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Climate change and banks: the trade-off between transition and physical risks

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Introduction

Climate change is a worldwide phenomenon with a great expansion in the last two decades. Due to the global massive industrialization that has taken place during the second part of the previous century and to the even faster world population growth, there are critical consequences for our planet and its "health".

Therefore, the core of this situation and its possible implication lies in the relationship between the human being and the environment, among all its sustainability looking forward. In recent years this concept, its progressive worsening and whatever workable solutions have become the central topic of discussion among countries and between governments. There is a substantial difference in the opinions and approaches around the world, even more if we look at developing countries. India, Africa, Sud America, and China seem to overlook the problem and even worse they are actually the main polluting countries, with China at the first place for detachment[1]. On the other side, more developed areas where there are a high concentration of industries and people live in densely populated cities the use of non-renewable energies[2], as fossil fuels, and the dependence on non-biodegradable materials, as plastic, is still heavily present. In an all-new evolutionary period for our planet, also called Anthropocene[3], where more than the 90% of environmental changes are addressed to the influence of the human behaviour, there are more than one alarm bell that rules out the necessity to threat this problem no more as marginally.

[1] The Climate Consulting Selectra has reported that with a total global carbon emissions of 32 billion tonnes of CO2 reached in 2020, China is responsible of almost the 30% of it, up to 9,9 billion tonnes of CO2 (more than double of USA with 4,4 billion), largely due to the export of consumer goods and its heavy reliance on coal (www.climate.selectra.com)

[2] Energy that is collected from renewable resources, which are naturally replenished on a human timescale (include: sunlight, wind, waves, tides, and biomasses).

[3] The Anthropocene website has reported that "Defines Earth's most recent geologic time period as being human-influenced, or anthropogenic, based on overwhelming global evidence that atmospheric, geologic, hydrologic, bio spheric and other processes are now altered by humans". (www.anthropocene.info)

The future survivorship of the world and of all its living beings, as for humans, is in our hands and this is why the main actors in the geopolitical field, like USA and Europe, have done substantial progress to raise awareness about the climate change evolution.

Within this framework and looking to the European countries mainly, central banks headed by the ECB[4] and the Supervisory Authorities[5] have a central role in mitigating the risk tied with the climate change.

The main purpose of this thesis consists in studying how the climate change risk is recognized and which are its financial implications want to be the purpose of this thesis. Starting from the fact that financial intermediaries are highly influenced by this kind of risk and looking at their ability to provide liquidity to firms closely related to a sustainable future, we address the role of Supervision, its guidelines, and recommendations. Furthermore, we focus on how financial analysts identify and distinguish between physical and transition risk linked to climate changes and on the models that are mainly used by banks to address this kind of credit risk.

Finally, the thesis includes an analysis of the ESG funds[6] and the related new possible financial bubble, the so called “Green Bubble".

[4] “The European Central Bank (ECB) manages the euro, frames, and implements EU economic and mainly monetary policy, aimed to keep prices stable. In the practise, the ECB sets the interest rates at which it lends to commercial banks in the eurozone”. (From the EU-site www.european-union.europa.eu)

[5] The European System of Financial Supervision (ESFS) is a network centred around three European Supervisory Authorities (ESAs), the European Systemic Risk Board (ESRB) and national supervisors. Within ESAs there are the European Banking Authority (EBA), the European Insurance and Occupational Pensions Authority (EIOPA) and the European Securities and Markets Authority (ESMA). The ESRB is responsible for macro-prudential supervision and the ESAs for micro-prudential one. (From the EU-site www.european-union.europa.eu)

[6] ESG funds are those funds whose asset allocation mostly includes share and bonds of companies that are evaluated based on the factors of environmental (E), social (S), and governance (G).

1. The central role of banks

Banks, as financial intermediaries, play an essential role in the global economy; they are broadly exposed to almost all types of business and, thus, to the so-called systematic risk[7]. This deep dependence comes from their wide intermediation between different financial counterparties, such as savers and borrowers, households, firms, generic financial entities, and governments.

1.1 The banking system

Commercial banks[8] are no more the core of the banking system, instead investment banks and even more universal banks[9] have had a widely expansion mostly due to the increase of commercial and private investment in the financial markets, where firms that need liquidity for their business sell their securities[10] purchasable from institutional or private investors. In this very simplified framework, banks have not only the role of liquidity providers but also of underwriters[11] and this means that banks must be more specialized and must have all the necessary competences to analyse the financial situation of a company, within its industry/sector, and to address its credit risk.

[7]Undiversifiable risk that affects all the firms in the markets. Also known as market risk.
[8]"Commercial bank mainly performs the functions of accepting deposits and lending loans to the public. It works with the motive of profit earning and does not provide any investment facilities" From www.askanydifference.com
[9] "Universal bank performs the function of different kinds of banks. It serves the parts of commercial bank and mainly of investment banking (function of underwriters and financial advisors), it also provides various other services which include insurance". From www.askanydifference.com
[10] Such as Stocks, Bonds, and derivatives.
[11] "Underwriting is one of the most important functions in the financial world, wherein an individual or more usually an institution undertakes the risk associated with a venture, an investment, or a loan in lieu of a premium. In the securities markets, underwriting involve determining the risk and the price of a particular security, it is a process seen most during initial public offering (IPO)". From The Economic Times' site www.economictimes.com

The banking system in the European countries, as also in the USA, have done an important integration in the economy with the common goal to create a single open market[12].

Banks start to be seen as shock absorbers for the global economy and this has as consequence the closely relation between the banking system stability and the financial markets' one.

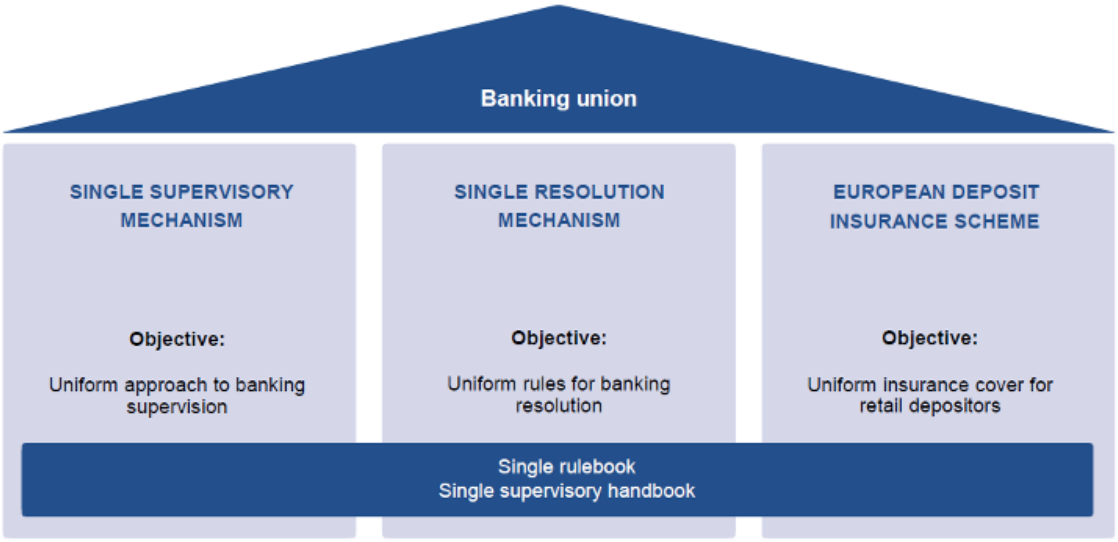


Figure 1 The EU Banking union, www.oenb.at

Furthermore, due to the globalization and the interconnection of economies in developed countries, big banks have become global financial intermediaries and there is a sort of aggregate risk among them, which is also called contagion risk phenomena[13].

[12] "The internal market of the EU is a single market in which the free movement of goods, services, capital and persons is assured, and in which citizens are free to live, work, study and do business. Since its creation in 1993, the single market has opened itself more to free competition by removing bureaucratic, legal and technical barriers; but with EU-wide rules for copyright and data protection". From www.european-union.europa.eu

[13] "The financial system can become more vulnerable to system banking crises as the potential for contagion across financial institutions increases. The many interconnections between different financial institutions, households and businesses allow the financial system to work efficiently in good times, but they can also make the system more vulnerable to bad events being transmitted rapidly across institutions and amplified into systemic events". From www.ecb.europa.eu

Although banks are usually more focused on their home economy and, looking to the European context, each central bank provide the necessary supervision by the home country control principle[14]; the main objective of the EU central bank, the ECB, is a common monetary policy among all member states[15].

This points out how much the integration of the financial system have taken place with consequences to the relation between companies present in the market and banks and the necessity from the latter to precisely extrapolate information about the financial wealth of the former.

In fact, companies which want to enter the capital market have been provided of specific guidelines from their supervisory authority, aimed to address all the relevant information necessary to implement a deeper financial analysis of their core business. Within this aspect, and talking more precisely about climate change risk, at almost all relevant firms have been asked to provide each year the so-called Sustainability Report[16]. This all-new set of information is used by banks to identify their dependence on actual polluting sector and consequently their credit risk related to new restrictions tied to climate changes, like the carbon tax[17].

[14] Under EU regulation, the home country control principle states that, across all the member states, when a business in conducted in a host country, its supervision is on hand of the country of home under the specific legislation and under the specific competent authorities.

[15] EU Member States are 27 in total and being part of them means to maintain the independency and sovereignty as a single state, but to delegate some of the decision-making powers to the shared institutions created by members themselves, so that decisions on specific matters of common interest can be made democratically at EU level.

[16] "Sustainability reporting is the disclosure and communication of environmental, social and governance goals (ESG) as well as a company's progress towards them. The benefit of sustainability reporting includes improved corporate reputation, building consumer confidence, increased innovation and even improvement of risk management. Firms can use established sustainability reporting frameworks such as GRI or CDP, including sustainability performance as part of your overall performance disclosure". From the Center for Corporate Citizenship's site www.ccc.bc.edu

[17] Under a carbon tax, the government set a price that emitters must pay for each ton of greenhouse gasses (GHG) emissions they have done. Businesses and consumers will take steps, such as switching to renewable energies or adopting new technologies, to reduce their emissions and avoid paying the carbon tax. Taxes on GHG come in two broad forms: an emissions tax, which is based on the quantity produced; and a tax on goods or services that are generally GHG-intensive, i.e. gasoline product. From the Center for Climate and Energy Solutions' site www.c2es.org

1.2 Climate change risk

When we think about climate changes, there are very different types of events and implications that can induce widely different impacts both to the banking system and to the financial one.

Risk, in its general specification, needs to be clearly identified and sectorized as precisely as possible using a specific risk management process[18], within the application of dedicated statistical models[19].

In the financial framework this results in a qualified branch of analysts whose goal is the identification and quantification of all possible risk present in the markets. Furthermore, all the financial institutions whose functions are lending money, provide loans or underwrite securities, need to be highly qualified and prepared to conduct a valid risks analysis of all the companies approaching them.

Among all the financial institutions, banks are for sure at the first place in the risk management sector; looking to the actual situation regarding the climate changes derived from human behaviour, they need to be able to identify and differentiate between risk defined as transition risk and the one defined as physical risk. Not only, but they have also to quantify which can be the impact of the two types of risks on firms or financial markets in general. Within this complex process, the main information needed is how much a firm, a financial institution or even a business as a hole is exposed to that specific kind of risk.

Furthermore, it is also necessary to achieve if the future sustainable perspective given by firms and governments are concretely realized within their relative time horizon.

[18] In business, the risk management process is defined as the procedure of identification, monitoring, and managing potential risks in order to minimize the negative impact they may have on an organisation. An effective risk management will help identify which risks pose the biggest threat to an organization and provide guidelines for handling them.

[19] Usually, the main statistical models used are stochastic models, such as AR ("auto-regressive"), MA (moving-average), ARMA, ARIMA; and for analysis of residuals models such as ARCH or GARCH.

1.2.1 Physical risk

As the word suggest, the physical risk is something related to changes of a physical nature, i.e. the risk whose impact is associated to environment's changes and thus to the risk of substantial losses to properties, plants, equipment and the most critical one: human lives.

From an economic and financial point of view these potential huge damages can imply massive reduction of production capacity, important decrease in companies value and in the worst situation, the complete default[20]. There are various examples of physical risk related to climate changes, as the glaciers melting followed by the increase in the sea level and in the possibility of floods, mudslides followed by earthquakes or/and tsunami, enlargement of the ozone hole followed by temperature increase and subsequent possibility of storms, wildfires or/and drought periods.

All of them, from a statistical point of view, given their periodic frequencies and the likelihood of their occurrence address the risk profile of that specific firm, business sector or even of a generic geographical area. When we look at the physical risk from banks perspective, this turns into concrete deterioration of lending facilities, of the access to capital markets and to insurance covers for financial entities whose geographic area of business is more exposed to catastrophic events linked to physical changes.

Some real examples come from almost all the Pacific and Atlantic coast, mainly in countries like California, Florida, and a substantial part of the Gulf States[21], where the frequency and consequently the probability of tropical storms, wildfires and floods start to highly increasing in the last years.

[20] Default, in particular the financial default, is the complete failure of a financial entities to payback its major debt, both principal and interest payments at maturity. Financial default could be followed be total or partial cessation of business activities, which at its turn can induce into bankruptcy.
[21] US States bordering Gulf of Mexico, mainly Texas, Mississippi, Alabama and Louisiana.

In Latin America, especially in Brazil where the rigid internal policy seems to act against the health of the environment with massive deforestation plans, the critic situation leads to long period of drought and periodic sightings of huge wildfires.

In a lot of other countries, especially in developing ones where there is not an efficient green policy, the same problems are taken place with as consequences longer than normal period of cut of agricultural production and on food supply, whose lead to greater poverty and increased difficulty to access the sovereign debt market[22]. In all this places, from a financial point of view, consequences mean the deterioration of properties value, especially of the recovery one[23], or even the cut of some business area where the risk of catastrophic events is become particularly high. Furthermore, for both households and firms, in geographical areas subjected to this critic situation, banks have seen the real estate lending facilities becoming more riskier and some cases also insurance covers against these catastrophic events are avoided, or at least heavily increased in the policy premium[24].

1.2.2 Transition risk

Looking to the second type of risk related to climate changes, it is the so-called transition risk and as the name suggest it is tied to all the green policy actions taken with the goal of incentivize and accelerate the transition to a more sustainable economy.

[22] "The sovereign debt market is a public market for governments to access to public debt, an important way to finance investments in growth and development. However, it is also critical that governments can continue servicing their debt and that their debt burden remains sustainable. Entering into sovereign debt distress is often a painful process which may threaten macro-economic stability and set back a country's development for years". From the IMF's site www.imf.org

[23] The recovery value of an asset is linked to the recovery rate (RR) associated to that specific asset class, due to company's probability of default. Given the RR, the recovery value, also called estimated recovery value (ERV) is computed as RR x Book value (of the specific asset). In case of firm liquidation, the net sum of all assets' ERV is the liquidation value for all the creditors.

[24] The policy premium is the sum that a firm must pay to an insurance company for that specific insurance cover. Higher is the probability and the frequency of a loss (event that cause a damage covered by the policy) higher will be the premium asked.

Obviously, banks have a crucial role in implementing these policies, headed by the central banks, and controlled by the supervisors. Some general examples could be: the previously described carbon taxes aimed to heavily reduce our carbon footprint; energy efficiency requirements for houses, business offices and apartments; use of new technologies aimed to product more efficient renewable energies, like solar panels and wind turbines; use of more sustainable transport means, like electric cars. All these policies are implemented with the common goal of reduction of global emission of GHG and the consequent reduction of the rate of increase in temperature, which is the most critical aspect in the climate change scenario.

Up to now, the transition risk is the one with which the economy has to face up in the shorter time horizon because of the necessity of substantial changes on human behaviour, especially in the consumption preferences, and in the production and use of renewable energies. The latter are facing a big problem, the grade of efficiency in comparison to the fossil fuels because of extremely high cost of production and transport, or even more, due to the difficulty in disposing them[25].

The principal aspect concerning the transition risk, especially for big carbon intensive industries, is the huge costs incurred to make these changes concretely achievable.

So, banks come in place and can be seen as companion in the transition with an intensive, but rational, use of green lending[26]; with the proceed of a rebalancing in pricing and risk monitoring for low carbon companies/financial sectors and for carbon intensive[27] ones.

[25] Solar panel, as like for wind turbines, have huge cost of disposal. For solar panels it is approximately from 20$ to 30$ for a standard panel; for wind turbines approximately from 200 000$ to almost 500 000$.

