Financial stability

Fund portfolio networks: a climate risk perspective

Contact: adrien.amzallag@esma.europa.eu

Summary

Within the European financial sector, investment funds are more exposed to climate-sensitive economic sectors than banks, insurers and pension funds. However, few investment fund climate-related financial risk assessments have been conducted. This article provides a first attempt to fill this gap, using a data set of EUR 8 trillion of European investment fund portfolio holdings. Funds whose portfolios are tilted towards more polluting assets (brown funds) distribute their portfolio over a larger number of companies than funds with cleaner portfolios (green funds). This apparent diversification hides a concentration risk: brown funds are more closely connected with each other (have more similar portfolios) than green fund portfolios, which tend to 'herd' less (have less similar portfolios to those of other green funds). This suggests that widespread climate-related financial shocks are likely to disproportionately affect brown funds. A preliminary climate risk scenario exercise confirms this: besides total system-wide losses of EUR 152 billion to EUR 443 billion, most brown funds' losses range from about 9 % to 18 % of affected assets, in contrast to green funds' losses, which usually range from 3 % to 8 %. In addition, brown funds have more systemic impact: they contribute more to total system-wide losses (by virtue of their greater interconnections within the fund universe) than green funds. These findings provide support for ongoing EU regulatory and supervisory initiatives on sustainable finance.

Introduction

Within the European financial sector, investment funds are considered to have the largest exposure to climate-sensitive economic sectors such as utilities, transport and fossil fuel extraction (ESRB, 2020; Battiston et al., 2017). However, whereas a number of efforts have been made to conduct climate-related financial risk assessments of the European banking and insurance sectors, there has been little similar analysis of the European investment fund universe (Allen et al., 2020; Bank of England, 2015, 2018, 2019; EIOPA, 2020; ESRB, 2020). This article aims to help fill this gap, based on a hitherto unexplored data set of EUR 8 trillion of European investment funds' portfolio holdings of approximately 14 million direct and indirect exposures to equity and corporate bond instruments[106].

This article applies a network perspective to investment funds' exposures to climate (transition) risk[107]. Such a perspective could be

[106] An earlier version of this article included a larger dataset in terms of monetary value of portfolio holdings. This has been revised downwards as part of unclear currency indications provided in the portfolio holdings dataset purchased for this analysis: currencies indicated next to each portfolio asset do not in fact refer to the currency of the value reported for that asset, but to some currency associated with the asset issuer that is provided "for information" only and has no link with the monetary value reported. A separate portfolio-level currency denomination is available in a separate location from the data provider, which must be merged in with the dataset and subsequently applied to each asset value reported within the portfolio. This currency conversion process leads to a reduction in certain extremely large fund portfolio totals, which has the effect of reducing the overall dataset size. Although absolute figures have been adjusted to reflect this adjusted currency conversion process, the conclusions of the article remain unchanged.

[107] There are two generally accepted types of climate risk: physical risk and transition risk. Physical risk relates to either event-driven (e.g. floods) or longer-term (e.g. sustained higher temperatures) developments that either cause direct damage to organisations' assets or indirectly affect their operating environment (e.g. supply chains). Transition risk relates to the financial and reputational risks faced by legal entities as part of the extensive policy, legal, technological and market changes that arise to

critical when considering financial stability, because:

- In addition to buying equities, corporate bonds, sovereign debt and other such assets, investment funds can also invest in other funds, which themselves have exposures to climate-sensitive sectors. It is necessary to look through these exposures in order to 'unpack' the indirect exposure of investment funds to climate risks, via their holdings of other funds' shares.
- The extent to which climate risk shocks affect multiple funds at the same time depends on how similar their portfolios are (i.e. how dense are the interconnections between investment funds).

Using this approach and data set, the article aims to answer the following questions:

- How can we measure and compare investment fund portfolios, from a climate risk perspective?
- What methods exist to assess the density of the network of fund portfolio holdings, and how can these methods shed light on investment funds' relative (and joint) vulnerability to future climate-related financial shocks?
- Given a set of climate risk scenarios, which funds suffer the greatest asset losses, and what are key areas of focus for supervisors and policymakers as a result of this exercise?

This work forms part of ESMA's strategy on sustainable finance (ESMA, 2020) and reflects ESMA's growing focus on sustainable finance-related topics, in line with the recently revised ESMA Regulation[108]. ESMA aims to continue expanding its efforts in the area of sustainable finance and investment funds in the coming years, including on climate risk stress testing.

The remaining sections describe the data set employed, approaches to measure investment portfolios from a climate risk perspective, the network-based analysis of investment fund holdings, a description and results of the asset valuation exercise, and implications and next steps.

Data set and methodology

The data set includes the following:

- detailed (ISIN-level) portfolio holdings data for EU-domiciled investment funds, obtained from a commercial provider;
- additional descriptive fund information, such as inception date and investment strategy; and
- information on the firms issuing the assets held by these funds, such as CO_2-equivalent emissions, revenue and country of domicile.

Portfolios from 23 352 EU-domiciled investment funds have been recovered, covering the most recent data available for each fund at the time of analysis (4Q20) – one share class per fund. Table RA.1 below provides further details on the size and magnitude of the data set: a total of EUR 8 trillion of investments are included, spread out over 3.2 million positions. This compares with roughly EUR 15.7 trillion net assets among EU UCITS and AIFs at the end of 1Q20 (EFAMA, 2020)[109]. This suggests that the present data set is sufficiently representative of the EU investment fund sector overall.

address the efforts required to mitigate and adapt to climate change. See TCFD (2017) for further discussion. This article focuses on transition risk.

108 Regulation (EU) No 1095/2010.

109 Out of these 23 352 funds, 18 513 are classified as UCITS according to the commercial data provider, with total assets worth roughly EUR 6.3 trillion. Using ESMA supervisory AIFMD data, a further 1 555 AIFs can be identified, with assets worth EUR 0.33 trillion. This leaves 3 284 funds in the data sample, with EUR 1.3 trillion of assets, that could either be UCITS or AIFs but could not be explicitly classified. These figures compare with EUR 9.4 trillion and EUR 6.2 trillion net assets for EU UCITS and EU AIFs overall, according to EFAMA statistics. From another perspective, there are 21 242 actively managed funds with total portfolio assets worth EUR 6.7tn, 2 108 passively managed funds with assets worth EUR 1.2tn, and a small number of funds (2, total assets worth c. EUR 0.03 billion) that cannot be classified. In this article we do not distinguish between ETFs and non-ETFs, or between actively and passively managed funds, although this is a potential avenue for future research.

