Climate-related risk and financial stability

Data Supplement

by

ECB/ESRB Project Team on climate risk monitoring

ESRB
European Systemic Risk Board
European System of Financial Supervision

Contents

Introduction

This technical supplement to the report on Climate-related risk and financial stability[1] focuses on data and measurement issues in physical and transition risk analysis and provides a specific methodological application for each type of risk. Chapter 1 presents conceptual considerations for assessing physical risks and provides details about the data and methodology used in the banking sector Section 2.2 of the main report for the assessment of banking sector exposures to physical risks. It also complements the analyses presented in Box A of the main report on flood risk in Europe by describing the models used by (re)insurers to estimate flood risk, one of the most important physical risk drivers in Europe. Chapter 2 provides an overview of the main approaches in current transition risk assessments, based on predefined sectoral (e.g. climate policy-relevant sectors (CPRS) or EU Taxonomy alignment) or emissions-based assessments, before discussing the role of sustainable investment strategies. The chapter also presents a sensitivity analysis of emission intensity to different levels of data granularity. Moreover, each chapter considers the forward-looking aspects of climate risk analyses, focusing especially on data needs. Finally, the supplement contains an overview of recent developments in the EU regulatory framework on climate-related disclosures, which will contribute significantly to closing climate-related data gaps.

1 ECB/ESRB Project Team on climate risk monitoring, July 2021.

1 Physical risks

1.1 Conceptual considerations for assessing physical risks

1.1.1 Granularity of physical risk analyses

Mapping financial system exposures to physical risks requires granular information on the geo-spatial characteristics of financial institutions' exposures together with data on physical risk drivers. While granular geo-spatial characteristics of exposures are usually not the focus of existing financial data collections (e.g. AnaCredit), data in these collections can still be used as a first step in the analysis once carefully cleaned. A shift from traditional aggregate statistical data to more granular data collections that can be used to accurately identify counterparties is essential to capture the localised effects of physical risks. For a more comprehensive physical risk assessment, additional geo-coding of counterparty addresses into geospatial coordinates (longitude/latitude) is needed together with granular datasets containing such information (see Table 1).

Spatial granularity of physical risk analysis requires both the granularity of the data describing physical risk drivers and the granularity of financial system exposures. The granularity ("horizontal resolution") of data describing physical risk drivers depends on the granularity and type of the underlying observational data (e.g. station measurements, satellite data) or models and can vary substantially depending on the data compilation methodologies and respective hazards. In order to combine these data with financial system exposures, information on hazards can either be extracted at the address level or aggregated at different levels of territorial units. The user should therefore not only check the level of granularity at which a data provider can extract information (this will in many cases be the address level), but also for granularity of the underlying physical risk data.

The requirement of high spatial granularity paired with preference for a wide geographical coverage makes physical risk analysis technically challenging. Much of the data on counterparties or physical risk drivers are not available at such high spatial granularity, but can to some extent be obtained through statistical downscaling.

- **Information on the location of the counterparty** is often only available at a more aggregated level, even in granular data collections, for example indicating not the exact address of a counterparty, but only its postcode or NUTS[2] territorial unit. In addition, these data collections usually do not include the geographical locations of all relevant subsidiaries or counterparty facilities.
- **Data on physical risk drivers** are often available through public or commercial data providers, but users would require an advanced understanding of how to

[2] Nomenclature of Territorial Units for Statistics. For further detail see the Eurostat explanatory website.

integrate the data into the financial risk assessment. For example, output from global climate models usually has a horizontal resolution of approximately 100 km x 100 km, and models may "… overlook essential (small-scale) features of high-impact events, for which [they were] not designed" (Sillman et al., 2020). In order to extrapolate the results to smaller spatial scales, some data providers use "statistical downscaling", which establishes a relationship between past granular observational data and model simulation results, which is then applied to model projections in order to spatially extrapolate results to a higher granularity. While widely used and established, this procedure is based on historical data and may therefore not capture impacts or relationships outside the previously observed range (see, for example Fiedler et al., 2021).

Different physical hazards may require different levels of granularity if their impact is to be appropriately mapped to counterparties. For example, the impact of flood events is often very localised, with a steep gradient of flood probability and depth near rivers. This makes spatial averaging for flood events challenging. By contrast, temperature-related hazards spread more widely across areas and therefore require lower spatial granularity. Given the materiality of individual hazards, the catastrophe modelling community has developed very granular models for individual hazards such as floods (see Section 1.1.2), which are sometimes combined with data stemming from global climate models.

Table 1

Required data for assessing different components of physical risks, characteristics, availability and data gaps

	Type of data	Characteristics	Availability	Gaps
Hazard **"climate-related physical events or trends or their physical impacts" (IPCC, 2018)**	Data describing probability, intensity, spatial variability and temporal evolution of different physical hazards Basis of datasets is observational data (station, satellite, etc.), climate models, geophysical data	Optimal spatial granularity depends on hazard Possible spatial granularity depends on underlying data sources/models Ideally covers both current and projected hazard	Available through third-party data providers, both public and private Spatial granularity and temporal characteristics depend on data provider Further processing by the user may be required	Climate models not originally designed for such high granularity data; uncertainties related to extrapolation Uncertainties related to projections
Exposure **"presence […] in places and settings that could be adversely affected" (IPCC, 2018)**	Information on the location at which entities might be impacted by physical risks; for NFCs throughout the whole company structure, production process and supply chain	Can be obtained at different granularity, e.g. address level, postcode level, NUTS3 level, country level	NFCs: information on firm location partly available through credit registry data (e.g. AnaCredit)	NFCs: information often only refers to headquarters; missing geo-locational information on facilities and supply chains Households: no detailed information on location-based exposure of households available
Vulnerability **"propensity or predisposition to be adversely affected"** **(IPCC, 2018)**	Data on sensitivities of infrastructure, production processes or supply chains to individual hazards Data on existing protection measures, including physical protection measures and the potential adaptation of production processes and supply chains	Data may relate to different levels of granularity, including firm, sector, local, regional, and country level	Regional or sector-specific features partly integrated in public or private third-party datasets, e.g. regional flood protection, sensitivity of building type to water stress or heat stress Sector vulnerabilities can be qualitatively assessed based on literature	Firm-specific and local information largely missing, e.g. resilience of infrastructure, substitution of suppliers, flexibility of processes
Insurance coverage and risk mitigation	Data on insurance coverage of buildings Data on planned climate change adaptation measures	Granularity should be consistent with granularity of exposure	Pilot dashboard on insurance coverage available at country level (EIOPA), see Section 2.3 in the main report	Granular information not comprehensively available

Source: ECB
Notes: NFC stands for non-financial corporations; NUTS3 stands for Nomenclature of Territorial Units for Statistics – units of small regions for specific diagnoses.

1.1.2 Flood risk modelling

Flood risk is one of the most important drivers for physical risks in the European Union (EU) and a more detailed description of the underlying assessments is therefore warranted. Understanding the underlying data and modelling assumptions used to estimate potential losses from floods is an important step in understanding the uncertainty and limitations of these estimates. The focus on flood risk modelling is partly shaped by its relevance for the insurance sector in determining their liability risk.

Most (re)insurers use stochastic flood models to manage their inland flood risk. These models use a combination of observed climate data and mathematical simulation methods to simulate multiple flood events in an attempt to capture all the possible floods that might occur in cities and countries around the world in the near future. The impact of these events is evaluated in terms of expected losses and distributions of possible losses by combining the simulated hazard for the flood events with detailed exposure maps and vulnerability models which take into account the vulnerabilities of different types of buildings. These models are designed to represent the current and near-future climate, since this is the time period of most relevance to the insurance industry. They are not typically designed to quantify future risks arising from climate change owing to the expected changes in frequency and severity of future weather-related events.

A recent study from the commercial model provider RMS[3] sheds some light on the likely magnitude of changes in flood risk for the European insurance sector from a climate-change perspective. RMS used the EURO-CORDEX[4] simulated changes in daily maximum rainfall (as provided by CMCC)[5] to adjust their riverine and pluvial flood model to estimate the expected changes in losses for (re)insurance undertakings under different representative concentration pathway (RCP)[6] scenarios and time horizons.

The results of the RMS study show that average annual insurance losses[7] owing to inland flooding are expected to increase under all scenarios with a higher impact in northern and western European countries compared with southern and eastern areas. Although there is a high level of uncertainty with regard to the projected loss increases, especially for the most extreme and long-term scenarios, it is possible to expect a clear impact of climate change on the (re)insurance sector in terms of an increase in average annual flood losses (between 26% and 80%, relative to the RMS reference view) already by mid-century, with all other factors remaining constant. In particular, these results assume that no action would be taken to counteract increasing flood risk through mitigation or adaptation measures, such as changes in building codes and practices, and/or increased investment in flood defence systems. If targeted risk-reduction efforts are made, the modelled impacts could likely be reduced. The study also provides insights into the expected increase in annual aggregate loss[8] for the 200-year return period (RP)[9] under different RCP scenarios. Consistently with the findings previously described, the northern and western European countries would be the most impacted. Under the RCP 2.6 scenario, the expected increases in losses are similar by mid- and end-

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[3] For further information, see the RMS White Paper "Modelling Future European Flood Risk". See also Box A in the main report on flood risk in Europe.

[4] In line with a similar study on future precipitation patterns in Europe, EURO-CORDEX results project an increase in extreme rainfall most of the year in northern and central Europe. For further details, see the EURO-CORDEX website, https://euro-cordex.net/index.php.en.

[5] Centro Euro-Mediterraneo sui Cambiamenti Climatici. Changes in the 95th percentile of daily maximum rainfall expected under the RCP4.5 scenario for the 2041-2070 period (relative to the base period 1981-2010).

[6] The results are presented for three RCPs scenarios: RCP 2.6, RCP 4.5 and RCP 8.5. The RCP 2.6 scenario is a so-called "peak" scenario which aims at keeping global warming likely below 2°C above pre-industrial temperatures. The RCP 4.5 is considered a moderate-emissions-mitigation-policy scenario and a stabilisation scenario as it assumes that radiative forcing level stabilises before 2100, while RCP 8.5 is considered a high-end emissions scenario as it assumes that no efforts are made to limit greenhouse gas emissions. For further details, see IPCC (2014) Climate Change 2014 Fifth Assessment Report, Topic 2, Future Climate Changes, Risks and Impacts.

[7] The average annual loss is the expected loss per year, averaged over many years.

[8] Based on the sum of all event losses each year.

[9] A "return period" loss describes the likelihood of a loss of a given *size*, and not of a specific event or events, occurring within a given time frame (e.g. in 200 years).

century for both regions (around 30% for the north-western, and around 20% for the south-eastern region), while the results diverge under the other scenarios. For example, under the RCP 4.5 pathway, the annual aggregate losses for the 200-year return period for floods in north-western European countries are projected to increase by 51% in 2050 and by 90% by 2090. The corresponding impacts are again milder in south-eastern European countries, where modelled losses show an increase of 31% and 42% by 2050 and 2090 respectively, under the RCP4.5 pathway. Naturally, the uncertainty surrounding estimates 30-70 years into the future is substantial owing to uncertainties in the EURO-CORDEX climate projections, the underlying risk model, and the methods used to combine the two.

Table 2

Modelled increase in average annual insured losses

(percentage change compared with current RMS reference view)

Region	Countries	RCP 2.6 2050	RCP 2.6 2090	RCP 4.5 2050	RCP 4.5 2090	RCP 8.5 2050	RCP 8.5 2090
North/West	BE, FR, DE, IE, LI, LU, CH, UK	35%	35%	52%	85%	80%	276%
South/East	AT, CZ, HU, IT, PL, SK	26%	26%	40%	62%	58%	212%

Source: RMS.

