpreted as a relative loss of equity of an actor i due to its exposure A_{ij} to the actor j, where ΔA_{ij} is actual asset loss of an actor i due to its exposure A_{ij} to the actor j.

Then, similarly to equation 2, in case of an initial shock $\Delta A_i(t_0)$ to a sector i (where the shock $\Delta A_i(t_0)$ shows changes in assets of the sector i), a sector j, will have a shock proportional to the relative equity loss of a sector i as a result of the shock ("leverage of the sector i to the shock"):

$$\Delta A_{ji} = \Delta A_i(t_0) \cdot \frac{A_{ji}}{E_i} = \frac{\Delta A_i(t_0)}{E_i} \cdot A_{ji} = \lambda_{i,shock} \cdot A_{ji}. \tag{5}$$

Similarly, propagation of the shock that affected initionally sector i through a chain of financial interdependencies in a chain $A_i \leftarrow A_m \leftarrow A_f \ldots \leftarrow A_n \leftarrow A_j$ (where arrows are in the direction of exposure and the shock propagates in the opposite direction of the arrows) can be described as:

$$\Delta A_{ji} = \lambda_{i,shock} \cdot \lambda_{mi} \cdot \lambda_{fm} \ldots \cdot \lambda_{jn} \cdot A_{jn} = \lambda_{i,shock} \prod_{m,k \subset s} \lambda_{mk}. \tag{6}$$

Please note, that in case of a closed chain a shock will come back to the sector it originated from or affected. In case of several chains of exposures between the sectors through wich the shock could propagate, in order to estimate the overall losses [21] to the sector, one needs to sum up all the losses through all the chains.

3.4 Assessment of exposure of institutional sectors to climate-sensitive sectors

We estimate *direct exposure* of an institutional sector (economic actor, e.g. banks) to climate-sensitive sectors of the economy similarly to Battiston et al. (2016a):

$$A^{\text{Direct}}_{i(s)} = \left(\sum_{s \in \mathcal{S}} A^{\text{Equity}}_{i(s)} + A^{\text{Bond}}_{i(s)} + A^{\text{Loan}}_{i(s)} \right) \; + \; R_i \tag{7}$$

[21] could also be gains, in case of equity exposure and as a result of a positive shock that increases assets

where $A_{i(s)}^{\text{Equity}}$ denotes the monetary value of exposure of actor i to climate-sensitive sectors ($s \in \mathcal{S}$=[*fossil-fuel, utility, energy-intensive, transport, finance*])of the economy through equity holdings, $A_{i(s)}^{\text{Bond}}$ – through bond holdings, $A_{i(s)}^{\text{Loan}}$ – through loans, and R_i – is a residual accounting for the exposure to other sectors of the economy[22] and instruments not considered in our analysis.

We also define *indirect exposure* of an actor to climate-sensitive sectors of the economy as exposure through counterparties of the considered actor[23]. An indirect exposure of the actors to climate-sensitive sectors is estimated taking into account financial exposures between the sectors through various financial instruments as follows:

$$A_{i(s)}^{\text{Indirect}} = \sum_{j \in \mathcal{J}} A_{j(s)}^{\text{Direct}} \cdot w_{ij}, \tag{8}$$

or, in case of a chain of exposures as in eq. 3, one has to take into account exposures along the chain. For the simplicity, i the empirical results later we use only chains of exposures no longer than two, as the consideration of longer chains of exposures considering this particular mechanism of chaock propagation - does not alter the results.

Taking into account a shock propagation mechanism through leverage of the sectors, equation 9 takes form the following form:

$$A_{i(s)}^{\text{Indirect}} = \sum_{j \in \mathcal{J}} \lambda_{j,s} \cdot A_{ij}, \tag{9}$$

for the first step of indirect exposure[24]. For the case of longer chains, this formula has to be modified according to eq. 6.

A full exposure is, thus, calculated as follows:

$$A_{i(s)}^{\text{Full}} = A_{i(s)}^{\text{Direct}} + A_{i(s)}^{\text{Indirect}}. \tag{10}$$

4 Results

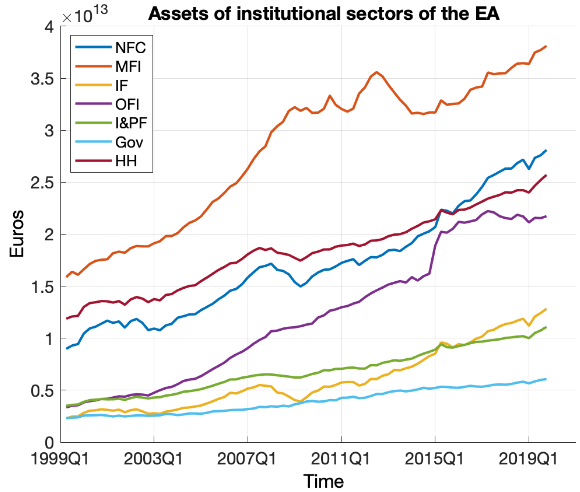
4.1 Macroview on the Euro Area economy: institutional sectors and financial instruments

Prior to the estimation of exposure of the Euro Area to climate change-related sectors of the economy, it is important to review stakeholders and detect major channels of financial exposures. We start by analyzing the time evolution of financial assets and liabilities on the balance sheets of institutional sectors of the Euro Area. The results are

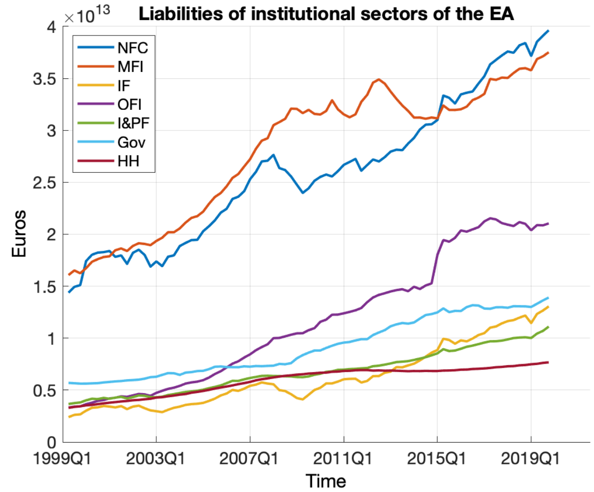
[22]all economic sectors outside $\mathcal{S}$.

[23]E.g., if a bank buys equity shares of investment fund that is investing in climate-sensitive sectors, in this case a bank would have indirect exposure to climate-sensitive sectors.

