Climate Risk and Macroprudential Regulation

Monica Varlese
University of Naples Parthenope
Department of Economic and Legal Studies.
Via Generale Parisi 13, 80133 Naples (Italy).

Simone Taddeo
University of Naples Parthenope
Department of Economic and Legal Studies.
Via Generale Parisi 13, 80133 Naples (Italy).

Abstract

Global economies were clearly left unprepared by the climate crisis outbreak. Climate risks may entail catastr ophic financial risks that undermine macroeconomic and financial stability. The macroprudential regulation in force and the envisaged instruments are not sufficient to implement a "green" macroprudential policy to miti gate climate risks, necessary for a transition towards a low-carbon economy. In this uncertain context, is gro wing acknowledgment among policymakers' new measures need aimed at considering the systemic nature of c limate risk should arise. Central banks should promote more sustainable finance, including climate risks in p ursuing their objectives as well. This paper explores financial climate-related risks features and their measure ment instruments adopted by individual institutions. Moreover, it highlights limits of regulation in force in the face of such risks. This will provide readers a clear picture of this topic and point to potential insights usefu l for a macroprudential regulation in view of challenges associated with climate change.

Keywords: Macroprudential policy, Financial Stability, Central bank, Climate risk, Climate change, Financial risk, Low-carbon economy.

1 Introduction

Nowadays, the discussion of climate change is a widespread issue in the world debate. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), the global average temperature of the Earth increased by 0.87 degrees Celsius since 1900. At this rate, if emissions levels continue to rise, global warming is expected to reach 1.5 degrees Celsius above pre-industrial levels (IPCC, 2018).

In accordance with some recent data from the World Meteorological Organization (2018), the world has embarked on a growth path above 3 ° Celsius and, based on these considerations, the Peseta III report (2018)[1]has highlighted that, in the future, environmental phenomena will significantly affect the real economy, especially in some geographic areas.

In particular, the impact of the climate change is expected to be more marked in Southern Europe, where continuous heat waves will lead to increased mortality, biodiversity loss and the quantity of products due to drought. In Northern Europe, on the other hand, the greatest damage will occur mainly from increasing coastal floods, melting of mountain glaciers and rising sea levels.

Sectors and industries that depend strongly on certain temperatures such as tourism, energy, agriculture and forestry are particularly influenced by the global warming.

In this context, the financial system meets challenges from the effects of climate change too. A report by the Network For Greening the Financial System (NGFS, 2020) advises banking and financial institutions to take timely and decisive measures in response to the climate crisis, in order to avoid losing credibility and creditworthiness and therefore to continue in proper functioning in terms of monetary policy. This because international financial and banking organizations revealed great worries and concerns about the negative consequences of climate change for the financial balance and banking solidity in general(NGFS, 2020).

Specifically, climate change risk can impact financial stability through two types of risk: physical and transitional. Furthermore, climate-related risks are the cause of financial risks as well, and therefore can affect the stability of the financial system[2]. For example, climate risks can reduce the ability of borrowers to repay their debt.

[1]Report Peseta III (2018), https:// ec.europa.eu/jrc/en/peseta-iii

[2]Currently, climate-related financial risks are not defined either legally or in any other globally recognized form, but are based on the definitions and recommendations of international standardization bodies, such as the Basel Committee for

This, in turns, increases the probability of default of institutions (credit risk). Moreover, climate risks can cause a change in the perception of the profitability of some financial assets, leading investors to sell them off (market risk) as well as. Finally, the banks may in turn not be able to obtain short-term financing (liquidity risk). In addition, if the banking operators have a direct exposure linked to the climatic risks, they could see their own operations compromised (operational risk). In other words, the nature of the risk linked to the climate changeis to be considered as systemic kind, since it can exogenously and endogenously affect both the real economy and the financial system, threatening their stability (Koumbarakis et al., 2021).

The increase in global temperatures led to the strengthening of the international action towards a green transformation. For this reason, regulatory and supervisory authorities are putting climate risks at the top of their industry agenda and, as climate change measures becomes more urgent, it appears increasingly important to take a proactive role in mitigating the risks derived from global warming (NGFS, 2020). Moreover, the green transformation substantially involves the financial sector, which plays a crucial role in allocating resources towards a sustainable economy. This is the reason why climate and environmental risk management should be the prerogative of macroprudential regulators and central banks.

The paper addresses two questions: what are the specific features of climate-related financial risks that could compromise the stability of the financial system? What are the limits of the macroprudential regulatory framework and what are the options to face these risks?

The rest of the paper is organized as follows. Section 2 describes the evolution of macroprudential policy. Section 3 describes climate change as a source of financial instability. An overview of the financial climate-related measurement instruments is reported in section 4.Section 5 highlights some limits of the macroprudential policies. Section 6 concludes.