1.2 Banking sector exposures to physical risks: data and methodology

1.2.1 Data and methodology overview

The analysis presented in Section 2.2 of the main report builds on data from two different providers combined with euro area banking system credit exposures from AnaCredit:

- **Four Twenty Seven physical risk indicators:** data from Four Twenty Seven[10] for approximately 1.5 million firms in Europe were used for this analysis. These data include risk indicators for six risk categories, including floods, sea level rise, water stress, heat stress, tropical cyclones and wildfires. The data are extracted by the data provider at address level. Four Twenty Seven indicators integrate information on both current hazard frequency and intensity, and projected changes until 2040 (see also Section 1.2.3).
- **Joint Research Centre (JRC) flood risk data:** data from the JRC are in part publicly available on the JRC's Risk Data Hub ((RDH), also see Section 1.2.2). The data focus on river and coastal floods in Europe. The original data have a horizontal resolution of 100 m x 100 m and are aggregated to NUTS3 level for this analysis (see Box A), covering 1,215 NUTS3 regions. The data are based

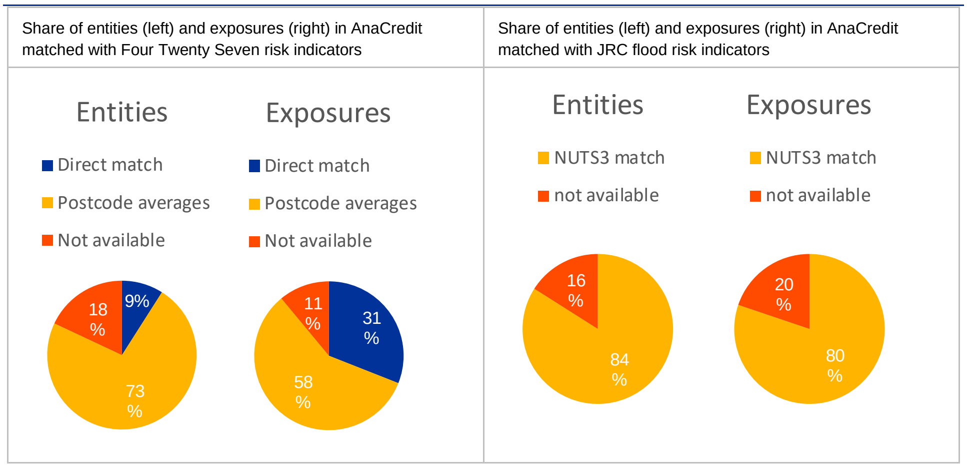
10 Four Twenty Seven is an affiliate of Moody's.

on simulations from a flood model and refer to currently observed hazard probabilities and intensities.

- **AnaCredit credit exposures:** AnaCredit is the dataset containing granular information on all credit exposures to corporations (and other legal entities) granted by domestic and foreign banks domiciled in the euro area, if the aggregate exposure of a bank against a client is above €25,000. More than 26 million credit instruments are reported in AnaCredit every month, connecting 2,400 banking groups with 4.5 million borrowers around the world. The information collected comprises more than 80 different attributes, including information about allocated protections and details about the counterparties involved, such as economic sector, geographical location, size and turnover.

Chart 1.1

Coverage of AnaCredit exposures matched with physical risk data



Sources: AnaCredit, Four Twenty Seven, JRC RDH and ECB calculations.
Notes: For details on data matching and averaging see below and Section 1.2.5.

The datasets on physical risks are combined with AnaCredit as follows (see Section 1.2.5). JRC physical risk data are matched with AnaCredit based on the NUTS3 region of the firm[11]. Four Twenty Seven risk indicators are matched with AnaCredit based on the firm's address, if available. If no match for a firm in AnaCredit is found, a postcode average indicator based on all Four Twenty Seven datapoints within the postcode area is used instead. In addition, information on the location of physical collateral from AnaCredit is joined with physical risk data from both datasets based on NUTS3. An aggregate coverage of 80% of non-financial corporation (NFC) credit exposures with JRC physical risk data, and of 89% of NFC credit exposures with Four Twenty Seven data (of which 31% matching directly at firm address level) can be achieved (Chart 1.1), with some relevant differences across countries. For the mapping of physical risk and credit exposure datasets the firm's headquarters location is considered as the location of the credit exposure.

[11] For a detailed explanation of how data were processed, see Box A.

1.2.2 The JRC Risk Data Hub and its potential use in physical risk assessments

Records of disaster loss from past events in Europe are only available through global multi-hazard databases - some owned by reinsurance companies such as NatCatSERVICE (Munich Re) and Sigma (Swiss Re), while others are freely available like EM-DAT (Centre for Research on the Epidemiology of Disasters). A comprehensive dataset accessed form open source is hosted by the Disaster Risk Management Knowledge Centre (DRMKC) Risk Data Hub,[12] an EU-wide web-based geographical information system platform, developed by the Joint Research Centre at the European Commission (RDH). The underlying database collects data on disaster loss associated with historical natural hazards at various geographical scales (local, subnational and national level). Beyond the risk data, the platform also provides georeferenced exposure, vulnerability and risk assessments. Data in the RDH can be used for physical risk monitoring and climate stress-test modelling, as the RDH allows to identify multi-hazard exposed and vulnerable areas, compare risk against past impacts, perform statistical analysis and estimate trends.[13]

The RDH structures the information needed for climate stress-testing into two modules covering historical events and risk analysis respectively.

- **Historical events**: this is an EU-wide disaster loss database providing information on past events with records on the impacts (quantified as human losses and economic damage) and geographical location of the event. The module contains more than 18,900 records covering floods, earthquakes, forest fires, landslides, drought, windstorms, tsunamis and volcanoes. As an example, the module has records on floods covering the period from 1870 to 2019. Floods are also categorised into river, flash, and costal floods (see Chart 1.2). For each event, the RDH provides an estimate of human losses (considered as fatalities, injured and affected people) and of the associated economic loss in euro and the area affected, further disaggregated by sector (buildings, critical services, and the environment).

- **Risk analysis**: the module presents the potential impact (risk) on various assets as a consequence of the severity and likelihood of different hazards, exposure and vulnerability (see Chart 1.3 for an example of the exposure to hydrological risks aggregated to country level). Each of the hazard types is covered with a specific grid resolution depending on the hazard type: the grid is 100 m for river floods, coastal floods and forest fires; 200 m for landslides; and 1,000 m for subsidence; while windstorms, heatwaves and droughts of course have a coarser resolution (4-5 km or more). Whenever the grid allows, an aggregation at the level of local administrative units (LAU) is also available.[14] The risk data currently included in the RDH are structured in categories and subcategories and cover buildings, population, critical services and the

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12 https://drmkc.jrc.ec.europa.eu/risk-data-hub#/

13 Further details are available in the reports of the Disaster Risk Management Knowledge Centre: Ferrer el al. (2019).

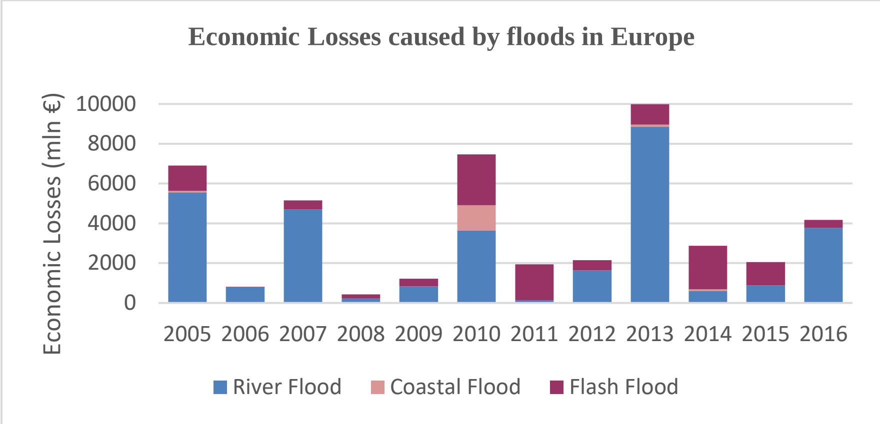
14 For further details, please see Eurostat: Local Administrative Units.

environment. The following hazards are considered for climate-related risks: forest fires, river floods, coastal floods, subsidence, windstorms, and landslides.

Chart 1.2

Economic losses by flood type in Europe

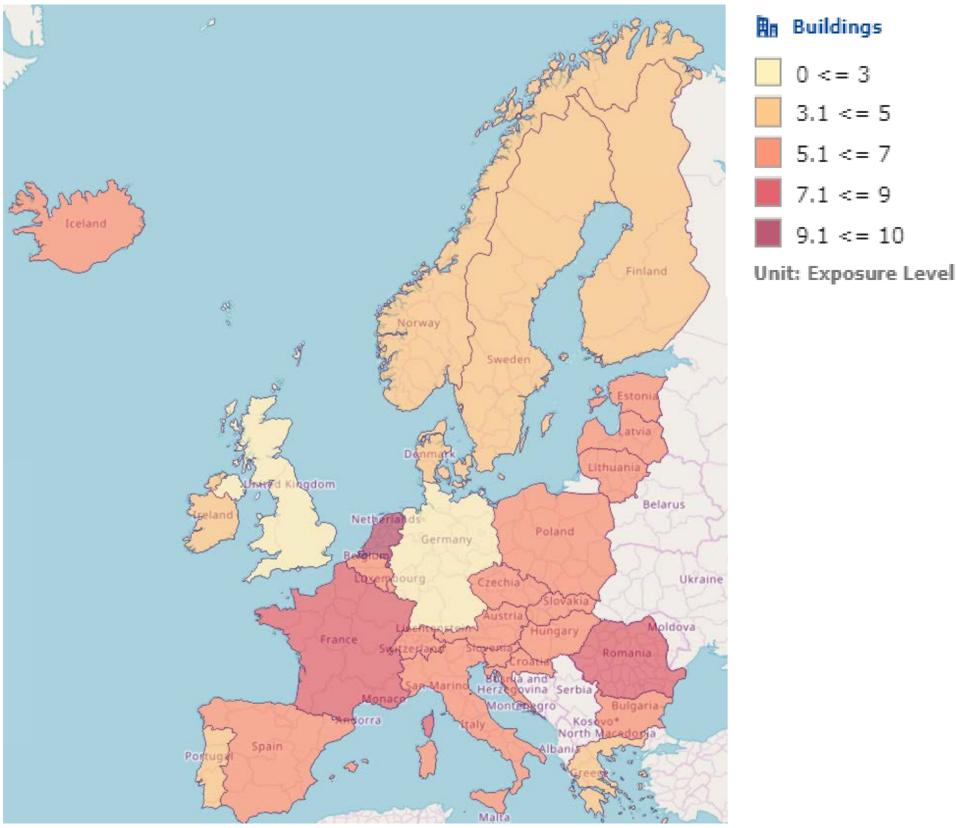
(EUR millions)



Source: JRC Risk Data Hub.

Chart 1.3

Exposure of buildings to hydrological hazards



Source: JRC Risk Data Hub.

Despite being a key factor, exposure is not sufficient in itself to determine the final risk, as it is possible to be exposed but not vulnerable to a particular hazard. For a risk assessment, two additional dimensions have been integrated: vulnerability and risk. Vulnerability is aimed at assessing the predisposition, deficiencies or lack of capacity of the exposed elements to withstand natural hazards and is assessed as a multidimensional indicator comprising a social, economic, political, environmental and physical dimension. The risk considers the probability of potential impacts, after combining exposures and vulnerabilities.

For stress testing, the risk assessment would be the more relevant module. In this context, one could construct scenarios associated with different (increased) probabilities of disaster compared with the historical ones. In the RDH, these are expressed in terms of "return periods", which are estimates of the interval of time between events (see footnote 9). For example, a return time of 100 years indicates that the event will occur once in 100 years on average, therefore the probability that a similar event could occur in the same interval of time is 1% (1/100). Stress-testing would involve shorter return periods and hence higher probabilities.