[24]corresponding to one intermidiary actor between the climate-sensitive sectors and a chosen actor



(a) Assets



(b) Liabilities

Figure 3: Assets and liabilities of institutional sectors of the Euro Area (Non-financial Corporations, Monetary Financial Institutions, Governments, Households, Non-MMF Investment funds, Insurance and pension funds, Other financial Institutions).

presented on figure 3. A distinctive feature of the graph - is a drop in financial assets and liabilities of non-financial corporations (NFC) and non-MMF investment funds (IF) during the financial crisis 2008-2009. In addition, it is important to note the transition that takes place starting from 2015 for banks (MFIs) and other financial institutions (OFIs) on both asset and liability sides, which could be linked to the public sector purchase programme (PSPP), popularly referred to as quantitative easing [25]. However, further studies are needed to verify this hypothesis which is out of the scope of this manuscript. On the other hand, at the end of 2015, an important climate policy event took place - the Paris Agreement on climate change. Schuetze et al. (2018) have shown that climate policy announcements can have a signalling effect for global financial markets resulting in stocks re-evaluations and impacting assets and liabilities of institutional investors. In this manuscript, we aim to assess the exposure of EA institutional sectors to climate-change-related economic sectors and discuss the effect of climate policies announcements on the asset composition of the institutional sectors in the Euro Area. The results of this analysis are discussed in the following sections.

In order to analyse the exposure of the institutional sectors of the Euro Area to climate-relevant sectors and, as a result, to climate policy risks, we first look at the asset side of institutional sectors and distinguish their assets by instruments. The exposures of each financial actor can be decomposed along the main types of financial instruments: equity holdings (e.g. ownership shares including both those tradable on the stock market and

[25] https://www.ecb.europa.eu/press/key/date/2015/html/sp150825.en.html

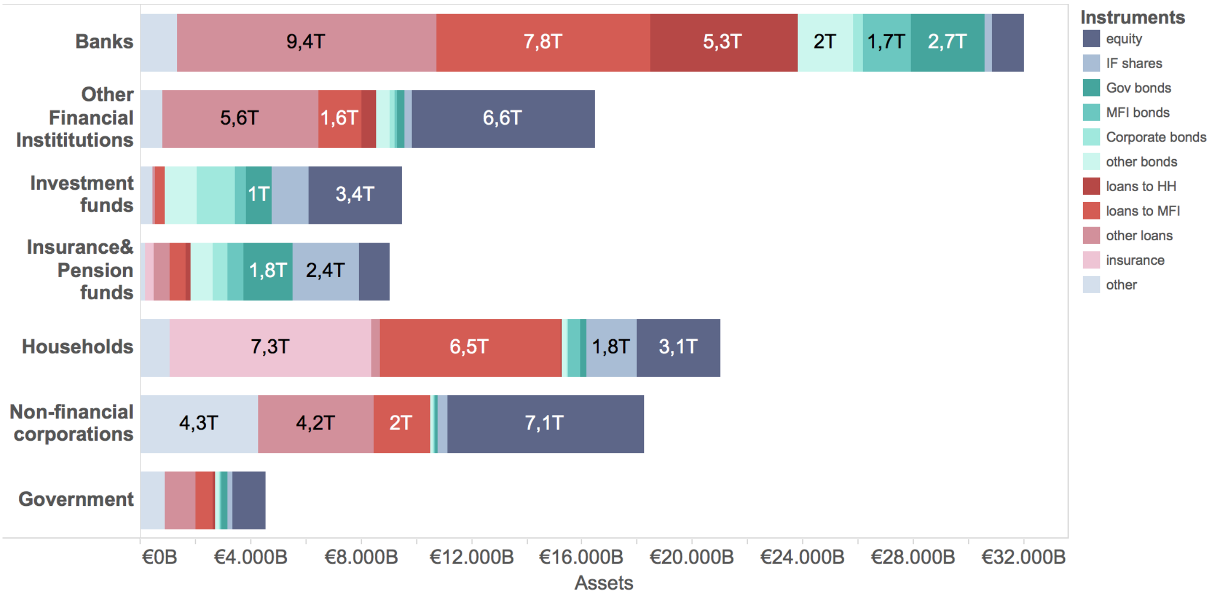


Figure 4: Breakdown of assets of the balance sheet of Euro Area institutional sectors (Non-financial Corporations, Monetary Financial Institutions, Governments, Households, Non-MMF Investment funds, Insurance and pension funds, Other financial Institutions) by market type (equity shares (black), short-term and long-term bonds (green), loans and deposits (red) and all remaining assets (significant part of which is derivatives)). Important to note a) the big portion of the loans and deposits of the MFIs in the Euro Area, most of which in interbank lending, b) small amount of loans of the non-MMF Investment funds.

those non-tradable), bond holdings (e.g. tradable debt securities) and loans (e.g. non-tradable debt securities). Figure 4 shows the breakdown of asset side of financial actors of the Euro Area[26].

It is important to note that banks represent the biggest institutional sector with the total assets of €32T. Together with insurance and pension funds (€9.3), non-MMF investment funds (€10.3T) and other financial institutions (€26.8T) they comprise the financial sector of the Euro Area with €46.4T of total assets, while the real economy sector includes non-financial corporations (€21T), government (€5T) and households (€22T) with total assets of €48T euros.

From an analysis of figure 4, the following findings emerge:

1. The major direct exposures of financial actors to the real economy are concentrated on loans and bonds for banks, while they are concentrated on equity holdings for investment funds, pension funds, and other financial institutions (figure 4).

[26]Data are taken from ECB data Warehouse: `http://sdw.ecb.europa.eu/reports.do?node=1000002344`

2. A large portion of assets held by financial institutions are in fact securities issued by other financial institutions (see figure 4). For instance, about 40% of banks' balance sheet in the Euro Area and about 25% of the market capitalization is invested in equity issued by companies in the financial sectors; about 40% of the bonds market is represented by outstanding obligations issued by financial institutions.

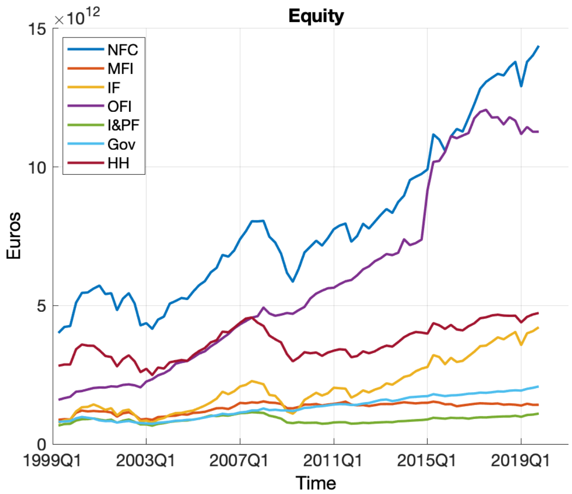
3. The banking sector is by far the largest in terms of total assets (€32 trillions) sector, around 24% of its assets is interbank lending, meaning that a large fraction of financial resources is not channeled to the real sectors of the economy (e.g. non-financial corporations).