RA.1
Portfolio holdings data set description
EU fund portfolio holdings by asset type

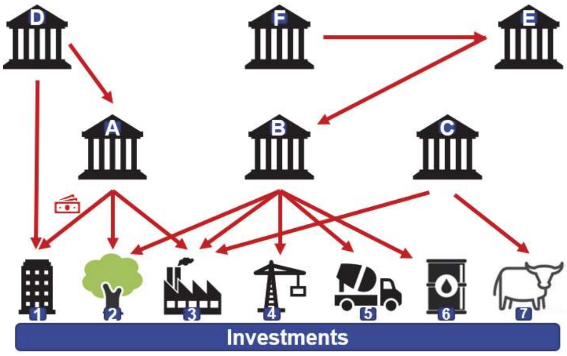
Asset type	Number of investments (thousands)	Value of investments (bn EUR)
Equities	1 321	3 019
Corporate bonds	811	1 319
Funds	280	1 166
Government/supranational debt	124	1 061
Cash and cash equivalents	207	824
Structured finance	71	188
Real estate	251	200
Derivatives	50	98
Other	42	65
Commodities	1	2
Total	3 158	7 942

Note: 'Cash equivalents' comprises commercial paper, time deposits, certificates of deposit, and cash set aside to offset forwards, options, repurchase agreements, swaps or futures. 'Derivatives' comprises futures, forwards, swaps, options and CfDs. 'Other' comprises bank loans, infrastructure assets, 'Other assets and liabilities', and 'Undefined'.
Sources: Morningstar, Refinitiv, ESMA.

As further shown in Table RA.1 above, the largest investment positions held by funds are equities (c. EUR 3tn), and corporate bonds (c. EUR 1.3tn), which are spread over 21 107 unique companies (located anywhere in the world). Holdings of shares issued by other investment funds (either UCITS or AIFs) make up the fourth largest asset class by value (c. EUR 1.1tn, spread out over 12 290 funds)[110]. Sovereign and supranational debt instruments, and cash holdings make up the largest remaining categories of investment positions. For the purposes of this article, the focus is on holdings of equities, corporate bonds and lastly shares issued by other investment funds.

Chart RA.2 below demonstrates some of the relationships that can exist between investment funds: Funds A, B and C invest directly in downstream entities 1 to 7. Fund D invests in Fund A and also directly in entity 1, and thus Fund D has both direct and indirect exposures to entity 1, as well as purely indirect exposures to entities 2 and 3. Elsewhere, Fund E, via its investment in Fund B, has indirect exposure to assets 2 to 6. Lastly, Fund F is one step further removed but still can be said to have indirect exposure to assets 2 to 6, via its sole exposure to Fund E.

RA.2
Possible investment relationships
Perspectives on the portfolio holding network



Source: ESMA.

Unpacking this investment network, for example by substituting Fund D's shares in Fund A with the downstream assets held by Fund A (assets 1 to 3), enables a full overview of exposures to climate-sensitive assets. Doing so creates a further 12 million indirect exposures to equity and corporate bond instruments, worth an extra EUR 0.7 trillion[111]. After various data-cleaning and consistency checks, the unpacked data set, which is used throughout this article unless otherwise noted, amounts to approximately 14 million equity and corporate bond holdings, worth a total of EUR 5 trillion. Useful descriptive variables are merged with this information, such as the fund's inception date, parent entity and domicile.

Next, we merge in the latest available (from Refinitiv) issuer information for the equity and/or corporate bonds held by the investment funds. Variables retrieved include total assets, revenue (earnings before interest, taxes, depreciation and amortisation (EBITDA)), and economic sector (Statistical Classification of Economic Activities in the European Community (NACE) four-digit). One key variable is firm emissions: total CO_2 and CO_2-equivalent emissions are included (i.e. CO_2 plus methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorinated compounds (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3)). We include both direct emissions and emissions arising from the generation of energy purchased by the firm (i.e. scope 1 and 2 emissions). The data source is the firm's regulatory filings or, where not available, an estimate based on either past filings or the firm's

110 The constituents of certain ETFs and some indices are not always available. This is relevant to the 'unpacked' network discussed in the subsequent paragraphs (and affects 4 % of the fund-to-fund exposures).

111 Some funds in the sample do not invest in any equity or corporate bond instruments. This is why the additional euro investment values from the unpacked data set do not match the total value of fund investments in Table RA.1.

relative position in its industry (Refinitiv, 2019)[112]. A total of 81 % of equity and corporate bond holdings are associated with emissions data.

Table RA.3 below summarises this information for the most polluting sectors (measured by total emissions vs total revenue)[113]. The sectors displayed match well with expectations (Ge and Friedrich, 2020). For example, the 90 firms that 'Manufacture other non-metallic mineral products' constitute the most environmentally damaging economic sector within the sample.

RA.3
Breakdown of downstream assets by economic sector
Top five most polluting economic sectors

Sector	Carbon footprint	Number of firms in sector	Total investments per sector (bn EUR)
Manufacture of other non-metallic mineral products	17 639	90	29
Manufacture of basic metals	16 541	115	24
Utilities	10 273	223	166
Air transport	6 186	58	16
Waste management	5 195	25	17
All equity and corporate bond holdings	2 126	7 071	4 821

Note: Carbon footprint is measured as total emissions (CO_2-equivalent, tonnes) divided by total revenue (EBITDA, million EUR) across unique firms in the sector (using only firms for which at least one equity or corporate bond position is held in the portfolio holdings data set, and for which both emissions and revenue figure are available). We use total CO_2 and CO_2-equivalent emissions. Both direct emissions and emissions arising from the generation of energy purchased by the company (i.e. scope 2 emissions) are included. 'Total investments per sector' refers to total equity and corporate bond positions held in that sector by EU investment funds in the portfolio holdings data set (bn EUR).
Sources: Morningstar, Refinitiv, ESMA.

Comparing fund portfolios from a climate perspective

This section discusses measures by which fund portfolios can be assessed from a climate risk perspective. One simple method is to examine the share of portfolio exposures to firms that are deemed to be 'green' or 'brown'. To do this, we classify firms into four categories:

— firms whose emissions are below the bottom third (33rd percentile) of all firms in the data sample (i.e. 'green' firms);
— firms whose emissions are greater than or equal to the top third (67th percentile) of all firms (i.e. 'brown' firms);
— firms whose emissions lie between these groups (i.e. 'neutral' firms);
— firms missing emissions information.

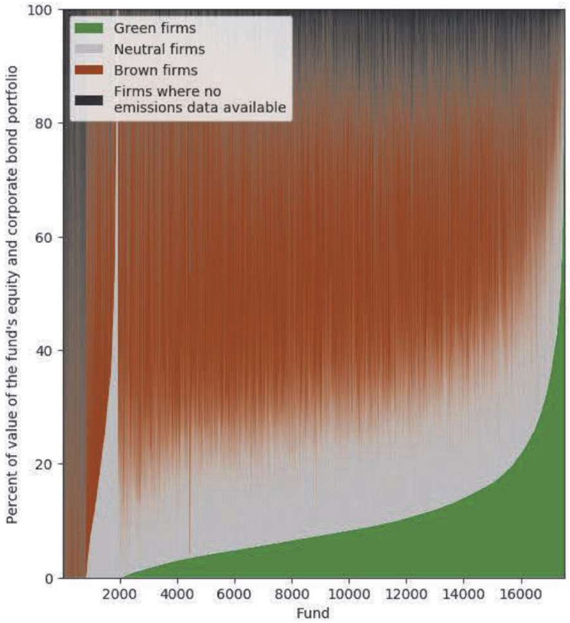
Chart RA.4 below displays these respective shares, and shows that many fund portfolios underweight green firms. In other words, the share of EU funds' equity and corporate bond investments in green firms is lower than 33 % of the value of their portfolio[114] (the mean share of portfolio holdings in green firms, across all funds in the sample, is 11 % and the median is 8 %). In addition, many fund portfolios overweight brown firms. That is, the share of exposures to brown firms tends to be greater than 33 % (the mean and median shares are 53 % and 55 %).