Forward-looking scenarios are available in the RDH from the JRC PESETA IV project. [15] The report assesses socioeconomic impacts of global warming within a specific "state of the economy" setting, which can be the economy as of today (static approach) or the economy of the future (dynamic approach). The project evaluates how the climate at different global warming levels would impact EU society, focusing on economic losses, annual population exposed and annual fatalities. The scenarios analysed correspond to 1.5°, 2° and 3° global warming levels. The last one is expected to be reached by 2100 if adequate mitigation strategies are not introduced. Projections are available at country level for all hazards but river flood, for which information is provided at subnational level (NUTS2). For drought, projections of economic losses are disaggregated by sectors (i.e. agriculture, buildings, power generation, shipping and water supply).

In the context of the new EU Strategy on adaptation to climate change, the JRC Risk Data Hub will become the reference platform for standardising of the recording and collection of comprehensive and granular climate-related losses and physical climate risk data at EU level.[16] To reach this objective, public-private partnerships to collect and share such data will be encouraged, especially at subnational level. The strategy advises establishing a common terminology and metrics, based on the RDH.

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15 JRC (2020a).

16 See European Commission (2021) "Forging a climate-resilient Europe - the new EU strategy on adaptation to climate change", COM(2021) 82 final, 24 February.

Box A: JRC calculation of river flood indicators from raw data

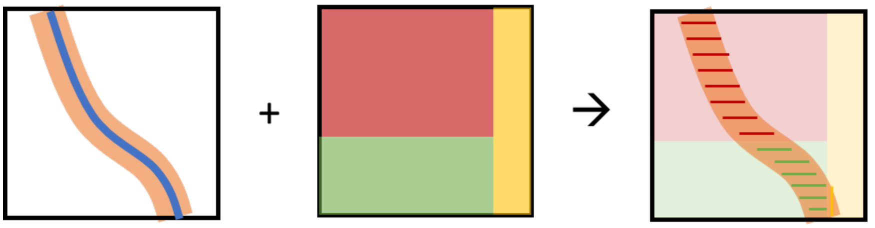
Data from the JRC Risk Data Hub were further processed for the purpose of the analysis presented in the main report. The processing steps are described in this Box; the results of the analysis are displayed in Chart A.1 in the main report.

Flood frequency

The raw data include the share of area at risk of being flooded by a flood with return periods of 10, 50, 100, 200 and 500 years. The share of area at risk of being flooded refers to a specific territorial unit, e.g. NUTS3. In addition, it is calculated relative to the type of area ("land use type") within a territorial unit, i.e. for each territorial unit information is available on the share of industrial/commercial, residential and agricultural area at risk of being flooded by a flood with a specific return period (see Chart A.1).

Chart A.1

Illustration of type of data provided by the RDH



Source: ECB illustration.
Notes: The squares represent one territorial unit, with the area at risk of flooding in orange, and different types of area (land use types) in red, green and yellow. In processing the data, the JRC intersects information on the area at risk of flooding (LHS) with information on land use (middle square). The resulting data show the share of area at risk of being flooded by land use type, represented by red, green and yellow dashes in the right-hand square.

From the raw data and for each land use type, the probability for a firm allocated to a specific NUTS3 area and land use type can then be calculated as follows (see Antofie et al., (2020) for details):

Step 1: Calculation of the "probability of exceedance" $P_{e,RP}$ in a given year, indicating the probability that a flood with a given return period (RP, in years) takes place, $P_{e,RP} = 1/RP$

Step 2: Calculation of the "probability of occurrence" in one year, p_{RP}, with

$p_{500} = P_{e,500}$

$p_{200} = 1 + (P_{e,200} – 1)/(1 – p_{500})$

$p_{100} = 1 + (P_{e,100} – 1)/[(1 – p_{500})*(1 – p_{200})]$

$p_{50} = 1 + (P_{e,50} – 1)/[(1 – p_{500})*(1 – p_{200})*(1 – p_{100})]$

$p_{10} = 1 + (P_{e,10} – 1)/[(1 – p_{500})*(1 – p_{200})*(1 – p_{100})*(1 – p_{50})]$

Step 3 [optional]: Calculation of the "probability of occurrence" over a longer time horizon n

$p_{RP}(n) = 1 – (1-p_{RP})n$

Step 4: Calculation of the average loss expected Un, i.e. the area at risk of being flooded A by a flood with a given return period RP, which we interpret as the probability of being flooded

$U_n = p_{500}(n)*A_{500} + p_{200}(n)*A_{200} + p_{100}(n)*A_{100} + p_{50}(n)*A_{50} + p_{10}(n)*A_{10}$

Table A.1

Example calculation of probability of being flooded in a given year from JRC data

Flood return period	Step 1: Probability of exceedance	Step 2: Probability of occurrence in one year	Raw data: Area at risk of being flooded (% of commercial/industrial area within a NUTS3)	Average loss by return period
500 years	1/500 = 0.002	0.002	100	0.002*1 = 0.002
200 years	1/200 = 0.005	0.003	80	0.003*0.80 = 0.0024
100 years	1/100 = 0.01	0.005	60	0.005*0.60 = 0.003
50 years	1/50 = 0.02	0.010	40	0.010*0.40 = 0.04
10 years	1/10 = 0.1	0.082	20	0.082*0.20 = 0.0164
Step 4: Probability of being flooded in a given year				0.0638 ≈ 6.4%
Step 5: Probability of being flooded in a given year, with flood protection up to a return period of 100 years				0.0044 ≈ 0.4%

Step 5: Flood frequency, including flood protection

Additional data provided by the JRC indicate the flood protection by NUTS3 area, i.e. the flood return period during which an area is (on average) protected. In calculating the probability of being flooded, only the loss estimates for floods with a return period longer than the flood protection return period can be considered (see Step 5 in Table A.1).

Flood intensity

Data provided by the JRC indicate an average (mean and median) flood depth by NUTS3 or land use type. In addition, as flood depth may vary significantly across one NUTS3 or land use type area, 95th, 75th and 5th percentiles were provided.

1.2.3 Four Twenty Seven risk indicators

Data from Four Twenty Seven for approximately 1.5 million firms in Europe were used for the analysis, selected by the ECB to cover the most important European firms in Orbis (the database of Bureau van Dijk, a Moody's Analytics Company).

Physical risk data from this provider include risk indicators for six risk categories, including floods, sea level rise, water stress, heat stress, tropical cyclones and wildfires (Chart 1.4). Each of these indicators is based on the aggregation of information across a varying number of sub-indicators (21 in total), which are derived from a combination of peer-reviewed climate model-based datasets and environmental datasets. The risk indicators include, in particular, the following.

Wildfire, temperature and precipitation-based indicators are based on outputs from the NASA NEX-GDDP project[17], which spatially downscales results from

[17] See the publicly available dataset (NEX-GDDP) NASA Earth Exchange Global Daily Downscaled Projections.

CMIP5 models[18] to a horizontal resolution of approximately 25 km x 25 km. Indicators are based on a comparison of model results for the periods 1975-2005 and 2030-2040. Projections are based on the highest emission pathway (RCP 8.5)[19].

- **Floods, hurricanes, sea level rise and water stress indicators** are also based on additional datasets, including the World Resources Institute Aqueduct tool,[20] hurricane data from the World Meteorological Organization and historic and simulated high resolution flood data (including elevation and regional flood infrastructure) from the flood analytics provider Fathom.

Table 3 lists the different components contributing to the calculation of risk indicators and the definition of high physical risk for each hazard.

Table 3

Hazards considered for the analysis of physical risks, and definition of high risk

Hazard	Description	Definition of high risk	Potential impacts on firms
Floods	Change in rainfall conditions and size and frequency of possible floods	Susceptible to some flooding and inundation during rainfall or riverine flood events	Property and building damage Compromised infrastructure Business interruptions
Heat stress	Increase in temperature	Relatively high changes in extremes compared to global average	Increased energy costs Heightened risk of power outages Stress on human health/labour force
Hurricanes/ Typhoons	Exposure to past cyclones	Situated in the regular path of cyclones	Severe property damage Permanent loss of property value Relocation costs
Sea Level Rise	Heightened storm surge, augmented by sea level rise	Susceptible to some degree of coastal flooding in 2040, though relative changes in flood frequency are small	Property damage Permanent loss of property value Relocation costs
Water Stress	Change in water supply and demand	Already has high water stress, or water supplies are diminishing	Reduced water supply Increased water costs Erosion of social license to operate and/or reputation
Wildfires	Change in fire potential	Has high wildfire potential with sizable increases in future wildfire potential severity and high-risk days	Permanent loss of property value Stress on human health (air quality) Stress on ecosystem services Business interruption

Source: Four Twenty Seven.

Exposure levels

For the purposes of the analysis in the main report, the different firm exposure levels to physical risks, consistent with the data provider's definitions, are described as follows:

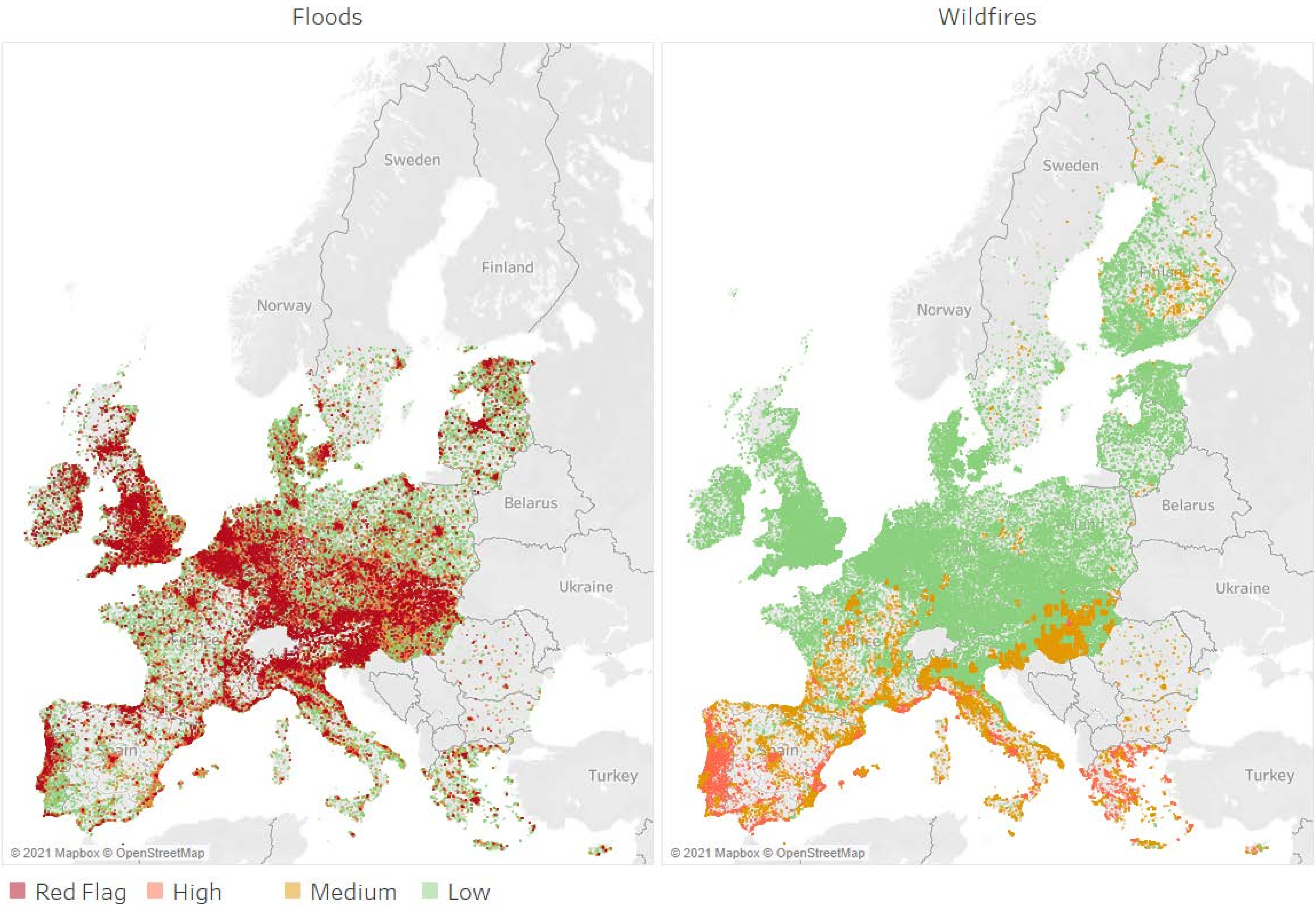
[18] CMIP5 models are used in the IPCC's Climate Change Fifth Assessment Report (IPCC (2014)), see Taylor et al. (2012).