We have also analyzed how the composition of assets of institutional sectors of the Euro Area changed with time. The results are presented on figure 5. Important to note that equity is the major asset class for non-financial corporations (NFC) and Other financial institutions (OFI), which the later began heavily rely on since the first quarter of 2015. The majority of bonds are held by MFIs of the Euro Area, with significant representation on the balance sheet of insurance&pension funds and investment funds. Loans remain the major financial instrument in the assets of MFIs with increasing representation on the balance sheets of OFI and NFC. Understanding the composition of the balance sheet of institutional sectors on the macro-level is crucial for the estimation of the exposure of the Euro Area economy to climate change-related risks as it allows to combine macro-level data with microlevel data and provide the assessment of the quality of the estimates in the following section.

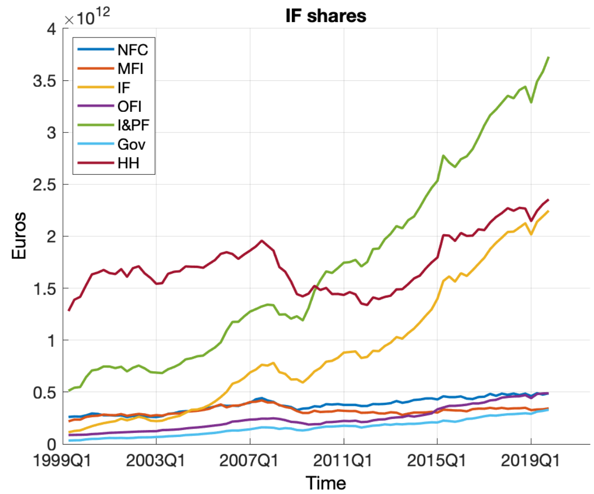
4.2 Estimation of direct exposure of the Euro Area institutional sectors to climate-relevant sectors through equity, bonds and loans

Using the microlevel (individual firm-level) data, we first reconstruct the direct exposure of the Euro Area institutional sectors to climate-sensitive sectors of the economy through for one of the layers of exposure – equity shares. The results are presented on the figure 6. We find that for banks, government, households, insurance&pension funds, and investment funds, the exposure to the fossil-fuel sector through equity shares is very small (1%-3%), however, the overall exposure to climate-sensitive sectors (including finance sector) exceeds 60% of the total equity holdings of these institutional sectors. The largest exposure (around 10% of the total equity shares holdings) to fossil-fuel sector through equity shares is found for the non-financial corporations and other financial institutions. Important to note also a large portion of intra-financial exposure within the financial sector of the Euro Area, which should be taken into account while assessing climate policy risks and gains.

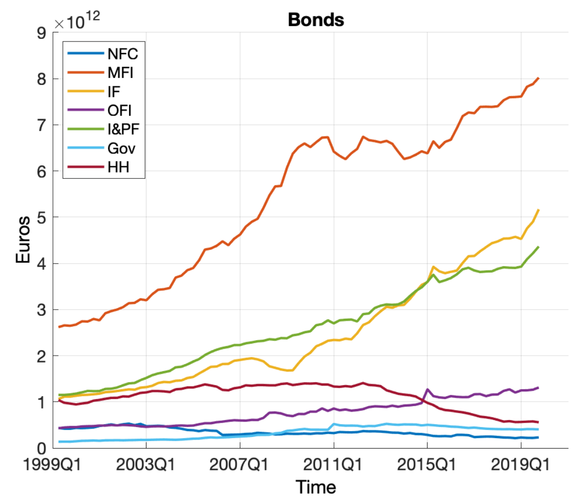
We also analyzed geographical distribution of listed equity holdings of the Euro Area shareholders. The results show that majority of the holdings are in the Euro Area which



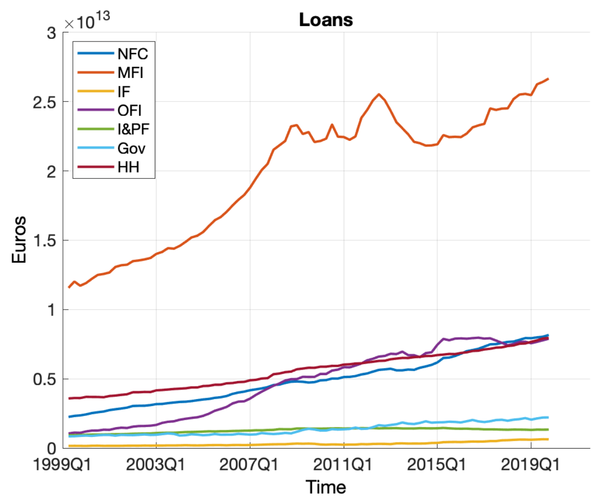
(a) Equity shares: listed and unlisted.



(b) IF shares.



(c) Bonds: short- and long-term.



(d) Loans: short-term, long-term, and deposits.

Figure 5: Assets of institutional sectors of the Euro Area (Non-financial Corporations, Monetary Financial Institutions, Governments, Households, Non-MMF Investment funds, Insurance and pension funds, Other financial Institutions) by financial instrument: equity (including listed and unlisted shares), bonds (including short- and long-term debt securities), and loans (including short-,long-term loans and deposits).