2 The evolution of macroprudential policy

Before the financial crisis of 2007-08, policymakers pursued the objective of financial stability through the implementation of monetary and micro-prudential policies. The formers aimed at a low level of inflation while microprudential regulations mainly aimed to ensure the solidity of financial institutions. The Basel framework for capital regulation was designed to increase stability and to guarantee the safety of the global banking system. However, as for systemic risk measures, the Basel process was more effective for smaller banks, but it did not significantly limit systemic exposures (Gehrietg e Iannino, 2021). In light of that, some empirical evidence suggested that regulation failed to pursue these goals. Indeed, microprudential policies aimed at containing the risk of financial crises of individual institutions but neglected their impact at the global level. Therefore, acknowledgment among policymakers that there was a need for a renewed conception of financial stability policy was grown.

In this context, a new macroprudential perspective has developed based on policies focusing to limit systemic risk and ensure the stability of the monetary and financial system at a macro level. Thus, macroprudential policies seek to reduce the probability that systemic financial crises occur, their intensity, and their harmful consequences. The main macroprudential instruments are the countercyclical capital buffer and other capital requirements for banks and systemically important intermediaries, the leverage ratio, the loan-to-value or debt-to-income ratios, and so on. Some of these tools represent an extension of the previous micro-prudential rules. Others, instead, have been built to go beyond the limits both of procyclicality and the incapability to contain systemic risk, typical of some of the microprudential tools. In this regard, Basel 3 could be considered as an extension of the pre-existing regulatory framework of Basel 2 and not a new paradigm of risk assessment criteria.

Indeed, the risk-weighted capital ratio, introduced by Basel 1 to ensure the solvency conditions of banks, is still the main prudential regulatory tool in the Basel 3 framework. The risk-weighted capital ratio is computed through mathematical models which take in account the past risk as historically materialized. In other words, it is based on the definition of risk which considers historical data as significant sources of systemic risk. However, for causal events as climate changes, historical data are not available. The reason lies on the rare and statistically insignificant nature of climate risk (Le Quang and Scialom, 2021). Although this risk concept is consistent with that defined in the Basel 3 framework which refers to the market[3], the lack of reliable data on its entails a challenge to the application of the Pillar 1 framework.

Banking Supervision (BCBS), International Organization of Financial Market Supervisory Authorities (IOSCO), International Association of Supervisory Bodies in the Insurance Sector (IAIS) and is guided by the principles of the Central Banks and Supervisors Network for Greening the Financial System (NGFS)(NGFS, 2020).

[3]Basel 3 framework indicates the market as the basis of banking regulation.

The available data, which are not of sufficient qualitative in terms of completeness and availability of past information, makes the translation of climate risks into financial risks more difficult (Baranović I, 2021). Hence, a new problem in terms of financial stability ensues.

Macroprudential regulators should then consider green or social objectives in their decisions for two reasons: the first is linked to the financial and macroeconomic nature of climate risk, meanwhile the second refers to the failures of the credit market and, in particular, to the ability of financial intermediaries to allocate resources between green and "brown" firms, namely carbon-intensive firms (Koumbarakis et al., 2021). In this regard, "under Pillar I (minimum capital requirements), a 'green supporting factor' (GSF) or a 'brown penalizing factor' (BPF) could give, respectively, lower risk weights to climate-friendly ('green') investments or higher risk weights to carbon-intensive investments, thereby allowing for the integration of the added 'carbon risk' to overall risk-return assessments" (Grünewald S., 2020). In other words, policymakers could help to create and allocate credit in a sustainable way and mitigate the risk deriving from carbon-intensive economic activities as well as (Koumbarakis et al., 2021).

2.1 From Basel 3 to Basel 4

The 2017 Basel 3 reform, namely Basel 4, was one of the most important issues in the regulatory reorganization, which has shaped banks and financial institutions following the great financial crisis. Its implementation date has been postponed until January 2023 and the new legislation will be implemented gradually by 2028, due to the COVID-19 epidemic. One of the main objectives of the Basel 3 reform is to restore the credibility of the capital ratios computation for banks. Indeed, banking assets' definition quality and the minimum capital requirement ratios have been tightened through the integration of new requirements, following the financial crisis (BIS, 2018). Furthermore, Basel 4 requires banks, especially those using the internal ratings-based approach, to be more standardized. Credit risk measurement models based on internal ratings (IRB), such as the IRB-Foundation and IRB-Advanced (IRB-A) approach, will be more standardized and, therefore, more comparable. Models for estimating risk' parameters, such as the probability of default (PD), exposure in case of default (Exposure at Default, EAD), and loss in case of default (Loss Given Default, LGD), will be more freely adopted by banks that use the IRB-A approaches. However, internal models will not be used for low-default portfolios anymore given that it may be difficult for banks to estimate parameters for such portfolios in a reliable way (Stam et al., 2020).