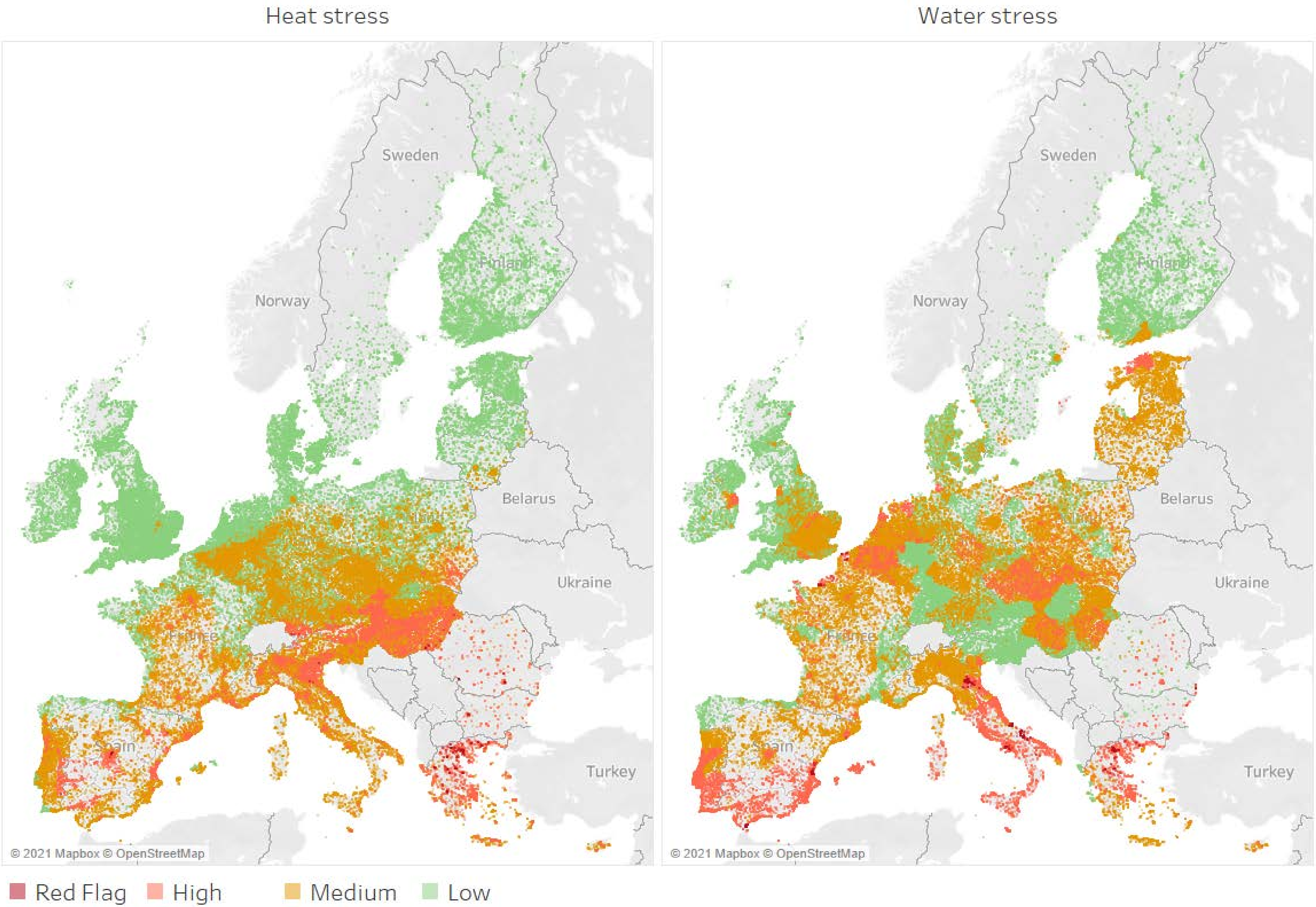
[19] Average climate model results until the mid-century do not differ significantly in different (RCP) scenarios; see also Four Twenty Seven (2019): Demystifying Climate Scenario Analysis for Financial Stakeholders and IPCC, (2013): Chapter 11: Near-term Climate Change: Projections and Predictability, Figure 11.8.

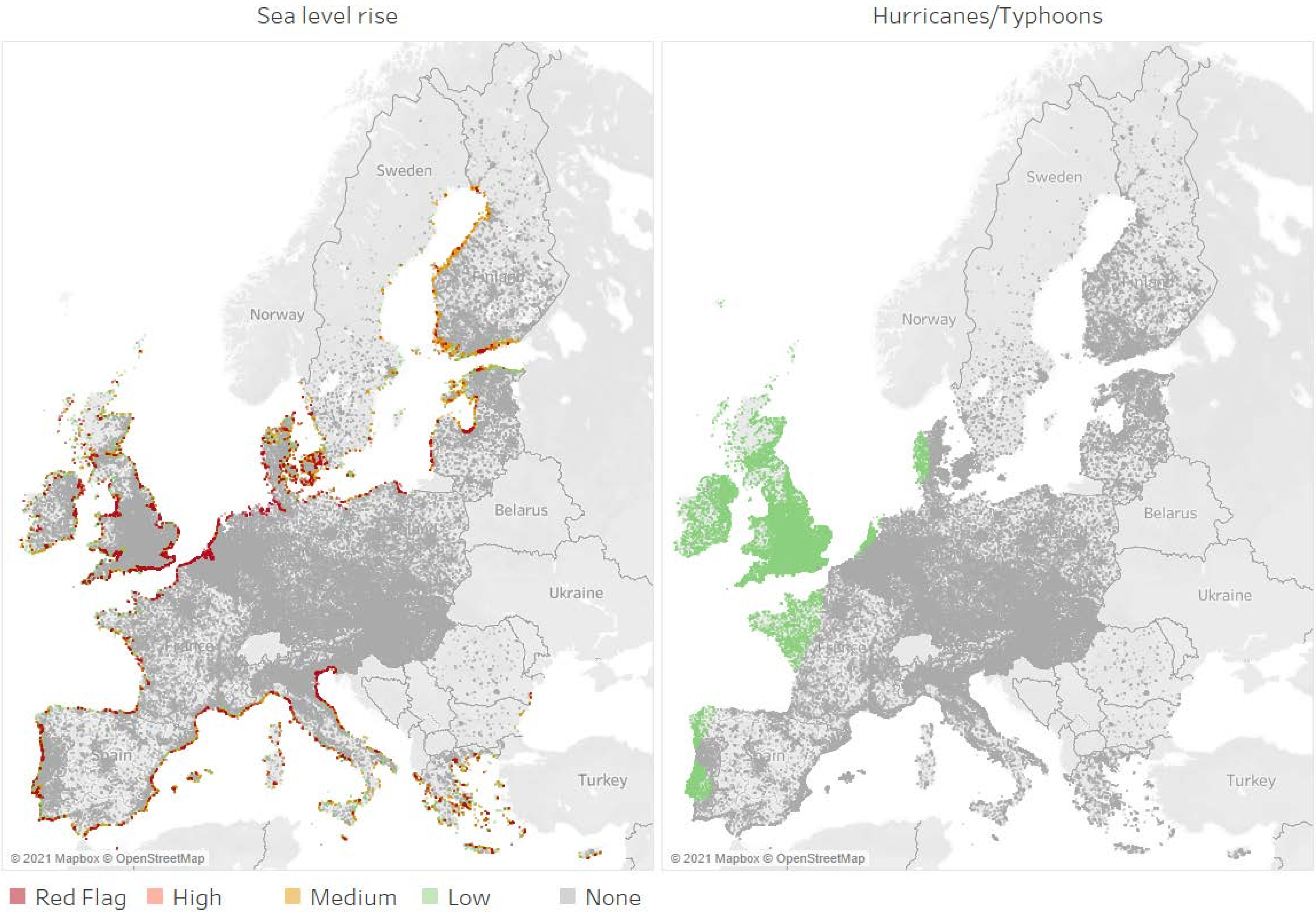
[20] World Resources Institute tool: Aqueduct Global Maps 2.1 Data.

- Very high risk/red flag: highly exposed to historical and/or projected risks,
- High risk: exposed today and exposure level is increasing,
- Medium risk: exposed to some historical and/or projected risks,
- Low risk: not significantly exposed to historical or projected risks,
- No risk: no exposure.

Chart 1.4: Exposure levels to individual physical hazards for 1.5 million firms in Europe




Heat stress
Water stress
Sweden
Finland
Norway
Belarus
Ukraine
France
Turkey
© 2021 Mapbox © OpenStreetMap
Red Flag
High
Medium
Low



Sources and Notes: Four Twenty Seven, ECB calculations. Firm exposure levels refer to those described in Section 1.2.3.

1.2.4 Comparison of Four Twenty Seven and JRC indicators for selected hazards

The respective characteristics of the Four Twenty Seven and JRC datasets for physical risk analysis are illustrated in the charts below. Charts 1.5-1.8 compare qualitatively data retrieved from the JRC with selected indicators from the Four Twenty Seven dataset. It should be noted that, from the Four Twenty Seven dataset, we display those sub-indicators which are the most comparable with the data available from the JRC; these are not the aggregate hazard indicators described in Table 3, which are used to calculate banking system exposure to firms subject to physical risks.

The spatial distribution of hazards seems broadly consistent across the JRC and Four Twenty Seven datasets, but quantitative comparisons require more in depth investigations, advanced spatial data processing methodologies and high computing power. The following detailed observations can be made from the comparison.

- **River flood probability and flood depth (Chart 1.5 and Chart 1.6)**: The spatial distribution of areas with high flood probability is broadly consistent across both datasets (Chart 1.5). While the resolution and methodology of the underlying datasets is similar for both data providers, differences emerge given the differences in granularity at which the data are compared. Similarly, the location of areas estimated to be impacted by more severe floods (focusing on floods with a return period of once in 100 years) is broadly consistent across both datasets (Chart 1.6). Differences in both flood probability and flood depth are likely to arise owing to (i) coverage of Four Twenty Seven data (the dataset extract used here is limited to 1.5 million firms in Europe therefore regions represented by only a few firms tend not to be covered by these data); (ii) spatial averaging of JRC data across NUTS3 land-use regions. These differences may, on the one hand, mask differences in flood probability and depth across different regions, but on the other hand also result in very small areas over which averaging can be applied, for example if the share of industrial area within one NUTS3 region is very small. For both flood probability and flood depth, a quantitative comparison could be facilitated by extracting data at address level from the JRC high-resolution flood maps.[21] However, such a quantitative comparison is outside the scope of this report.

- **Coastal floods (Chart 1.7)**: The datasets available for this comparison differ, but the localization of risks is nevertheless consistent. The differences can likely be explained by the different time horizon considered in the datasets, as JRC data refer to the current coastal flood risk and Four Twenty Seven data refer to flood risk projected for 2040. It should be noted that the sea level will react (i.e. rise) comparably slowly to global

[21] See Joint Research Centre datasets, River Flood Hazard Maps at European and Global Scale.

warming.[22] Coastal floods are therefore expected to have larger impacts towards the end of the 21st century, even if the global temperature stabilises.

