Fund portfolio networks: a climate risk perspective

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. We attempt to help fill this gap, using a dataset of EUR 8 trillion of European investment fund portfolio holdings. We recover the network of fund portfolio overlaps (interconnections) and augment this with information on the relative environmental performance (‘dirtiness’) of fund portfolios. 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 climate risk scenario exercise confirms this: within 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.

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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 dataset of EUR 8 trillion of European investment funds’ portfolio holdings of approximately 14 million direct and indirect exposures to equity and corporate bond instruments.

We apply a network perspective to investment funds’ exposures to climate risk. Such a perspective could be 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. In addition, 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 dataset, we examine the following questions:

1. How can we measure and compare investment fund portfolios, from a climate risk perspective?
2. What do network density measures of fund portfolio holdings indicate with respect to investment funds’ relative (and joint) vulnerability to future climate-related financial shocks?
3. 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?

We find that 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). However, 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. We then conduct a climate risk scenario exercise confirms this: within 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. This implies that 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.

The remaining sections describe the dataset employed, approaches to measure investment portfolios from a climate risk perspective, a network and econometric analysis of investment fund holdings, the results of a climate-transition risk asset valuation exercise, and lastly conclusions and avenues for future research.

Dataset and methodology

The dataset includes detailed (ISIN-level) portfolio holdings data for EU-domiciled investment funds, and additional descriptive fund information, such as inception date and investment strategy—both obtained from Morningstar. We include portfolios of 23 352 EU-domiciled (including the UK) funds, covering the most recent data available for each fund at the time of analysis (2020Q4) – one share class per fund. Table RA.1 below provides further details on the size and magnitude of the dataset: a total of EUR 8 trillion of investments are

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2 A recent exception is ECB/ESRB (2021), which includes portions of this article.
3 There are two generally accepted types of climate risk: physical risk and transition risk. Physical risk relates to either events (e.g. floods) or longer-term developments (e.g. sustained higher temperatures) 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 extensive policy, legal, technological and market changes that arise as part of efforts required to mitigate and adapt to climate change. See TCFD (2017). This article focuses on transition risk.
included, spread out over 3.2 million positions. This compares with roughly EUR 15.7 trillion net assets among
EU funds at the end of 2020Q1 (EFAMA, 2020).4

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

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 Contracts for Difference. ‘Other’ comprises bank loans, infrastructure assets, ‘Other assets and liabilities’, and ‘Undefined’. Sources: Morningstar, ESMA.

As further shown in Table RA.1, the largest investment positions held by funds are equities (c. EUR 3 trillion), and corporate bonds (c. EUR 1.3 trillion), 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 1.1 trillion, spread out over 12 290 funds).5 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.

4 Out of these 23 352 funds, 79% are classified as Undertakings for Collective Investment in Transferable Securities (UCITS), with total assets worth roughly EUR 6.3 trillion. A further 1 555 (6%) Alternative Investment Funds (AIFs) can be identified, with assets worth EUR 0.33 trillion. The remaining funds are either 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 (EFAMA, 2020). From another perspective, 91% of the sample are actively managed funds, with total portfolio assets worth EUR 6.7 trillion, and the remaining 9% are passively managed funds (total assets worth EUR 1.2 trillion).

5 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).
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 trillion⁶. After various data-cleaning and consistency checks, the unpacked dataset, which is used throughout 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 CO₂ and CO₂-equivalent emissions are included (i.e. CO₂ plus methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorinated compounds (PFCs), sulphur hexafluoride (SF₆) and nitrogen trifluoride (NF₃)). 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 relative position in its industry (Refinitiv, 2019)⁷. 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)⁸. 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.

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⁶ 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 dataset do not match the total value of fund investments in Table RA.1

⁷ Emissions data are subject to data provider-specific issues, and are not entirely standardised (see Kalesnik et al., 2020). Nevertheless, as improved data arrives it can be incorporated in a methodology similar to that presented in this article.