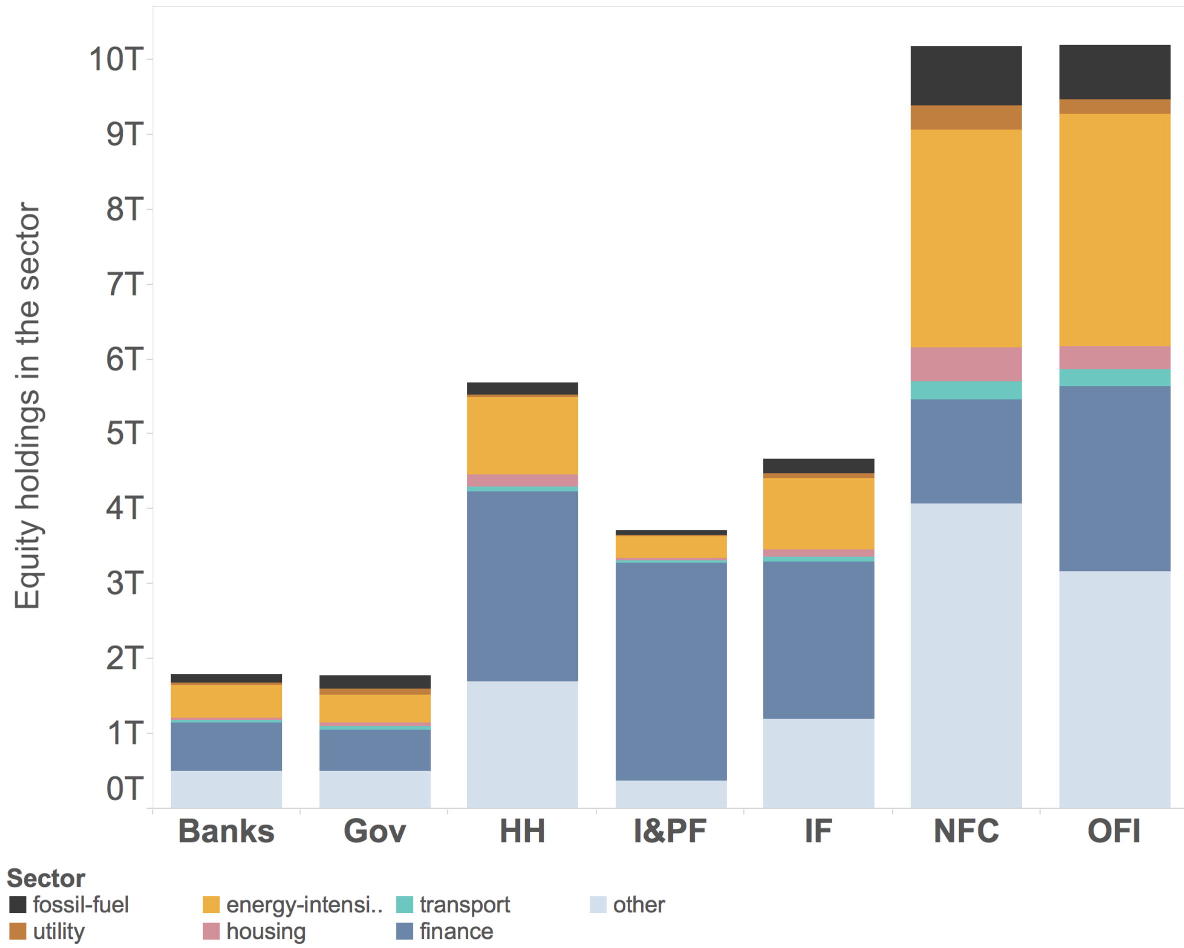


Figure 6: Equity shares of Euro Area institutional sectors (Non-financial Corporations, Monetary Financial Institutions, Governments, Households, Non-MMF Investment funds, Insurance and pension funds, Other financial Institutions) worldwide.

confirms both from the perspective of macro and micro data. Microlevel data also allow us to obtain the information on country specific allocation of exposures, which is not possible with macro-level data.

We also carried out a similar analysis for the breakdown of exposure to climate-sensitive sectors for both bonds and loans. Combined, these exposures provide us with a first estimate of a direct exposure of the Euro Area institutional sectors to climate-sensitive sectors of the economy, which could be affected either positively or negatively as a result of climate policies. The results of this analysis are incorporated as a part of figure 8.

4.3 Macro-network of financial interdependencies in the Euro Area: equity, bonds, loans, insurance&pension schemes guarantees

However, it is important to highlight that institutional sectors in the Euro Area are also connected through a network of financial contracts, e.g. equity shares, bond holdings, and loans holdings. Introduction of climate policies can be regarded as a positive or negative shock to the non-financial corporations. As a result, assets of institutional sectors exposed to non-financial corporations will have to be re-evaluated. This re-evaluation in turn, could lead to distress of certain institutional sectors, which will affect their ability to pay out their liabilities, and this fact would have to be reflected in the balance sheet of other institutional sectors holding their assets (so-called "second-round effects"). Therefore, to avoid underestimation of potential risks or gains coming from the introduction of climate policies, it is crucial to compute an indirect exposure to climate-sensitive sectors, taking into account the exposures of the institutional sectors to each other.

We perform this estimation of indirect exposure by first reconstructing the interdependencies among the institutional sectors of the Euro Area using data on mutual financial interdependencies provided by ECB. The results are shown on figure 7. The most important dependencies are i) exposure of the households to insurance&pension funds through the life insurance and pension schemes (33%), ii) a large exposure of households to banks (30%), iii) exposure of the insurance&pension funds to government of the Euro Area through bond holdings. There are also large indirect exposures of financial actors to the real economy. Remarkably, pension funds hold an exposure of about 30% of their total assets in equity shares of investment funds, which in turn hold an exposure of about another 27% in equity to non-financial corporation outside of the Euro Area.

4.4 Estimation of the full exposure (direct and indirect) of the Euro Area to the climate-relevant sectors of the economy

Finally, taking into account both direct exposures of the institutional sectors to climate-sensitive sectors and their exposures to each other, we estimate the indirect exposure of the Euro Area institutional sectors and the whole Euro Area economy to climate-sensitive sectors (see figure 8). We find that exposure of all institutional sectors to climate-sensitive sectors, excluding finance, is relatively small (between 10%-20% of their balance sheet), therefore, they should not oppose the transition to a low-carbon economy. However, all institutional sectors have a large exposure to finance (the largest single sector exposure for each institutional sector), which highlights the importance of intra-financial dependencies for the estimation of costs and gains of the Euro Area on the way to decarbonization of the economy. Our analysis also shows that for banks the second largest exposure is mortgages, for insurance&pension funds - government bonds, for investment funds and other financial institutions - exposures to non-climate-sensitive sectors. Finally, the overall exposure of