- **Wildfires (Chart 1.8)**: We compare indicators from Four Twenty Seven with results published in the context of the JRC Peseta IV project, focusing on the change in the number of days with high wildfire potential. Although the definition of indices used to determine high wildfire potential differs across both datasets, the spatial distribution of changes in days with high wildfire potential, as well as the order of magnitude of days with high wildfire potential, are comparable.

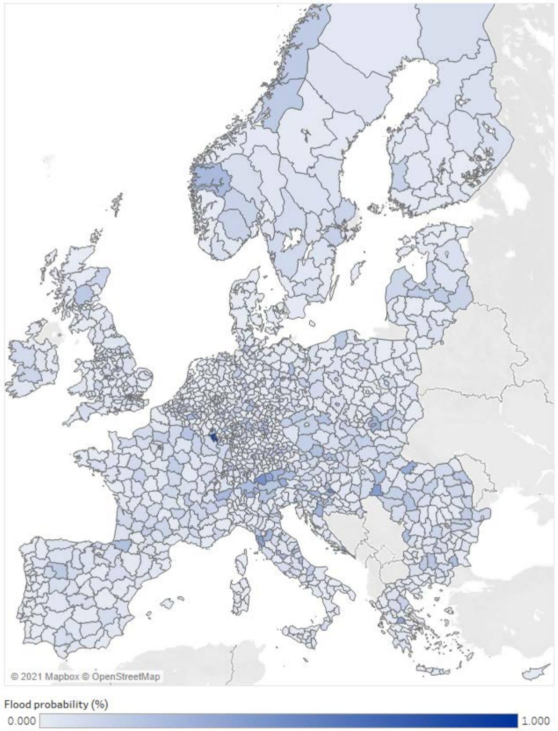
[22] See, for example, Joint Research Centre (2020b), "Adapting to rising coastal flood risk in the EU under climate change", JRC Peseta IV – Task 6, *JRC Technical Report*, p. 5.

Chart 1.5

Comparison of river flood probability

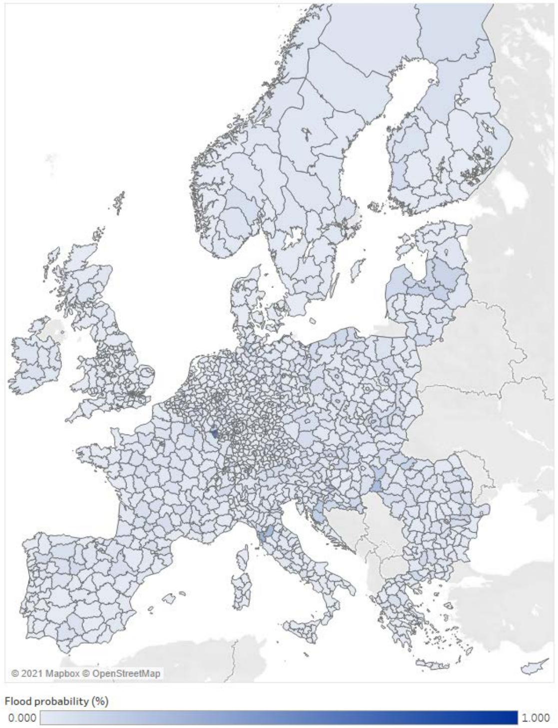
JRC: average over industrial/commercial areas within each NUTS3

Annual river flood probability; percentages



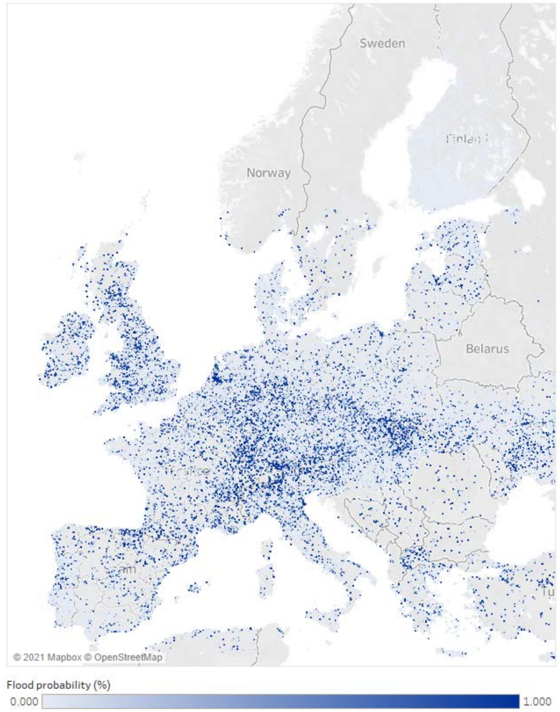
JRC: average over residential areas within each NUTS3

Annual river flood probability; percentages



Four Twenty Seven: extracted at firm address level, 1.5 million firms

Annual river flood probability; percentages

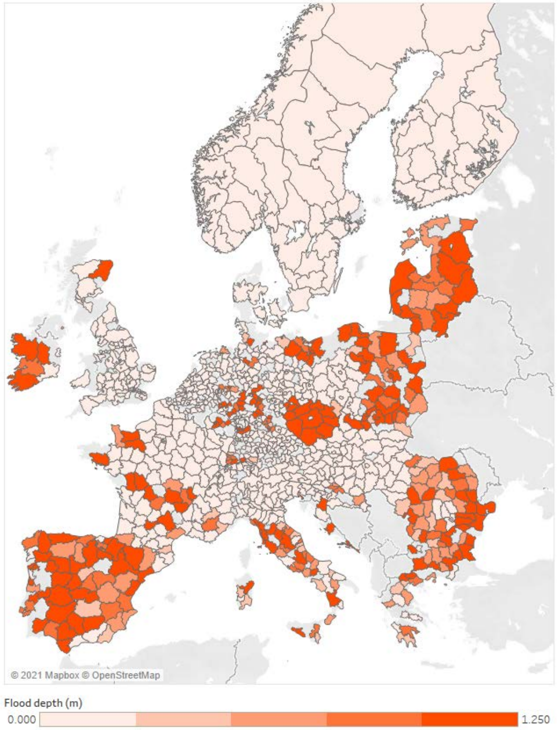


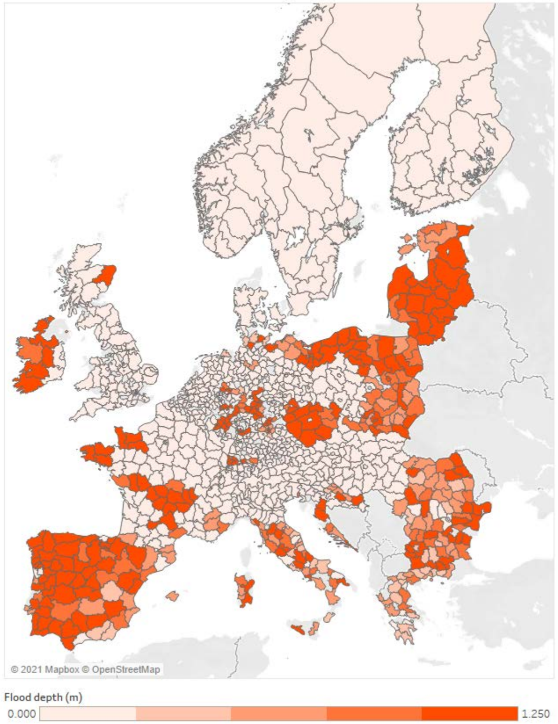
Sources: JRC RDH, Four Twenty Seven and ECB calculations.
Notes: JRC river flood probability calculated as indicated in Box A.

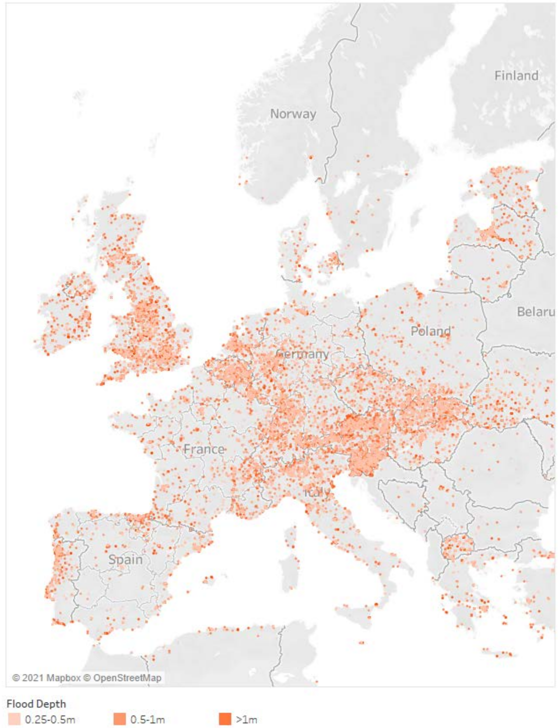
Chart 1.6

Comparison of flood depth of floods occurring with a return period of once in 100 years

JRC: average over industrial/commercial areas within each NUTS3	JRC: average over residential areas within each NUTS3	Four Twenty Seven: extracted at firm address level, 1.5 million firms
Median river flood depth for a flood with a return period of 1 in 100 years; metres	Median river flood depth for a flood with a return period of 1 in 100 years; metres	Flood depth for a flood with a return period of 1 in 100 years; metres





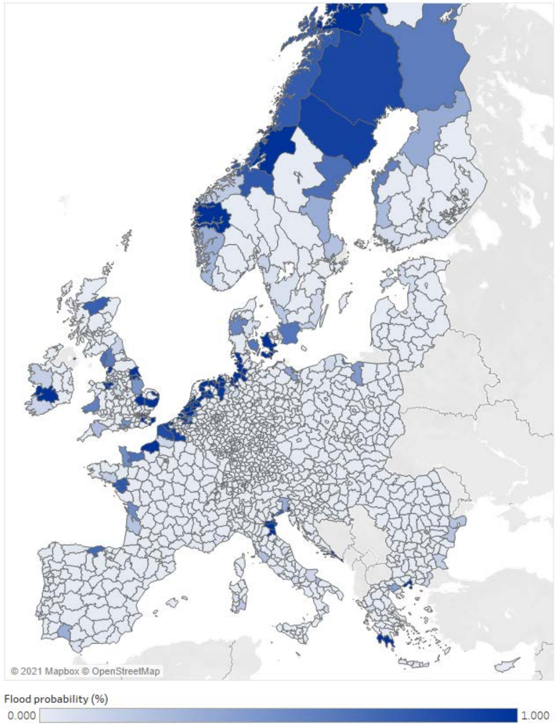


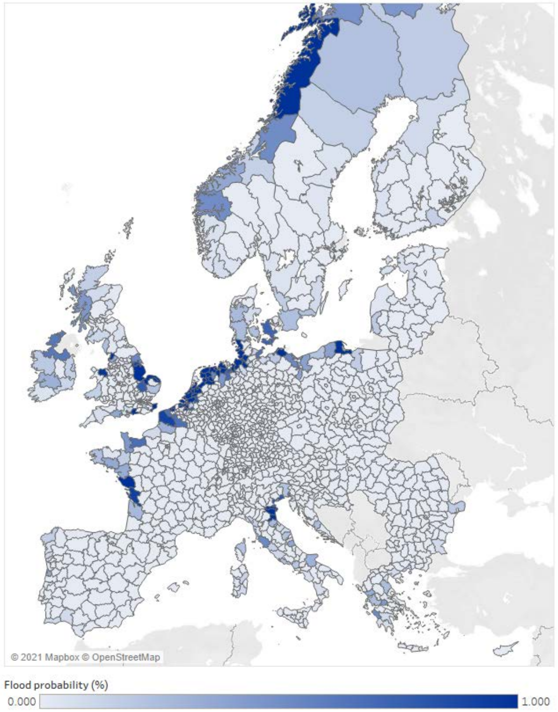
Sources: JRC RDH, Four Twenty Seven and ECB calculations
Notes: JRC RDH – scale corresponds to flood depths between 0-0.25m, 0.25-0.5m, 0.5-0.75m, 0.75-1m, >1m. Areas that are protected from floods with a return period of once in 100 years are allocated a flood depth of 0 m. Median corresponds to average across respective land use area (industrial/commercial or residential) within each NUTS3 region. See main text for a brief discussion of potential under-/overestimation effects of such averaging procedure. Four Twenty Seven: for better readability, only firms for which a flood depth of above 0.25m is estimated are shown.