Although the IRB approach is more flexible than the Standardized Approach (SA)[4], there are considerable conceptual and data limits in relation to capturing climate-related risks. More specifically, given that the IRB approach is based on historical data, it may fail to capture future developments from the climate risk perspective. Moreover, this approach often uses specific methods, such as logistic regressions, that could be not able to capture the complexities of climate risks. Finally, the IRB approach is based on the portfolio invariance' assumption which is not suitable to vulnerability to climate risk across EU regions, sectors, and financial institutions (Baranović I, 2021).

Other new aspects introduced by the Basel Committee for Banking Supervision (BCBS), as part of the Basel 3 reform, are constraints known as "input and output floors" relating to the use of internal models. It is a matter of parameters, higher than pre-established minimum values, envisaged to correctly quantify the expected loss. Moreover, the new legislation on the definition of default (New Definition of Default, New-DoD), issued by the European Banking Authority (EBA), came into force with the publication of an EU Delegated Regulation and specific guidelines in the application of Article 178 of Regulation (EU) no. 575/2013, namely CRR (Capital Requirement Regulation). The New-DoD indicates two requirements for which the European Banking Authority considers an obligor "defaulting": (1) credit obligation is 90 days past due (DPD); (2) materiality threshold has been broken. Finally, the Basel Committee on Banking Supervision has issued a new circular (BCBS 239) entitled "Principles for effective risk data aggregation and risk reporting", which invites banks to highly automate and standardize their risk reports and the provision of data relating to the latter as well (Stam et al., 2020). Better and quality data could favor the accuracy of risk-weighted assets and, therefore, could lead to a reduction in the capital set aside. In turn, well-capitalized banks which hold high-quality liquid assets could contribute to improving stability not only of individual banks but also of the banking system (Vodenska et al., 2021).

The introduction of standardized models, input and output floors, as well as adaptation to the New-DoD, represent new challenges for banks including finding new data, carrying out new customer segmentation, and comparing the standardized and IRB models' computation. In other words, a real gradual revolution in the management and business planning of banks is taking shape, and the focus is on both costs and revenues' control precisely.

[4]SA approach considers that the banks have to use risk weights set by the macroprudential authorities based on settled drivers such as external credit ratings or the loan-to-value ratio.

Moreover, the management of risks related to the climate crisis has become a fundamental prerogative for the central banks of the main economies of the world, who were clearly left unprepared to face the new climate crisis. Therefore, the need to cooperate for the purpose of defining common and coherent regulation, that includes new risks that may originate outside the traditional market logic, arises (Stam et al., 2020).

3 Financial climate-related risks and transmission channels

The two main risk factors which fall within the context of climatic and environmental hazards are known under the name of physical and transition risk, which represent the causal linkages that clarify the interdependence that exists between climate change and financial stability (NGFS, 2020).

Physical risk consists of external weather conditions such as heat waves, landslides, floods, fires and storms that may lead to damage in physical assets (property, infrastructure and houses) and disrupt labor and operations on which companies depend on (BCBS, 2021a).In this regard, physical risk could be either from acute or chronic, depending on the intensity of natural events. On one hand, acute physical risks refer to those climate phenomena that are event-driven and do not lead to longer-term shifts, which may concretize in an increased severity of extreme weather events such as cyclones, hurricanes, or floods. Chronic physical risks, on the other hand, arise from long-term progressive change in climate patterns such as ocean acidification, sea level rise and extreme temperatures that could lead to undesirable effects such as loss of ecosystem services, desertification, soil quality degradation or marine ecology (BCBS, 2021a).

The definition of energy and environmental policies in relation to climate risk mitigation will also have repercussions in terms of firm value, prompting a review of the business model. A disorderly adjustment process from a fossil fuel-intensive economy to a low-carbon economy could undermine the stability of the entire financial system. In this regard, it is called transition risk. According to the Basel Committee for Banking Supervision (2021a), transition risk is understood as the set of all the risks associated to the transition from a carbon-intensive to a zero-emission economy in terms of climate policies, legislation and regulation, or sudden changes in technology and market preferences. Therefore, transition risk may arise when the introduction of significant mitigation policies, major technological innovations or rapid changes in market sentiment led to a quick and different evaluation of financial assets by the markets and financial intermediaries.

Unlike physical risk, transition risk may not be continuous and permanent; however, it could be systematic, that is, it could affect entire industrial sectors or even the economy as a whole. In this context, central banks and supervisory authorities play an important role, both in improving information on the risks associated with climate change and mitigating its impact on financial stability, as well as in the safeguard of the proper functioning of the financial industry.

Climate change risks could undermine the stability of the financial system in different ways. The first refers to the microeconomic channels, which consist of all those drivers arising from climate change that affect the proper functioning of the individual bank and its counterparties. This, in turn, impacts bank's daily operations and their ability to collect money to finance themselves.