⁸ 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.
## RA.3

### Breakdown of downstream assets by economic sector

#### Top five most polluting economic sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Carbon intensity</th>
<th>Number of firms in sector</th>
<th>Total investments per sector (bn EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture of other non-metallic mineral products</td>
<td>17,639</td>
<td>90</td>
<td>29</td>
</tr>
<tr>
<td>Manufacture of basic metals</td>
<td>16,541</td>
<td>115</td>
<td>24</td>
</tr>
<tr>
<td>Utilities</td>
<td>10,273</td>
<td>223</td>
<td>166</td>
</tr>
<tr>
<td>Air transport</td>
<td>6,186</td>
<td>58</td>
<td>16</td>
</tr>
<tr>
<td>Waste management</td>
<td>5,195</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>All equity and corporate bond holdings</td>
<td>1,684</td>
<td>7,068</td>
<td>4,821</td>
</tr>
</tbody>
</table>

Note: Carbon intensity is measured as total emissions (CO₂-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 dataset, and for which both emissions and revenue figure are available). We use total CO₂ and CO₂-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 dataset (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:

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

Chart RA.4 below displays these respective shares and shows that many fund portfolios underweight green firms. An equal weighting would imply that a typical fund’s portfolio exposure to green firms is 33 % by value (corresponding to the 33rd percentile used to classify firms as green). However, the share of EU funds’ equity and corporate bond investments in green firms is about 11% on average (the median is 8%). Conversely, many fund portfolios overweight brown firms: the share of exposures to brown firms is often greater than 33% (the mean and median shares are 51% and 53%).

No distinction (tolerance) is made in terms of whether a firm belongs to a particularly polluting sector⁹; 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.

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⁹ An exception is when the emissions data are estimated by the data provider, as discussed in the previous section.
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.

We also measure each fund portfolio’s ‘importance’ from a climate risk perspective\(^\text{10}\). We first take the average emissions of the portfolio, using the relative share of each investment as weights, calculated according to equation 1 below:

\[
\sum_{i=1}^{N} \left( \frac{\text{current value of investment}_i}{\text{current portfolio value}} \times \text{company } CO_2 \text{ emissions}_i \right)
\]

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.

We also normalise each firm’s emissions by its revenue (i.e. calculate its carbon intensity) and average this across all firms in the portfolio, again weighted by each investment’s relative share. This is calculated as set out in equation 2 below:

\[
\sum_{i=1}^{N} \left( \frac{\text{current value of investment}_i}{\text{current portfolio value}} \times \frac{\text{company } CO_2 \text{ emissions}_i}{\text{company EURm revenue}_i} \right)
\]

The carbon intensity measure is perhaps more closely reflective of each fund’s strategy and regulatory constraints: funds investing in firms with a high carbon intensity 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.

We then combine these perspectives, 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 intensities 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

\(^{10}\) For useful comparisons of possible approaches see Raynaud et al. (2015), Swiss Sustainable Finance (2019), and World Resources Institute et al. (2015).
portfolio emissions), are relatively less concerned about the impact of investing in climate-inefficient firms (i.e. high average portfolio carbon intensity) and manage the largest portfolios in the EU.

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 intensity (tonnes of CO2-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) CO2 and CO2-equivalent emissions. Sources: Morningstar, Refinitiv, ESMA.

Examining the portfolio network

The previous section considered funds’ portfolios from the perspective of outward environmental impact. We now 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 depends on:

1. How many investment funds are directly investing in the affected firms (and how much)
2. How many upstream funds are indirectly exposed to firms via their holdings of shares in intermediate funds (see Chart RA.2 above).

To better understand the first risk driver, Chart RA.6 compares the unweighted network degree distribution for green firms and brown firms. It is clear from this chart that fewer funds invest in the same green firm. 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 average11. 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 firms12.

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11 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).
12 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.
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 CO₂ and CO₂-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.

Taking the fund perspective, if climate-related financial risks affect brown firms more than green firms, then this indicates that climate-related shocks will affect more funds than otherwise, because more funds are invested in brown firms (i.e. the distribution of fund investment in firms by environmental profile is non-symmetric). This provides a first indication of how a climate-related shock would be distributed across the fund universe—an intuition that is explored in greater detail in the next sections.