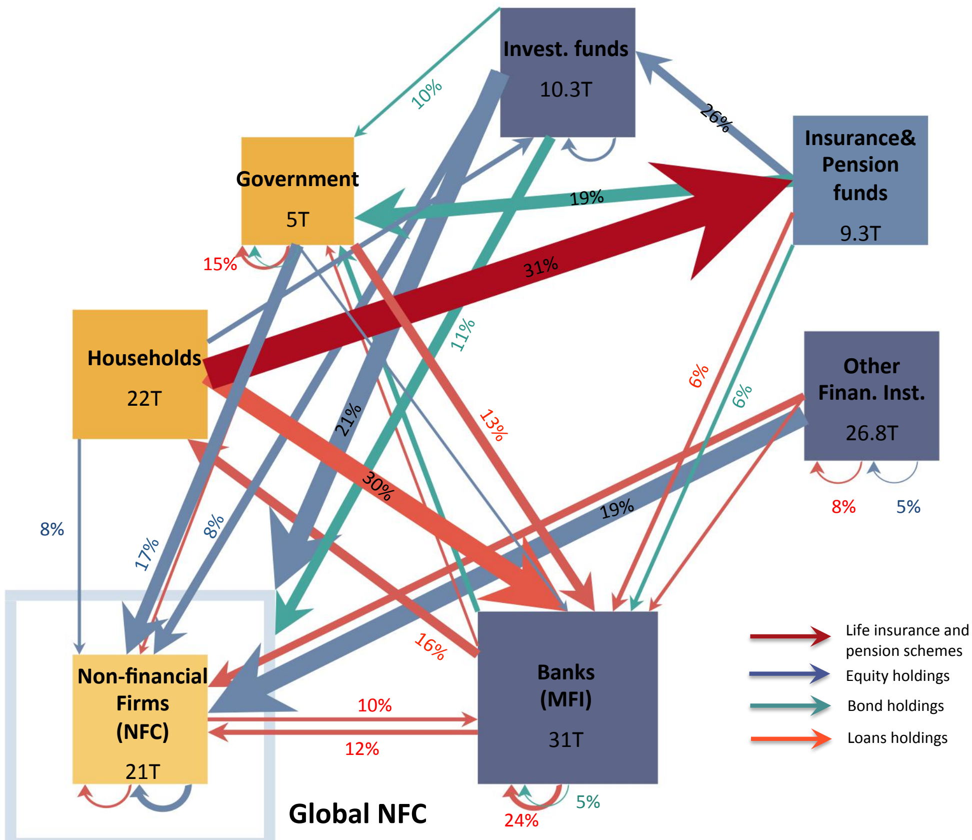


Figure 7: Macro-network of financial interdependencies among actors in the Euro Area (e.g. non-financial corporations, investment funds, banks, insurance and pension funds, governments and households) across instrument type (loans(light red), equity (blue), bonds (green), insurance guarantees (dark red) and other instruments (light blue)). This macronetwork can be regarded as a multiplex weighted network in which multiple types of links correspond to different financial instruments: equity holdings (ownership shares), corporate and sovereign bonds (tradable debt obligations) and loans (non-tradable debt obligations). The weight of the link represents the amount of financial exposure of a "Source" institutional sector to a "Target" institutional sector in euros. The links are normalized by total assets of the source.

the Euro Area economy to climate sensitive sectors: 1% to the fossil fuel sector (negatively affected by climate policies), 9% to energy-intensive sector (more likely negatively affected by climate policies, unless it goes through the restructuring), 32% to finance sector (could be affected both positively and negatively, depending on the portfolio).

Then, we also include the effect of financial interdependencies among institutional

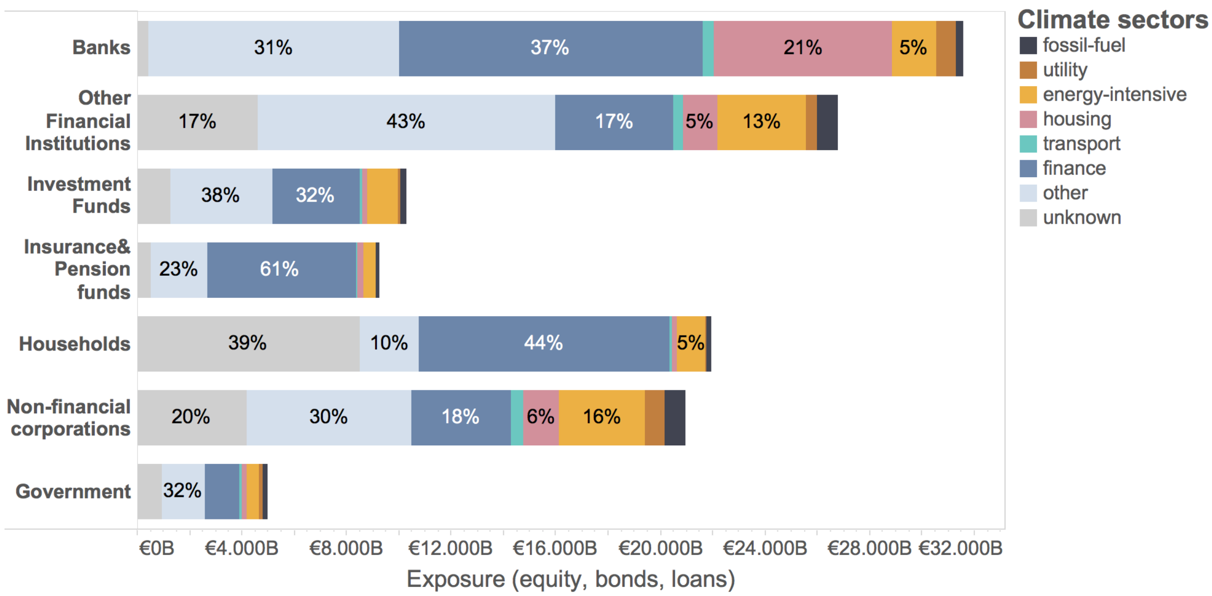


Figure 8: Total exposure of the Euro Area financial sector (banks, investment funds, insurance&pension funds, other financial Institutions) to climate-sensitive sectors worldwide.

sectors of the Euro Area in the assessment of financial gains and losses linked to climate change and climate policy. Considering a substantial evidence from academic literature that financial interconnectedness, especially in the financial sector, could significantly amplify financial losses caused by the shocks to the asset side of investors (see e.g. Battiston et al. (2016d)), here, we assess the impact of financial interconnectedness at the macro-level on amplification of financial gains and losses associated climate change-related shocks. Important to note, that while full analysis of the impact of financial interconnectedness on the micro-level would hypothetically give a more thorough and precise estimate, taking into account that these data are not publicly disclosed and currently not fully available even to regulators, here we rely on a macro-level data for such estimate. However, it is important to highlight, that conditional upon micro-level data availability, this analysis and the proposed framework, in general, can be directly extended to such data.

Building on cyclic DebtRank methodology (Battiston et al., 2012), we adopt it for the institutional sectors of the Euro Area as described in the section Methodology. Assuming the shock to financial assets equivalent to fossil-fuel exposure through financial assets of institutional sectors of the Euro Area, we estimate a so-called "second-round" effects in the Euro Area as a result of an abrupt loss of full value of all fossil-fuel stocks, bonds and loans that institutional investors of the Euro Area invest in. The value of the "second round effect" should be considered as indirect losses of the institutional sectors of the