[26] "Banks, almost of all types up to now, provide green loans or credit lines for clients and projects that contribute to the banks' overall green goals. Eligibility for green loans is usually tied to the compliance with technical eligibility criteria. Such eligibility criteria can be accompanied by taxonomies listing technologies or products that can be considered as green without further in-depth assessment". From the Final Report of European Commission "Defining green in the context of green finance"

[27] Carbon-intensive industries, firms or assets are the ones that are direct or indirect high producer of GHG emissions; or in other word, they have a very high carbon footprint related to its business.

This first briefly analysis of the climate change risk rules out how substantial and intensive could be the exposure of the financial economy to both the types of risk and even more how wide can be the heterogeneity of sensitivity[28] across all the financial sectors. In addition, the way in which these sensitivities, with respect to the specific physical or transition risk, are detached seems not completely exhaustive and objectively applicable. This is probably due to the novelty of the climate change scenario and to the uncertainty about future perspectives. Mainly because respective sustainability policy applied by world governments have been settled only in the last years with high possibility of not being realized in time or even with concrete necessity to be revised among time. Within this scenario, the main effort needed in the climate change risk analysis lie in the capacity from banks and from all the financial institutions acting in the risk management framework to address the most realistic credit risk related to a business in the trade-off between physical and transition risk.

1.3 "Net Zero" banking

Knowing that banks through their lending facilities can facilitate and incentivize the transition to a more sustainable future, it seems that only some marginal actions have been taken and that the transition to a lower carbon economy is far from being realized.

Within the EU area, supervisory authorities and the one regulating the systemic risk, the so-called ESRB[29], has emphasized the increasing correlation between the climate change risk and the general credit risk, precisely it is in the scope of the FSB[30] to achieve a major sensitivity for the markets and all the financial entities concerning this critical situation.

[28] The magnitude and its sign. A sort of coefficient of correlation between that sector and the specific type of risk.
[29] "The European Systemic Risk Board (ESRB) composed by representatives of the national central banks of EU countries, the chairs of the three Supervisory Authorities and the President of the ECB as the Chair. The ESRB cooperates with the ESAs, collects and analyse relevant information about systemic risks and issues related warnings and recommendations". From www.bankingsupervision.europa.eu
[30] "The Financial Stability Board (FSB) is an international body that coordinates EU-national financial authorities in the developing of strong regulatory, supervisory and other financial sector policies". From www.bankingsupervision.europa.eu

This first set of guidelines and recommendations is running among the European Union from the beginning of 2017. Although the last two years there has been a substantial turnround from almost all the relevant banks at that time the general behaviour regarding the transition risk associated with climate changes was negligible, as underlined by the consulting company Oliver Wyman[31] in 2018 with the collaboration of the IACPM[32].

Looking to most recent years and to the supervisory board, the most important and EU-widely established entity, the BCBS[33] has formed the TCFR[34] in February 2020, a special task force in charge of the prudential supervision of the banking system concerning the climate change risk on the global agenda.

If instead, we expand the view to the entire financial economy, the first big step has been made by the FED[35] in December 2020, when it embraces the NGFS[36], which is a worldwide network within, up to now, more than 90 between central banks and supervisory authorities.

[31] A survey on 45 leading banks has found that just the 16% have captured either indirectly or directly the climate risk in the credit rating process, the latter is only 5%. From the paper of the Oliver Wyman consulting company: "Banks and climate change risk".

[32] "The International Association of Credit Portfolio Managers (IACPM) is an industry association composed if 129 financial worldwide institutions across 26 countries to further the practice of credit exposure management". From www.iacpm.org

[33] "The Basel Committee on Banking Supervision (BCBS) is the primary global standard setter for the prudential regulation of banks. It is composed by 45 members comprising central banks and their supervisors from 28 jurisdictions". From www.bis.org

[34] "The Task Force on Climate-related Financial Risks (TCFR) is the special entity within the BCBS that meet senior representatives from internationally active banks to discuss how banks assess and address climate-related financial risks in practice". From www.bis.org

[35] The Federal Reserve (FED) is the central bank of the United States.

[36] "The Network of Central Banks and Supervisors for Greening the Financial System (NGFS) was established in December 2017 at the Paris "One Planet Summit" from eight central banks and supervisors. From that moment the membership of the network has grown dramatically all over the World". From www.ngfs.net

These institutions jointly enhance the global response to the climate changes with the definition and improvements of appropriate lending facilities according to the Paris Agreement[37] with the common commitment to reach a low-carbon economy through the use of green investments.

As consequences there have been, and there are actually, concrete improvements for the banking system to enhance the financial response for the present, but especially for the future "health" of the economy. The first big step has been made in April 2021 when the biggest worldwide banks alliance has been convened, the so-called Net-Zero Banking Alliance (NZBA), from the UNEP-FI[38].

The importance of the Paris Agreement and all the specific responses to the climate change risk escalation given by the Legislation, with a focus on the eurozone scenario, will be seen more in depth in Chapter 2.

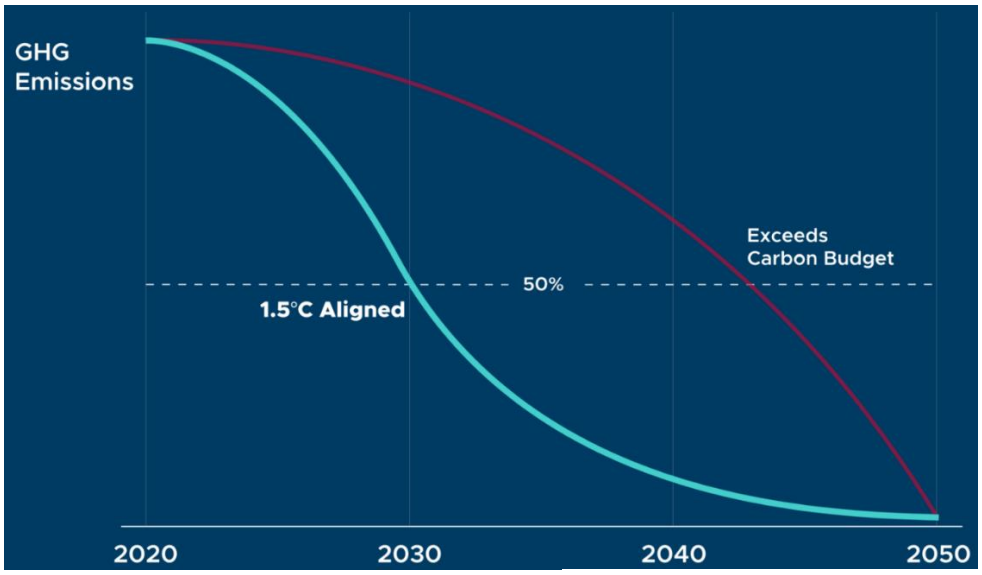


Figure 2. NZBA objective. https://rmi.org/

[37] "The Paris Agreement is a legally binding international treaty on climate change adopted by 196 Parties at COP 21 in Paris, December 2015 and in force from November 2016. The goal is limit global warming to 1.5°C compared to pre-industrial levels". From www.unfccc.int

[38] "The United Nations Environment Programme – Financial Initiative (UNEP FI) is a Unit within the UN Environment Programme's Resources & Market Branch, based in Geneva, Switzerland. It is a partnership between UNEP and a global network of financial institutions (banking, insurance and investment industries)". From www.unepfi.org

The NZBA in a recent successful report have reached a very important milestones, the 100th member has signed the alliance, which now represent over than the 43% of global banking assets across approximately 40 countries; in less than one year it has more than doubled the number of banks signing it (at the beginning it was 43), meaning that the fateful alarm bell has been listen.

The NZBA have been founded with the crucial invitation of the Prince of Wales, within which the first founding banks, whose have settled down the Sustainable Markets Initiative (SMI), have established the FSTF[39] with the common goal of achieving the "net-zero" emission plan.

Looking to the Figure 2 it is enough clear which is the aim and the time to maturity for the NZBA's strategies; however, the specific common commitment relies in the "Commitment Statement" signed from all members and have the following features:

- As the commitment is embraced, banks have to start the transition by aligning its investment and lending portfolios structure with the pathways of net-zero emissions by 2050.
- In the sequent 18 months, banks must define their 2030 targets and adopt specific procedure aimed to achieve them. From 2030 to 2050 there will be additional targets every 5 years.
- The 2030 targets must be focused on banks' most influenced sectors by a GHG emissions scale.
- For every target and for every reviewed mechanism, banks have to publicly disclose all the relevant information and specifically their portfolios' absolute emissions.
- Banks perspective have to be consistent with the UNEP-FI guidelines.

[39] "The Financial Service Task Force (FSTF) operates as an industry sub-group of the SMI and is chaired by Noel Quinn, Group Chief Executive of HSBC. Its members are drawn from the founding banks". From www.sustainable-markets.org

Tied with the Commitment Statement there is the "Guidelines for Climate Target Settings for Banks, where the main principles have been outlined and are the following:

- Banks shall establish and annually publish their specific target (both the intermediate and the long-term) aimed to achieve the Paris Agreement's goals. The same shall be made with their emissions profile linked to portfolios both for lending and investments.
- Banks shall follow science-based decarbonisation scenarios to decide realistic targets both for long and intermediate term; and they shall be consistent with these scenarios every year, reviewing their targets if needed.

The NZBA is only a sub part of an even larger alliance, the so-called Glasgow Financial Alliance for Net Zero (GFANZ)[40] which near future aim is to create a worldwide alliance representative of almost 160 financial institutions, comprising over 70 trillion of dollars of financial assets.

[40] "The Glasgow Financial Alliance for Net Zero (GFANZ) is a global coalition of leading financial institutions committed to accelerating the decarbonization of the economy, or more precisely achieving the objective of the Paris Agreement". From www.gfanzero.com

2. Supervision and relevant policies

Supervisory Authorities and central banks have the upper hand in this intricate process of sensibilization about climate change risk and the right means to achieve a future sustainable economy. Looking to the EU the consolidated Banking Union, guided by the ECB, has conducted a structured integration of the financial economy among all the member states and has established a close cooperation between countries' central banks. The ECB has a precise scope in his strategies of monetary policy, mainly aimed to maintain the financial markets stability. On the other side the ESFS[41] has established qualified institutions to have an eye on all the financial entities present in the markets and aim to harmonise the financial supervisory structure and rules. The ESRB conduct macro-prudential supervision of the EU-financial system as a whole; the ESAs together with national supervisors conduct the micro-prudential supervision for the banking system (EBA), for the insurance system (EIOPA) and for the markets one (ESMA).

If instead we look at the US, the principal actor in both the monetary and fiscal policy is the FED, and it has also the scope of banking supervision. Regarding the financial markets' supervision, instead, there is the SEC[42] that oversees the activities of all market's participants with the goals of investors' protection and markets efficiency.

Given the features of the climate change risk descripted above, its mitigation is at first place for policymakers and supervisors to avoid that it may result in triggered event and consequently the escalation of a systemic risk[43]; thus, their more recent moves in this regard are described as follows.

[41] "The European System of Financial Supervision (ESFS) is a multi-layered system of micro- and macro-prudential authorities that aims to ensure consistent and coherent financial supervision in the EU". From www.europarl.europa.eu

[42] The Securities and Exchange Commission (SEC) is the Supervisory Authority of the financial markets in the U.S.

[43] The systemic risk is the risk that a specific event (trigger event) tied to financial vulnerabilities can induce an all-financial markets collapse.

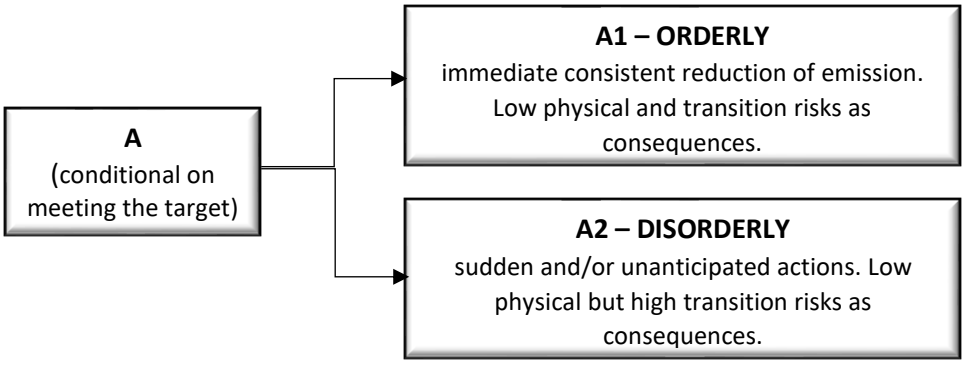
2.1 NGFS climate scenarios

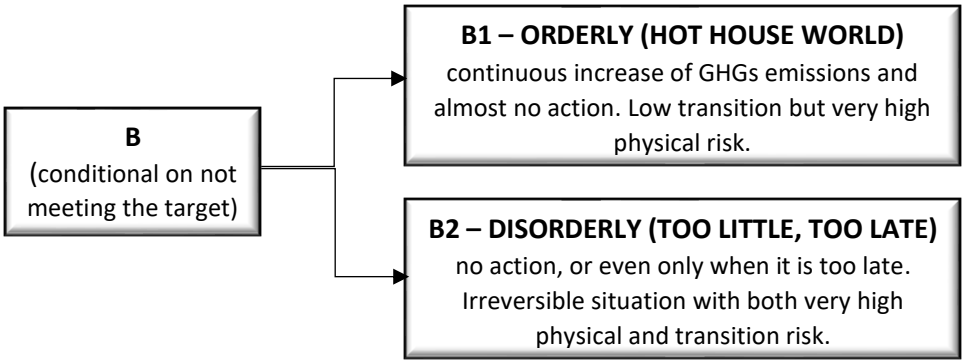
Given that the climate change risk regards mainly a long-term perspective, it is obvious that there can be different possible scenarios associated with year-by-year evolution of the situation and the action taken in concern. For this purpose, the NGFS has released an important report in June 2020 on six possible scenarios and the relative consequences; it is a framework essential for being warned about realistic scenarios and, in fact, it is deeply used by the GFANZ, precisely the NZBA, to follow concrete strategies aimed to be in line with the desired scenario. This concept is linked to the fact that the NGFS encloses a lot of relevant banks, up to almost 66, and the major of them are within the NZBA; this is crucial to be on the same track both in theory and in practice.

These ambitious projects need to take track of more than one factor and their possible evolution on time, thus it has taken almost 6 months to be produced and a several number of competent analysts from the participant financial entities, among all central banks' risk management bodies. The project has required a set of subsequent iterations given different input of factors and the use of several statistical models to address possible estimates of future emission of GHGs (or mainly emissions of CO_2).

The first big distinction has the aim to address four macro-groups of clearly different scenarios due to the conditional input of achieving or not the prospected climate targets.

Objectives tied to the NZBA future perspective, at their turn strongly related to the Paris Agreement. It is also called First NGFS Comprehensive Report and point out the following frameworks:





The scenarios A2 and B2 share the same transition pathways, called disorderly, which means a sequence of actions not commonly followed and without a clear anticipation; as if there is a little, or even absent, cooperation in the attempt to achieve the targets and obviously a persistently high transition risk. The B2 scenario, also called "too little, too late" is the most pessimistic one and it will mean the absolute failure in the climate-related risk mitigation; thus, in fact, it is not even taken in consideration. The B1 scenario, instead, called "hot house world" is the worst possible scenario that has been evaluated, mainly because it is the one more in line with the actual critical situation if no concrete policy and action is taken.

The second step is the distinction of six alternative scenarios under the related representative scenario (orderly, disorderly, hot house world).