Measuring fund portfolio similarity

Another perspective on interconnections is the similarity of investment fund portfolios. This is complementary to the firm-centric perspective discussed above: 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. The greater the extent of co-investment (i.e. portfolio similarity), the greater the potential for large climate-related (and other) financial shocks to spread across the network and for second-round effects across funds (Georg et al., 2020).

We calculate portfolio similarity by projecting the bipartite network of fund portfolio holdings onto the specified nodes (i.e. funds), using the number of common investments between each pair of funds, normalised by the total number of firms considered by either of the two funds. This measure indicates the extent to which funds are co-investing relative to the amount that they could have co-invested, given their combined portfolios. We then examine whether there are meaningful differences in portfolio similarity between pairs of funds whose portfolios are in the lowest percentile cut-off (‘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 cut-off (‘pairs of brown funds’). Thus, we explore whether brown fund portfolios have more in common with each other than green fund portfolios.

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13 At the extreme, each investment fund could be choosing to invest its entire portfolio in a single company, which would imply very little portfolio overlap across funds. Conversely, 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 (in terms of number of shared investments).

14 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’.

15 Other similarity measures exist. For example, the value of common investments across two funds’ portfolios can be compared against their joint total portfolio value. Alternatively, the number of investments held in common across two funds’ portfolios can be divided by the minimum number of investments across the two portfolios (i.e. the maximum number on which the funds’ investment choices could realistically overlap). See Borgatti and Halgin (2016). The number of common investments by the two funds can also be normalised by investments received by each firm from all funds (i.e. not just the pair of funds under consideration), added up across all firms in the funds’ overlapping portfolios. See Newman (2001). Other similarity approaches exist and could also be considered, like cosine similarity or Euclidean distance (Girardi et al., 2020; Georg et al., 2020).
Portfolios have in common with each other. If this is the case, then brown funds will suffer in a coordinated way following climate-related financial shocks, relative to the joint behaviour among green funds.

Portfolio similarities can be represented as interconnections between funds, due to common assets held. Chart RA.7 below visualises the largest similarities across the fund universe, with funds grouped into quartiles in terms of their weighted average emissions, for ease of visualisation. Funds have no obligation to invest in one or more of the same firms; therefore, if two funds do not have any investments in common, they will not appear in this graph. Therefore, the presence of a specific colour is itself a sign that interconnections exist among funds in that environmental grouping (i.e. more of a particular colour in the overall graph implies more interconnections). Moreover, 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.

Chart RA.7 below contains several interesting messages.

1. 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.

2. 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.

3. Many funds for which no emissions information is available for any firm in their portfolio (i.e. funds coloured in black in Chart RA.7 below, 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 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.

4. Two shifts may therefore 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.

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16 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.
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 (the sample size is too large—32 million similarities—to display entirely). 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 of 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 CO₂ and CO₂-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 in Chart RA.7 above. Chart RA.8 below examines the full sample in simplified form, by comparing 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\textsuperscript{17}.

\textsuperscript{17} 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 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
Econometric investigations of the portfolio network

To complement the visual evidence provided in the charts above, we also econometrically investigate the extent to which portfolio ‘greenness’ is associated with similar portfolios. More specifically, we wish to check whether the visually-observed correlation between ‘dirtier’ portfolios and portfolio similarity is not driven by other observable characteristics between pairs of funds, such as the same investment strategy, similar fund sizes, similar past performance, and so forth. As discussed above, such a statistical exercise is worth pursuing with the goal of understanding future fund investment behaviour across the EU: if there is a strong association between portfolio ‘dirtiness’ and portfolio similarity, then this is indicative of future co-movement in funds’ investment behaviour, insofar as climate-related financial shocks will disproportionately affect more polluting issuers, relative to less polluting issuers (which seems to be a reasonable assumption—further explored in the next section).