Chart 1.7

Comparison of coastal flood probability (JRC RDH) with coastal flood frequency in 2040 (Four Twenty Seven)

JRC: average over industrial/commercial areas within each NUTS3	JRC: average over residential areas within each NUTS3	Four Twenty Seven: extracted at firm address level, 1.5 million firms
Coastal flood probability; percentages	Coastal flood probability; percentages	Coastal flood frequency; 0.01 = 1%



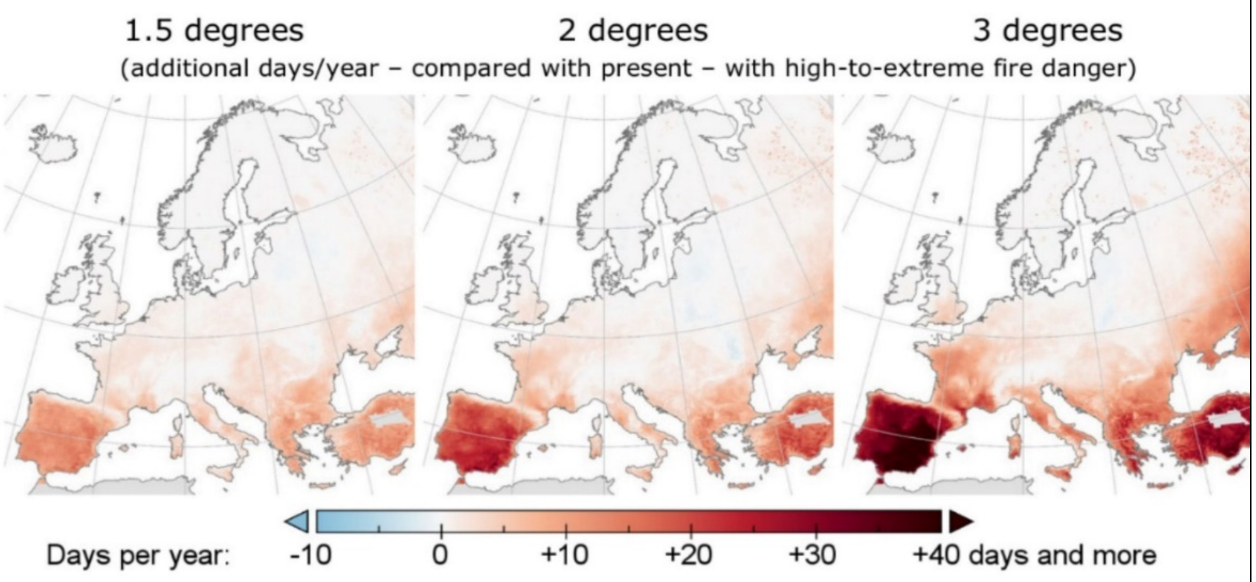


Sources: JRC RDH, Four Twenty Seven and ECB calculations
Notes: JRC coastal flood probability refers to current values. Four Twenty Seven coastal flood frequency refers to 2040 values, only non-zero values are shown.

Chart 1.8

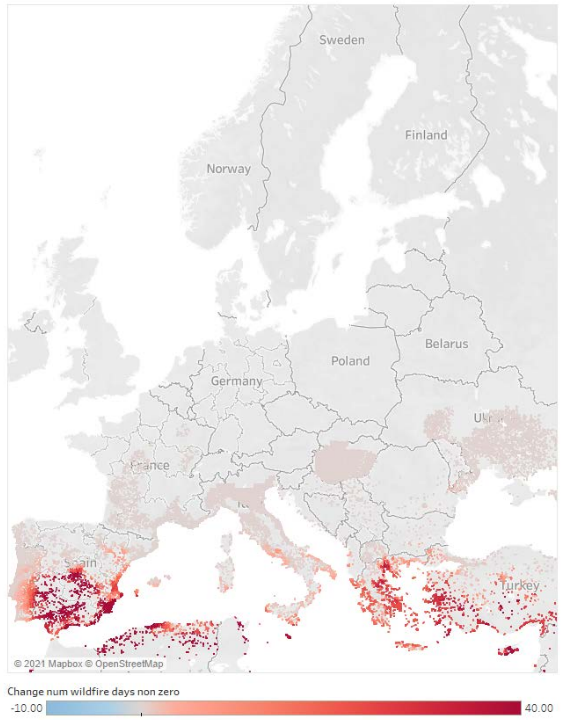
Comparison of change in the number of days with high wildfire potential

JRC Peseta IV



Four Twenty Seven

Change in the number of high risk wildfire days



Sources: JRC Peseta IV on wildfires; Four Twenty Seven and ECB calculations.
Notes: The methodology to calculate the days with high wildfire potential differs; Four Twenty Seven values are roughly comparable to a situation with global warming of 1.5C-2C. Not shown for Four Twenty Seven are firms for which no change in the number of wildfire days is expected.

1.2.5 Matching physical risk data with AnaCredit

Four Twenty Seven: spatial extrapolation for missing firms

Indicators for this analysis are available for approximately 1.5 million firms in Europe. When matching with other data sources (e.g. granular credit data such as AnaCredit), spatial extrapolation of available scores is necessary to fill gaps for firms that cannot be directly matched with scores. The matching can be done by spatial averaging over existing scores, for example at postcode or NUTS3 level. The extrapolated scores can then be joined with other data sources, provided they contain the same spatial identifiers (postcode or NUTS3).

Depending on the location and type of hazard, this averaging introduces some imprecision in the extrapolated scores. For example, floods, sea level rise, hurricanes/typhoons and wildfires may vary within only a few metres or hundreds of metres. By contrast, heat and water stress are usually more homogeneous across a larger area and using averages may therefore be less problematic. An additional source of variability is introduced owing to an inhomogeneous spatial distribution of scores available for the analysis presented here. For example, for some territorial units (e.g. urban centres), a higher number of scores may be available because a higher number of firms in the sample are located there, whereas other territorial units may be only represented by only a small number of firms.

JRC: matching based on NUTS3 and land use/economic activity

JRC data can be matched with AnaCredit exposures and AnaCredit collateral based on two criteria: location of counterparty/collateral and economic activity of the counterparty (NACE[23] level 1). For matching the location, the NUTS3 area in which the AnaCredit counterparty is located is used, thereby corresponding to the location of the counterparty's headquarters. The economic activity of the counterparty is used as a proxy for the type of area (land-use) in which the firm is located, thereby further refining the granularity beyond NUTS3. The proposed mapping is documented in Table 4.[24]

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[23] Statistical classification of economic activities in the European Community.

[24] This mapping is based on very simplified assumptions on the typical location of a firm of a given economic activity. It can vary substantially depending on the country and region.

Table 4

Mapping of economic activity to dominant land use type of area in which the firm is located

Letter	Sector	Land use
A	agriculture, forestry and fishing	agriculture
B	mining and quarrying	industrial/ commercial
C	manufacturing	
D	electricity, gas, steam and air conditioning supply	
E	water supply; sewerage, waste management and remediation activities	
F	construction	
G	wholesale and retail trade; repair of motor vehicles and motorcycles	
H	transportation and storage	
I	accommodation and food service activities	residential
L	real estate activities	
J-U	service activities	
T	activities of households as employers; undifferentiated goods and services-producing activities of households for own use	

Source: JRC RDH.

2 Transition risks

2.1 Assessing transition risks

There are two main categories of approach for assessing transition risks across the financial system: the first defines the notion of climate relevance for specific firms or sectors, and the second is based on actual or future emissions. The first category uses a predefined set of key sectors that are relevant for climate change. The approach is simple to implement and has relatively smaller data requirements on climate-related dimensions. It, however, does not take into account granular information on emissions intensity of firms across or within sectors and cannot account for changes in emissions or emission intensity over time. The second (emissions-based) method uses emission data of total exposures which requires more granular data, has the benefit of accounting for emissions (intensity) across exposures and changes over time.

The first approach starts with the existing NACE classification and adjust it for the relevant climate dimension. A commonly used classification across the predefined climate-sensitive subsets is the classification of climate policy relevant sectors (CPRS), developed by Battiston et al (2017), which defines climate policy relevant sectors based on emissions, relevance for climate policy and position in the value chain. The five CPRS are the fossil-fuel, energy-intensive, housing (buildings), utility and transportation sectors, which are based on subsets of NACE4-digit sectors that can be applied across EU countries. The approach can be further adjusted by using criteria to take country specificities into account, for example by considering emissions or policy relevance in a particular country. A separate approach is the PACTA method, developed by 2° Investing Initiative, which looks at key climate-relevant sectors and the technologies used in production. For example, the utility sector can be subdivided into subsectors of renewable versus fossil-fuel energy sectors, or the transportation sector can be divided into the electric vehicle segment and the internal combustion engine (ICE) segment.

Additional classifications are emerging from the nascent EU regulatory framework for sustainable finance, including the EU Taxonomy Regulation. [25] The Taxonomy Regulation provides that an economic activity is environmentally sustainable where it contributes substantially to at least one of the six main environmental goals set down in the Regulation and do not significantly harm the others, while complying with strict technical screening criteria on assessing the environmental sustainability of an activity.[26] It is therefore possible to examine the

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[25] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (OJ L 198, 22.6.2020, p. 13).

[26] The six environmental objectives cover climate change mitigation, climate change adaptation, the sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, and the protection and restoration of biodiversity and ecosystems. The Taxonomy may be amended to include performance criteria for non-green activities, as envisaged by a review clause on its scope, with regard to social objectives and environmentally harmful activities.

alignment of portfolios of financial institutions with the EU Taxonomy. This could represent the basis for establishing a harmonized green asset ratio (see EBA Pilot Analysis (2021))[27]. A Taxonomy of environmentally harmful activities may usefully complement the existing green classification for the purpose of assessing transition risk.

The approaches summarised above represent a variety of predefined sectoral subsets which differ in whether they capture the "green" or the "non-green" (high-emitting) dimension of a portfolio and its definition. This is a fundamental question for assessing transition risks, as they increase with the share of "non-green" exposures (e.g. CPRS, own definition) or decrease with the share of "green" exposures (e.g. EU Taxonomy alignment). Other approaches are more all-encompassing or may capture other factors (e.g. technological ones), such as the PACTA method.

The multitude of assumptions and criteria used to characterise NACE sectors by their relevance for climate change requires a careful assessment of the associated caveats and their implications for the assessment of transition risks. For example, country-specific CPRS classifications may differ from the CPRS classification at the EU level (for example owing to different CO2 emissions structure) and limit comparability. Moreover, these mappings are based on the NACE classification which was not originally designed for sustainability or climate-related considerations and may thus entail bias.

The emission-based approach takes into account all exposures in the portfolio of financial institutions and allows for greater flexibility when assessing transition risks. It therefore enables a more comprehensive assessment of transition risks. This could entail calculating, for example the carbon footprint or emissions intensity of the portfolio of a financial institution. The emission-based estimates might be sensitive to the source of emissions (carbon versus total greenhouse gas (GHG)) and the granularity of the data (firm-level or sectoral). Moreover, since they capture the whole portfolio, emission-based indices allow for further flexibility, for example by weighing the portfolio[28] using the market share or the share in the own portfolio of the financial institution.