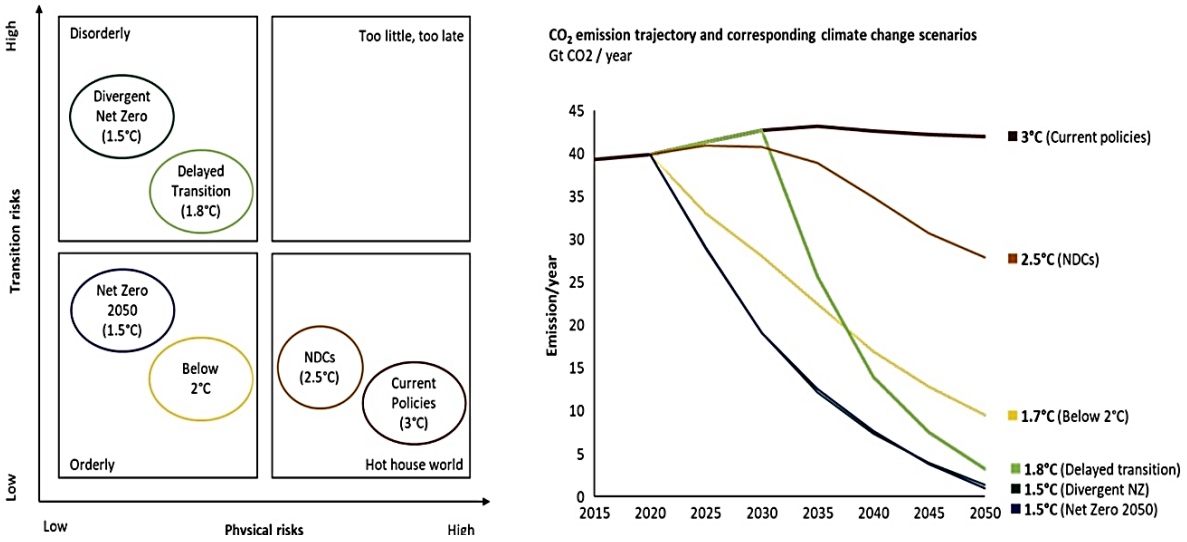


Figure 3. Illustration of Oliver Wyman in a recent paper, *Banks and Climate Change Risk, 15 Nov. 2021*

A previous, more detailed, representation of the three representative scenarios is the following:

- Orderly: assuming that climate policies are immediately implemented and are gradually revised to be more stringent, there can be a "passive"[44] cooperation aimed only to stay "just below 2°C" of increase in temperature around 2050; or a more intensive coordination to achieve the goal of 1.5° in 2050 (Paris Agreement).
- Disorderly: assuming that climate policies are implemented not in a coordinated manner and/or are delayed until 2030, in both cases to keep sufficiently low the global warming, and consequently, the increase in temperature (under the 2°C in 2050) there will be the necessity of a sharper reduction of emission in the next years.
- Hot house world: assuming that only actual policies are maintained and/or are implemented only with the inclusion of NDCs[45] (sort of pledged policies); thus, there can be adverse scenarios with a dramatic increase in global temperature up to 3°C before 2100[46].

Now looking to the Figure 3 we can identify:

1. An orderly and well-coordinated scenario, the *Net Zero 2050,* with as consequences a moderate low transition risk and a low physical one (the more ambitious and optimistic scenario, but probably up to now the furthest from realty!).
2. An orderly but "passive" scenario, the *Below 2°C,* with as consequences quite low transition risk and a moderate low physical one.

[44] "passive" to be understood as a gradual and smooth revision of the policies in time, but with the minimum effort in reducing the emissions.
[45] Nationally Determined Contributions.
[46] The time horizon for targets in climate change analysis is quite different between financial analyst and climate scientific expert, the latter usually look at a timeline up to 2100. This could be a factor in the different response of the financial markets and the possibility that a "green bubble" is forming.

3. A disorderly and not well coordinated scenario, the *Divergent Net Zero*, with as consequences a high transition risk and a low physical one (the more similar to the *Net Zero 2050* one for reduction of emissions in time).
4. A disorderly and delayed scenario, the *Delayed Transition,* with as consequences a high transition risk and a high transition risk and a moderate low physical one (probably the most critical scenario if we look at the transition risk, because of the necessity of drastic reduction of emissions in a more strictly time horizon).
5. A hot house world with only actual policies including pledged ones (the NDCs), the *NDCs* scenario, with as consequences a low transition risk and a moderate high physical one (being at an increase of 2.5°C in 2050 means serious possibilities of periodical catastrophic events due to climate physical changes).
6. A hot house world with absolutely no action except for the implementation of actual policies, the *Current Policies* scenario, with as consequences a low transition risk and a high physical one (the most dramatic and pessimistic scenario, but probably up to now the closest to reality one!).

The first orderly scenario, the *Net Zero 2050,* and the first disorderly one, the *Divergent Net Zero,* aimed to achieve the Paris Agreement of 1.5°C[47] increase of global warming in 2050, are the scenarios for which the NZBA has been convened; and this is why banks are asked to make a great effort in pursuing efficient green lending activities. However, it is not only on banks' hand the concrete possibility to achieve this goal, there is another factor that can influence this transition, which regard the possibility for firms and consumers to deploy carbon-intensive technologies in a limit manner or not, through the development of new technologies and sustainable projects.

This concept is tied to the estimation of CDR[48] parameters for the industries and the NGFS has illustrated the possible orderly/disorderly scenarios as following.

[47] NGFS has estimated that there is a chance of 67% to reach this value in 2050 if the correct scenarios are followed.
[48] Carbon Dioxide Removal (CDR).

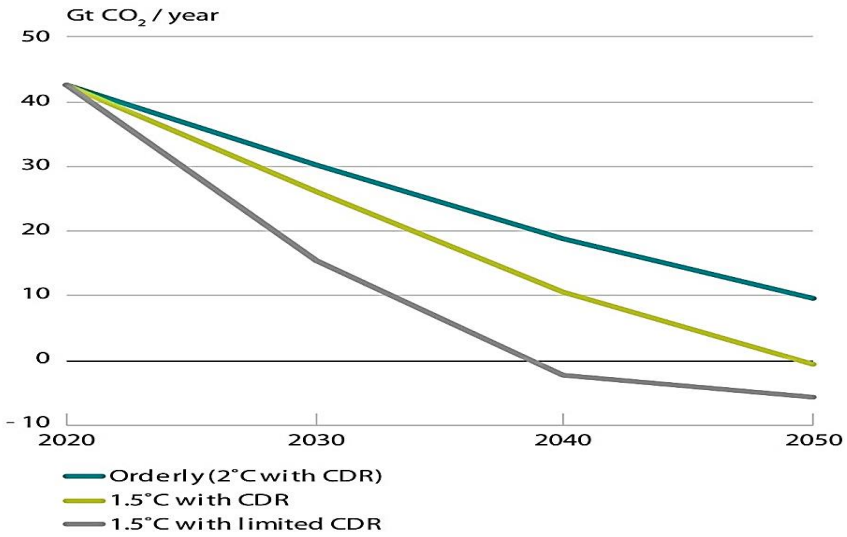


Figure 4. From the "*NGFS Climate Scenarios for central banks and supervisors"* report, June 2020

In Figure 4 the main distinction is between an orderly *Below 2°C* scenario with full CDR availability (the light blue line), in which the possibilities to deploy old carbon dioxide producing technologies are high, thanks to cut of production cost for new more sustainable ones and increased CAPEX[49] on new sustainable future projects. Similar is the orderly *Net Zero 2050* scenario with full CDR availability (the dark yellow line), in which the only difference is the necessity to reduce CO_2 emission in time more strictly than in the previous case to reach the goal (1.5°C). And, finally, the orderly *Net Zero 2050* scenario with limited CDR availability (the grey line), in which the deployment possibilities are low, or even restricted to limited areas, and the necessity to reduce CO emissions in time is sharply to reach the goal.

Similarly happen for the disorderly scenarios, both for the *Divergent Net Zero* and the *Delayed Transition* scenarios with or without limited CDR availability, in which differently from the orderly ones the reduction of emissions in time will be even sharper.

[49] Capital Expenditure (CAPEX). In this case, funds used fpr R&D (Research&Development) of sustainable technologies.

Therefore, which can be the impact on the real economy, on industries and on consumer preferences strongly depend to the scenario we will follow and furthermore to the persistency of a trade-off between physical and transition risks. As address by the NGFS, the main problem lies in the high level of uncertainty around the spreading of the transitions risk, due to the deep interconnection of its transmission channels[50], and in the persistency of knowing gaps in the climate-related risk assessment process, mainly due to fundamental assumptions[51] of models used. The consequence is a wide range of estimated forecasts about the possible magnitude of the impact both for the physical and the transition risk.

Under this uncertainty, the NGFS has release some possible GDP impacts estimates relatively to the three representative scenarios:

- For an orderly scenario: from a loss of 2% by 2030, and similar by 2050 to a maximum loss of 4% by 2100.
- For a Disorderly scenario: from a loss near to 1% by 2030 to a loss of more than 6% by 2050 and a final maximum loss of almost of 10% by 2100.
- For a Hot House World scenario: from a loss of 5% by 2030 to a maximum loss of 25% by 2100 (more than -10% just in 2050), mainly due to physical risk escalation.

2.2 ECB and climate-related monetary policy

Now looking to the banking system and its exposure to the climate change risk, the main actors in providing relevant implications, economy impacts, and related policies adaptation are obviously the policymakers, above all the central banks.

[50] Such as consumer preferences, climate-related monetary policy, changes in adaptation, migration and sentiment, technologies progress, and others…

[51] Such as: migration and adaptation to increase in warming, market frictions, efficient markets hypothesis, perfect rational investors and others..

With a focus on the European Union, we will see how the Central Bank of central banks, the ECB, has address the climate-related risks, the consequences for EU financial stability and how it has implemented the monetary policy. The ECB is in close cooperation with the ESRB and the NGFS to take concrete actions in response to the spreading of climate-related risks; and, precisely, in the distinction of climate changes' relative shocks for the economy due to the trade-off between physical and transition risks.

Through the monetary policy, the first objective is exactly the identification of the risks' nature that can deteriorate the financial stability and secondly how big and persistent will be their impacts relatively to the banking system, the insurance one and the financial markets as a whole.

A first, brief but very interesting, analysis has been made by B.Coeuré[52] on November,2018 at the conference "*Scaling up Green Finance: The Role of Central Banks"* organized by the NGFS where in his speech he has address the ECB's monetary policy strategies to mitigating climate-related risks. The first step for policymakers lies in identifying the nature of the risk, which then specify its possible impacts. Given the features of the climate change risks and the distinction between physical and transition risk the former affect mainly the insurance sector through the erosion in assets value, recovery value and collateral pledged value. The latter, instead, is mainly linked to changes in policies, restrictions in emissions and technological improvements and, thus, affects more persistently all the financial markets.

Knowing these aspects of climate-related risk, it is fair to identify its possible impacts as supply-side shocks[53], which means reduction of production capacity that led to a cut of output and on the other side an increase in inflation rate.

[52] Benoit Coeuré, member of the executive board of the ECB.

[53] Usually, policymakers distinguish between two main risk-related shocks categories: demand-side shocks and supply-side shocks (as for the climate change risk).

The difficulties in managing this kind of shocks lie in the ability of central banks to achieve an equilibrium in this trade-off between inflation stability and output one, even if the priority will be the price stability in any case. I this context a first big problem could rise, the different time horizon of the monetary policy and the climate changes one, because usually the former is usually more short-term, and policymakers' actions do not persist for a long period in the economy. The latter instead has a medium-long term horizon normally, but without previous efficient responses to its changes it has been hugely shortened and the actual framework is completely different.

Up to now, the ECB has done important changes in its behaviour toward climate-related risks and an active implementation of a relative monetary policy has been started.

In any case, as addressed by the NGFS, many of the present and future actions taken from central banks and supervisors depends on our capacity to reduce emissions, thus to the scenario we will follow.

Another interesting speech is the one made by Y.Mersch[54] on November,2018 at the workshop discussion *"Sustainability is becoming mainstream"* where he address some important aspects of both the macroeconomic impact and the financial stability one. For the former the ECB has identified as key driver the inflation rate in its objective of price stability, with reference from increasing inflation in energies prices. For the latter instead the description is quite more intricate and depends on different factors.

Three main sources of risk related to climate change risk have been pointed out by ECB analyst in collaboration with the FSB-TCFD[55], the ESRB and other EU-central banks.

A briefly view of their implication is the following:

[54] Yves Mersch, member of the Executive Board of the ECB.

[55] "Financial Stability Board's Task Force on Climate-Related Financial Disclosures (FSB-TCFD) is established in December 2015 and consist of 32 members from across the G20, chaired by the founder of Bloomberg L.P. and its goal is to develop recommendations for more effective climate-related disclosures to support informed capital allocation". From www.fsb-tcfd.org

1. The physical risk exposure, to which is majorly affected the insurance system followed by the banks one. More in depth, the risk of losses in loan value rises when the exposure to physical risk for the borrower rises, particularly when the loans are covered by physical collateral. When banks conduct international banking services and are heavily interconnected with other EU-banks or governments, this can result in a spreading of the physical risk on all the economy, similarly to a systemic risk phenomenon.
2. The transition risk influences in the asset pricing adjustments mainly due to restrictive policies, in examples the bans for some category of diesel cars in city-centres and the house heating restrictions.

   All these gradual restrictions induce a deterioration of balance sheets for important industry sectors where the CDR availability is very low.
3. The euphoria for green investments, especially for private investors whose are the first affected by miscalibration in pricing the risks. This concept is tied with the formation of possible markets bubbles and will be better described in the last Chapter.

Now looking to the ECB direct changes on its activities, it is necessary to underline the fact that main central banks have built up monetary policy portfolios aimed to achieve price stability with less constrains.

With respect to the principle of market neutrality[56], ECB is entitled to purchase assets under the APP[57] and, in fact, can directly contribute to pursuing the climate-related goals.

[56] "Market neutrality principle posits that corporate bonds purchased under the ECB's 270 bn euros CSPP should be made in a neutral way: they should reflect the overall eligible market to ensure they do not distort the relative pricing of securities". From www.omfif.org

[57] "Assets Purchase Programme (APP) is part of a package of non-standard monetary policy measures initiate in mid-2014 to support the monetary policy transmission mechanism and provide the amount of policy accommodation needed to ensure price stability". From www.ecb.europa.eu

A substantial part of this policy portfolios is purchased from the public, under the so called PSPP[58] and reach almost the 80% of the total; the remaining part instead is purchased from the corporate sectors, under the so called CSPP[59].The ECB in 2018 has already purchased up to the 24% of "green bonds" of all the green universe from the former for a total of 48 million euros, and up to 20% of "green bonds" of all the green corporate bond underwritten from the latter for a total of 31 million euros.

The benchmark used to compute spread and yield curves in the green bonds market is given by the EIB, which has been the first to issue a green bond in the world, in 2007.

How to distinguish if an activity is sustainable or not and consequently if a security is "green" or "brown" is at the centre of latest discussions in the supervisory framework and for policymakers. Thus, the necessity of an efficient and universal taxonomy and its harmonization is ruled out. The taxonomy is strictly tied with the ESG criteria and thus to specific sustainable thresholds, crucial for supporting the investors to move their capital in realistic green activities. It is in the scope of the EU commission, under the principle of transparency, to avoid the so called "green washing", which is the reason under possible green bubbles.

In the last year, on July 2021, the ECB has released a more detailed report regarding the climate-related risks and the financial stability. Thanks to a deeper knowledge of the risk profile and to the recent more effective collection of climate changes-related data, the Banking Union is embracing the climate stress testing methodologies. Within the framework of banks stress testing and the incorporation of the climate change risks, other entities come in place and have a crucial role in developing the correct methodologies in conducting a climate-related stress test.

[58] "Public Sector Purchase Programme (PSPP) includes nominal and inflation-linked central governments bonds, bonds issued by recognised agencies, regional and local governments, international organisations and multilateral development banks located in the euro area". From www.ecb.europa.eu
[59] "Corporate Sector Purchase Programme (CSPP) to support market liquidity and collateral availability in the market". From www.ecb.europa.eu

The FSB-TCFD, the ESRB, the NGFS, the IMF[60] and the BIS[61] have joined the ECB with the scope of conducting at least 18 different climate-related stress testing to the financial sector, mainly for banks and insurance companies in the EU.

The IMF together with other world central banks has planned also other 15 stress testing initiatives to cover almost all the world economy, but up to now most of them have an undetermined date of publication and have not yet implemented an effective methodology.

One of the first big problems is tied to the uncertainty in the trade-off between physical and transition risk, and even if some complex models have taken both in considerations, the better way to address the more realistic exposure to each kind of risk is to maintain and analyse them separately. Another possible misleading input is the time horizon, because usually it is of one to three years for conventional stress testing. Thus, it needs to be stretched to be consistent with the 2100-time horizon of the climate scenario analysis, with latest extension up to a 30-year horizon climate-related stress testing framework.

Due to the heterogeneity of climate-related impacts on a wide range of sector and thank to a more granular data collection the approach followed in the stress testing framework is a top-down approach from the sector-level to the firm one (see Figure 5 below).