Our portfolio similarity measures are bounded on the interval [0,1] and, judging from Chart RA.8 above, there may be significant non-linear relationships between the similarity of two fund portfolios and other observable characteristics. We therefore, we employ a fractional probit regression model (Papke and Wooldridge, 1996) of the type set out in equation (3) below:

\[
E(y_i\mid X) = G(\beta_1 + \beta_2 \times \text{both\_low\_emiss}_i + \beta_3 \times \text{both\_med\_emiss}_i + \beta_4 \times \text{both\_high\_emiss}_i + \beta_5 \times X_i) \quad (3)
\]

Where \(G(\cdot)\) is the standard normal cumulative distribution function satisfying \(0 < G(z) < 1\) for all \(z \in \mathbb{R}\), thus ensuring that the predicted values all lie within the interval [0,1], and the family of correlation coefficients \(\beta\) is recovered using quasi-maximum likelihood estimation using the log-likelihood function set out in equation 4 below:

\[
lnL = \sum_{i=1}^{N} y_i \times ln(G(x_i\beta)) + (1 - y_i) \times ln(1 - G(x_i\beta)) \quad (4)
\]
As in the previous paragraphs, we allocate funds into groups, based on their portfolio weighted average emissions. Funds whose emissions are in the lowest/middle/highest third among the fund universe are deemed to have low/medium/high emissions. Based on this, we set the indicator variable $both\_low\_emiss_i$ to 1 whenever portfolio similarity $y_i$ involves a pair of funds each of whose portfolio emissions are in the lowest third among the fund universe, with the same reasoning for funds in the middle and highest third of emissions. The coefficients on these indicator variables can thus be interpreted relative to the situation where the pair of funds whose portfolio similarity is being examined have their respective portfolio ‘dirtiness’ that are not in the same emissions group.

We also control for other possible drivers of portfolio similarity. This includes whether the two funds share the same investment strategy, similar past performance, the same management style (i.e. Active or Passive), the same legal structure (i.e. UCITS vs. Alternative Investment Funds) as assessed by Morningstar and ESMA, the same fund ultimate parent, or have the same domicile. We make use of several continuous variables as additional controls, including the natural log of the difference in weighted average emissions between the two funds, as well as the difference in the carbon footprint between the two funds, the natural log of the difference in total portfolio size between the pair of funds, the difference in the number of instruments held by each fund in the pair, and lastly the difference (in years) between each fund’s inception date. See Table RA.9 below for further details.
**RA.9**