The macroeconomic transmission channels, on the other hand, which are related to the financial system and real economy *in toto*, refer to those climate change determinants that affect macroeconomic variables such as GDP and economic growth which, successively, influences the economy in which bank operates (BCBS, 2021b).

In this view, the financial climate-related risks could be materialized in the form of traditional risk categories or constitute determining factors of existing classes risks such as credit, market, liquidity, operational and reputational risks.

For instance, climate change drivers increase credit risk when borrowers, who are exposed to physical and transition risk, are unable to reimburse debt and honor their burdens (income effect).Credit risk can also increase by climate change factors even when banks and financial institutions fail to recover the loan value caused by the counterparty's insolvency (wealth effect).Firms that operate in geographic areas where the risk of climate change is more likely to occur, could experience a decrease in the productivity and in profitability, which may lead to a deterioration of the creditworthiness(Ascui and Cojoianu, 2019).This negative association is demonstrated also by Barrot and Sauvagnat (2016), who claim for an inverse relationship between firms' profitability and extreme climatic situations, which in turn impact the firms' prosperity and wealth.

In addition to that, it has been proved that countries which are not resilient in climate change policies may experience higher borrowing costs and thus greater sovereign bond spreads (Cevik and Jalles, 2020).This is the case of some Caribbean countries, which have faced greater rates in borrowing money from financial markets as extreme weather events became more frequent (Mallucci, 2020).

In a nutshell, financial institutions are exposed to the possibility of not having their mortgage' loans repaid by those firms which operate in an area where physical risks are more likely to happen. Consequently, banks face large

losses in their balance sheets, increasing non-performing ratios and have the value of the collateral asset lowered (Noth and Schüwer, 2018).

Similarly, the transition to a low-carbon-intensive economy could undermine the ability of many companies to generate wealth and repay their debts. (Monnin, 2018).
This poses a great risk for bank portfolios which are exposed to all those sectors that suffer most from extreme climate risk events such as utilities, transportation, agriculture, mining and petroleum (UNEP, 2019).

The stringent regulations for greenhouse gas emissions have also shaped the nature of the technology employed in the industrial processes. Companies that depend on carbon-intensive technologies and are unable to convert their processes into renewable or eco-sustainable technologies, could experience a decrease in competitiveness and contribute to higher credit-related losses.

Risks deriving from environmental and atmospheric changes could also erode the value of financial assets, resulting from an increase in the market volatility of the traded assets conducting to a shock in the market prices. Climate change could hit the financial stability in terms of market risk, which the risk is related to the unexpected effects on the market value of the real and financial assets. For instance, there are observational data which confirm the negative correlation that exists between market value losses and severe environmental events (Ortega and Taspinar, 2018).Households who live in areas where the physical risk is greater, especially for those who are exposed to acute physical risk like floods, could face a negative effect of home prices (Bin and Polasky,2004).

A shortfall in the value of real assets could be also a direct consequence of the damages caused by extreme climate events to physical capitals employed in the industrial processes such as machineries, equipment, factories and rental properties which, as a result, hit the performance and profitability of a firm in negative terms (Collier et al., 2020).

Nevertheless, equity and debt investors are beginning to incorporate climate risk considerations in their decision-investment processes. Increasing number of market operators are asking higher compensations for those firms exposed to climate change and that are carbon inefficient. This results in a higher stock price returns demand for those companies that emit more carbon emissions. The impact of climate change could then materialize in terms of price adjustments mainly when physical and transition risks are not yet reflected into prices (Bolton and Kacperczyk, 2020a).

Climate change drivers could also threat the day-to-day operational activities. Operational risk may arise when there is an issue about internal process, fail systems or practices caused to climate-related activities which compromises the daily functioning of the firm (BCBS, 2021a). For instance, physical risks may damage firms' assets and resources such as data centers, property and IT infrastructures, harming the daily operation activities of the business (Hosono et al, 2016).

In this regard, the process of operational management could be also affected in terms of reputational risk. Indeed, banks face loss of reputation when they finance economic activities that have negative impact on the environment or if they lend money to those companies that are not environmental-friendly and climate-sensitive (Migliorelli and Dessertine, 2020).

As awareness for green issues has increased, public pressure, indeed, could redirect banks' lending choices to those companies which act better in the environmental framework (Rayner, 2004). Therefore, there is a growing interest for banks' reputation in the eyes of its shareholders and depositors in lending activities. This is amply demonstrated by literature where investors prefer to provide funding for those firms which have less carbon emissions and not to address money for those which have environmental issues (Bolton and Kacperczyk, 2021b).

Climatic and environmental risks could also materialize in the form of liquidity risk, intended as the risk that a market participant is unable to meet payment obligations for lack of cash, and threatens its financial position. According to the European Central Bank (2020), climate change could occur in term of liquidity risk when customers withdraw money from their bank accounts in order to settle the debt caused by the damages derived by climatic catastrophes.