Environmental, social and governance (ESG) investing is becoming increasingly popular in asset management, which may have implications for transition risk assessments. Sustainable investing strategies range from *passive* exclusion or screening, in which investments into specific sectors or firms (e.g. carbon-intensive ones) are excluded, to more sophisticated and *active* ones, such as ESG integration and impact investing that aim to engage with investee firms, e.g. for the purpose of greening their activities[29]. In this context "green finance" is often used as a synonym for ESG, but sustainable investment strategies do not necessarily

[27] See the EBA Pilot Analysis (2021), also EBA (2021),

[28] See Monasterolo et al (2017) for further emission-based indicators.

[29] According to market intelligence and surveys of asset managers, the latter have become more popular in the last five years. See for example the Eurosif (2018) survey of European professional asset managers. The classification of strategies is based on Eurosif and the United Nations-supported Principles for Responsible Investment (PRI).

imply investing only in firms and activities that are considered as green. ESG strategies can further rely either on the ”green” or ”non-green” characteristics of assets (e.g. EU Taxonomy or carbon intensity) or just ignore environmental considerations to focus instead on social and governance aspects.

However, a lack of consistency in categorising sustainable investing strategies,[30] as well as the absence of standardised definitions for ESG funds, hampers the ability of authorities, investors and researchers to understand the broader implications of recent ESG market trends, and their impact on the transition to a low carbon economy. There is limited information available on how these strategies are implemented in practice. Moreover, the co-existence of different definitions for ESG funds until recently has led to very different estimates of the actual size of the market and its key features, while there is currently very limited evidence on the relative impact of these strategies and their long-term implications for the transition.

The EU regulatory framework for sustainable finance will contribute to ameliorating the aforementioned issues, although data imputation techniques will remain necessary in the near to medium term. The harmonised environmentally sustainable activity definition under the EU Taxonomy regulation will enable a standardised assessment of the greenness of the banking or the investment portfolio. Nevertheless, it does not provide climate-related information on other economic activities, and accordingly on the potential transition risk from exposures to sectors that are not covered by the Taxonomy Regulation. A more informative approach might therefore entail assessing the transition risk of the whole portfolio, for example by considering exposures and climate data for all sectors. Moreover, it is important to take into account forward-looking elements, for example related to emissions reduction targets.

Box B: The EU regulatory framework on climate-related disclosures

The European Commission’s Action Plan on financing sustainable growth, published in March 2018, aims to reorient capital flows towards a more sustainable economy; mainstream sustainability into risk management; and foster transparency and long-termism. An important element of the Action Plan is the transparency and availability of sustainability-related information. These transparency requirements aim to improve the availability, consistency and quality of information that can be used by financial institutions, investors and supervisors alike to assess climate-related risks. Drawing from international initiatives such as the Task Force on Climate-related Financial Disclosures (TCFD) recommendations[31] and the International Financial Reporting Standards (IFRS) Foundation, they should bring further clarity on the impact of business activities on environmental and social matters, including climate change. There are five specific pieces of legislation that concern ESG disclosures, including climate-related ones.

30 For examples of divergence, see the classifications used in CFA Institute (2015), Morningstar (2019) and Eurosif (2018).

31 See TCFD (2017), “Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures”, June.

The **Non-financial Reporting Directive (NFRD)**[32], lays down rules on disclosure of non-financial information, including ESG disclosures, which are mandatory for large public-interest companies with over 500 employees. These include listed companies, banks, insurance companies and other companies designated by national authorities as public-interest entities. Companies subject to the NFRD follow the principle of double materiality. They must disclose details of the impact of their operations on ESG matters ("inside-out"), as well as the main ESG risks which are likely to have an adverse impacts on the company's operations ("outside-in"). The European Commission has recently proposed amendments to the NFRD through a **Corporate Sustainability Reporting Directive** (CSRD).[33] The CSRD would extend the scope of reporting to all listed companies (except micro-enterprises) and require auditing of the reported information. The text also proposes the development of common and simplified sustainability reporting standards, and that the reported information should be digital (i.e. machine-readable) so that it is easily accessible through a European single access point. Companies would apply the standards for the first time in 2024, covering the financial year 2023.

The Regulation on **sustainability-related disclosures in the financial services sector (SFDR)**[34] lays down sustainability disclosure obligations for entities offering financial products and financial advisers. Financial market participants are required to integrate sustainability-related information in the product design and disclose that information in the pre-contractual documentation and periodic reports and on their websites. Moreover, they must disclose information as regards adverse impacts on sustainability matters at entity and financial products levels, i.e. whether they consider there to be negative externalities on ESG issues of the investment decisions/advice and, if so, how this is reflected at the product level. The Draft Regulatory Technical Standards from the European Supervisory Authorities (ESAs)[35] published in February 2021 include twelve mandatory adverse climate and other environment-related indicators, including six on GHG emissions, to be disclosed by financial market participants. The SFDR began to apply in in March 2021, with the first principal adverse impact disclosures from 2023.

The **Taxonomy Regulation**[36] establishes an EU-wide classification system which identifies a list of environmentally sustainable economic activities, according to six environmental objectives. For financial products that contribute to an environmental objective, under the SFDR information must be disclosed on which environmental objective(s) they contribute to and on how and to what extent they qualify as Taxonomy-aligned. For financial products that promote environmental characteristics, in addition to the previous information, a statement must be included for in respect of the financial product which does not meet the Taxonomy criteria. Moreover, the Taxonomy Regulation requires any undertaking subject to the NFRD to disclose how and to what extent the undertaking's activities are associated with economic activities that qualify as environmentally

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[32] Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups (*OJ L 330, 15.11.2014, p 1-9*).

[33] Proposal for a Directive of the European Parliament and of the Council amending Directive 2013/34/EU, Directive 2004/109/EC, Directive 2006/43/EC and Regulation (EU) No 537/2014, as regards corporate sustainability reporting (COM/2021/189/final).

[34] Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector (*OJ L 317, 9.12.2019, p. 1*).

[35] Joint Committee of the ESAs, Final report on draft Regulatory Technical Standards with regard to the content, methodologies and presentation of disclosures pursuant to Regulation (EU) 2019/2088, see also the accompanying press release.

[36] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (*OJ L 198, 22.6.2020, p. 13-43*).

sustainable. In February 2021, the ESAs published technical advice on the content and format of the disclosures. The Taxonomy Regulation entered into force in July 2020 and the first delegated acts, related to the climate change mitigation and adaptation objectives, were adopted in April 2021. For these two objectives, the first investor disclosures using the EU Taxonomy are due at the beginning of 2022.

Amendments to the **Capital Requirements Regulation** (CRR)[37] require large institutions which have issued securities that are admitted to trading on a regulated market of any Member State to disclose information on ESG risks, including physical and transition risks. The European Banking Authority (EBA) is mandated to develop Implementing Technical Standards (ITS) for Pillar 3 disclosures. Starting from June 2022, the information must be disclosed on an annual basis for the first year and twice a year from then on. Similarly, under the Regulation on the prudential requirements of investment firms (Investment Fund Regulation)[38] it is mandatory for investment firms above a certain size to disclose information on ESG risks, including physical and transition risk.

While these rules and requirements will go a long way in addressing climate-related data gaps in Europe, they may further incentivise voluntary disclosure beyond the European Union. A minimum degree of alignment with data standards in countries outside the EU would add to those incentives, in particular between climate taxonomies, with a view to making data comparable across borders and to limit the burden on firms while facilitating investors understanding of the impact of climate-related risks on their investments.

2.2 Sectoral approach: an application of the PACTA method

The transition risk assessment for the insurance sector discussed in the main report is based on an application of the PACTA method to the insurance portfolio to identify holdings. The key elements of the mapping are described below, and key findings are summarised in the main text of the report.[39]

2.2.1 Holdings mapped to issuers

For corporate bond holdings the most important asset classes are considered (i.e. common corporate bonds (plain vanilla), convertible bonds, hybrid bonds and subordinated bonds). These cover about three quarters of all assets classified as corporate bonds at the highest level of classification (CIC code 2) in the insurance portfolio. Corporate bond holdings in the European Economic Area (EEA) for about €1.2 trillion are considered. Of these, 86% are matched to issuers in the PACTA tool

[37] Regulation (EU) 2019/876 of the European Parliament and of the Council of 20 May 2019 amending Regulation (EU) No 575/2013 as regards the leverage ratio, the net stable funding ratio, requirements for own funds and eligible liabilities, counterparty credit risk, market risk, exposures to central counterparties, exposures to collective investment undertakings, large exposures, reporting and disclosure requirements, and Regulation (EU) No 648/2012 (*OJ L 150, 7.6.2019, p. 1-225*).

[38] Regulation (EU) 2019/2033 of the European Parliament and of the Council of 27 November 2019 on the prudential requirements of investment firms and amending Regulations (EU) No 1093/2010, (EU) No 575/2013, (EU) No 600/2014 and (EU) No 806/2014 (*OJ L 314, 5.12.2019, p. 1-63*).

[39] Full details are available at EIOPA, Sensitivity analysis of climate-change related transition risks.

(11% are not listed[40] and 3% could not be mapped). The share of equity assets mapped is overall smaller than for corporate bonds, with about a third of equity holdings being matched to assets covered in the PACTA tools. A key reason for this is that a large part of common and preferred equity holdings are actually participations or holdings in related undertakings. These holdings are generally in other insurance undertakings and not in PACTA sectors. If we exclude or correct for these participations, only 2% of the equity holdings remain completely "unmapped".[41] Taking advantage of the data made available via the PACTA service, it was also possible to identify 44% of the underlying assets in these fund holdings, and those holdings have been taken into consideration in the analysis. Matched assets can be assigned to a climate policy-relevant sector or defined as non-climate policy relevant.

2.2.2 Summary of identified holdings

It was possible to assess about €2.3 trillion in corporate bond and equity holdings. About €350 billion worth of these holdings are in climate policy-relevant sectors as described above. The parts that have been classified as non climate-policy relevant in this context are mainly investments in financial assets, public administration or property.

For a large share of assets with a sector identification, technologies used in production have been further identified. A security may be mapped to several technologies depending on the operation of the issuing company. Using the data available in PACTA, we can positively identify the technology used for investments worth around €227 billion. This represents about 5.4% of the relevant corporate bond, equity and fund investments, and 10% of all the investments mapped with the PACTA toolset. It is important to note the caveat that this excludes unmapped assets, agriculture and property (as well as the indirect effect on the financial sector). The results of this mapping are presented in the main text of the report.

It should be noted that all of these represent conservative estimates of the overall holdings because even the highest estimate does take into account holdings in other asset classes other than those defined for this study (e.g. covered bonds were not included, but might still contain climate policy-relevant holdings).[42]

2.3 An emissions-based approach: challenges for data comparisons and remaining climate data gaps

Emissions-based assessments have revealed large degrees of heterogeneity in emissions not only across countries, but also across sectors within

[40] The PACTA service covers *listed* bonds and equity.

[41] Participations were not excluded completely from the input data because some participations could be mapped, indicating that there could be minor reporting errors or certain group structures where financial data were available. While including participations in the input data does reduce "mapping coverage" as presented here, it does not affect any of the results.

[42] The small amounts held in shipping are excluded in the price sensitivity analysis due to limited data.

countries and across firms within sectors. While sectoral analysis is a first step, it limits the types of assessments needed for financial stability purposes as regards concentration of risks and the potential support in the transition to a low-carbon economy. Comprehensive and granular data[43] are needed to differentiate between the emission intensity and credit exposure as the main drivers for potential financial stability risks and to reveal potential shifts in credit from high-emitting to low-emitting firms.