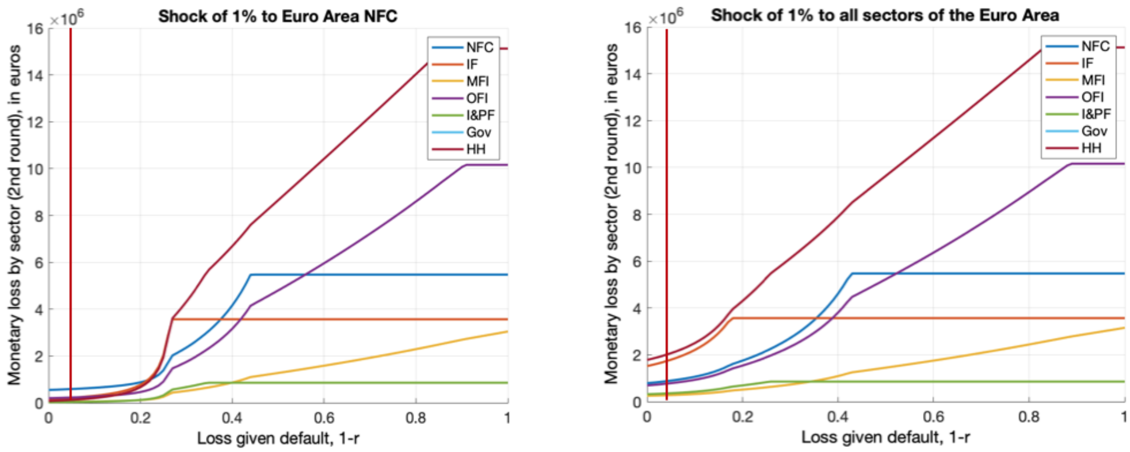


Figure 9: Second round monetary loss of the Euro Area as a result of reevaluation of financial exposures at the macrolevel following a 1% shock to the value of financial assets (equivalent to exposure to fossil fuel firms).

Euro Area, which occur as a result of financial distress impacting each institutional sector through their financial contracts with other institutional sectors. The results are shown on figure 9. Left panel illustrates the estimates for the case when only fossil-fuel assets of the non-financial corporations of the Euro Area have lost their full value; right panel illustrates the estimates corresponding to the immediate loss of value of 1% of assets of each institutional sector which corresponds to the scenario when all institutional sector immediately loose all their fossil fuel assets. Such scenario should be viewed as an extreme stress-test scenario and can be achieved in case of a sudden and unexpected introduction of a very stringent climate policy. It also can be used as an upper bound estimate of financial distress propagation at the macro-level. In order to link our estimation to empirically determined values of loss-given-default, we use the values corresponding to the period of the financial crisis 2008-2009 (red line on figure 9). Our estimates show, that in the case of a shock to fossil-fuel assets of non-financial corporations only, the second-round would mostly affect non-financial corporations with the magnitude of €0.5 T; while in case of a loss of fossil-fuel assets for all institutional sectors, the loss of the households and investment funds would be the highest in monetary terms (€2T), however, investment funds and insurance&pension funds would be the most vulnerable sectors in terms of relative equity loss.

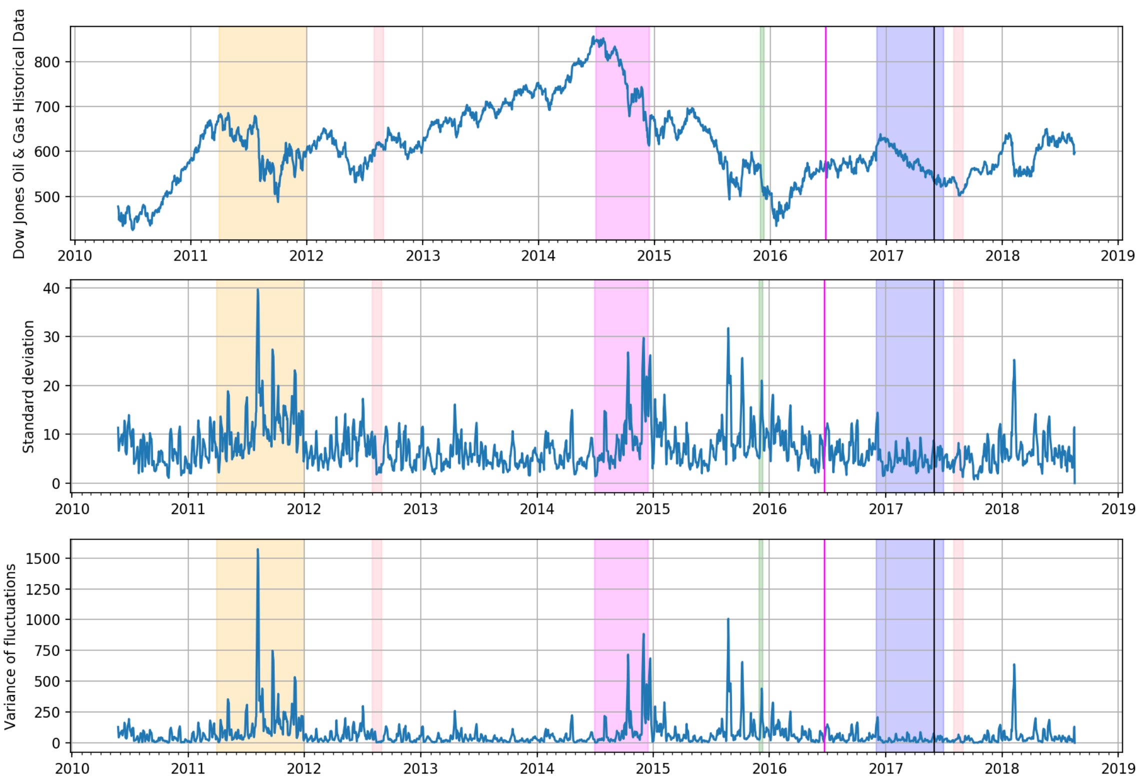


Figure 10: Dow Jones Oil&Gas Historical data and major policy events. a) DJ Oli&Gas (running average of seven days), b) standard deviation, b) variance of fluctuations. Major policy events affecting oil and gas prices are marked in color. Political events: light orange - Arab Spring, dark pink - Russian financial crisis, Brexit - magenta line. Physical damages due to climate change: light pink (left - hurricane Harvey damaged production facilities for oil and gas, right - US refineries closed because of hurricane). Climate policy events and announcements: light green - COP21, black - US President announces pulling out of the Paris Agreement, blue - oil market stabilization plan by OPEC.