In addition to that, climate change drivers could negatively affect both the capital and profitability of companies, deteriorating gradually their liquidity and increasing the risk of insolvency that could impact the real economy and financial stability (Dafermos et al., 2018).

However, Alvarez et al.(2020) advocate that is very rare that climate change risk makes an asset less liquid, but liquidity risk is caused firstly by other risk categories such as market, credit, or operational risk which, in turn, reduce the value of the bank's high-quality liquid assets, influencing in negative way the liquidity reserves of the financial institutions.

To sum up, protecting the climate is the challenge of the century and there is a broad consensus among political leaders and regulatory authorities that climate change poses real financial risks. In the international framework, there are demands on policymakers and supervisor authorities to assume new responsibilities to encourage the transition to a more sustainable economy, mitigating the risk derived from climate change.

4 Financial climate-related measurement instruments

International supervisor bodies adopted a range of action plans to combat climate change in recent years. The most significant one is the Paris agreement, which was one of the first international treaty capable of tackling climate change and still represents a milestone in the process of identifying the requirements to ensure a low-carbon world. The treaty has been signed in 2015 and universally recognized by over 190 countries, both developing and industrialized ones, converging to the achievement of the decrease in world temperature within the limits of 2 degrees centigrade at pre-industrial levels. At the forefront of the fight against climate change, the European Union is committed to playing a leading role in the global fight against climate change. EU leaders aim to achieve an ambitious goal: to make Europe a climate-neutral continent by 2050, launching a series of regulatory policies to sustain, encourage and promote an economy that is careful to environmental and social issues.One of the most important is the EU Action Plan for Financing Sustainable Growth[5]signed in 2018, which goals are to address the financial flows for the transition to a low-carbon economy, to manage the financial risks deriving from climate change and to promote transparency and long-term vision in economic and financial activities. These three macro-objectives are structured into ten main actions involving all the players of the financial system to reduce information asymmetries in relation to climate risks and improve the allocation of capital to sustainable investments, decreasing the risk of "greenwashing". Particularly relevant is the integration of sustainability into prudential requirements, according to which the European Commission aims to incorporate the risks associated with climate change into risk management policies and, at the same time, to calibrate the capital requirements of financial intermediaries under the Capital Requirements Regulation (CRR) and the Capital Requirements Directive (CRD).

The first supervisor authority to contemplate climate considerations in the existing set of supervisory tools was the Bank of England which, through the Supervisory Statement published in 2019, encouraged financial institutions under their authority to include how the risks deriving from climate change could impact their business model in terms of capital. Specifically, banks were asked to indicate a self-assessment of all financial-related climatic risks together with a self-evaluation on how these exposures were computed in their business model.

Given the high exposure of the banking stability to risks related to climate change, the European Commission believes that is important to include sustainability considerations into prudential requirements of financial institutions so as to avoid assets being excessively vulnerable to climate warming risks.

In general, banking sector plays not only an important primary role as a primary lender, facilitating the transition to a low-carbon economy, increasing investment in green projects and promoting new long-term financial sustainability strategy, but also in defending the stability of the economic system as a whole. The European Commission, following the path taken by the Bank of England, recommends to all financial institutions to internalize the climate risks within the financial risk framework. This, in turn, will help supervisors to undertake better regulatory capital requirements for all financial institutions exposed to climate change-related risks. In doing this, supervisory authorities mention both quantitative and qualitative methods to better manage and mitigate climate risks. Among the conventional risk management measurements currently adopted by financial institutions to combat climate change, there are:

- **Climate Stress testing**: in general, the stress tests used by regulatory entities and individual banks are seen as a risk management tool to quantify the proportion of capital needed against any kind of shocks that could affect capital. Particularly, climate stress test is a quantitative test that allows to prove the resilience of the banking or financial system to climate-related risks and therefore refers to adverse events derived from climate change.
- **Scenario analysis**: climate scenario analysis is a simulation technique that is based and applied on a series of historical or hypothetical circumstances, in order to assess the impact of a future event on the financial system, on a particular sector, on a bank, on a portfolio or on a specific product.

  The scenarios must be designed according to conditions that are coherent and achievable, and therefore plausible, and should present alternative paths with respect to the current or expected situation, which implies the consideration of a series of scenarios, relating to different events and degrees of severity, meaningful and feasible.

  Therefore, consistency is required for the narrative of the scenario, which reflects on the main risk factors and related future predispositions based on the different triggering conditions (in this case natural disasters and damages provoked by climate change). Furthermore, the narrative of the scenario should demonstrate the non-contradictory nature of the co-movements of the risk factors and the corresponding reaction of the market logic; in fact, it is essential that the risk factors behave in a manner consistent with the interactions with other factors and that at the same time they include a description of the structure of dependence between the main risk elements and those underlying them.