Description of main econometric variables

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Similar Portfolio Emissions</strong> (High/Medium/Low)</td>
<td>Whether the pair of funds both have weighted average portfolio emissions in the same third of the fund universe. Weighted average portfolio emissions are calculated using weights equal to size of each investment position in the fund’s respective portfolio.</td>
</tr>
<tr>
<td><strong>Same Portfolio Carbon Footprint</strong> (High/Medium/Low)</td>
<td>Whether the pair of funds both have carbon footprint in the same third of the fund universe. Carbon footprint is calculated as the total emissions divided by firm total revenue, averaged over the fund portfolio using the size of each investment positions as the weight. Calculated as the log of the absolute difference in weighted average portfolio emissions between the two funds. Weighted average portfolio emissions are calculated using weights equal to size of each investment position in the fund’s respective portfolio.</td>
</tr>
<tr>
<td><strong>Difference in Portfolio Emissions</strong></td>
<td>Calculated as the absolute difference in carbon footprint between the two funds. Carbon footprint is calculated as the total emissions divided by firm total revenue, averaged over the fund portfolio using the size of each investment positions as the weight.</td>
</tr>
<tr>
<td><strong>Difference in Portfolio Carbon Footprint</strong></td>
<td>The absolute difference in the number of equities and corporate bonds held in each fund portfolio. We apply a look-through approach to each fund’s ultimate holdings—via other investment funds—of these instruments.</td>
</tr>
<tr>
<td><strong>Difference in Assets under Management (AuM)</strong></td>
<td>Calculated as the log of the absolute difference in AuM between the two funds.</td>
</tr>
<tr>
<td><strong>Difference in # Instruments Held</strong></td>
<td>Difference (in years) between the inception date of each fund’s oldest share class, as provided by Morningstar.</td>
</tr>
<tr>
<td><strong>Difference in age</strong></td>
<td>Investment strategy is measured using the Morningstar Global Category, which is the primary description of the fund strategy, and is assigned by Morningstar based on asset-specific, geographic, and/or strategy-based features of the fund (see Morningstar 2018). Examples include “Canadian Large Cap Equity”, “Energy Sector Equity”, “Cautious Allocation”, and “Long/Short Credit”. Pairs of funds assigned to the same Morningstar Global Category are deemed to have similar investment strategies.</td>
</tr>
<tr>
<td><strong>Same investment strategy</strong></td>
<td>Fund classification as UCITS is determined using Morningstar’s “UCITS” field, and Alternative Investment Fund (AIF) status is determined using European Securities and Markets Authority supervisory data. Actively-managed status is determined using Morningstar’s “Index Fund” field. A passive fund is defined as one for which no Index is recorded in Morningstar, i.e. a fund that does not track any specific index nor attempts to match returns from an index.</td>
</tr>
<tr>
<td><strong>Both are UCITS / Both are AIFs</strong></td>
<td>Funds having the same parent is determined using the “Registration Company” and “Firm Name” fields in Morningstar.</td>
</tr>
<tr>
<td><strong>Both are actively-managed</strong></td>
<td>Similar fund overall performance is measured using the “Morningstar Rating (Overall)” field, which is a standardised score based on each fund’s position (in terms of risk-adjusted performance—using the Sharpe Ratio) relative to other funds in the universe, using a weighted average of performance at both three, five, and ten-year horizons. The Morningstar Rating Overall is the weighted average of the fund’s rating produced for these three horizons, where the weights vary depending on the number of months of fund total returns that are available—see Morningstar 2016. Funds with the same Morningstar Rating (Overall) are deemed to have similar performance.</td>
</tr>
<tr>
<td><strong>Have same parent</strong></td>
<td>Sources: Morningstar, Refinitiv, ESMA.</td>
</tr>
<tr>
<td><strong>Have similar performance</strong></td>
<td>Results for different specifications and portfolio similarity measures are displayed in Table RA.10 below.</td>
</tr>
<tr>
<td><strong>Column (1)</strong></td>
<td>provides a first indication that the portfolio similarity for pairs of funds whose weighted average</td>
</tr>
</tbody>
</table>

---

18 Given the large number of interconnections between funds in our sample (up to c. 130 million pairs), we calculate robust standard errors and statistical significance is based on two-tailed tests, using critical values adjusted for large sample sizes (see Giles 2019, Good 1982, Leamer 1978, and Lin et al. 2013).
portfolio emissions are both ‘high’ (i.e. in the highest third among the fund universe) is larger, compared with funds whose portfolio emissions are not in the same group (i.e. not in the same emissions tercile). Indeed, funds in this group tend to have a relative portfolio similarity that is 30 percentage points higher relative to the control group. Similarly, funds whose portfolio emissions are both in the ‘low’ group (i.e. in the lowest third of the fund universe) tend to have lower (c. 22 percentage points) portfolio similarity compared with funds whose portfolio emissions are not relatively similar (i.e. are not in the same emissions tercile).

The divergence in correlation with portfolio similarity, when comparing pairs of funds in the ‘high’ emissions group with pairs of funds in the ‘low’ emissions group, is persistent after adding in additional controls in columns (2) and (3). Interestingly, the coefficients on the difference in portfolio emissions between the two funds, and on the difference in portfolio carbon footprint between the two funds, are both negative. This lends support to the findings discussed above: the smaller the gap between the two funds (either in terms of weighted average portfolio emissions or carbon footprint), the greater the portfolio similarity. Columns (4), (5), and (6) examine whether the results are robust to different types of portfolio similarity calculation (see footnote 15 above for a description). Finally, as a further robustness column (7) presents the results from segmenting funds into groups using the portfolio carbon footprint rather than the weighted average portfolio emissions. Interestingly, the results are reversed: pairs of funds with similar portfolio carbon footprints (and both having carbon footprints in the highest third of the fund universe) tend to have slightly less similar portfolios relative to funds with dissimilar carbon footprints. This illustrates the importance of choosing an appropriate climate change metric—ultimately climate change-related risks are likely to affect firms that pollute the most in absolute terms, rather than relative terms.
### Correlations of portfolio similarity across pairs of funds vs. fund attributes