[112] Although emissions data are subject to data provider-specific issues, and are not entirely standardised (see Kalesnik et al., 2020), this represents a preliminary exercise that can subsequently be updated in future years once more robust and supervised data are available.

[113] The corresponding five least polluting sectors are (beginning with the most polluting) advertising and market research; activities auxiliary to financial services and insurance activities; insurance, re-insurance and pension funding; public administration and defence; and forestry and logging.

[114] An equal weighting would imply that the average fund's exposure to green firms is 33 % (corresponding to the 33rd percentile used to classify firms as green).

RA.4
Share of portfolios in green vs brown firms
EU fund portfolios underweight green firms



Note: The chart displays the percentage (in terms of value) of each individual fund's equity and corporate bond portfolio (y-axis) that is allocated to firms classified according to their portfolio emissions. Portfolio percentage exposures are split into the following four categories: firms whose emissions are below the 33rd percentile for the data sample ('green' firms); firms whose emissions are greater than or equal to the 67th percentile ('brown' firms); firms whose emissions are in between these groups (i.e. the 33rd percentile and the 67th percentile; 'neutral' firms); and also firms for which no emissions information is available. The x-axis denotes individual funds, sorted according to the percentage of exposures to green firms in the portfolio (from lowest to highest share).
Sources: Morningstar, Refinitiv, ESMA.

No distinction (tolerance) is made in terms of whether a firm belongs to a particularly polluting sector[115]; the focus here is on the pure environmental impact of firms and the extent to which fund portfolios are exposed to these firms. Further sector-specific analyses could of course be attempted in order to provide a complementary visualisation of fund strategies; this is discussed further below.

One can also measure each fund portfolio's 'importance' from a climate risk perspective. There are several possible ways to do so, each of which has its relative advantages[116].

One approach is to take the average emissions of the portfolio, using the relative share of each investment as weights[117]. The advantage of this approach is that it most accurately characterises the relative damage of the fund's asset mix on the environment and is thus more 'credible' from an environmental perspective (Institut Louis Bachelier et al., 2020). Put differently, from the perspective of the planet and the climate, it is the absolute emissions that matter, not emissions normalised by other metrics (such as revenue). The impact of a higher-emitting company will be greater on the planet than that of another, possibly smaller, company.

One can also normalise each firm's emissions by its revenue (i.e. calculate its carbon footprint) and average this across all firms in the portfolio, again weighted by each investment's relative share[118]. This measure is perhaps more closely reflective of each fund's strategy and regulatory constraints: funds investing in firms with a high carbon footprint can be more clearly identified as less sensitive to the climate impact of their investments. In contrast, funds investing in firms with high overall emissions may simply have little choice, for example if their regulatory requirements or their investment mandate is limited to investing in investment-grade firms (which tend to be larger) or if cleaner firms issue fewer purchasable instruments.

These perspectives can be combined and also coupled with the size of each fund's portfolio to produce an overall assessment on the most environmentally damaging fund portfolios. Chart RA.5 below demonstrates that there are many funds with high average portfolio emissions, high average portfolio carbon footprints and extremely large portfolios (exceeding EUR 20 bn). It is these funds that would appear to be of greatest supervisory interest: among EU funds, the portfolios in this subgroup hold assets with the greatest impact on the planet (i.e. high average portfolio emissions), are relatively less concerned about the impact of investing in climate-inefficient firms (i.e. high average portfolio carbon footprint) and manage the largest portfolios in the EU.

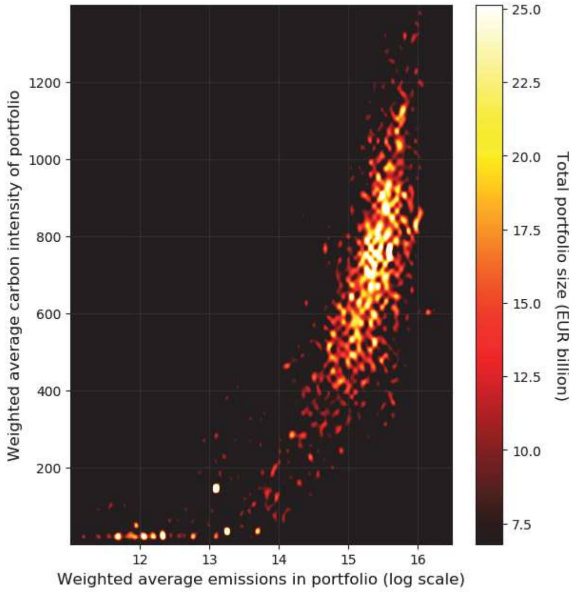
[115] An exception is when the emissions data are estimated by the data provider, as discussed in the previous section.

[116] See Raynaud et al. (2015), Swiss Sustainable Finance (2019) and World Resources Institute et al. (2015).

[117] This is calculated as $\sum_{i=1}^{N}(\frac{current\ value\ of\ investment_i}{current\ portfolio\ value} \times company\ CO_2\ emissions_i)$.

[118] This is calculated as $\sum_{i=1}^{N}(\frac{current\ value\ of\ investment_i}{current\ portfolio\ value} \times \frac{company\ CO_2\ emissions_i}{company\ EURm\ revenue_i})$.

RA.5
Comparing fund portfolios across climate risk metrics
Which fund portfolios are most damaging?



Note: The x-axis is the average emissions within each fund portfolio (weighted by value of each investment position) and in log scale. The y-axis is the average carbon footprint (tonnes of CO_2-equivalent per m EUR revenue, measured as EBITDA) of investments within each fund portfolio (weighted by the value of each investment position). The colour scale (right) illustrates the total size of each fund's portfolio, measured in bn EUR. Higher asset sizes are paler. Includes direct (scope 1) and indirect (scope 2) CO_2 and CO_2-equivalent emissions.
Sources: Morningstar, Refinitiv, ESMA.

Portfolio networks: brown funds overlap strongly

The previous section considered investment funds' portfolios from the perspective of outward environmental impact. This section and the next take the opposite perspective: the inward vulnerability of funds' portfolios to climate-related financial risks. Assessing these risks requires the interconnections between funds to be explored. This is because the impact and spread of climate-related financial shocks will depend on:

— how many (and how much[119]) investment funds are directly investing in the affected firms; and
— subsequently, how many upstream funds are indirectly exposed to firms via their holdings of shares in intermediate funds (see Chart RA.2 above).