[5]https://ec.europa.eu/info/publications/sustainable-finance-renewed-strategy_en

Where, on the other hand, the risk factors show contradictory elements, their timely identification is necessary, aimed at identifying new sensitivities. The macro-prudential authorities should ensure that the design of the scenarios is forward-looking, "future-oriented", but that at the same time they should take into account systematic and specific changes in the institution.

- **Sensitivity analysis**: which consist in the stress of a single variable, while keeping the other system components unchanged. In particular, financial institutions should perform assessments at the level of individual exposures, portfolios or business units, at the level of the institution and for specific types of risk, adequately to their complexity in full compliance with the principle of proportionality.

  Generally, when making sensitivity assessments of individual factors, the methods used are represented by historical and hypothetical calibrations or by an approach based on probability distribution.

  According to the historical calibration, the shock measurement is taken in reference to the largest change that the variable to be analyzed immediately, during a period of time between 10 and 25 years; hypothetical calibration, on the other hand, consists in setting a shock value based on an assumption not yet observed in the past. Another method consists in evaluating and obtaining the probability distribution of the major observed changes of the variable, taking into consideration the tail of the adverse events of the distribution.

- **Climate risk scores**: are a set of ratings that measure the exposure to climate risk of companies, portfolios or even nations. These quality scores are based on a series of grading criteria, which can be conducted using both qualitative and quantitative approaches, facilitating the work of banks and supervisors in the assessment of financial climate-related risks. However, climate risk score approaches differ in terms of criteria and methodologies between banks and entities. To sum up, there is no unique way to build up a climate risk scores/ratings but there are a range of approaches developed according to different entity-specific information and context.
- **Climate value-at-risk:** consist of a range of assessments based on the traditional VaRtechnique in order to estimate the maximum financial loss caused by climate change events within a financial entity or portfolio over a specific time frame (Dietz et al, 2016).

  The assessment of the effects of climate change and environmental degradation involves each individual financial institution, regardless of size. An institution, considering its business model and risk profile, may be exposed in a specific market, sector or geographic area where physical and transition climate risks are more likely to materialize. However, the design and the intensity of the measurement methodologies should be conducted according to the nature, size and the significance of the banking institutions' activities.

  While individual institutions are already adopting the mentioned above conventional risk management measures to combat climate change, the role of macro prudential regulations is still debated. We discuss it in the following section.

5 The limits of the current macroprudential regulatory framework

Global economies have made no preparation for the climate crisis outbreak. This event, caused by human activity, drew the attention of many experts and entailed the growing acknowledgment among policymakers that climate change may give rise to financial risk. The green transition policies, towards a low-carbon economy promoted by the 2030 Agenda for Sustainable Development and the Paris Climate Agreement, have accelerated the carbon-intensive sectors' failures. This, in turn, had important consequences on financial stability, both in terms of strong depreciation in some assets and in terms of difficulties in facing losses of income, profits, and jobs (Le Quang and Scialom, 2021). It follows, therefore, that the financial system plays a fundamental role in allocating resources towards a sustainable economy by directing investments towards sustainable technologies and businesses, financing long-term sustainable growth, and helping to create a climate-resilient circular economy (Koumbarakis et al., 2021). In light of what has been said so far, it follows that macroprudential policies should take into account the transformation of the risk' nature to ensure financial stability. In other words, it is necessary to define a macroprudential policy that can prevent and mitigate the financial risks associated with climate change (Le Quang e Scialom, 2021). Indeed, the growing acknowledgment among policymakers that global warming represents a danger to the real economy and to financial stability is driving central banks to promote more sustainable finance, considering climate risks in pursuing their objectives (Koumbarakis et al., 2021).

However, macroprudential policies are characterized by a temporal inconsistency issue, linked both to the impossibility of directly observing its successes in stabilizing the financial cycle and to the time lag between its costs and benefits. Indeed, firsts are immediate while benefits are deferred and difficult to measure. Moreover, this issue is even more emphasized in the case of green macroprudential policies that should aim to protect the financial system from systemic risks related to the transition to a low-carbon economy.

The macroprudential regulation in force and the envisaged instruments are not sufficient to implement a "green" macroprudential policy to mitigate climate risks. Rather, this policy should introduce new measures aimed at including the systemic nature of climate change risk.

A first measure could be to integrate sustainability factors and sustainability and environment, social and governance (ESG) criteria to reduce (or eliminate) the shares of brown companies of a given portfolio. Another measure could be to integrate sustainability-related aspects into the reserve management process by purchasing green bonds[6]. In addition, a useful tool would be to inject liquidity into the markets through repo transactions or agreements linked to sustainability factors. Thus, "green repo operations" would arise, whose repo rates would be favorable if the collateral is green (Koumbarakis et al., 2021).