[60] "The International Monetary Fund (IMF) was established in 1944 by 44 founding members to build a framework for international economic cooperation. Today, its membership embraces 190 countries". From www.imf.org

[61] "The Bank for International Settlements (BIS) was established in 1930 by 63 central banks, representing countries around the world that together account for about 95% of world GDP. Its goal is to support central banks to pursuit monetary and financial stability". From www.bis.org

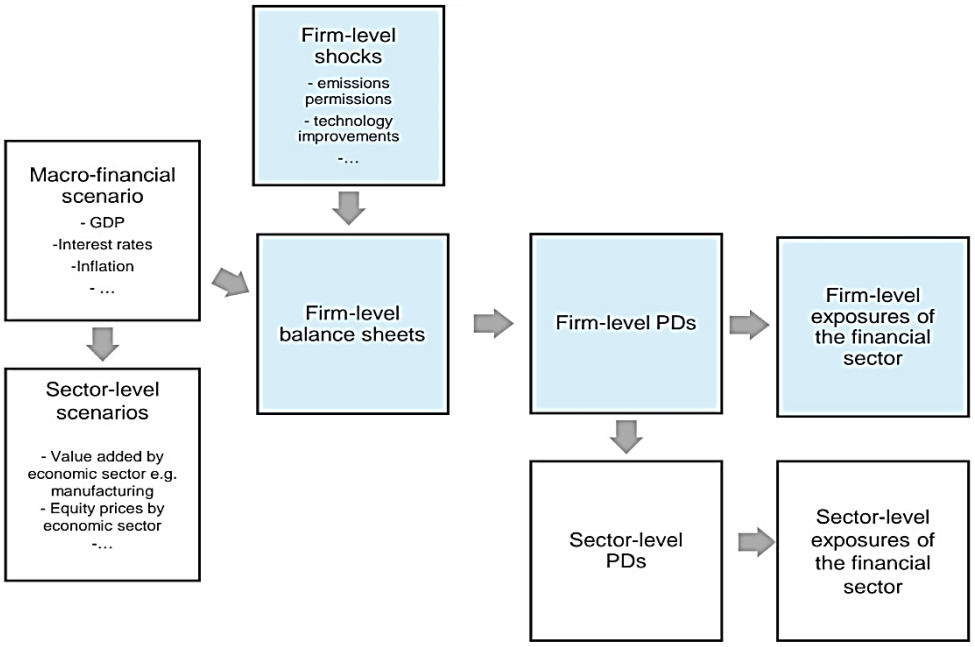


Figure 5. From the ECB "*Climate-related risk and financial stability"* report, July 2021.

As shown in Figure 5, the approach address from the firm-specific PDs[62] to the aggregate sector-level PDs and to the whole sector exposures, or even to the single-firm exposures.

These is the same approach used by the ECB in its first climate-related stress test where it integrates the effects of both the physical and the transition risk. The first important information pointed out is that the physical risk tied to catastrophic events can affect more the debt structure of the firms and, instead, the transition risk tied to policies restrictions on emissions can affect more the marginal cost and revenues of all the firm with a high carbon footprint. Looking to the PDs in a 30-year time horizon it shows that, in a hot house world where no further implementation of more restricted climate policies has been made, by 2050 the median will be almost at 15%. In a disorderly scenario, instead, there will be short-term cost for the transition a bit lower than in the orderly scenario and in the long period the median of PDs will rise to 5% by 2050. Obviously, as in the scope of a stress test, the scenarios taken in consideration are the worst (disorderly, hot house world) and not the most optimistic one (orderly).

[62] Probability of Defaults.

Finally, as ruled out from the ECB the industry-sectors toward which the banking system in EU is more exposed is the electricity/utility sector and the real estate one, that count for more than the 50% of the total impact to banks. The following Figure 6 shown what is previously described as outputs of the ECB climate stress test.

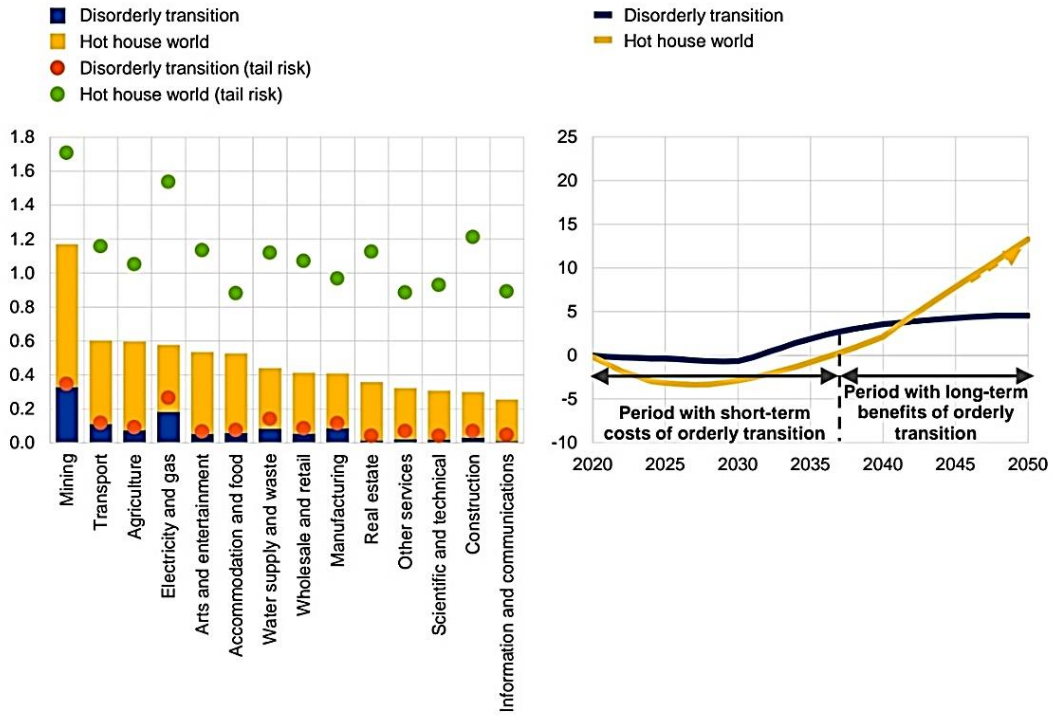


Figure 6. From the ECB "*Climate-related risk and financial stability"* report, July 2021.

2.3 Bank of England stress tests

One of the most advanced central banks in the field of climate-related stress tests is of course the Bank of England (BoE). Looking to the specific actions taken by the UK national Central Bank, it is necessary to distinguish between two main type of stress testing procedure implemented by the BoE.

The first is the more "traditional" one, conducted annually for all the financial intermediaries, within banks, insurance companies and investments funds in the UK framework and aimed to address their solvency profile.

The second instead is less common and not run from all the EU central banks and is the so-called BES[63]. This particular type of stress testing is generally conducted to explore the exposure profile of all the UK banks to risks not commonly attributed to the financial cycle, such as the liquidity risk, the persistency of particularly low interest rates or, as in this case, the climate-related risk.

The first ever biennial exploratory scenario conducted by the BoE regarding the exposure of UK banks to the climate change risks is the so called CBES[64], aimed to address their resilience to both the physical and the transition risks under the relative pathways followed and enhance the climate-related risk management process.

Differently from traditional stress tests, the CBES is intended to be a sort of guidelines, or learning exercise, for both the BoE itself and banks, thus it is not implemented to point out specific capital requirements or concrete actions to be taken immediately by participants.

Another key difference is that it is the first stress test conducted for banks and insurance companies together and will be used to highlight possible critical issues toward which the CBES' participants in strictly cooperation with the FPC[65] and the PRA[66] will plan further approaches.

As done by the NGFS with its possible alternative scenarios, the CBES uses three possible scenarios under relative emissions pathways for a 30-years horizon and consistent with the NGFS representation.

The first two scenarios are implemented mainly to explore the impact of the transition risk, the third instead the impact of the physical risk, and are the following:

[63] Biennial Exploratory Scenario (BES) conducted by the BoE since 2017.
[64] Climate Biennial Exploratory Scenario (CBES) implemented for the first time in June,2021 and will be published in May,2022.
[65] "The Financial Policy Committee (FPC) was established in 2013 as a sub-group of the BoE and identifies, monitors and takes action to remove or reduce systemic risks in the UK financial system". From www.bankofengland.co.uk
[66] "The Prudential Regulation Authority (PRA) was established in 2013 as a sub-group of the BoE and prudentially regulates and supervises financial services firms". From www.bankofengland.co.uk

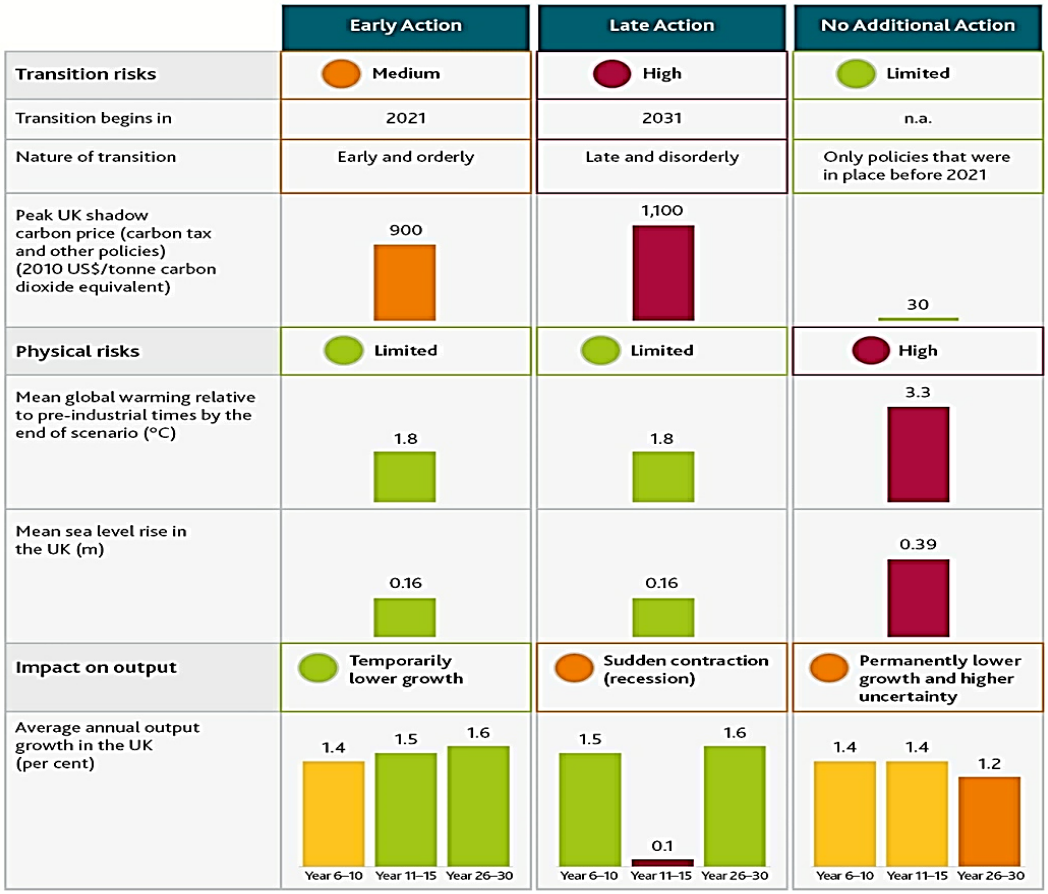


Figure 7. From the BoE "*Key elements of the 2021 Biennial Exploratory Scenario: Financial risks from climate change"* report June,2021.

- *Early action:* as the name suggest, it is the scenario in which the pathways followed is an immediately implementation of climate-related policies and gradual but intensive further restrictions on GHG emissions. This is the most optimistic scenario and can be compared to the representative *Orderly* scenario described by the NGFS, thus achieving the net-zero by 2050 and limit the global warming to 1.8°C relatively to pre-industrial levels. As consequences there will be a contraction of the GDP in the first half due to the huge effort for the transition, but lately there will be the integration of efficient green investments in the economy and consequently expansion of GDP growth.

- *Late action:* it is the scenario more like to the representative *Disorderly* scenario described by the NGFS, in which climate-related policies and further restrictions are implemented only from 2031 but with the final objective of net-zero emissions by 2050 and global warming limited to 1.8°C. As shown on Figure 7, the consequences, is a temporary expansion in GDP growth until 2031 where more intensive restriction policies are implemented and, thus, there will be the disruption of the global economy growth (recession[67]) for a period not well define up to now. Finally benefits start to be realised in the last years and the GDP growth return to the expansion level (+1.6% annually) as in the *Early action* scenario.
- *No additional action:* as for the *Hot house world* scenario described by the NGFS this is the worst possible scenario we could follow, under which no responses are taken in mitigate climate-related risks and impacts. Only current policies already implemented remain for the entire period with critical consequences for the global warming, which could reach an increase up to 3.3°C by 2050 or before, relative to pre-industrial levels. In a chain reaction the glaciers melting, the sea level and the frequencies of floods and wildfires starts sharply increasing with consequent critical escalation of the physical risk.

  Looking to the economic impacts, they are probably even worse, because industries are no more able to manage the carbon prices, whose are extremely low, and the GDP growth will be permanently lower with continue deterioration in the future.

As shown in Figure 7, the CBES is tied to the carbon price evolution related to the scenario followed; this is a fair association due to the deep interconnection between policies aimed to reduce GHG emissions and the cost of emissions[68] .

[67] An economic period with a huge depression in GDP for at least two consecutive quarters.
[68] Cost of carbon dioxide emissions implicitly increased by the necessity of investment in sustainable technologies and reduction of emissions, due to restrictions of climate-related policies gradually implemented.

Due to the positive correlation between costs and prices if the former increases the same will do the latter. Therefore, as climate-related policies increase restrictions in time, the same will do the carbon price; the higher is the slope of the former, the higher will be the one of the latter. In this case the carbon price can be seen as a representation of the level of transition toward net-zero and, as in the CBES, it is address as a shadow price[69] of GHG emissions (see Figure 8).

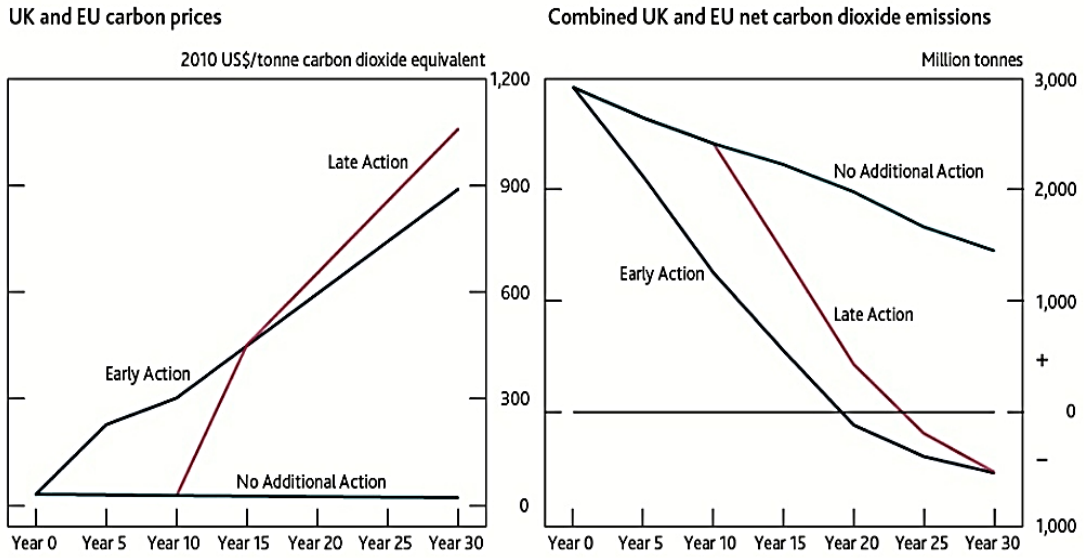


Figure 8. From the BoE "*Key elements of the 2021 Biennial Exploratory Scenario: Financial risks from climate change"* report June,2021.

According to the CBES scenario followed:

- from a carbon price of approximately 30$ today to almost 900$ by 2050 in the *Early action* scenario (a gradual increase).
- from the actual 30$ carbon price to over 1000$ by 2050 (approximately 1100$) in the *Late action* scenario (a stepper increase).
- From 30$ to almost the same or even worse, lower carbon price by 2050 (emissions of 992 megatons per year by 2080).

[69] Shadow price to be intended as the marginal abatement cost of an incremental tonne of emissions or as US dollar/tonne of carbon dioxide equivalent.