Measuring funds exposed to firms

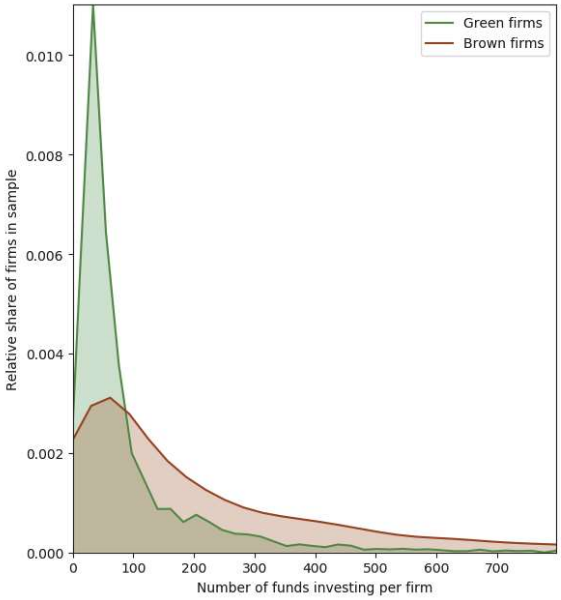
To better understand the first of these two risk drivers, Chart RA.6 compares the distribution of the number of fund investments per firm, for green firms and brown firms (see previous section for a description of this grouping). The green (brown) line displays the distribution of the number of fund investments in green (brown) firms. The number of fund investments shown is normalised, and represents the share in the total investments in the fund data set that is captured by each firm[120].

It is clear from Chart RA.6 that fewer funds invest in the same green firm (i.e. the green line is peaked). Put differently, more funds invest in each brown firm than in each green firm, as reflected in the heavier tail of the brown line – about four times more on average[121]. From the perspective of the issuers (i.e. brown and green firms), this suggests that brown firms are less vulnerable to liquidity risks than green firms[122].

Taking the fund perspective, however, if climate-related financial risks affect brown firms more than green firms (discussed further below), then this indicates that climate-related shocks will affect more funds than in the opposite situation (i.e. more funds invest in each green firm than in each brown firm). This provides a first indication of how a climate-related shock would be distributed across the fund universe.

119 See previous section.
120 Formally, this is the degree of each downstream firm normalised by the total network degree. Only direct fund investments in firms are included (i.e. the network degree only reflects fund-to-firm connections).
121 A green firm can expect to sell its equity and/or bond instruments to 85 EU funds on average (median: 38 funds), whereas a brown firm will attract investments from 314 EU funds on average (median: 138 funds).
122 There may also be structural reasons for this situation, however: insofar as emissions are linked with the size of a firm, and if there are minimum denominations for issuances of financial instruments (especially corporate bonds), then green firms may be able to sell their liabilities to fewer funds and other financial market participants than brown firms.

RA.6
Comparing the number of fund investments per firm
Contagion risk: polluting firms are more popular



Note: The lines represent the distribution of the number of funds directly investing in each firm (relative to total number of investments, i.e. the normalised degree of each firm), for firms that are in the bottom third in terms of emissions ('green' firms) or in the top third ('brown' firms). Emissions are of total CO_2 and CO_2-equivalent emissions including direct (scope 1) and indirect (scope 2) emissions. The two distributions are different with at least 97 % confidence according to a two-sample Kolmogorov–Smirnov test. Distributions are truncated at the 90th percentile for ease of visualisation.
Sources: Morningstar, Refinitiv, ESMA.

Measuring fund portfolio similarity

Another perspective on interconnections is the similarity of investment fund portfolios. This is complementary to the firm-centric perspective of the preceding subsection: the fact that more polluting companies attract investments from a greater number of funds does not indicate whether funds are investing in the **same** companies[123]. The greater the extent of co-investment (i.e. portfolio similarity), the greater the potential for large climate-related (and other) financial shocks to propagate across the network (Acemoglu et al., 2015[124]) and for second-round effects across funds (Georg et al., 2020).

There are numerous ways in which portfolio similarity can be calculated. In this article, we consider the value of investments held in common across two funds' portfolios, divided by the joint total portfolio value of the pair of funds[125]. This measure indicates the extent to which funds are co-investing relative to the amount that they could have, given their combined portfolios[126].

We then examine if there are meaningful differences in portfolio similarity between pairs of funds whose portfolios are both in the lowest third ('pairs of green funds') in terms of weighted average emissions across the universe of fund portfolios, and pairs of funds whose portfolios are both in the highest third ('pairs of brown funds'). Thus, we explore whether brown fund portfolios have more in common with each other than green fund portfolios have in common with each other. If this is the case, then brown funds will be jointly affected (i.e. suffer in a coordinated way) following climate-related financial shocks, relative to the positions among green funds.

Chart RA.7 below compares the distribution in portfolio similarity across pairs of green fund portfolios (green line) with the corresponding distribution for pairs of brown fund portfolios (brown line). It is clear that brown fund portfolios are often more similar to each other than green fund portfolios are similar to each other. This suggests greater concentration risks existing across funds whose portfolios contain more-polluting assets[127].

123 To take an extreme case, each investment fund could be choosing to invest its entire portfolio in a single company, which would imply very little portfolio overlap across funds. Alternatively, each fund could invest a small amount in each firm in the universe, which would imply that there is a perfect overlap across all fund portfolios.

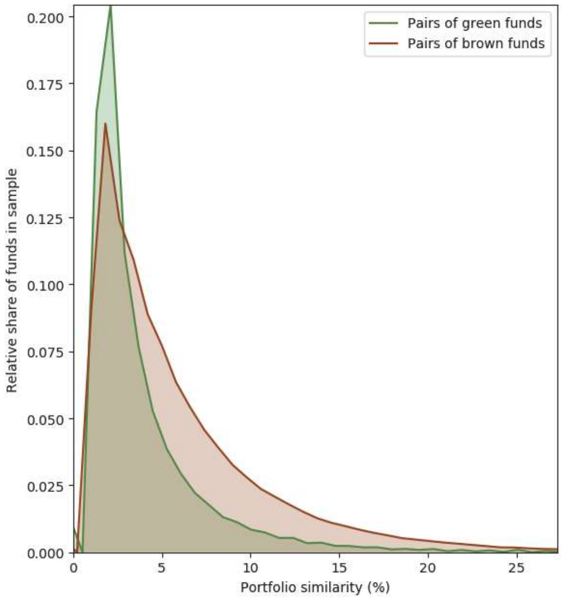
124 As explained by Acemoglu et al. (2015), for large negative shocks (as is likely to be the case for climate risk), a more interconnected network is a source of fragility: 'beyond a certain point, dense interconnections serve as a mechanism for the propagation of shocks, leading to a more fragile financial system'.

125 For two funds, A and B: Fund A invests EUR 100 each in firms P and Q; Fund B invests EUR 60 each in firms Q, R and S. The portfolio similarity between Funds A and B is then 42 % = (100 + 60) / (100 + 100 + 60 + 60 + 60).