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) Portfolio Similarity (# overlap vs. total joint investments)</th>
<th>(2) Portfolio Similarity (# overlap vs. total joint investments)</th>
<th>(3) Portfolio Similarity (# overlap vs. total joint investments)</th>
<th>(4) Portfolio Similarity (# overlap vs. min. # investments)</th>
<th>(5) Portfolio Similarity (value of combined portfolio network)</th>
<th>(6) Portfolio Similarity (value of overlap vs. combined portfolio value)</th>
<th>(7) Portfolio Similarity (# overlap vs. total joint investments)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar Portfolio Emissions (High)</td>
<td>0.301*** 1.063</td>
<td>0.271*** 834.9</td>
<td>0.262*** 793.5</td>
<td>0.255*** 625.9</td>
<td>0.116*** 168</td>
<td>0.280*** 725</td>
<td>-0.0451***</td>
</tr>
<tr>
<td>Similar Portfolio Emissions (Medium)</td>
<td>0.140*** 440.6</td>
<td>0.0154*** 33.83</td>
<td>0.0172*** 39.54</td>
<td>0.0197*** 97.18</td>
<td>0.00434*** 4.705</td>
<td>0.03377*** 67.57</td>
<td>-93.55</td>
</tr>
<tr>
<td>Similar Portfolio Emissions (Low)</td>
<td>-0.222*** -574.7</td>
<td>-0.368*** -753.9</td>
<td>-0.358*** -786.6</td>
<td>-0.349*** -625.5</td>
<td>-0.258*** -254.7</td>
<td>-0.404*** -770.4</td>
<td>-511.9</td>
</tr>
<tr>
<td>Similar Carbon Footprint (High)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Similar Carbon Footprint (Medium)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Similar Carbon Footprint (Low)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference in Portfolio Emissions</td>
<td>-0.0460*** -290.7</td>
<td>-0.0404*** -317.8</td>
<td>-0.0253*** -169.5</td>
<td>-0.0672*** -261.8</td>
<td>-0.0356*** -255.1</td>
<td>-0.0251*** -256.2</td>
<td>-511.9</td>
</tr>
<tr>
<td>Difference in Carbon Footprint</td>
<td>-0.000646*** -707.7</td>
<td>-0.000611*** -707.7</td>
<td>-0.000544*** -707.7</td>
<td>-0.000252*** -707.7</td>
<td>-0.000592*** -707.7</td>
<td>-0.000540*** -707.7</td>
<td>-511.9</td>
</tr>
<tr>
<td>Difference in Assets under Mgmt.</td>
<td>0.0150*** 231.6</td>
<td>0.0142*** 210.1</td>
<td>0.0266*** 205.4</td>
<td>0.000837*** 214.6</td>
<td>0.0140*** 214.6</td>
<td>0.000849*** 214.6</td>
<td>-539.6</td>
</tr>
<tr>
<td>Difference in # Instruments Held</td>
<td>2.35e-05** 61.21</td>
<td>0.00744*** 1.499</td>
<td>0.000491*** 866.3</td>
<td>0.000630*** 358.6</td>
<td>0.003505*** 358.6</td>
<td>0.003586*** 358.6</td>
<td>93.81</td>
</tr>
<tr>
<td>Difference in age</td>
<td>0.000385*** 41.4</td>
<td>0.000415*** 39.2</td>
<td>-0.000477*** 21.5</td>
<td>0.000126*** 111.2</td>
<td>0.000558*** 60.4</td>
<td>0.000549*** 60.4</td>
<td>60.45</td>
</tr>
<tr>
<td>Same domicile</td>
<td>0.0418*** 143.6</td>
<td>0.0423*** 120.6</td>
<td>0.0485*** 124.7</td>
<td>0.0530*** 157.9</td>
<td>0.0459*** 157</td>
<td>0.0459*** 157</td>
<td>157</td>
</tr>
<tr>
<td>Same inv. strategy</td>
<td>0.434*** 1.056</td>
<td>0.481*** 998.6</td>
<td>0.434*** 552.4</td>
<td>0.479*** 1034</td>
<td>0.441*** 1068</td>
<td>0.441*** 1068</td>
<td>1068</td>
</tr>
<tr>
<td>Both are UCITS</td>
<td>-0.0297*** -84.7</td>
<td>-0.0566*** -129.5</td>
<td>-0.000285*** -392</td>
<td>-0.000282*** -92.3</td>
<td>-0.0326*** -92.3</td>
<td>-0.0326*** -92.3</td>
<td>-92.3</td>
</tr>
<tr>
<td>Both are AIFs</td>
<td>0.0778*** 150</td>
<td>0.0230*** 34.98</td>
<td>0.128*** 119.8</td>
<td>0.0700*** 115.1</td>
<td>0.0777*** 142</td>
<td>0.0777*** 142</td>
<td>149.2</td>
</tr>
<tr>
<td>Both are actively-managed</td>
<td>-0.00348*** -10.25</td>
<td>0.0216*** 53.04</td>
<td>-0.118*** -174.1</td>
<td>-0.0342*** -85.9</td>
<td>-0.00860*** -25.2</td>
<td>-0.00860*** -25.2</td>
<td>-25.2</td>
</tr>
<tr>
<td>Have same parent</td>
<td>0.309*** 121.5</td>
<td>0.201*** 86.51</td>
<td>0.380*** 100.9</td>
<td>0.225*** 99.68</td>
<td>0.306*** 123.5</td>
<td>0.306*** 123.5</td>
<td>123.5</td>
</tr>
<tr>
<td>Have similar performance</td>
<td>0.00365*** 11.16</td>
<td>-0.0349*** -87.8</td>
<td>0.0112*** -16.5</td>
<td>-0.000179*** -476</td>
<td>0.00748*** -22.7</td>
<td>0.00748*** -22.7</td>
<td>22.78</td>
</tr>
<tr>
<td>Constant</td>
<td>-2.398*** -20.73</td>
<td>-1.570*** -66.28</td>
<td>-2.036*** -880.5</td>
<td>-1.671*** -604.2</td>
<td>-2.530*** -540.1</td>
<td>-1.445*** -558.2</td>
<td>-1.153</td>
</tr>
<tr>
<td>Observations</td>
<td>129.177,458</td>
<td>112,281,364</td>
<td>95,889,713</td>
<td>95,889,713</td>
<td>95,875,434</td>
<td>95,863,737</td>
<td>95,889,713</td>
</tr>
<tr>
<td>Pseudo R-squared</td>
<td>0.0127</td>
<td>0.0269</td>
<td>0.0389</td>
<td>0.0819</td>
<td>0.0853</td>
<td>0.0509</td>
<td>0.0310</td>
</tr>
</tbody>
</table>