Another measure would be to reduce banks' capital requirements for green lending or increase them for lending to climate-damaging companies (Quang and Scialom, 2021). Furthermore, the introduction of sector-based leverage ratios improves excessive indebtedness on assets linked to sectors with high emissions and which presents a greater risk of devaluation. Alternatively, the implementation of "credit guidance" policies could divert funding from unsustainable to sustainable sectors. Finally, another tool that can be applied to protect against climate-related financial risks is the activation of the Systemic Risk Buffer (SRB), defined by article 133 of the IV directive on capital requirements (CRD IV) (Le Quang and Scialom, 2021).

In summary, the macroprudential regulation should consider climate risk as a source of the financial system risk and, therefore, should avoid the boomerang effect of a larger increase in the financial climate-related risks.

6. Conclusion

This paper highlights the main features of climate risk and its dangerous consequences both in real terms and in financial terms. Moreover, it investigates macroprudential regulation evolution with a focus on its limits related to the complex nature of financial climate-related risks.

Climate changes represent a danger to the real economy and to financial stability. For this reason, climate risks management has become an important prerogative for the policymakers of the main economies of the world. Financial climate-related risks distinguish themselves fundamentally from conventional financial risk, both in terms of time horizon and in terms of the irreversibility of their consequences. The acknowledgment of macroprudential regulators to rely in their decision-making on improved risk analysis ignores the complexities and interconnections of the climate and financial systems. Therefore, the need to cooperate to define common goals and coherent regulation that take into account new risks such as climate risks arises. In other words, the need for a coordinated policy mix is affecting Central Banks. Specifically, the expectations about their role to contribute to the transition to a low-carbon economy are high. Starting from the consolidated interconnection between financial stability and climate risk, central banks' mandates should be extended to integrate ESG criteria to pursue sustainability goals as well. To do that, they should integrate macroprudential regulation in force with innovative measures aimed at the transition towards a low-emission economy, based on portfolio management policies and on the adaptation of capital requirements from a green point of view. Finally, it would be necessary are also initiatives to raise awareness of the climate change risks of the economic agents involved in the financial system.

References

Alvarez, N., Cocco, A., & Patel, K. B. (2020). A new framework for assessing climate change risk in financial markets. *Chicago Fed Letter, 448*(1), 1-8.

Ascui, F., & Cojoianu, T. F. (2019). Implementing natural capital credit risk assessment in agricultural lending. *Business Strategy and the Environment, 28(6)*, 1234-1249.

Barrot, J. N., & Sauvagnat, J. (2016). Input specificity and the propagation of idiosyncratic shocks in production networks. *The Quarterly Journal of Economics, 131*(3), 1543-1592.

Basel Committee on Banking Supervision (2021a):*Climate-related risk drivers and their transmission channels*, [Online] Available: https://www.bis.org/bcbs/publ/d517.pdf (April, 2021)

Basel Committee on Banking Supervision (2021b):*Climate-related risk drivers and their transmission channels*, [Online] Available: https://www.bis.org/bcbs/publ/d517.pdf (April, 2021)

Baranović, I., Busies, I., Coussens, W., Grill, M., & Hempell, H. (2021). The challenge of capturing climate risks in the banking regulatory framework: is there a need for a macroprudential response?. *Macroprudential Bulletin, 15*.[Online] Available: https://www.ecb.europa.eu/pub/financial-stability/macroprudential-bulletin/html/ecb.mpbu202110_1~5323a5baa8.en.html

Bin, O., & Polasky, S. (2004). Effects of flood hazards on property values: evidence before and after Hurricane Floyd. *Land Economics, 80(4)*, 490-500.

BIS (2018), Promoting global monetary and financial stability, Annual Report, June.

[6]The Central Bank of Switzerland, the Monetary Authority of Singapore, and the Central Bank of China have invested heavily in low-carbon corporate bonds to ensure sustainable management of their activities.

Bolton, P., & Kacperczyk, M. (2020a). Carbon Premium around the World (No. 14567). *CEPR Discussion Papers.*[Online] Available:https://repec.cepr.org/repec/cpr/ceprdp/DP14567.pdf (April, 2020)

Bolton, P., &Kacperczyk, M. (2021b). Do investors care about carbon risk?.*Journal of Financial Economics, 142(2)*, 517-549

Carney, M., de Galhau, F. V., &Elderson, F. (2019). Open letter on climate-related financial risks. *London: Bank of England.*[Online] Available: https://www.bankofengland.co.uk/news/2019/april/open-letter-on-climate-related-financial-risks

Cevik, S., Jalles, J. T., & Goretti, M. (2020). This Changes Everything: Climate Shocks and Sovereign Bonds. *IMF Working Papers, 20(79)*,1-24

Collier, B. L., Haughwout, A. F., Kunreuther, H. C., & Michel- Kerjan, E. O. (2020). Firms' management of infrequent shocks. *Journal of Money, Credit and Banking*, *52*(6), 1329-1359.