126 Many other similarity measures exist, which often begin from the number of investments held in common across two funds' portfolios. These are then divided by the total investment universe, by the minimum number of investments across the two portfolios or by the total investment universe considered by either the two funds. Formally, these are all the projection of the bipartite network of fund portfolio holdings onto the specified nodes (i.e. funds), with various weights corresponding to the neighbourhoods of the two funds in the original bipartite network. See Borgatti and Halgin (2016). The number of common investments by the two funds can also be normalised by all of the investments that each firm receives from all funds (i.e. not just the pair of funds under consideration), added up across all the companies in the funds' overlapping portfolios. See Newman (2001). The results in this section are robust to all of these other similarity measures (results available upon request). Other similarity approaches could be considered, e.g. cosine similarity or Euclidean distance (Girardi et al., 2020; Georg et al., 2020).

127 The number of available pairs is also indicative of relative concentration among fund portfolios: there are approximately 2.6 million interconnections (i.e. overlapping fund portfolios) among green funds, and

RA.7
Extent of overlapping portfolios across pairs of funds
Brown funds have more similar portfolios



Note: The lines represent the distribution of portfolio similarity across pairs of investment funds (in %). Two sets of pairs are shown: pairs of funds each of whose portfolios are in the bottom third in terms of weighted average emissions ('pairs of green funds') and pairs of funds whose portfolios rank in the top third in terms of weighted average emissions ('pairs of brown funds'), based on the fund portfolio holdings data set. Portfolio similarity is expressed as the number of common investments between each pair of funds, normalised by the total number of firms considered by either of the two funds. Emissions are CO2 and CO2-equivalent emissions (scopes 1 and 2 included). The two distributions are different with at least 99 % confidence according to a two-sample Kolmogorov–Smirnov test.
Sources: Morningstar, Refinitiv, ESMA.

Visualising the fund portfolio network

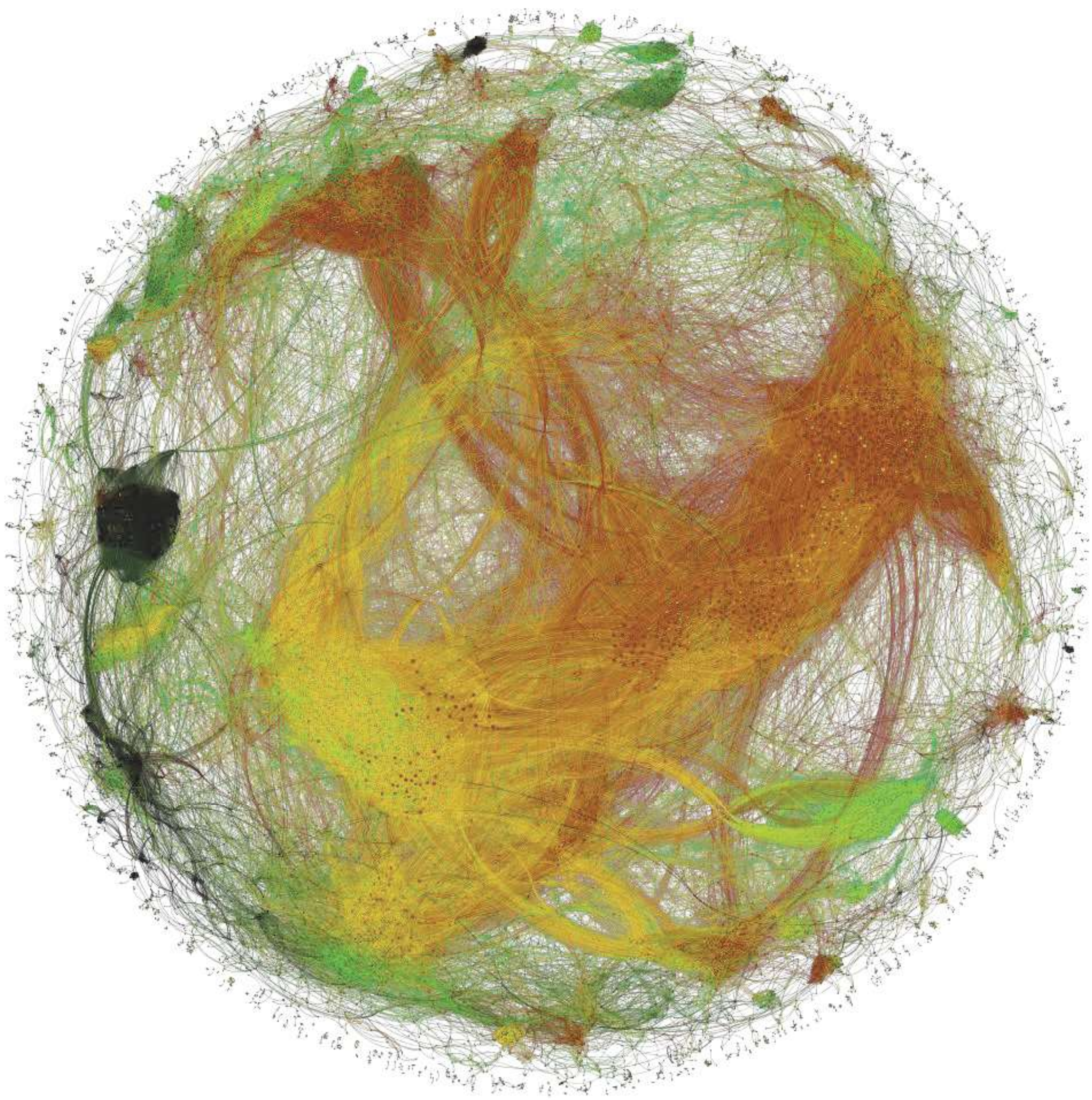
As discussed above, portfolio similarities can be represented as interconnections between funds, due to common assets held. Chart RA.8 below visualises the largest portfolio similarities in the fund universe, using the emissions-based fund grouping discussed above (funds are grouped into quartiles here, rather than terciles, for ease of visualisation). The location of funds in the graph reflects the strength of their relationships, i.e. how much their portfolios overlap. Thus, colour clouds indicate clusters of funds that collectively invest in similar assets. In addition, it is important to recall that funds have no obligation to invest in one or more of the same firms, and if two funds do not have any investments in common they will not appear in this graph. Therefore, the presence of colour is itself a sign that interconnections exist (i.e. more of a particular colour in the overall graph implies more interconnections).

about 5.1 million pairs of overlapping portfolios among brown funds (out of approximately 32 million portfolio overlaps between all funds in the universe). This is meaningful because, at the start of the exercise, the fund population was segmented into equal thirds. Despite starting from an even split of funds in the universe, there appear to be roughly twice as many interconnections between brown funds as between green funds. This also suggests a greater relative concentration of investments among brown funds and, therefore, a greater risk of funds' portfolios co-moving, following a climate-related financial shock, than funds whose portfolios are oriented towards less-polluting assets.