5 Climate policy shocks on the fossil-fuel economic sector and its impact on the Euro Area

In this section, we analyze the impact of political and climate policy events on the Oil&Gas prices so far in the last decade. The results show, that most of the price drops were caused by major political events such as Arab Spring and Russian financial crises. However, stabilization of the oil market program by OPEC resulted in significant decrease of the oil and gas prices, which took place gradually over the half a year period of the program. Also, physical risks of climate change such as hurricanes - noticeably impacted prices, while the Paris Agreement and President Trump announcement caused short-term fluctuations of

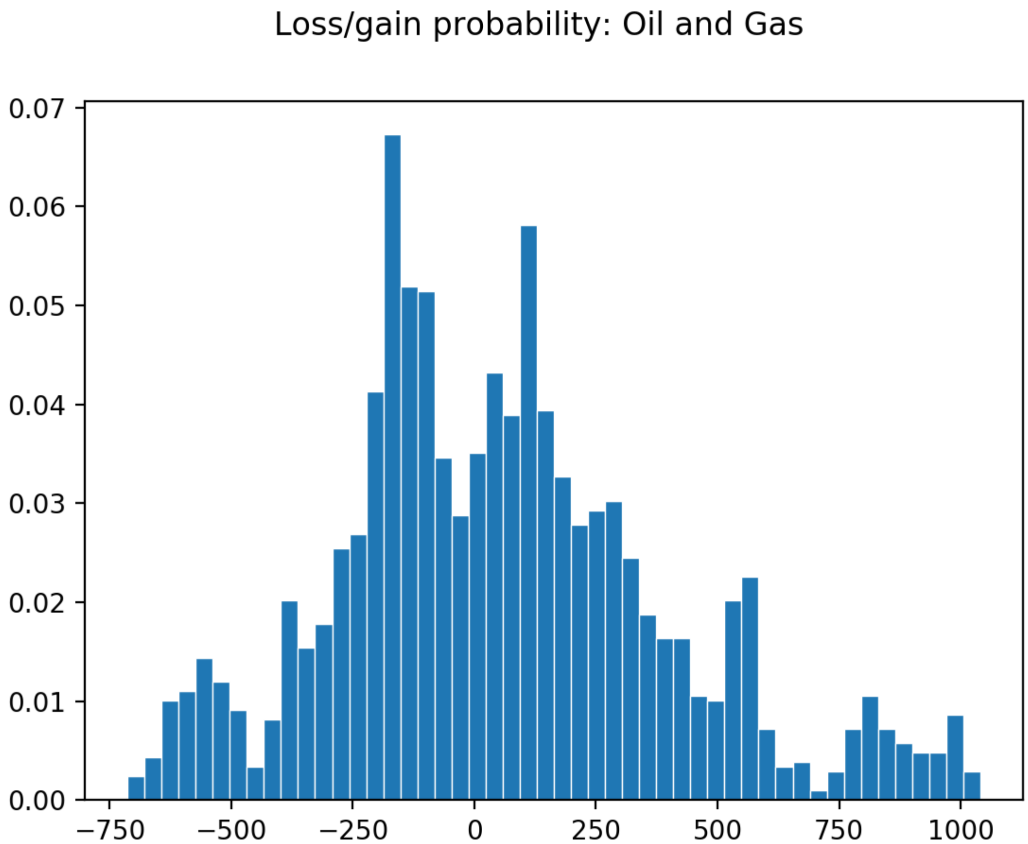


Figure 11: Probability density of potential loss/gain as a result of climate policy introduction affecting Oil&Gas, in bn euros.

the price. Then, we estimate potential gains and losses of the economy as a result of climate policy targeting oil and gas sector. For this purpose, we consider historical data of Dow Jones Oil&Gas Index to derive the probability of potential shocks to the fossil-fuel sector. Probability density of potential loss/gain as a result of climate policy introduction affecting Oil&Gas, in bn euros is shown on figure 11. Taking into account the overall assets of the Euro Area amounting to €122T, potential losses of €150 bn with the probability of 6% could be considered negligible for the Euro Area economy. In addition, institutional sectors would not experience an immediate loss/gain of such magnitude, but over a period of time, giving them the chance to re-allocate their assets to less climate-sensitive sectors.

6 Policy Implications

The estimate of the magnitude of financial exposures of Euro Area institutional sectors to climate-sensitive sectors of the economy has a number of crucial policy implications.

First, it addresses the fear of both investors and policy makers [27] in implementation of climate policies by providing them with monetary estimates of the potential effect of climate policies on various economic sectors. To our knowledge, this study is a first attempt of estimating a monetary value of financial assets of the Euro Area which are subject to positive or negative re-evaluation as a result of climate policy introduction. This information could help the policy makers to design and implement climate policies better fitting the current state of the economy by taking into account measures to prevent systemic risk potentially associated with any policy introduction.

Second, it calls for better financial disclosure of firms and investors on the issues related to climate change and on environmental, social and governance factors (ESG factors). Despite the increasing amount of firm-level information on climate change related risks and enormous efforts of the Task Force on Climate Related Financial Disclosure (TCFD) lead by M. Bloomberg, there are still significant gaps in understanding the exposure of global firms to climate-related risks, and existing data so far are very inhomogeneous and sparse.

Third, it provides a basis for estimation of potential gains and losses associated with the implementation of different types of climate policies for the financial system and the real economy on the macro-level. For example, the estimations above show that the exposure of all institutional sectors to fossil-fuel economic sector is small, which points out the fact that a climate policy solely affecting only this sector would very mildly affect both the financial system and the real economy. While at the same time, positive climate policy shock (e.g. subsidies for renewable energy usage) could be beneficial for sectors like utility, transport and energy-intensive sector, and therefore, for the real economy, in particular, households and non-financial firms. These estimates could also be used while stress-testing the real-economy and the financial system for different scenarios of climate policy introduction and for various pathways towards decarbonization of the economy in order to ensure a safe and smooth transition to a sustainable, environmental friendly and growing economy.

7 Conclusions

Our findings contribute to addressing the problem of estimation of the impact of climate change and the introduction of climate policy on the financial sector and real economy of the Euro Area. By combining the balance sheet data, data on mutual exposures and micro-level (firm-level) data, we provide estimates of the exposures of the institutional

[27] President Trump, https://www.bbc.com/news/election-us-2016-36401174

sectors to climate-relevant sectors of the economy. Also, we assess the magnitude of gains/losses of the economy caused by shocks to climate-relevant sectors while taking into account the effect of financial loss/gain amplification through the financial interdependencies among the institutional sectors. In particular, we estimate the monetary value of exposure of the Euro Area financial sector (banks, investment funds, insurance&pension funds) and real sector (households, government and non-financial firms) to climate-relevant sectors and provide an estimate of potential gains and losses as a result of climate policy introduction/climate-related announcements using the case study of shocks to Oil&Gas sector. From our analysis, the following findings emerge:

1. The major direct exposures of financial actors to the real economy are concentrated on equity holdings for investment funds, pension funds, and other financial institutions, while they are concentrated in loans and bonds for banks (holdings of government debt).

2. There are large indirect exposures of financial actors to the real economy. Remarkably, pension funds hold an exposure of about 30% of their total assets in equity shares of investment funds, which in turn hold an exposure of about another 27% in equity of non-financial corporation in the Euro Area and the US. Pension funds also hold another exposure of 12% of their total assets in bonds and loans to banks, which in turn hold an exposure of about 12% (of their total assets) to the real economy. In contrast, the direct exposure of pension funds to non-financial corporations of the Euro Area is only about 8%. These findings imply that adverse shocks on the real economy and increased volatility in asset values of the real economy could affect large portions of pension funds assets but this would occur more through indirect exposures than through direct exposures.