Note: The sample is based on a dataset of fund portfolio holdings, augmented with firm-level observations on CO2-equivalent emissions, as at end 2021Q1. The overlap (similarity) between pairs of fund portfolios is regressed on various fund-level observations, using a fractional probit specification. Fund similarity in columns (1)-(3) and (7) is the number of common investments between each pair, normalised by the total number of firms considered by either of the two funds. Column (4) measures similarity as the number of investments held in common across two funds’ portfolios divided by the minimum number of investments across the two portfolios. Column (5) measures similarity as the number of common investments by the two funds normalised by investments received by each firm from all funds in the universe, added across all firms in the funds’ overlapping portfolios. Column (6) measures similarity as the value of common investments across two funds’ portfolios vs. their joint total portfolio value.

***: Coefficient is significant beyond the 1% level. Robust standard errors. Statistical significance based on two-tailed tests, using large sample-adjusted critical values (Giles 2019, Good 1982, Leamer 1978, and Lin et al. 2013). T-statistics displayed under each coefficient.
Quantifying fund-level climate-related impacts

We now explore 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. We draw on the scenarios developed by Vermeulen et al., 2018 and incorporated in ESRB (2020), which focus on transition risks arising from two shocks. 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. The resulting cost increase leads to an economic slowdown, while interest rates rise as the central bank attempts to curb inflation.