RA.8

Visualising the investment funds portfolio universe, categorised by extent of average portfolio emissions

Funds with more polluting portfolios have greater interconnections (i.e. greater portfolio similarity)



Note: The chart displays the 0.5 % largest portfolio overlaps among EU investment fund portfolios. Portfolio overlap/similarity is measured as the number of common investments between two investment funds, normalised by the total number of firms considered by either the two funds. This portfolio similarity measure indicates how often two funds co-invest relative to the number of times that they could have, given their portfolios. Funds are segmented into five groups, based on the weighted (by value of the investment position) average emissions of their portfolios: black (no emissions data available for any firms held in the fund portfolio), dark green (fund portfolio is in the cleanest quarter of funds in the sample, i.e. the 0–25 % range in terms of weighted average emissions), light green (fund portfolio is in the next-cleanest quarter, i.e. the 25–50 % range), yellow-brown (fund portfolio is in the third quarter, i.e. the 50–75 % range) and brown (fund portfolio is in the fourth quarter, i.e. its portfolio weighted average emissions is among the top 75 % of funds in the sample). Emissions are CO_2 and CO_2-equivalent emissions (scopes 1 and 2 included).
Sources: Morningstar, Refinitiv, ESMA.

Owing to the very large sample size, only the 0.5 % largest portfolio similarities can be displayed (the full sample is shown in a simplified form in RA.7). Nevertheless, the following is clear.

— Brown funds (most-polluting portfolios) and yellow-brown funds (next most-polluting) have many more interconnections (i.e. portfolio overlaps) than dark green funds (cleanest portfolios) and light green funds (next cleanest). Put differently, green funds invest in different green firms, whereas brown fund portfolios tend to invest in many of the same brown firms. This can be seen by the fact that there is more yellow-brown and brown colour in the graph than there is light and dark green.

— Green funds are, by virtue of not being clustered so tightly together, located on the periphery of the investment fund universe. Thus, green funds are less likely than brown funds to play a central connecting role (i.e. hubs) within the fund universe. In addition to the above visual interpretation, this is also confirmed statistically: green funds are consistently less likely than brown and yellow-brown funds to act as 'connectors' among funds in the network[128].

— Many funds for which no emissions information is available for any firm in their portfolio (i.e. funds coloured in black in Chart RA.8 above, which are highly clustered to the left) tend to have highly similar portfolios. This suggests both that some firms consistently do not disclose emissions information and that a key set of funds are only interested in these firms. This observation illustrates how network visualisation can assist supervisors to identify priorities for potential supervisory action. It also suggests that climate-related disclosures by a relatively limited set of firms appear to be a priority in the light of the degree of concentration of investments in these firms.

— Two shifts may be desirable to obtain a 'balanced' network. First, brown funds should diversify away from the same assets. Second, green funds should co-invest more, and thus, perhaps, provide lower-emission firms with more broad-based and stable funding.

This section has shown that green funds tend to be overweight in idiosyncratic risks relative to brown funds, which in contrast are more exposed to climate-related systemic risks (by virtue of their greater portfolio overlap) than green funds. The next section quantifies the implications of these observations using some climate-related financial scenarios.

Risk outlook: clean funds better protected

This section now outlines the impact of several possible forward-looking climate scenarios on investment fund assets, in order to provide some early-stage evidence to support the previous sections. There are many caveats associated with this work, including the fact that translating climate risk into financial shocks has only recently begun to be explored in earnest, and that gaps remain in terms of scope, transmission channels and data coverage (Vermeulen et al., 2018: ESRB, 2020; NGFS, 2020).

Recent and ongoing work by the ESRB (see ESRB, 2020, which draws on scenarios developed by Vermeulen et al., 2018[129]) has focused on transition risks for the EU banking and insurance financial sectors. Two shocks underpin the scenario. The first is a policy shock: following a delay in implementation, there is an abrupt shift in policymaking activity and a set of stringent policy measures enter into force, whose goal is to mitigate the adverse impact of climate change. In this situation, the carbon price is assumed to rise globally by USD 100 per ton[130].

The second driver, a technology shock, is linked with technological breakthroughs that manage to lower CO_2 emissions but, in doing so, lead to dramatic revaluations across economic sectors (also implying defaults and write-offs of carbon-intensive assets). This second driver has relatively more benign effects on the macroeconomy insofar as the assumed doubling in the share of renewable energy leads only to a temporary economic slowdown (driven by old-technology industries that suffer asset losses), before the newly available technologies help support a return to economic growth.

Four scenarios are developed that relate to these two shocks, including one scenario (confidence shock) in which the absence of both shocks triggers a drop in the confidence of consumers, businesses and investors. The other three scenarios are the policy shock, the technology shock and a combination of both. Each scenario is represented relative to a baseline where non-disruptive policies are adopted.

The scenarios employed cover a time horizon of 5 years, which is admittedly short from the perspective of long-term climate change risks. As a result, the scenarios ignore second-round effects in terms of the interplay between energy transition risks and climate change. Nevertheless, the shorter time horizon works well

128 In other words, green funds have consistently lower betweenness than brown funds. Betweenness is the fraction of the shortest paths between any two funds (*s*,*t*) in the portfolio holdings network that pass through that particular fund, relative to all of the shortest paths between two funds (*s*,*t*). In other words, what is the proportion of times that our fund of interest acts (through the overlap of its portfolio with those of other funds) as a bridge between any two funds (*s*,*t*) in the network? Results are available upon request.

129 The author would like to thank Vermeulen and colleagues for sharing detailed scenario information.

130 The resulting cost increase leads to a general economic slowdown, while interest rates rise as the central bank attempts to curb inflation. See Vermeulen et al. (2018) for further details.

from the perspective of investment fund assets, which are relatively short-term, in contrast to longer-term exposures such as bank loans or life insurance policies. The horizon is also long enough to allow an abstraction from the more typical concerns faced when simulating stressful situations for investment funds, including liability-side measures such as lock-out periods and other liquidity management tools (ESMA, 2019).

These scenarios are sector-specific, and cover 88 individual NACE sectors (56 unique sectors). Asset write-downs for equity and corporate bond instruments can be assessed, by linking macroeconomic conditions to their exposure to carbon prices (via CO_2 emissions). Therefore, the magnitude of the asset valuation impact varies depending on the economic sector in which a company is operating (i.e. depending on that sector's exposure to the type of climate risk being modelled). The sectors most affected by the abrupt policy adjustment (electricity, gas and steam production) are different from those that are worst hit by asymmetric technological change (mining and quarrying, and certain manufacturing activities). Moreover, as mentioned previously, certain manufacturing sectors would actually observe improving equity valuations (up to 22 %).

Table RA.9 below illustrates the (weighted) average asset write-downs across investment fund holdings of equities and corporate bonds for the different scenarios, and also presents total asset reductions in absolute and relative terms. this scenario valuation exercise includes 20 937 EU fund portfolios. Depending upon the scenario, overall losses range from EUR 152 billion to EUR 443 billion, or between 3.1 % and 9.0 % of fund portfolio assets included in the exercise.