The goal of the BoE's CBES is the disclosure of climate-related exposure at sector/industry level, given each participants climate-related credit risk and their cross-sectional interconnection.

3. The climate-related credit risk assessment

Going more in depth in the risk management process regarding the climate changes risk, the first step for banks and supervisors in its mitigation relies in the fairer identification and classification of climate-related risk drivers. The high heterogeneity in sensitivities across different geographical areas, between sectors, and firms addresses the necessity of a granular exposure mapping jointly with a common methodology for credit risks assessment.

An interesting overview of this process and its implementation is given by the report of the BCBS released in April 2021[70]. The main critical aspect, as the Supervisory Authority explain, is the difficulty to incorporate the climate-related risks into specific categories of financial risks, which could be further analysed with standard risk management approaches. The fact that this typology of risk comes from factors uncorrelated with the financial economy and markets, and their magnitude strictly depends on future perspectives induces a high level of uncertainty around its recognition. Banks and supervisors are making continuous implementations of new reliable standards to achieve quantifiable financial metrics for climate-related risk drivers and their transmission channels. As previously described in Chapter 2, the macro distinction in the climate change framework is between physical and transition risk, and usually, given their specific features they are treated separately. However, as addressed by the NGFS in its scenario analysis, there is a persistent correlation between the two kinds of risk, even more if we look to future perspectives and consequent climate responses. The high uncertainty around the concrete reductions of GHG emissions and the achievement of future targets of global temperature increases are features related to the transition risk mainly, even if consequent scenarios of limited CDR availability will induce a higher probability of catastrophic events and thus a higher exposure to physical risk drivers.

[70] The "Climate-related financial risks – measurement methodologies" published by the BIS (Bank for International Settlements) ww.bis.org

On the other side, the consequences of actual non-linear acceleration of climate changes and relative frequency of disruptive events are pushing policymakers and firms to take preventive actions in the emissions field aimed at reducing their future exposure to the physical risk and avoid huge losses in assets. If we look to banks perspective, due to the heterogeneity of their counterparties and consequent climate-related risks sensitivities, the necessity of a high degree of granularity in exposures mapping is crucial. For banks and supervisors, the quality of estimated banks' exposures strictly depends on data availability, methodologies used for measurements and models assumptions. As described in Figure 9 below, the risk management process tied to climate-related risk drivers is quite untangled and necessitate a substantial cooperation between firms, banks, and supervisors to achieve a fairer estimation of exposure metrics.

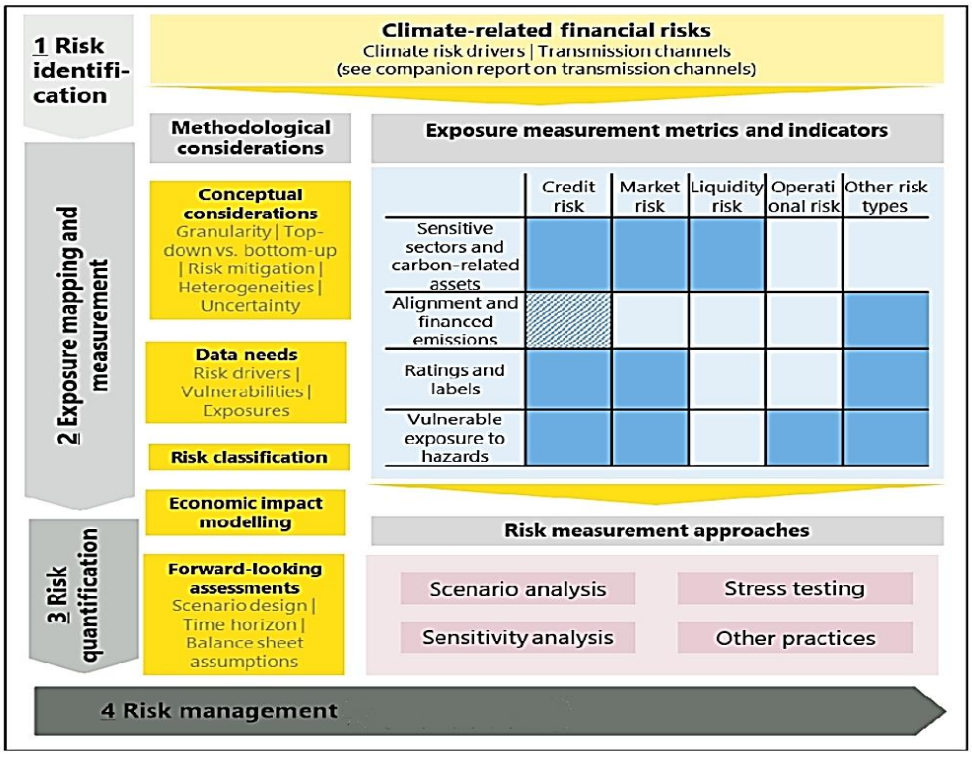


Figure 9. From the BCBS "*Climate-related financial risks – measurement methodologies"* report April,2021.

Banks are enrolled to implement a micro prudential climate-related risks differentiation to achieve the financial vulnerabilities of their counterparties relative to the specific risk driver and develop reliable metrics for their credit risk, mainly.

Therefore, in the banking framework a bottom-up approach is preferred to a top-down one[71] and although this approach increases the computational complexity and data granularity, it avoids possible miscalibrations in allocating the correct parts of aggregate risk to the single sector components.

3.1 IAMs and the Social cost of carbon (SCC)

The most commonly methods used by banks and supervisors in the climate change framework are the so-called IAMs (Integrated Assessment Models) due to their high applicability to climate-policies problems, even if they present some weaknesses. These models, that cointegrate approaches from economic growth modelling and climate change ones, are mainly focused on impacts of the transition risk drivers to the economy growth but do not capture the impacts of catastrophic weather events or even release too much approximative projections of physical risk exposures. This problem is tied to the uncertainty around realistic measurements of losses derived from extreme events, mainly due to magnitude unpredictability and the absence of similar precedents, which at its time induces underestimation for the tail events. Therefore, many models deployed assign a zero probability to these events or at most consider only some chronic extreme events, as happens for the IAMs. These models have been used broadly among banks and supervisors and each of them have different features, the NGFS in developing its climate scenario analysis used a GCAM[72] (a partial equilibrium model that integrates the relation between five different systems: climate, economy, energy, water, agriculture and land use) plus two general equilibrium models[73].

[71] There is not a standard definition of top-down and bottom-up approaches, the ones given by the BIS is the following: "top-down approaches start by dimensioning risk at the general, or aggregated, level and then attribute the aggregate measure of risk to component parts. Conversely, bottom-up approaches dimension risk at the component level, aggregating these individual measures of risk up to provide a consolidated view of risk". www.bis.org

[72] Global Change Analysis Model (GCAM). (jgcri.github.io)

[73] REMIND-MAgPIE model (pik-potsdam.de) and MESSAGEix-GLOBIOM (docs.messageix.org).

These two models are widely used in the banking system due to the key assumption of the general equilibrium effects, for which the interaction between firms or agents in the markets is persistent and an economic shock will affect the behaviour of both directly and indirectly correlated entities.

A general interesting representation of IAMs structure is given by Oliver Wyman in its recent paper with an adaptation of the REMIND model, which is the most commonly deployed within the IAMs, from the PIK[74] (Figure 10).

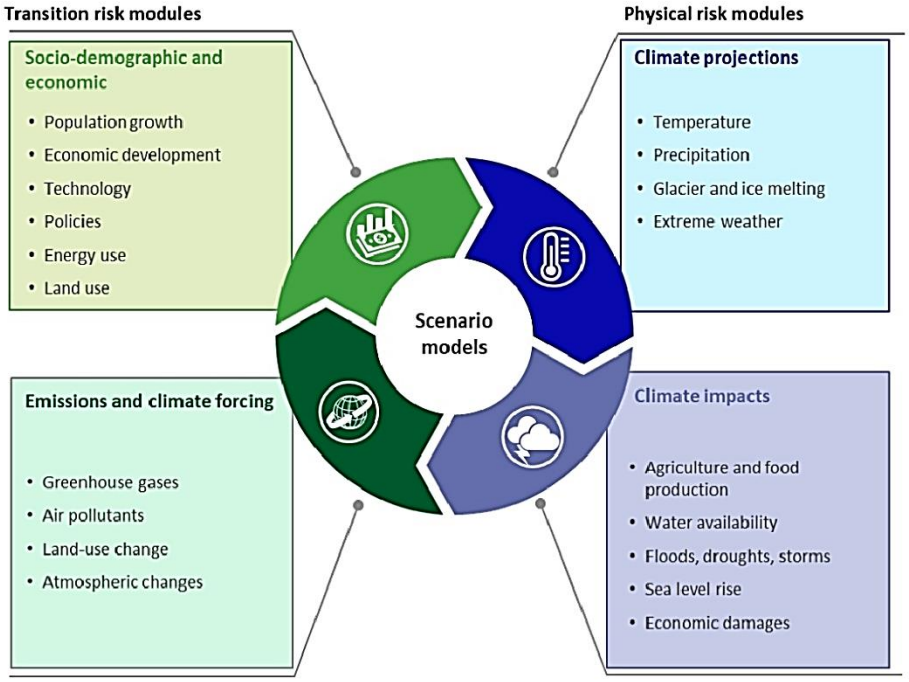


Figure 10. From an adaptation of Oliver Wyman in its recent paper, "*Banks and Climate Change Risk",* 15 November 2021.

As shown in Figure 10 above, the IAM defined as REMIND has both physical and transition risk drivers and thus relies highly to the general equilibrium effect. However, many of the IAMs outputs are used as inputs for other integrated models where policymakers and supervisors cointegrate more models with different assumptions to achieve a better estimation of the correlation between different drivers and across different sector, both directly and indirectly exposed.

[74] Potsdam Institute for Climate Impact Research (PIK), Germany.

Given that the main aim of IAMs is to project the exposures to the transition risk mainly, the direct indications obtained from scenarios representation is the so-called SCC, social cost of carbon, at its turn positive related to the carbon tax.

The SCC can be seen as a common indicator, or *price*, used within a damage function to achieve a fairer estimation of damages to the economy due to climate changes. In literature it is define as the "estimate of damages' discounted present values from an additional ton of CO_2 equivalent emitted at a certain moment in time"[75]. This indicator is widely used by policymakers to implement valid carbon taxes and it leads them to future changes in emission restrictions aimed to maintain the carbon price near or equal to the SCC. The green finance could in a sense reduce the SCC and consequently the pressure of future carbon taxes; however, the actual upward slop of term structure of carbon prices and the global economy expansion push up the exposure to the transition risk and to catastrophic event, with an indirect implication in investments. Therefore, investors and firms have been asked to hedge against their climate exposures in the short-term to increase real economy resiliency toward climate-related risks and avoid future huge increases of the SCC.

If we look at the investments perspectives, banks have to provide a fairer discount rate tied to the SCC depending on counterparties sensitivities to climate changes and their climate risk aversion. An agent with a higher risk aversion perceives a high cost of future bad outcomes and thus will pay a costly insurance for their mitigation, therefore the discount rate will be lower respectively to a less risk averse profile and the SCC will be higher. On the other hand, with an increasing probability of extreme events the insurance covers will be costly, the SCC increases, and the discount rate attached decreases (common discount rate used by banks and supervisors is up to now in a range between 3% to 6%). A more detailed analysis of them has been made by Giglio et al.[76] first in 2015 and then in 2020 in his studies of climate-related insurance policies.

[75] Definition of the SCC by Auffhammer in 2018, professor of international sustainable development at the university UC Berkeley, California.
[76] Climate changes researcher at the Universidade Federal do Estado do Rio de Janeiro.

The author aims to achieve a suitable term structure of discount rate in the long run to be used for actual policies' discounting. Given a 100-years horizon, Giglio et al. addressed a fairer discount rate for real estate policies subjected to a substantial exposure to climate-related risks near to 2.6%. Later he addresses this value as an upper bound that should have been used by banks and policymakers in hedging strategies.

3.2 SSPs and RCPs

A key role in the scenarios analysis through the use of integrated assessment models (IAMs) is represented by the core set of pathways provided by researchers and policymakers to achieve outputs for climate modelling and emissions estimation. The first set is composed of five different Shared Socioeconomic Pathways (SSPs) that are generated using six IAMs (Figure 11 below).

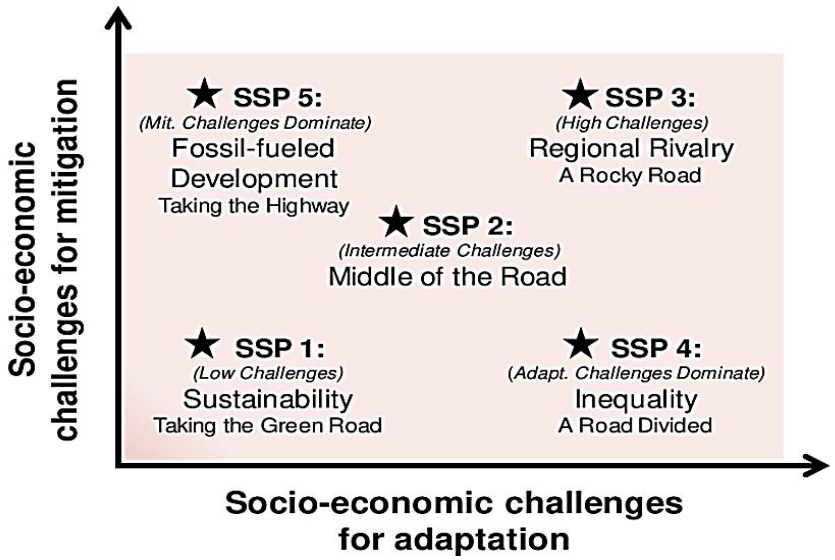


Figure 11. From Marc A. Levy representation, "*Five Shared Socioeconomic Pathways",* researchgate.net.

As shown in Figure 11, the pathways are the following (from the worst to the best in efforts made):

- SSP5 (*conventional fossil-fuelled development*): the actual dependence on fossil fuels persists and increase over time, with consequences of high economy growth and failure in climate-related risks mitigation.

  Low necessity of adaptation in consumer preferences but a critical high level of challenges in mitigation (*taking the highway*).
- SSP4 (*inequality in responses*): some developed economies united in efforts toward new sustainable technologies deployments and other lower-income economies that struggle in the road to net zero. A relative low level of challenges in mitigation but a critical high level of adaptation in consumer preferences (*a divided road*).
- SSP3 (*fragmentation at regional level-rivalry*): almost all local governments implement different climate-related policies with increases in nationalism behaviours and focuses on internal energy independence. Probably the pathways with the higher challenge in both adaptation and mitigation (*a rocky road*).
- SSP2 (*middle of the road*): there are traces of coordination among countries but with uneven developments of international climate-related targets and not common standards in green finance. Both the mitigation and the adaptation level are relatively medium.
- SSP1 (*sustainability*): the optimal level of global coordination is achieved and a gradual shift towards net zero is implemented. It's the best challenge for a low level both in adaptation and mitigation but requires important initial well-coordinated efforts (*taking the green road*).

The second set of pathways is composed by six different Representative Concentration Pathways (RCPs) mainly focused on the actions taken to reduce emissions and consequent changes in GHG concentration trajectories (Figure 12 below).

It is used by the IPCC[77] to produce its "Synthesis Report" aimed to provide firms, investors and mainly banks with information for measuring the physical risk possible impacts.

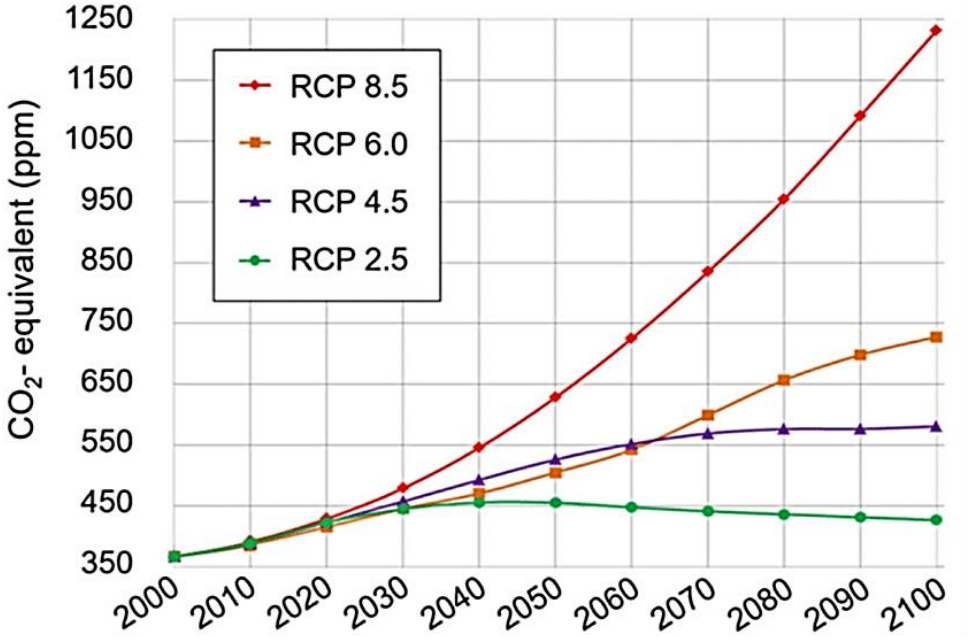


Figure 12. From Aaron Smith representation, "*Four Representative Concentration Pathways",* researchgate.net.