The second driver, a technology shock, is linked with technological breakthroughs that manage to lower CO\textsubscript{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. Nevertheless, the shorter time horizon works well 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), as well as fire sales\textsuperscript{19}.

Asset write-downs for equity and corporate bond instruments are then determined on a sector-specific basis, by linking macroeconomic conditions to each sector’s exposure to carbon prices (via CO\textsubscript{2} emissions). Out of the 88 NACE-level sectors included, those 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).

Table RA.11 below illustrates the total write-downs across investment fund holdings of equities and corporate bonds for the different scenarios, in absolute and relative terms for the 20 418 EU fund portfolios included in the exercise. 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\textsuperscript{20}.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total losses (bn EUR)</th>
<th>Total losses (% of fund assets included)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy shock</td>
<td>242</td>
<td>4.9</td>
</tr>
<tr>
<td>Tech shock</td>
<td>152</td>
<td>3.1</td>
</tr>
<tr>
<td>Policy + tech shock</td>
<td>443</td>
<td>9.0</td>
</tr>
<tr>
<td>Confidence shock</td>
<td>356</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Note: Percentages expressed in terms of total portfolio holdings of equity, corporate bonds and shares issued by other investment funds. Sources: ESRB (2020) Vermeulen et al. (2018), Morningstar, Refinitiv, ESMA.

Since the economic sector-specific stress impacts are calibrated according to the embodied CO\textsubscript{2} emissions in that industry, it is likely that funds with larger exposures to the highest-emitting sectors will face the greatest losses.

\textsuperscript{19} This exercise does not include second-round effects due to feedback or adaptation mechanisms such as portfolio rebalancing. 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.

\textsuperscript{20} The impacts above represent 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 dataset.
In other words, a fund with relatively greater exposure to CO₂-intensive industries is likely to suffer greater losses than a relatively less-exposed fund, all else being equal. However, the magnitude of variation in these losses across funds is worth examining.

Chart RA.12 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 emissions per portfolio. As shown in the chart, most fund losses range from 3% to 18% of their affected portfolio holdings. However, there is a clear difference in terms of vulnerability: 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%.

RA.12
Forward-looking climate risk scenario analysis
Cleaner portfolios are more protected; dirtier portfolios suffer greater losses

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 Vermeulen et al. (2018) and employed in 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. 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. Emissions are recorded as CO₂ and CO₂-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. Sources: Vermeulen et al. (2018), Morningstar, Refinitiv, ESMA.

It is important to disentangle losses suffered by a fund because of these shocks (the subject of Chart RA.12 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.13 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

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21 As a robustness check, alternative scenarios developed by NGFS (2020) were applied to the same portfolio data. Although absolute impacts in terms of total system-wide losses are smaller (owing to a different scenario calibration methodology), similar variation in percentage losses between green and brown fund portfolios were found—see ECB/ESRB (2021).
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.\(^{22}\)

**RA.13**

Contribution of each fund to system-wide losses

Brown portfolios have more systemic impact

![Diagram showing contribution of each fund to system-wide losses]

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 Vermeulen et al. (2018) and employed in 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. Sources: Vermeulen et al. (2018), Morningstar, Refinitiv, ESMA.

**Conclusions**

The above assessment has provided initial evidence on climate-related financial vulnerabilities among EU investment funds, using a new dataset 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 Action Plan).

\(^{22}\) 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. Older funds 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.
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.

Future research is required on how investment fund portfolios are likely to shift in response to climate-related financial risks, insofar as environmental performance. Moreover, observing the evolution in fund portfolios over time will unlock additional insights on how portfolio similarities evolve in conjunction with climate-driven financial risks. Lastly, incorporating additional asset classes, such as sovereign holdings, and additional sources of climate risk, such as physical risk, would further elucidate the roles and vulnerabilities of investment funds in the context of climate change.

References


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