3. Banks are very lightly directly exposed to climate-sensitive sectors (<1% - on fossil-fuel sector, 8% of total assets – to all climate-sensitive sectors of the economy), and, as a result, to climate policy risks. Thus, they should not be against climate policies and should be in favour of the rapid transition to decarbonization. On the other hand, insurance&pension funds bear a large exposure to climate relevant sectors (more than 22% of their equity or 14% of their total assets) through direct and indirect exposures. Therefore, they should take measures to ensure the safe transition to a low carbon economy. Estimated direct exposure of the Euro Area economy to fossil-fuel is about 1.5%, and to all climate-sensitive sectors is about 50% of the total assets of the Euro Area. In addition, 16% of the total assets of the Euro Area can not be classified as "other" or "climate-sensitive" sectors, as this information is unknown. This fact highlights the need of public disclosure of information on the climate-sensitive economic activity, which would allow to better estimate risks and gains of the Euro Area on the way to decarbonization of the economy.

4. A framework proposed here allows to estimate the monetary value of financial gains and losses of the economy as a result of climate policy announcements and help to better inform policy-makers for the purpose of effective climate policy design.

This study can be viewed as first attempt of an empirical estimation of the magnitude of climate change-related financial risks of the financial system and real economy of the Euro Area[28]. We provide a monetary estimate of the extent to which the Euro Area is exposed to climate change-related financial gains and losses. On the one hand, this study addresses the fear of climate policy implementation from the perspective of certain governments and individual investors by providing them with data-based evidence for supporting the decarbonization of the economy. On the other hand, these results serve as a base for stress-testing the economy with respect to climate policy shocks, and, thus, help the policymakers to choose the best pathway to a sustainable, environmentally friendly, and growing economy.

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Appendix

Major actors

In our study, we use classification of the institutional sectors of the Euro Area provided by the ECB [29]. This classification results in seven institutional sectors [30] that can be defined as follows:

[29] http://sdw.ecb.europa.eu/
[30] ESA 2010

1. *Non-Financial Corporations (NFC)* – corporations or quasi-corporations that are not engaged in financial intermediation but are active primarily in the production of market goods and non-financial services.

2. *Banks or Monetary Financial Institutions (MFI)* – financial institutions which together form the money-issuing sector of the Euro Area. These include the Euro system, resident credit institutions (as defined in EU law) and all other resident financial institutions whose business is to receive deposits and/or close substitutes for deposits from entities other than MFIs and, for their own account (at least in economic terms), to grant credit and/or invest in securities. The latter group consists predominantly of money market funds (MMFs).

3. *Non-MMF Investment Funds (IF).* An investment fund is a supply of capital belonging to numerous investors that is used to collectively purchase securities while each investor retains ownership and control of his or her own shares. An investment fund provides a broader selection of investment opportunities, greater management expertise and lower investment fees than investors might be able to obtain on their own. According to European Central Bank Data Warehouse, IFs can be classified into bond funds, equity funds, mixed funds, real estate funds, hedge funds, and other funds.

4. *Other Financial Institutions (OFI).* An OFI is a corporation or quasi-corporation other than an insurance corporation and pension fund that is engaged mainly in financial intermediation by incurring liabilities in forms other than currency, deposits and/or close substitutes for deposits from institutional entities other than MFIs, in particular those engaged primarily in long-term financing, such as corporations engaged in financial leasing, financial vehicle corporations created to be holders of securitized assets, financial holding corporations, dealers in securities and derivatives (when dealing for their own account), venture capital corporations and development capital companies.

5. *Insurance Corporations and Pension Funds (I&PF).* According to the ESA 2010, the insurance corporations subsector consists of all financial corporations and quasi-corporations which are principally engaged in financial intermediation as a consequence of the pooling of risks mainly in the form of direct insurance or reinsurance; the pension funds subsector consists of all financial corporations and quasi-corporations which are principally engaged in financial intermediation as a consequence of the pooling of social risks and needs of the insured persons (social insurance). Pension funds as social insurance schemes provide income in retirement, and often benefits for death and disability.

6. *General Governments (Gov)* – are defined as comprising resident entities that are engaged primarily in the production of non-market goods and services intended for

individual and collective consumption and/or in the redistribution of national income and wealth. Included are central, regional and local government authorities as well as social security funds. Excluded are government-owned entities that conduct commercial operations, such as public enterprises. Central governments include all administrative departments of the (central) state and other central agencies whose competence extends over the entire economic territory, except for the administration of social security funds. State governments comprise separate institutional units exercising some of the functions of government (excluding the administration of social security funds) at a level below that of the central government and above that of local government.

7. *Households (HH)* consists of one or more people who live in the same dwelling and also share meals or living accommodation, and may consist of a single family or some other grouping of people. A single dwelling will be considered to contain multiple households if either meals or living space are not shared.

Climate-sensitive sectors

Climate-sensitive sectors classification was taken from Battiston et al. (2016a). The full list of climate sensitive sectors and corresponding NACE 4 digit codes is provided on the table below.

The complete mapping from NACE Rev2 4-digit codes to our classification is showed in Table 2.

NACE 4-digit codes	Sectors
B5.1-B6.2, B8.9.2, B9.1, C19.1-C19.2, C20.1.1, C28.9.2, D35.2, F43.1.2, F43.1.3, H49.5	Fossil-fuel
B7.1, B7.2.9, B8.9.1, B8.9.3, B8.9.9, C10.2, C10.6.2, C10.8.1, C19.8.6, C11.0.1, C11.0.2, C11.0.4, C11.0.6, C13.1-C15.2, C16.2.9-C17.1.2, C17.2.4, C20.1.2-C20.2, C20.4.2, C20.5.3-C22.1.9, C23.1.1, C23.1.3-C23.5, C23.7, C23.9.1, C24.1-C24.2, C24.4-C24.4.6, C24.5.1, C24.5.3., C25.4, C25.7, C25.9.4-C28.9.1, C28.9.3-C29.1, C29.3.1, C30.3, C30.9, C31.0.9-C32.9,	Energy-intensive
C23.6.1, C23.6.2, C31.0.1-C31.0.3, F41.1, F41.2, F43.1-F43.9, I55.1, L68	Housing
D35.1, F42.2.2	Utilities
H49.1-H49.4, H50-H51.2.1, H52.5-H53.2.0	Transport
K	Finance
Other	Other

Table 2: Mapping of sectors from NACE Rev2 4-digit codes to classification in climate-policy-relevant sectors as in Battiston et al. (2016a).