As shown in Figure 12, the principal RCPs are the following (from the more to the less stringent):

- RCP 8.5 (*baseline scenario*): tied to the *Hot house world* scenario of the NGFS, where almost all the global economy remains strictly dependent on fossil fuels and no further restrictions on emissions are implemented, rising throughout the 2100 targets (global temperature rises of 4/5°C above the preindustrial level). As consequence the CO_2 concentration in the atmosphere increases from approximately 420 ppm[78] in 2020 to almost 1250 in 2100.

[77] "The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change" www.ipcc.ch and its last report is scheduled to be released in September 2022.
[78] Part per million (ppm).

- RCP 6.0 (*first intermediate scenario*): likely to a disorderly delayed transition, emissions of GHG reach their peak in 2080 whereas the CO_2 concentration in the atmosphere increases gradually up to almost 750 ppm in 2100, only by 2150 concentration start to be constant (global temperature rises of 2.5/3°C).
- RCP 4.5 (*second intermediate scenario*): likely to a disorderly but not delayed scenario, emissions of GHG reach their peak in 2050 whereas the CO_2 concentration in the atmosphere increases even more gradually than RCP 6 and reach approximately 570 ppm in 2100 and after remains constant (global temperature rises of 2/2.5°C).
- RCP 2.6 (*most stringent scenario*): likely to an orderly scenario where important efforts are taken to reduce GHG emissions to zero by 2100 and whereas the CO_2 concentration in the atmosphere reaches a peak in 2030/2040, then starts decreasing to the actual minimum and remains constant (global temperatures rises under 2°C).

The acronyms 8.5, 6.0, 4.5 and 2.6 refer to radiative forcing level at the end of the century (2100) and are expressed with Watts/m^2. After the objectives released by the Paris Agreement two more recent RCPs were released: RCP 1.9 and RCP 3.4. The former was developed to be consistent with the Paris Agreement goal (1.5°C above the preindustrial level). The latter, instead, was developed as a more realistic alternative to the RCP 2.6.

Usually, the SSPs and the RCPs are deployed in combinations but not all the sets are feasible given specific IAMs used, thus some of the cointegration of SSPs with RCPs should not be taken in consideration (see Figure 13 below). As shown, there are combinations of RCP 6.0 and RCP 8.5 with all five SSPs that constitute baselines for mitigation policies (over these levels of radiative forcing we should never go by the end of the century to avoid brutal climate scenarios and huge increments in global temperatures, thus policymakers use them as a “starting-point”).

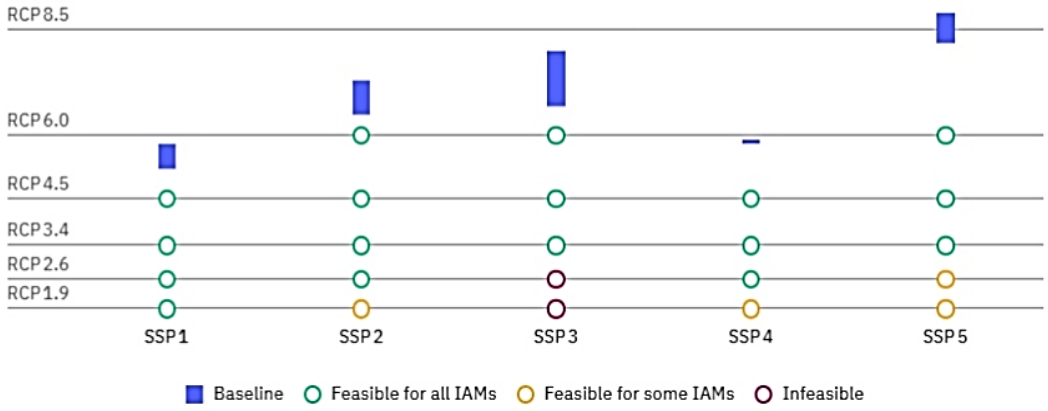


Figure 13. From climatescenarios.org/primer/mitigation/ by the SENSE Toolkit.

A consistent number of combinations are feasible for all IAMs and others only for some IAMs. Instead, the combinations of RCP 2.6 and RCP 1.9 with SSP3 are infeasible for all IAMs and could be excluded.

In the next section, instead there will be a deeper focus on banks' exposure indicators, recently released by the ECB, and on how banks are facing this multiple risk mitigation through a granular exposure mapping and the implementation of relative hedging strategies.

3.3 Bank credit risk assessment and exposure mapping

Looking at banks' exposures to climate-related financial risks, as previously described in Chapter 1, they play an essential role in the global economy and thus they are broadly exposed to almost all types of business and, thus, to the so-called systematic risk. This deep dependence comes from their wide intermediation between different financial counterparties, such as savers and borrowers, households, firms, generic financial entities, and governments.

Furthermore, it is fair to say that the green lending facilities highly used in the last years push-up the banks' exposure to both the physical and the transition risk and almost all typical banks' assets are included (loans, mortgages, and commercial/sovereign debt). In a general climate changes framework banks are mainly exposed to the energy sector and to the real estate one. The latter is the one with the higher concentration of physical risk drivers that increased substantially the banks' credit risk. The main driver of physical risk in the real estate sector is the so-called SLR (sea level rise) and in some recent analysis of geographical areas characterized by an increase of SLR, it has been addressed that houses' price is decreased from 7% to approximately 15%, depending on increasing probabilities of floods and relative time horizon[79]. In some cases, it is even worse, for example for the costal areas in Florida it has been addressed a reduction of 16/20% in pricing properties, mainly due to changes in households' behaviour[80].

Therefore, for banks the first step to assess their credit risk exposure to physical risk drivers is a granular exposure mapping of all the NFCs[81] present in their portfolios. An important set of these data has been released by the ECB in collaboration with Four Twenty-Seven[82] and is collected in the Anacredit dataset[83], which cover up to 89% of all banks credit within the EU[84]. The study is conducted for the main NFCs in the euro-zone (approximately 1.5 million firms) and achieves relevant aspects regarding physical risk drivers, such as wildfires and drought periods which affect mainly the Southern Europe and floods which instead affects mainly the Nord and the Central Europe. Within this framework, the ECB addresses that almost 30% of banks credit risk exposures is directly attributed to firms with one or more physical risk drivers.

[79] Bernstein, Gustafson and Lewis (2019).
[80] Keys and Mulder (2020).
[81] Non-financial corporations (NFCs).
[82] A Moody's affiliate firm based in California that collects and measures climate-related physical risk drivers.
[83] Anacredit dataset is an ECB project started in 2011 aimed to collect information about individual banks' loans and provide a granular EU credit risk mapping.
[84] "Climate-related risk and financial stability" ECB report, published in July 2021.

The key indicators for flood damages and relative credit risk exposures are represented by the probability and the intensity. The latter is featured with the sequent correlation: one metre flood equal to approximately a damage of 30% in value for commercial buildings. Therefore, the probability of a flood of one metre or more is around 59% for NFCs with an average annual probability of flood lower than 0.1% (low); around 73% for NFCs with an annual average of 0.1-0.2% (quite low); and finally, around 82% for NFCs with an average annual probability between 0.2% and 1.0% (considerable high). Generally, banks exposure to NFCs with flood as risk driver (10.6%), but also wildfires and drought have a relevance (4.8% and 12.2% respectively).

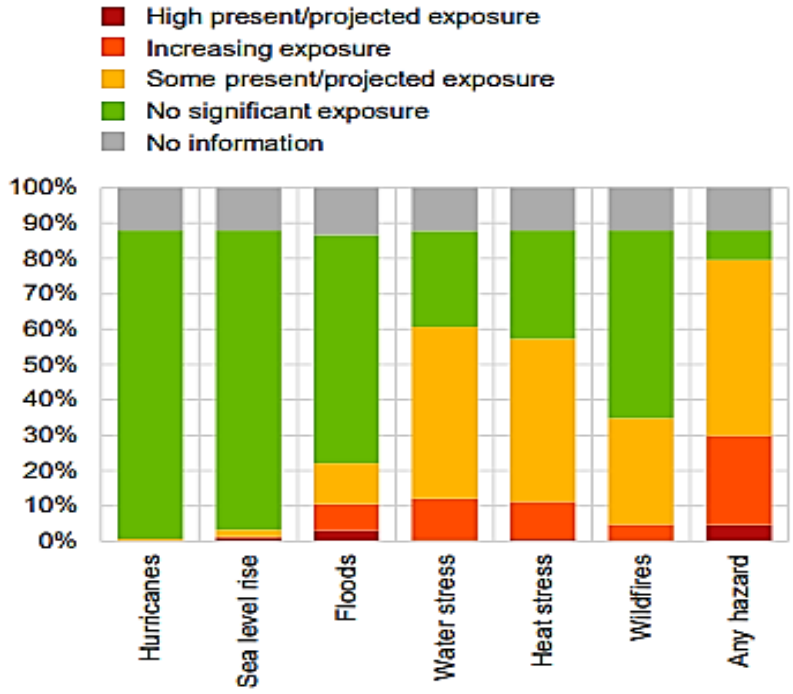


Figure 14. From the ECB report, "*Climate-related risk and financial stability",* July 2021.

As shown in Figure 14, the ECB through the use of cointegrated IAMs has addressed the level of banking exposures with a 20-years' time horizon (up to 2040) and it has warned that over 80% of the EU banking system is exposed to at least one physical risk driver.

However, projected exposures strictly depends on future implementation of climate-related policies aimed to cut GHG emissions, thus lower will be the reduction, higher will be the exposure to the physical risk.

Another interesting feature of the EU banking system exposures is the different geographical distribution among its Member States and the relative exposures to one or multiple physical risk drivers (see Figure 15 below).

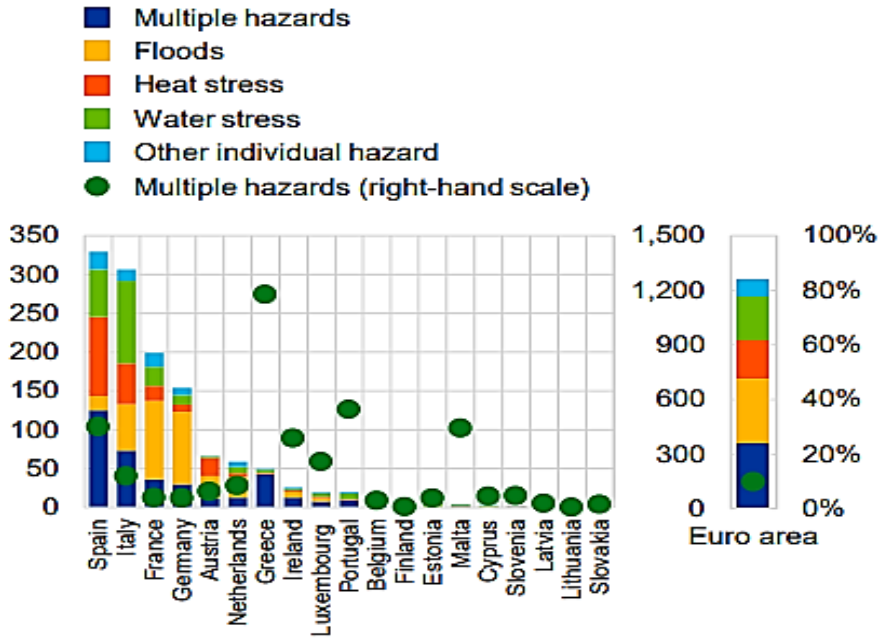


Figure 15. From the ECB report, "*Climate-related risk and financial stability",* July 2021.

As shown in Figure 15 (left panel, left-scaled in billions of asset cap., right-scaled in share of total banks loan) there is a substantial differentiation of banking exposures to physical risk drivers for each of EU Member States, respectively:

- Spain and Italy are the mostly exposed to heat and water stress, which could induce to drought periods, and have a total of 330 and 305 billion euro of bank assets exposed to physical risk drivers, respectively.
- France, Germany and again Italy are the mostly exposed to the floods risk, however the first two have a total of "only" 200 and 150 billion euro of bank assets exposed.

If instead we look to combinations of physical drivers, the major Member State exposed to multiple physical risk drivers is Greece for detachment, with a total of bank assets exposed up to almost 1200 billion euro. Following, there is Portugal with a total of 550 billion euro in assets exposed to multiple drivers and then Spain and Malta at the same level, with a total of approximately 400 billion euro exposed. Furthermore, the ECB has addressed that almost 10% of all EU banks exposures to the physical risk is due to more than one driver and even if over 70% of the EU banking exposures to physical risk drivers is addressed to few large banks (25 in total), they are not in a critical situation thanks to their high degree of diversification and capitalization (only 7% of total loans is directly exposed). On the other side, the ECB has warned that relatively small EU banks are the ones with the high degree of vulnerability toward physical risk drivers, in fact, it is stated that their median of exposure is six times the one of larger banks.

After depicting the banks physical risk exposures, it is important to take a focus at the transition risk drivers and relative exposures within the EU banking system. As previously described in Chapter 2, the key indicator of transition risk drivers is the gradual level of restriction to emissions settled by the policymakers, thus it is essential to assess banks credit exposure to sectors subjected to this evolution in climate-related policies, the so-called CPRS[85]. As addressed by the ECB, more than half of total loans amount to NFCs is represented by CPRS and mainly to the housing sector and the energy one (36% and 8% of total loans to NFCs, respectively). A fair indicator of banks exposure to transition risk drivers is the portfolio emissions intensity, computed as the ratio between emissions and firm revenues weighted by the bank loan, and even if it is less than 1/3 in comparison to firm specific emissions intensity, it is consistently influenced by the utility sector, usually high leveraged. In fact, banks exposure to this sector jointly with the manufacturing one (also highly leveraged) is only of 11% of total amount of loans portfolio, but they represent almost 2/3 of total portfolio emissions intensity and this addresses possible vulnerabilities (see Figure 13 below).

[85] Climate Policy-Relevant Sectors (CPRS).

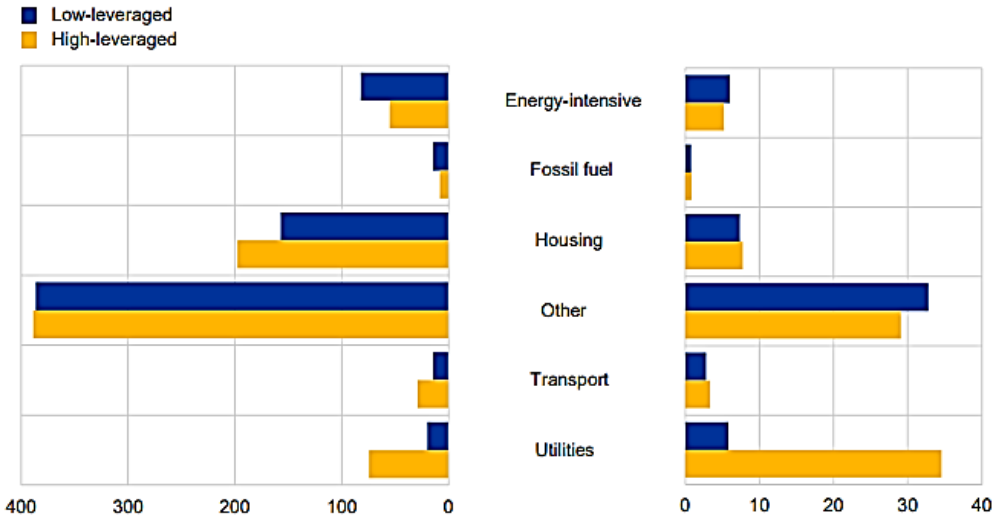


Figure 16. From the ECB report, "*Climate-related risk and financial stability",* July 2021.