Dafermos, Y., Nikolaidi, M., &Galanis, G. (2018). Climate change, financial stability and monetary policy. *Ecological Economics*, *152*, 219-234.

Dietz, S., Bowen, A., Dixon, C., &Gradwell, P. (2016). 'Climate value at risk'of global financial assets. *Nature Climate Change*, *6*(7), 676-679.

European Central Bank (2020), 'Guide on climate-related and environmental risks. *Supervisory expectations relating to risk management and disclosure',* [Online] Available: https://www.bankingsupervision.europa.eu/legalframework/publiccons/pdf/climate-related_risks/ssm.202005_draft_guide_on_climate-related_and_environmental_risks.en.pdf

Gehrig, T., & Iannino, M. C. (2021). Did the Basel process of capital regulation enhance the resiliency of European Banks?. *Journal of Financial Stability*, *55*,100904.

Grunewald, S. N. (2020). Climate Change as a Systemic Risk–Are Macroprudential Authorities up to the Task?.[Online] Available:https://www.ecb.europa.eu/pub/financial-stability/macroprudential-bulletin/html/ecb.mpbu202110_1~5323a5baa8.en.html

Hosono, K., Miyakawa, D., Uchino, T., Hazama, M., Ono, A., Uchida, H., and Uesugi, I. (2016). Natural Disasters, Damage to Banks, and Firm Investment. *International Economic Review, 57(4),* 1335–1370.

Intergovernmental Panel on Climate Change (2014): *Climate change 2014: mitigation of climate change,* Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, [Online] Available:www.ipcc.ch/report/ar5/wg3/.

Intergovernmental Panel on Climate Change (2018): "Impacts of 1.5oC global warming on natural and human systems", in Special report: *global warming of 1.5 ℃,* [Online] Available: https://www.ipcc.ch/sr15/chapter/chapter-3/.

Koumbarakis A.,Obst M., Hirschi S. (2021), The greenness of central banking, PwC, Zurich.[Online] Available:https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3821041

Le Quang, G., & Scialom, L. (2021). Better safe than sorry:: macroprudential policy, Covid 19 and climate change.[Online] Available:http://www.chair-energy-prosperity.org/wp-content/uploads/2021/02/publication2021-macroprudential-policies-covid19-climate_lequang-scialom.pdf

Mallucci, E. (2020). Natural Disasters, Climate Change, and Sovereign Risk (No. 1291). Board of Governors of the Federal Reserve System (US).[Online] Available:www.federalreserve.gov/econres/ifdp/files/ifdp1291.pdf (July, 2020)

Migliorelli, M., &Dessertine, P. (2020). Sustainability and Financial Risks. Palgrave Macmillan.

Network for Greening the Financial System, (2020)."The macroeconomic and financial stability impacts of climate change: Research priorities.", [Online] Available:https://www.ngfs.net/sites/default/files/medias/documents/ngfs_research_priorities_final.pdf

Noth, F., & Schüwer, U. (2018). Natural disasters and bank stability: Evidence from the US financial system.*SAFE Working Paper n.167*, 1-39

Ortega, F., & Taşpınar, S. (2018). Rising sea levels and sinking property values: Hurricane Sandy and New York's housing market. *Journal of Urban Economics*, *106*, 81-100.

Peseta III Report (2018),[Online] Available: https:// ec.europa.eu/jrc/en/peseta-iii

Monnin, P. (2018). Integrating climate risks into credit risk assessment-current methodologies and the case of central banks corporate bond purchases. Council on Economic Policies, Discussion Note, 4.[Online] Available:https://www.cepweb.org/wp-content/uploads/2019/02/CEP-DN-Integrating-climate-risks-into-credit-risk-analysis.pdf

Rayner, J. (2004). Managing reputational risk: Curbing threats, leveraging opportunities. John Wiley & Sons, (Chapter 6).

Stam C., Pommée F., Paniagua Avila E, Han S. (2020), There is no Basel IV solution, leverage on initiated finance and risk optimization.[Online] Available:https://www.capgemini.com/2020/11/there-is-no-basel-iv-solution-leverage-on-initiated-finance-and-risk-optimisations/.

United Nations Environment Programme (2019): "Changing course: UNEP FI and twenty institutional investors launch new guidance to implement TCFD Recommendations", May, www.unepfi.org/news/industries/investment/changing-course-unep-fi-and-twenty-institutional- investors-launch-new-guidance-for-implementing-tcfd/.

Vodenska, I., Aoyama, H., Becker, A. P., Fujiwara, Y., Iyetomi, H., & Lungu, E. (2021). From stress testing to systemic stress testing: the importance of macroprudential regulation. *Journal of Financial Stability*, *52*, 100803.

World Meteorological Organization (2018). Available online at:
https://public.wmo.int/en/media/press-release/state-of-climate-2018-shows-accelerating-climate-change-impacts.