Granular firm-level analysis can provide additional insights, albeit with multiple caveats, given the potentially non-representative coverage owing to limited and non-harmonised disclosures. The data on firm-level emissions generally stems from commercial data providers that differ in respect of their coverage, data processing, types of emissions (scope 1, 2 or 3 and/or all GHG or CO2 emissions) and the comprehensiveness and transparency of the method used for imputing missing firm-level climate-related data to fill gaps.

Granular firm-level emissions datasets from external providers may help to close climate data gaps, but the specific methodologies for imputing missing data could lead to differences in portfolio emission intensity estimates. Missing firm-level emissions can be inferred for non-reporting firms by looking at reporting firms in the same country and sector. A more detailed imputation would in addition condition firm size or technological characteristics, depending on data availability, thus introducing statistical bias. To illustrate the potential discrepancies, the emission intensity of approximately two million reporting euro area firms captured by Urgentem amounts to 102g of CO2 per euro of revenue (see Chart 2.1). When considering an alternative imputation method using national sectoral averages for all non-reporting firms, the emissions intensity can drop to 92 g per euro (or 98 g per euro) across the whole euro area. However, using country-sectoral data from Eurostat leads to a slight increase in the weighted emissions intensity estimates. The example illustrates the potential shortcomings of incomplete reporting of climate-related data and missing data imputation techniques for the average firm, which may not reflect firm heterogeneity fully.

In addition to the specific imputation methodology, the bank loan portfolio characteristics are also relevant for assessing bank exposure to transition risk. The analysis in this section focuses on domestic loan exposures given data availability in credit registries. However, cross-border bank loan exposures may be characterised by emissions intensities that differ significantly compared with domestic loans. For the majority of euro area countries, the carbon intensity of the NFC loan portfolio increases when foreign loans are included. Except for Estonia, Malta and Slovenia, the emissions intensity of the global portfolio is higher than that of their domestic portfolio, indicating that domestic (or euro area) companies to which banks grant loans are more efficient in terms of emissions intensity.[44]

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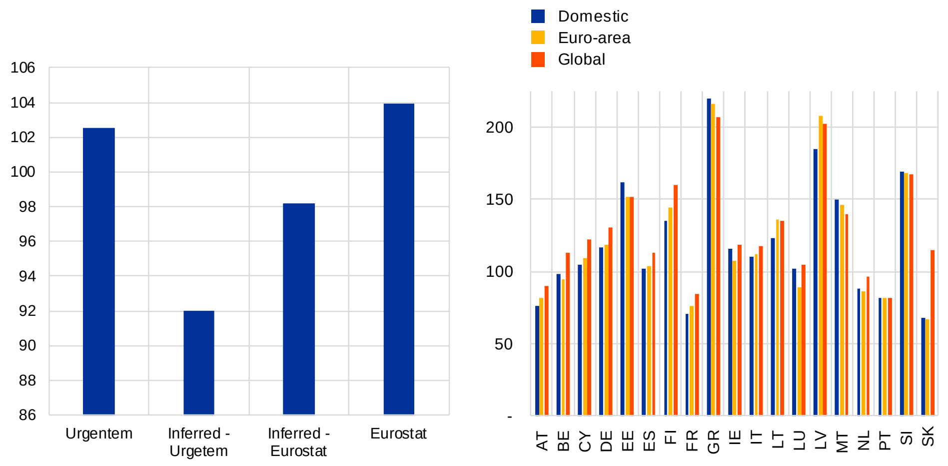
[43] See box B on EU regulatory framework on climate-related disclosures.

[44] The coverage of firms across individual countries may differ and thereby affect the representativity. The coverage in the case of Cyprus, Luxembourg, Slovenia and Slovakia reaches up to only 40% of loans to NFCs.

Chart 2.1

Weighted emission intensity of reporting firms across imputation methods

(emissions intensity in CO2 grams per euro of revenue)



Source: Eurostat, Urgentem and ECB calculations
Notes: Weighted emissions intensities in the first and fourth bar only include firms with reported emissions (Urgentem). For the second and third bar the remaining firms are included based on country-sectoral averages.

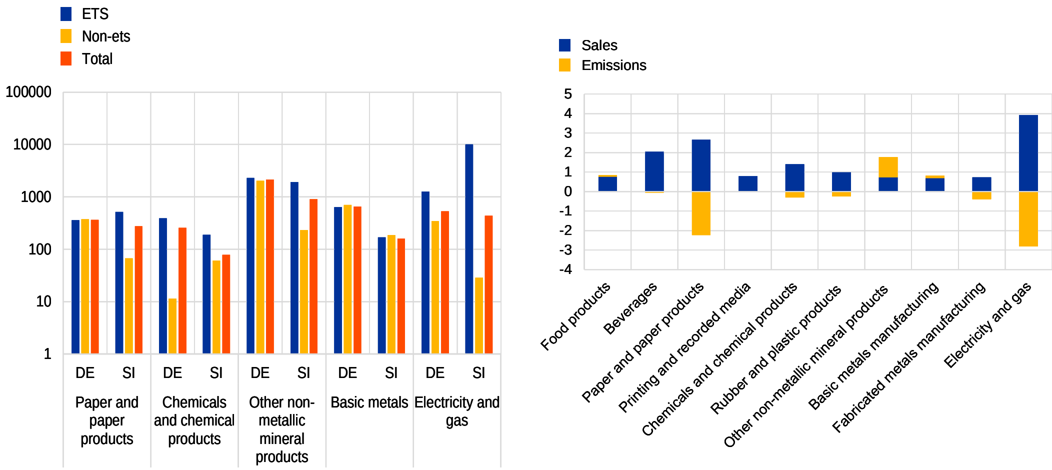
Beyond emissions datasets from Eurostat or commercial providers, the EU Emissions Trading System (EU ETS) offers an additional source for assessing emissions across certain sectors. The EU ETS provides data on verified emissions, thereby ensuring reliability,[45] along with data on free emission allowances (free allocated coupons) which are aligned with national emissions reduction goals, split between EU ETS and non-ETS sector goals. The data show that emission intensity is higher for the EU ETS subset compared with the non-EU ETS subset within the most polluting subsectors. However, the scope of the EU ETS is restricted to a limited number of sectors, and an economy-wide assessment of these differences in emissions across all sectors would require further work on especially the non-ETS emissions.

[45] The EU ETS provides verified data on Scope 1 emissions, for those firm activities (plants) which are captured under the EU ETS. For further analysis on the sensitivity of the carbon footprint of ETS firms to different reporting scopes see Busch, Johnson and Pioch (2020).

Chart 2.2

Emissions intensity of EU-ETS and non-ETS sector subsets for Germany and Slovenia and comparison of emissions intensities using various imputation methods

(emissions intensity in grams per euro of sales)



Sources: EU ETS and national authorities

Notes: Emission intensity per ETS subset refer to unweighted emissions intensity (left panel). The blue bars in the right panel show the ratio of emission intensities using sectoral averages for emissions and sales (Eurostat) compared with granular sales data; the yellow bar shows the remaining effect on firm-level emissions intensity when adjusting for granular sales and emissions (EU-ETS).

2.4 Forward-looking elements in transition risk assessments

Forward-looking analysis requires granular information on emission reduction targets which are not readily available, thus indicating the need for further proxies. A number of EU companies, albeit relatively few, disclose emission reduction targets (so-called "net zero" commitments)[46] which are aligned with the Paris Agreement goals. The EU ETS data could serve as a proxy for policy stringency, as the data may indicate future climate policy more broadly - based on the emissions allowances quotas and allocations over the current and future trading periods. As such the EU ETS data provide a gauge of forward-looking transition risk, (e.g. through the cost of emissions relative to firm profitability). In addition, developments on carbon markets contain forward-looking information as they reflect market pricing of future emissions reductions. Namely, higher carbon price increases should be observed where emission reductions are more credible or where emission reductions are expected to increase more abruptly over the near to medium term (See Section 2,4,1 of the main report for recent carbon market developments).

However, the long-term impact of recent market developments in ESG investing and green finance is not yet fully understood, particularly with regard to the effect of the financial system on climate. While there are on-going initiatives aimed at improving the availability of data on climate-related financial risks (FSB (2021); BCBS (2021)), efforts to improve our ability to measure in a holistic

46 See, for example, UN Climate Change, "Commitments to Net Zero Double in Less Than a Year", press release, 21 September 2020; Silverstein, K., "Banks Bet They Can Go Zero-Carbon And Still Boost The Bottom Line", *Forbes*, 16 November 2020; and the *Net Zero Asset Managers Initiative* launched in December 2020.

way the impact of the financial system on climate appear to be lagging behind. The roll-out of several EU regulatory initiatives should help to improve data availability and consistency at a microeconomic level. However, the absence of comparable initiatives in many other countries outside of the EU and possible fragmentation resulting from different approaches will create challenges for measuring at a global level the aggregate impact of on-going market transformations, and assessing their full implications.

More generally, backward and forward-looking metrics can provide useful additional information on firms' exposure to transition risk, albeit with various caveats. Backward-looking metrics include mainly exposure classification subsets, emissions metrics, ESG ratings, environmental pillar scores and other specialised products, such as climate scores or carbon risk ratings. However, there is no single method for assessing transition risks across the financial system. Moreover, emissions data are available across subsets of firms, with the need for data imputation techniques for the remainder. Across financial markets, the use of ESG assessments is currently hampered by high discrepancy rates between rating providers, as illustrated by the low correlation compared with credit ratings.[47] There are several sources of divergence between ESG ratings, including the underlying data; the choice of metrics; a lack of commonality in the definition of "E, S and G" (environmental, social and governance); the materiality assessment and corresponding selection of categories within each pillar and the aggregation rules used to build ratings and scores.[48] Similarly, forward-looking assessments such as implied temperature rise metrics suffer from a lack of consistency. Such caveats continue to hamper climate-related assessments.

47 See for example Berg et al. (2019).

48 Boffo, Marshall and Patalano (2020) show that environmental pillar scores are not always correlated with ESG scores, and that "E" (environmental) scores can be calculated in different ways, resulting, for example in low or negative correlation with CO_2 emissions.

Conclusions

The thoroughness of climate-related risk analysis depends crucially on the quality and consistency of climate-related data. For the assessment of transition risk, the EU regulatory framework for sustainable finance, if implemented consistently, will contribute to filling some of the existing data gaps. However, data imputation techniques will remain necessary in the near to medium term to address missing data points, particularly for the small and medium-sized enterprises (SME) segment. Moreover, the Taxonomy Regulation establishes criteria for determining whether an economic activity is green or environmentally sustainable, with further efforts needed to differentiate the remaining activities and categorise them appropriately for the purpose of risk assessments. Emissions-based transition risk assessments using sectoral or firm-level data and combined it with credit exposures from financial institutions provides a more granular assessment of transition risk for the financial system.

Notable progress is being made in terms of data collection for physical and transition risk, although insufficient data granularity remains a pressing issue. Assessing physical risks will depend on the spatial granularity of the data, the relevance of which may differ significantly across hazards. Riverine flood risk, for example, requires greater spatial granularity compared with temperature-related hazards affecting large areas. For transition risks, the assessment may differ significantly depending on the definition used for climate sensitivity (sectoral subset or emissions-based) and the source and granularity of the climate indicator, typically emissions data at the sectoral or firm level (Eurostat or commercial providers).

Forward-looking elements are essential for further climate risk analysis as an inherent characteristic of climate risks (physical and transition). Rather than relying solely on historical data, physical risk analysis would benefit from integrating existing and planned mitigation measures together with climate scenarios as relevant inputs for future physical risks. Transition risk analysis would benefit from integrating forward-looking policies (e.g. carbon markets and regulation) and transition strategies (scenarios or pathways, including innovations) across firms and countries.

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Imprint and acknowledgements

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PDF ISBN 978-xx-xxx-xxxx-x, ISSN xxxx-xxxx, doi:xx.xxxx/xxxxxx, QB-xx-xx-xxx-EN-N