As addressed by the ECB, the major banking exposures to the CPRS is due to loans portfolio rather than to securities one (54% and 39% respectively) and thus the main exposure is tied to sector vulnerabilities in repaying the debt rather than the securities repricing concern. However, as for the physical risk, the uncertainty around future perspectives plays a key role for the credit risk assessment toward the transition risk and therefore the substantial heterogeneity in sensitivities within CPRS could induce in a not fairer assessments, increasing the probability of tail events. A fundamental indicator of the transition is the carbon price, linked to the SCC, and the ECB has conducted a more granular exposure mapping relied to it. Starting from a baseline scenario (i.e. no further policies implementation) the analysts has estimated the transition-risk-adjusted default probabilities for each NFCs within the EU and study the evolution in probabilities of tail events due to changes in carbon price. The standard measure used is EUR/ton of CO_2 emitted and with an initial gradual implementation of restrictions the carbon price is increased by EUR 100/ton of CO_2 emitted, leading to an increment on probabilities of tail events up to 13% (99th percentile). In case of necessarily more stepper restrictions, the carbon price could rise of EUR 250/ton of CO_2 emitted, leading to an important increment on probabilities of tail events up to 40% (99th percentile).

Finally, as addressed by the ECB, it is fundamentals both for firms and banks to almost immediately implement climate-related policies to avoid a future transition risk escalation and the possibility for this risk to lead to systemic stress.

In the last Chapter, there will be a focus on the markets response to the climate changes risk and the possible formation on a green bubble within the ESG funds sector.

4.“Green Bubble”

Financial markets play an essential role in providing information about the investors’ behaviour toward the climate changes risk and given the high amount of liquidity injected for green investments, it is necessary to achieve the markets sentiment to address which is the ongoing climate risk pricing. In the following section there is an analysis of relevant firms with ESG scores aimed to underline if the transition and the physical risk are priced on their securities. Therefore, different samples with different approaches toward climate changes are analysed and the formation of possible “green bubbles” is extrapolated.

According to the BIS, there is the possibility that a financial bubble[86] is inflating in the green finance framework. Mainly due to the high level of uncertainty around climate-related risks and to the necessity of implementing a more efficient and common taxonomy, the consistent injection of liquidity for green investments is scaring the market-makers[87]. In a recent BIS speech, “Transparency and market integrity in green finance”[88], Agustin Carstens[89] explains how important is to achieve more specific standards for financial institutions and investors to access the correct green profile of assets and a more structured taxonomy to maintain markets integrity.

The fact that policymakers and supervisors are implementing actions oriented to improve green investments does not mean that firms future sustainable perspectives will be achieved and the consequences of such a huge expansion in green finance are misleading.

[86] A bubble both financial or economic is recognised when prices rise over and over the intrinsic/fundamental value of the securities. It is a phenomenon very hard to be previously detected.
[87] Market-makers are both firms and investors that provide liquidity to markets by taking profit from bid-ask spreads.
[88] BIS speech of 2 June 2021 at “The Green Swan Conference-Coordinating finance on climate”, Basel.
[89] Agustin Carstens is the General Manager of the BIS.

As explained by Carstens, due to investors demand of green investments, the market has replied by issuing new green labelled products with a total amount of more than $38 trillion in ESG funds in less than two years. The main uncertainty around these new products is their rating related to the sustainability and to effective future benefits of such investments. As addressed by the BIS, a substantial part of actual green labelled bonds is not fairly correlated with an effective reduction of emissions or CDR availability of the relative firm. This means that the process of validation and certification of green labels is not equal around the world, and this can induce investors to rely on not fairly indicators of environmental benefits.

The necessity of more specific and common standards, like new *green* KPIs[90], to achieve a fairer securities rating in green investments is triggered by the phenomenon of *green-washing*, which can induce carbon-intensive firms to find malfeasance ways to achieve the green label rating on their assets and obtain relative high liquidity. In 2020 there was a critical overvaluation of clean energies and in the long run this could lead to markets distortions, but it seems that a first awareness about it has been made in 2021 when the clean energy valuation returns almost to the long-term average (Figure 17).

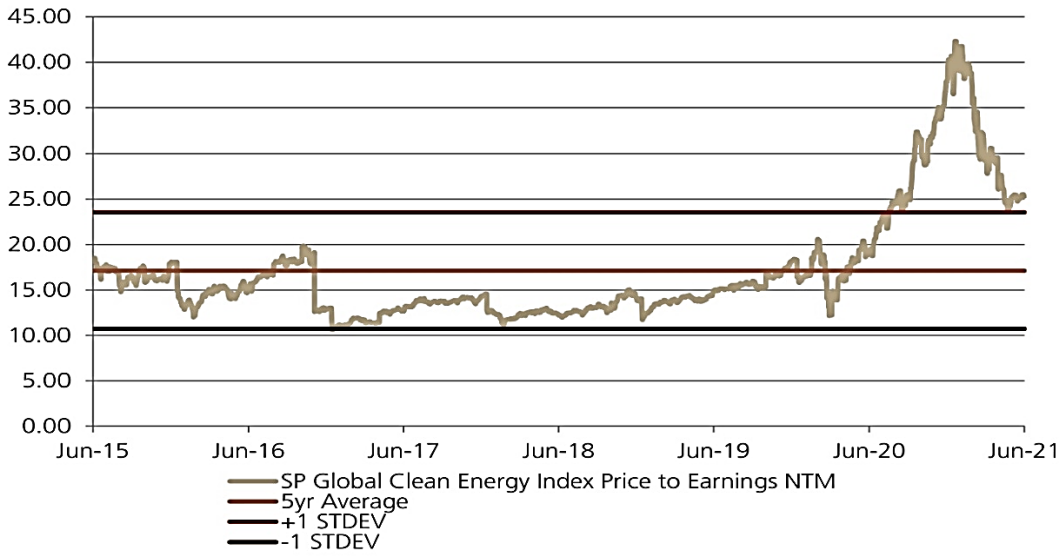


Figure 17. From the UBS "*Revisiting the green bubble"* research, Bloomberg data, June 2021.

[90] The Key Performance Indices (KPIs) are used to compare firms within the same sector or even that conduct the same business.

According to Bloomberg, the S&P Global Clean Energy Index has given to its tracked companies an overvaluation up to 41 times their expected profits, doubling in value in less than one year (comparing to common US-blue chips which have had a valuation at 23 times their earings in the same period).

4.1 The U.S. market

The United States financial market accounts for more than the 54% of the global markets' capitalization and therefore, it can be used to represent the world financial markets. A research aimed at addressing statistical indications about a possible green bubble is *"Disclosing green bubble indications in the U.S. renewable energy industry"*[91] by M. Jorgensen and H.O. Dyhrfjeld. Through time-series analysis and the use of autoregressive models the authors check for possibile indications of price bubbles in the US markets, where they divide in three macro-samples (green, grey and black) the energy industry. The first encloses all US firms that are actually considered sustainable and not in necessity of CDR technologies deployment, thus, they are not in the field of transition to net zero. The second sample instead, the grey one, encloses firm mainly exposed to the transition risk and that are actually in a period of renovation, thus they are the one more subjected to possible future benefits from renewables, sort of *green* premium. The last sample, the black one, encloses firms that are almost all carbon-intensive, the opposite of the green sample, thus strictly dependent from fossil fuels.

For all the three samples Jorgensen and Dyhrfjeld have conducted analysis of firms KPIs, such as P/E ratio, Debt/Equity ratio and the EBIT/Revenue ratio[92], under the main approach and an analysis of firms stock returns under the alternative approach.

[91] Copenhagen Business School.

[92] P/E ratio = market share price/Earnings per share (EPS); Debt/Equity ratio = Tot. debt/Tot. shareholders equity; EBIT/Revenue ratio = EBIT – margin (operating profit).

Both the analysis are conducted in the time period 2009-2019 on a quarterly basis and all the companies choosen are listed or on the NYSE or on the Nasdaq[93]. The main problem depitcted in this research is the difference in samples sizes, due to avaiablility of total green firms in the markets, which leads to the use of 10 to 20 firms in the green sample and of almost 50 to 70 firms in the black one (an average of 25/30 in the grey one instead).

The analysis of samples' KPIs reveal the following patterns (Figure 18).

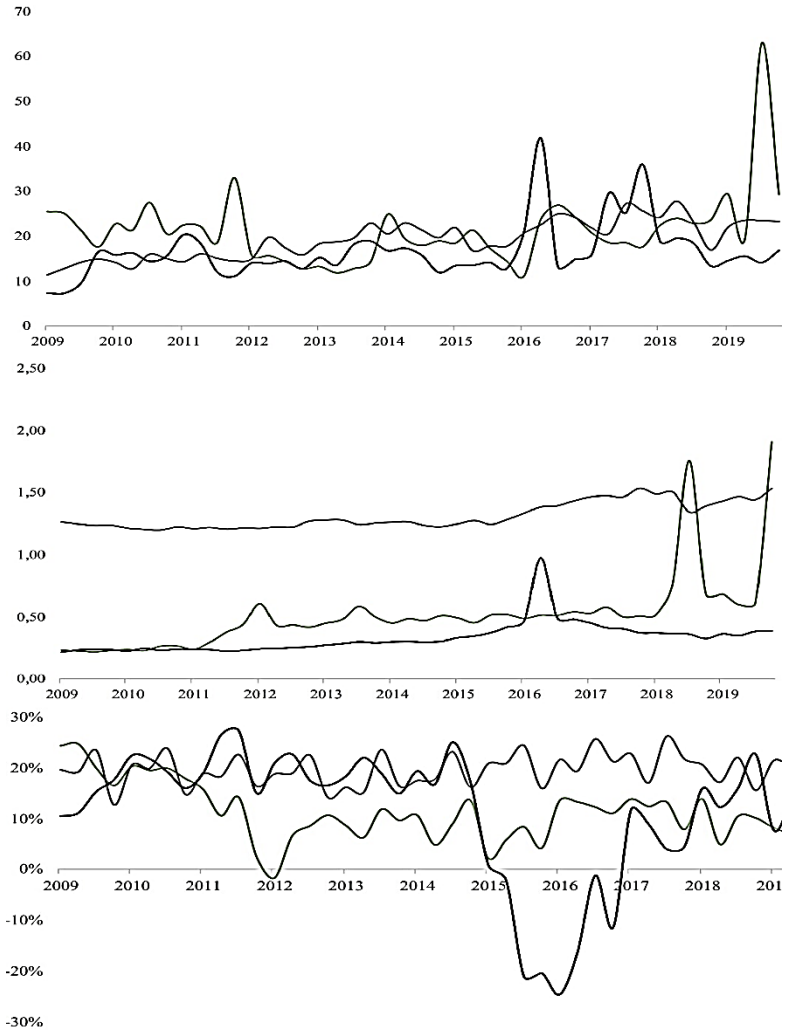


Figure 18. From the master thesis "*Disclosing green bubble indications in the U.S. renewable energy industry"*, Michelle Jorgensen, Helle Oye Dyhrfjeld, Copenhagen business school, 15 May 2020 (P/E ratio first panel, Debt/Equity ratio second panel, EBT/Rev. ratio third panel).

[93] NYSE (New York Stock Exchange) and Nasdaq (National Association of Securities Dealers Automated Quotations).

Relatively to each sample considered:

- *Green sample*: a volatile P/E ratio during the period 2009/2019 with a huge spike at the end of 2019 (first panel in Figure 18) due to policy incentives to green investments and changes in investors behaviour (some companies P/E ratio rise above 200 triggering for a bubble[94], more on them in the following). Fortunately, the high uncertainty of future benefits on these firms pushes it down at the beginning of 2020 to a more normal value, near to 30 (above industry average). Looking to the Debt/Equity ratio, also called financial leverage[95], generally the energy and utility sector requires extensive investments, especially for the renewable energies, which required high R&Ds in the last years (average of 0.7 to 0.9). For the green sample (second panel in Figure 18) the value remains on average until the end of 2018 and 2019 when there are two important spikes above 1.5 and which seems to persist in 2020. Finally in the analysis of the EBIT/Revenue ratio (third panel in Figure 18), also called profitability ratio[96], it is strictly tied to policy supports and the marginal costs and revenues for energy/utility sector. In the case of renewable energies its changes depend on changes in these variables, thus the green sample value is quietly affected and is usually below average.
- *Grey sample*: a more stable P/E ratio (first panel Figure 18) during the period and in line with the industry averages (10-20 for the energy sector, 15-25 for the utility one). Looking to the Debt/Equity ratio (second panel Figure 18) for the grey sample it is constantly above average and near 1.5, indicating high investments in the transition mainly financed by debt.

[94] Usually a P/E ratio higher or near 100 can induce into a price bubble (as happened in 2008).
[95] Firms can use debt to pursuit projects and business goals when in necessity of liquidity with the advance of a tax shield. A Debt/Equity ratio higher than 1 indicate use of leverage.
[96] An indicator of efficiency in operations is the Earnings Before Interest and Tax (EBIT) minus operating costs or EBIT/Revenue.

Finally, for the EBIT/Revenue ratio (third panel in Figure 18), given that the grey sample is a hybrid between the green and the black ones, it is less affected from changes in inputs, thus it remains stable in the period 2009/2019 and above average (around 20%).

- *Black sample*: similarly stable P/E ratio as for the grey sample, but presence of spikes in 2016/2017 (first panel Figure 18) mainly due to uncertainty of policy support to green projects and investors turnback to carbon-intensive firms (in the industry average). Looking to the Debt/Equity ratio (second panel Figure 18) for the black sample it remains always below or on average for all the period 2009/2019 with a small spike in the end of 2016 when climate-related policies have been momentarily left apart. Finally, the EBIT/Revenue ratio (third panel Figure 18) is volatile in comparison to the others, mainly due to the dependence on inputs, as happened in the period 2014/2017 with the massive crash in oil prices.

In their other analysis, under the alternative approach, the authors addressed the relevant stock prices for the three samples in question and the consequent markets framework. Going more in depth, the focus is on the grey sample, which is the one more exposed to climate-related policies and to the general climate change risk, and the one that has had a market response indicating a possible price bubble. After conducting a time series analysis for stock returns of firms in the grey sample, Jorgensen and Dyhrfjeld have found the persistency of non-stationarity in returns and the presence of trends in relevant KPIs and stock prices. Their alternative approach leads to the use of a cointegration method with as variables cointegrated: stock prices and fundamentals (Earnings, EBITDA and comparable[97]); if the two variables do not follow the same trend, which means that there is no cointegration between fundamentals and prices, it is the first alarm bell for a price bubble.

[97] EBITDA: Earnings Before Interest Taxes Depreciation&Ammortisation; EBITDNC: EBITDA + NWC (Net Working Capital) + CAPEX; EBITDN: EBITDA + NWC; EBIT: EBITDA – D&A; FCF (Free Cash Flow): EBIT(1-Taxes) + D&A - NWC - CAPEX.

Usually, these kind of patterns in the markets persist for a short period and are mainly due to the explosion of a niche sector, which could be the case of renewable energies, but need adjustments in fundamentals to be sustainable in the long run.