RA.9
Forward-looking climate risk scenario analysis
First-round EU fund losses in each climate risk scenario

Scenario	Average asset write-downs (%)	Total losses (tn EUR)	Total losses (% of fund assets included)
Policy shock	5.2	242	4.9
Tech shock	3.3	152	3.1
Policy + tech shock	9.7	443	9.0
Confidence shock	7.5	356	7.2

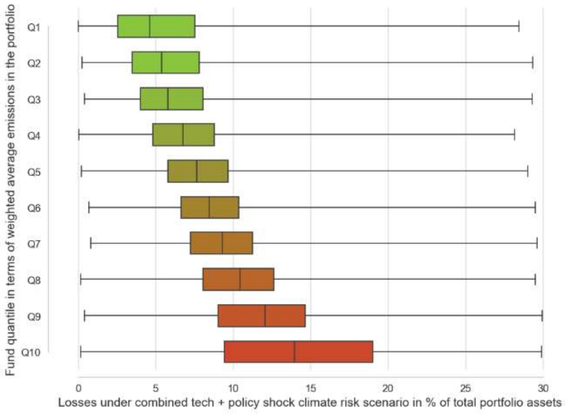
Note: Application of energy transition risk asset valuation scenarios to EU fund equity holdings, based on scenarios developed by Vermeulen et al. (2018) and employed by ESRB (2020). Average write-downs are weighed by total value of investments used in the asset valuation exercise. Percentages are expressed in terms of total portfolio holdings of equity, corporate bonds and shares issued by other investment funds. Indirect holdings are also included, i.e. we record losses on fund investments in other funds that are exposed to markdowns in asset values. The UK and the Channel Islands are included in this sample.
Sources: ESRB (2020) Vermeulen et al. (2018), Morningstar, Refinitiv, ESMA.

The impacts below are a lower bound for the potential losses faced by EU investment funds under these scenarios. First, because only EU funds are included in this exercise, indirect losses from EU fund holdings of non-EU funds that themselves invest in EU equities and corporate bonds are not included. Second, the constituents of certain ETFs and other benchmarks that are popular with investment funds are not included in the data set.

Percentage losses relative to total assets can vary significantly across investment funds. Furthermore, since the economic sector-specific stress impacts are calibrated according to the embodied CO_2 emissions in that industry, a fund with relatively greater exposure to CO_2-intensive industries suffers greater losses than a relatively less-exposed fund, all else being equal.

Chart RA.10 below presents the distribution of losses across funds under the most severe scenario: the combined policy and tech shock. Investment funds have been grouped into deciles, based on their respective weighted average (CO_2-equivalent) emissions per portfolio. Funds in the lowest decile in terms of emissions are denoted Q1 and are coloured green; funds in the highest decile are denoted Q10 and coloured red/brown.

RA.10
Forward-looking climate risk scenario analysis
Cleaner portfolios are more protected



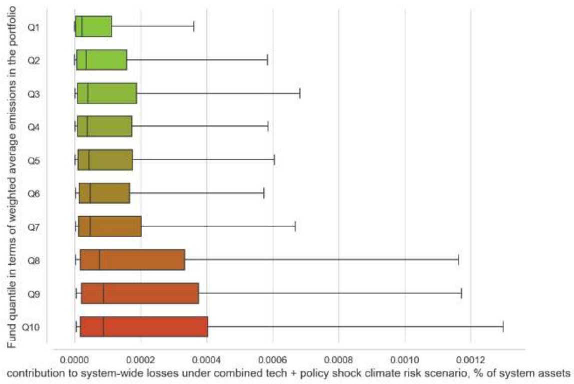
Note: Application of energy transition risk asset valuation scenarios to EU fund equity and corporate bond holdings, based on the combined tech and policy shock scenarios developed by the DNB (2018) and employed by the ESRB (2020). Each set of distributions displays the range of losses, as a percentage of total portfolio holdings of equity, corporate bonds and shares issued by other investment funds, for funds within the respective quantile (quantiles determined based on each fund's average emissions per investment, weighted by value of each investment position) across funds recorded as domiciled in Europe. Emissions are recorded as CO_2 and CO_2-equivalent emissions (scopes 1 and 2). The vertical black line in each box shows the median percentage loss for funds in that emissions quantile. Box edges are the 25th and 75th percentiles of the fund losses for funds in that emission quantile, and additional lines ('whiskers') illustrate the percentage losses that are either below the 25th or above the 75th percentiles for funds in that emissions quantile, reaching to the 10th and 90th percentiles. Indirect holdings are also included, i.e. we record losses on fund investments in other funds that are exposed to markdowns in asset values. The UK and the Channel Islands are included in this sample.
Sources: DNB (2018), Morningstar, Refinitiv, ESMA.

As can be seen from Chart RA.10 above, most fund losses range from 3 % to 18 % of their affected portfolio holdings. However, there is a clear difference in vulnerability to these scenarios: many funds in the lower quantiles (i.e. funds investing in less-polluting companies) often bear losses that are below 5 %. In contrast, funds in the uppermost quantiles (i.e. funds with relatively more money invested in more-polluting companies) often bear losses that exceed 10 % and sometimes rise to beyond 15 %[131].

It is important to disentangle losses suffered by a fund because of these shocks (the subject of Chart RA.10 above) and the systemic losses that the fund creates. The latter is possible because, as illustrated in Chart RA.2 above, a fund transmits shocks to other funds that own its shares.

Chart RA.11 below displays the range in contribution to system-wide losses from funds grouped by different portfolio cleanliness quantiles. It is clear from this chart that the systemic impact of funds is highest where fund portfolios are oriented towards the most-polluting equities and corporate bonds (plus, indirectly, to funds owning those same equities and corporate bonds). In contrast, funds in the cleanest, and even the middle, quantiles have relatively less system-wide impact. This provides further illustration of the intuition discussed in the previous sections: funds with the most-polluting portfolios are the most vulnerable to climate-related financial risks, and also make the greatest additional contribution to system-wide losses when those risks materialise[132].

RA.11
Contribution of each fund to system-wide losses
Brown portfolios have more systemic impact



Note: Application of energy transition risk asset valuation scenarios to EU fund equity and corporate bond holdings, based on the combined tech and policy shock scenarios developed by the DNB (2018) and employed by the ESRB (2020). Each set of distributions displays the contribution to system-wide losses, as a percentage of total system assets included in the scenario exercise (equity, corporate bonds and shares issued by other investment funds), for funds within the respective quantile (quantiles determined based on each fund's average emissions per investment, weighted by value of each investment position) across funds recorded as domiciled in Europe. Emissions are recorded as CO_2 and CO_2-equivalent emissions (scopes 1 and 2). The vertical black line in each box shows the median percentage loss for funds in that emissions quantile. Box edges are the 25th and 75th percentiles of the fund losses for funds in that emission quantile, and additional lines ('whiskers') illustrate the percentage losses that are either below the 25th or above the 75th percentiles for funds in that emissions quantile, reaching to the 10th and 90th percentiles. Indirect holdings are also included, i.e. we record losses on fund investments in other funds that are exposed to markdowns in asset values. The UK and the Channel Islands are included in this sample.
Sources: DNB (2018), Morningstar, Refinitiv, ESMA.

This exercise represents a first methodological attempt to explore the asset valuation impacts

[131] It is clear that funds with larger exposures to the highest-emitting sectors will necessarily face the highest losses, since these losses are based on their CO_2 exposure. Chart RA.10 aims to demonstrate how large the variation is among funds, however. Chart RA.10 has been truncated to allow easier visualisation. The maximum loss under this scenario, as a share of portfolio holdings, amounts to 100 %. However, only several funds are in this extreme situation and these can be considered outliers.

[132] There is also evidence that older funds also make a greater systemic contribution, although this is perhaps not surprising insofar as funds that operate for a longer time are likely to become popular investment vehicles for other, more recent funds. They may also have more difficulties in adjusting their portfolios (for example, due to long-established investment mandates and client bases). This is a subject left for future research.

faced by EU investment funds across potential climate risk scenarios. There are, as previously mentioned, a number of caveats and gaps that need to be addressed, so these results should be seen as preliminary, and a stepping stone towards a comprehensive stress test for climate-related risks.

Importantly, this exercise does not include second-round effects due to feedback or adaptation mechanisms such as portfolio rebalancing (although fire sales, which typically happen over a few days, appear less relevant given the 5-year time horizon). However, it is likely that, over such a long time horizon, investment funds would orient their portfolios towards assets less affected by climate-related financial risks of the type explored above. Consequently, this asset valuation exercise can be seen either as a warning sign or as an indicator of opportunities for investment funds to anticipate future trends.

Implications and next steps

The above assessment has provided initial evidence on climate-related financial vulnerabilities among EU investment funds, using a new data set available to ESMA containing detailed (ISIN-level) portfolio holdings for 23 352 funds. In particular, the analysis suggests that EU investment funds whose portfolios are tilted towards more polluting assets (brown funds) distribute their portfolio across a larger number of companies than funds with cleaner portfolios (green funds). Brown funds are also more connected with each other (have more similar portfolios), in comparison with the connections (portfolio similarities) among green funds.

These two findings suggest that climate-related financial shocks are likely to disproportionately affect brown funds. A subsequent forward-looking climate risk scenario exercise appears to confirm this; in addition to total system-wide losses of EUR 152 billion to EUR 443 billion, most brown funds' losses range from about 9 % to 18 % of affected assets, in contrast to green funds' losses ranging from 3 % to 8 %. In addition, brown funds have more systemic impact: they contribute more to total system-wide losses (by virtue of their greater interconnections within the fund universe) than green funds.

This exercise also has broader implications and applications, regarding how both investors and supervisors can rank and compare funds from the perspective of climate risk (in terms of both contribution to and vulnerability from climate risk). This also relates to discussions around ESG ratings for investment funds, and the need for greater fund transparency on exposure to climate-sensitive sectors (in the context of the EU Sustainable Finance Disclosure Regulation (SFDR)). Moreover, the bottom-up portfolio emissions calculations rely on reporting of emissions data from issuers of financial assets purchased by investment funds. In order for systemic risks to be adequately assessed, high-quality disclosures by downstream firms are also crucial, which relates to ongoing work to review the EU Non-Financial Reporting Directive.

ESMA will continue to work on these topics, as part of the Risk Assessment pillar of its Sustainable Finance Strategy.

References

Acemoglu, D., Asuman, O. and Tahbaz-Salehi, A. (2015), 'Systemic risk and stability in financial networks', *American Economic Review*, Vol. 105, No 2, pp. 564–608.

Allen, T., Dees, S., Boissinot, J., Caicedo Graciano, M., Chouard, V., Clerc, L. and Vernet, L. (2020), 'Climate-related scenarios for financial stability assessment: An application to France', *Banque de France Working Papers*, No 774, July.

Bank of England (2019), 'The 2021 biennial exploratory scenario on the financial risks from climate change', Bank of England discussion paper, December.

Bank of England Prudential Regulation Authority (2015), 'The impact of climate change on the UK insurance sector: A climate change adaptation report', September.

Bank of England Prudential Regulation Authority (2018), 'Transition in thinking: The impact of climate change on the UK banking sector', September.

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F. and Visentin, G. (2017), 'A climate stress-test of the financial system', *Nature Climate Change*, Vol. 7, No 4, pp. 283–290.

Borgatti, S. P. and Halgin, D. (2016), 'Analyzing affiliation networks', in Carrington, P. and Scott, J. (eds), *The Sage Handbook of Social Network Analysis*, Sage Publications.

EFAMA (2020), 'Trends in the European investment fund industry in the first quarter of 2020', *Quarterly Statistical Releases*, No 81, June.

EIOPA (European Insurance and Occupational Pensions Authority) (2020), 'Second discussion paper on methodological principles of insurance stress testing', October.

ESMA (2019), 'Stress simulation for investment funds', economic report, September.

ESMA (2020), 'Strategy on sustainable finance', ESMA22-105-1052, April.

ESRB (2020), 'Positively green: Measuring climate change risks to financial stability', June.

Ge, M. and Friedrich, J. (2020), '4 charts explain greenhouse gas emissions by countries and sectors', World Resources Institute blog, February.

Georg, C.-P., Pierret, D. and Steffen, S. (2020), 'Similar investors', mimeo, March.

Girardi, G., Hanley, K. W., Nikolova, S., Pelizzon, L. and Getmansky Sherman, M. (2020), 'Portfolio similarity and asset liquidation in the insurance industry', mimeo, July.

Institut Louis Bachelier et al. (2020), The Alignment Cookbook – A Technical Review of Methodologies Assessing a Portfolio's Alignment with Low-carbon Trajectories or Temperature Goals.

Kalesnik, V., Wilkens, M., and Zink, J. (2020), 'Green data or greenwashing? Do corporate carbon emissions data enable investors to mitigate climate change?', mimeo, November.

Newman, M. E. J. (2001), 'Scientific collaboration networks: II. Shortest paths, weighted networks, and centrality', *Physical Review E*, Vol. 64, 016132.

Raynaud, J., Mary, S., Voisin, S. and Hazra, S. (2015), 'Carbon compass: Investor guide to carbon footprinting', Institutional Investors Group on Climate Change, November.

Refinitiv (2019), 'Refinitiv ESG carbon data & estimate models'.

Swiss Sustainable Finance (2019), 'Measuring climate-related risks in investment portfolios', November.

TCFD (Task Force on Climate-Related Financial Disclosures) (2017), 'Final report: Recommendations of the Task Force on Climate-Related Financial Disclosures', June.

Vermeulen, R., Schets, E., Lohuis, M., Kolbl, B., Jansen, D. J. and Heeringa, W. (2018), 'An energy transition risk stress test for the financial system of the Netherlands', *DNB Occasional Studies*, No 1607.

World Resources Institute, UNEP Finance Initiative and 2 ° Investing Initiative (eds) (2015), 'Climate Strategies and Metrics exploring Options for Iinstitutional Investors'.