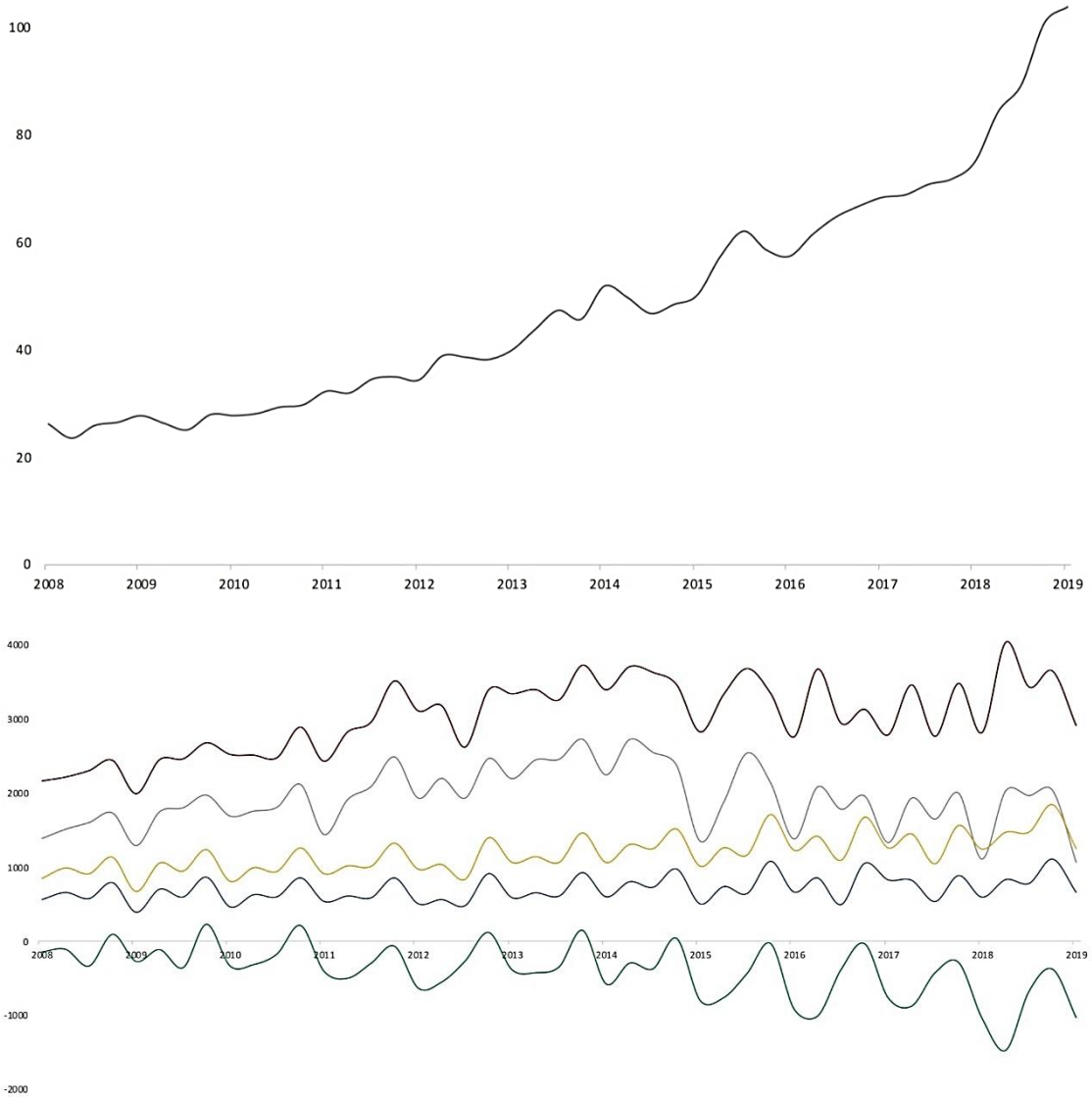


Figure 19. From the master thesis "*Disclosing green bubble indications in the U.S. renewable energy industry"*, Michelle Jorgensen, Helle Oye Dyhrfjeld, Copenhagen business school, 15 May 2020 (grey sample stock price first panel, fundamentals trends second panel).

As shown in Figure 19, the stock price for the grey sample rise from almost 20 in 2008 to over 100 in 2019 (first panel), approximately an increase of 400% in ten years.

Instead, fundamentals remain on the same constant range mainly (second panel) or rise more gradually, even if the firm-related free cash flow going also into negative. Respectively: EBITDNC (red line) rise of 50% (the best); EBITDN (grey line), EBITDA (yellow line) and EBIT (blue line) remain almost at the same level; FCF (green line) decrease of approximately 900% from 2008 to 2019 (the worst).

4.2 Enphase Energy Inc.

Look at specific firms we observe that the first signals of overvaluation of stock prices come directly from the major capitalized firms in the markets, the so-called "green pioneers". As stated by Jorgensen and Dyhrfjeld, the main problem for these companies and their exposure in the markets is the relative small numbers of firms characterized by renewable energies production only. Thus in the green sample only 10 to 20 firms can be classified and the most capitalized in the markets are: First Solar (almost 50% of market capitalization in 2012), Avangrid (capitalization of 30%) and Enphase Energy Inc. (around 10% of market capitalization).

The latter, traded at the Nasdaq from 2012, together with the former (First Solar) have been the main actor in the renewable energies field in the U.S. and they are the green firms that generate the relevant distortions in time series analysis of KPIs. Looking to the first panel in Figure 18 the spike in the average P/E ratio is due to Enphase energy and First Solar both with a P/E ratio over 200 at that time. In the second panel in Figure 18 instead, looking to the average Debt/Equity ratio in the green sample, the two spikes at the end of 2018 and 2019 are mainly due to financial vulnerabilities of Sun Power[98], which was near to bankruptcy, and the high increase in leverage by Enphase Energy to acquire one of its branches.

[98] Another green firm in the U.S. markets which microinverter branch was acquired by Enphase Energy Inc. due to liquidity issues.

If we give a look to the actual Enphase Energy stock price chart, it is represented as follow:

Figure 20. Enphase Energy Inc. stock price. *Source Yahoo Finance.*

As we can see from the Chart in Figure 20, the stock price increase from 2.4$ in 2018 to approximately 212$ at the end of 2020, a huge increment in less than three years of over 8700%; between 2020 and end of 2021 the stock price start triggering and probably due to market sentiment it reaches a new maximum in November,2021 at approximately 267$ (over +11000% from 2018). At that point the first alarm bell start singing for investors and the stock price drop under 124$ in less than two months, a decrease of almost 54%.

If we look to Enphase Energy fundamentals in the same period (data from *Morningstar*):

- Revenues: from $316ml in 2018 to $775ml in 2020, an increase of 145%.
- EBIT: from $-10.20ml in 2018 to almost $120ml in 2020, an increase of 1200%.
- Net Income: from $-11.60ml in 2018 to $134ml in 2020, an increase of 1150%.
- FCF: from $12ml in 2018 to $195.8ml in 2020, an increase of 1530%.

Fundamentals' data seems to have an uptrend as for the stock price, but it is more gradual in time and not comparable to the huge increase in price.

The recent drop instead is more comparable to recent Enphase Energy earnings report, which Net Income decrease from $73ml at the end of 2020 to $21ml in November 2021, a decrease of over 70%. Even if the stock price seems to be near to its intrinsic value (as address by analysts) its actual P/E ratio is critically high, approximately at 111 times its expected profit, but fortunately it is not using financial leverage, in fact its Debt/Equity ratio is near to zero.

4.3 First Solar Inc.

Another interesting example come from the first U.S. *green* firm for market capitalization in 2012, First Solar Inc. traded at Nasdaq, which up to now has reduced its exposure in the market but with interesting aspects for green bubble indications. In this case we take a focus in last two years chart to analyse stock price movements:

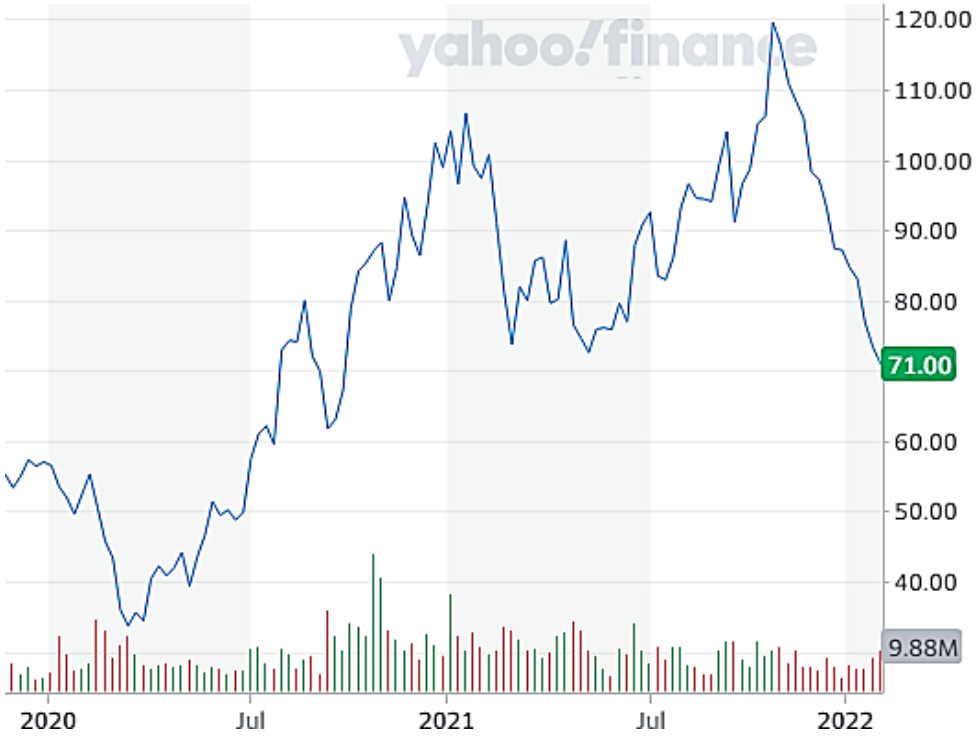


Figure 21. First Solar Inc. stock price. *Source Yahoo Finance.*

As shown in Figure 21, the stock price rise from 33,70$ at the beginning of 2020 to almost 107$ in 2021, an increase of 217% in less than one year, and up to approximately 120$ in October 2021, for a total increase of 256% in one year and a half. Similarly to Enphase Energy, the stock price of First Solar drop in the last two month, falling by almost 42% at 70$ in 2022. If we look to its fundamentals in the same period, in the last Earnings report we can see how almost all data are deteriorating with the Net Income decreasing from $115,7ml at the end of 2020 to $45,2ml. at the end of 2021, a total decrease of over 60%. Differently from Enphase Energy, Fist Solar has a lower P/E at approximately 17 times its expected profit, in line with the sector average, and a financial leverage near to zero, as for Enphase Energy.

4.4 The grey sample

Taking in consideration the climate-related risks, as addressed by Jorgensen and Dyhrfjeld, the main firms exposed to these risks are the ones in the grey sample, whose are at the centre of the transition to a green economy and are enrolled to take important actions on this road, above all the cut of emissions and deployment of sustainable technologies. Due to these specific features, these kinds of firms are experiencing huge increases in stock prices in the last years, mainly because of changes in investors behaviour tied to changes in climate-related policies, the so-called market sentiment[99].

So, taking in consideration the previous analysis of the grey sample, we can take a focus on some of the relevant firms and their markets stock prices. The major firms within this sector are NextEra Energy, Duke Energy and Pacific Gas&Electric Corp, with market capitalization of respectively 20%, 10% and 5%.

[99] Investors are usually guided in their decisions by irrational biases, which induce in mispricing the market value of firms. The branch of finance that studies this phenomenon is the so-called Behavioural finance and, in this framework, seems that the Momentum effect and the FOMO (fear of missing out) are present.

This segment of the energy sector is more fragmentated than other and can induce small/medium firms to pursuit a malfeasance mechanism aimed at obtaining government supports, fiscal benefits, and even more high liquidity from the markets.

This could be the key in a green bubble formation, and it is associated to the *greenwashing* phenomenon, which will be further extrapolated.

In the following analysis of the *grey* firms' stock prices, it is necessary to take into consideration this phenomenon and the consequent high use of financial debt[100] by those firms, which usually have a Debt/Equity ratio persistently above average. It is interesting to notice that the behaviour of *grey* stock prices seems to be like the one of firms in the green sample when, first in 2018 and then in 2020, the substantial increases in use of financial leverages was followed by an explosion in stock prices (see Figure 18 second panel). The key problem for firms in the transition phase is to be able to materialize all future sustainable projects and not only within the climate-related targets horizon, but mainly in a timely manner to satisfy investors and markets perspectives to avoid a critical overvaluation and the possibility of a *bubble burst*[101].

4.4.1 NextEra Energy Inc.

The first relevant indication of a possible price bubble comes from the main capitalized company within the sector, the NextEra Energy Inc., traded at NYSE for almost 50 years and with a market capitalization of over $148 bn. It is the major distributor of energy in Florida (U.S.) with a total of 5 million of costumers and operates also across all the United States and Canada.

[100] in the financial markets, debt is better described as bonds issuance, which can see as a loan agreement where the lender sets the repayment terms (how and when).
[101] Markets panic followed by short squeeze (all investors in a short time frame short sell the stocks and consequently other investors follow them for an irrational market sentiment (FOMO)). Most of the time when the bubble burst is over the price fell deeply under its intrinsic value.

As addressed by Jorgensen and Dyhrfjeld in their alternative approach, there seems to be not cointegration in trends between the market price of the stock and its fundamentals and this could imply an overvaluation in its stock price (see Figure 22 below).

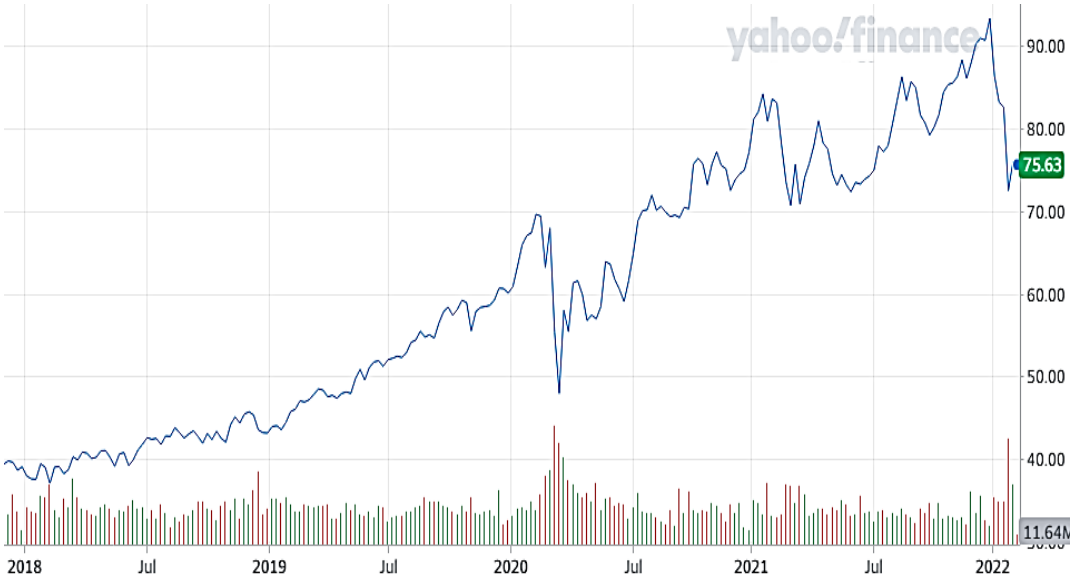


Figure 22. NextEra Energy Inc. stock price. *Source Yahoo Finance.*

As shown in Figure 22, the firm stock price increase from approximately 38$ in 2018 to 69.40$ at the end of 2020, an increment of almost 83%, and to 93.30$ at the end of 2021, for a total increment of over 145%. Given that the drop at the beginning of 2020 has to be attributed to the COVID-19 pandemic crisis, a first signal of changes in markets sentiment and an increased uncertainty around the price can be seen at the beginning of 2021 and even more in 2022 when the stock loose respectively 16% and almost 24% in less than two months. If we look instead to the fundamentals trend for the same period (data from *Morningstar*):

- Revenues: from approximately $16,7bn in 2018 to almost $18bn in 2020, an increase of 7.8%.
- EBIT: from $7,35bn in 2018 to approximately $2,4bn in 2020, a decrease of almost 68%.

- Net Income: from $6,63bn in 2018 to almost $2,92bn in 2020, a decrease of approximately 56%.
- FCF: from $ 553ml in 2018 to $224ml. in 2020, a decrease of almost 60%.

Almost all NexEra Energy fundamentals have deteriorated in the same period in which its stock price consistently rise. If we look at its actual KPIs, NexEra Energy has a P/E of 62,55 time its expected profit, over the average and the firms is actually using the financial leverage, the Debt/Equity ratio is 1,15 on average. Last two trading months seems to has addressed the firm stock price in a similar situation of the Enphase Energy's one.

4.4.2 Duke Energy Corp.

Another interesting example of a *grey* firm which features could induce into a price bubble is the one of Duke Energy Corp, which is on of the largest utillities in the U.S. with a market cap. of over $80.3bn and mainly distributing energy in Florida, Carolina and Ohio with more than 7 million of costumers. The firm business structure is quite similar to the one of NexEra Energy and thus it is at the beginning of the transition phase and necessitate heavily investments in new sustainable technologies. In any case, the firm up to now is mainly dependent on fossil fuels and only a small part of its distribution consists of renewable energies. The Duke Energy stock is traded at the NYSE since 1980 and its price chart is the following (Figure 23).

Figure 23. Duke Energy Corp. stock price. *Source Yahoo Finance.*

As shown in Figure 23, the stock price rise from approximately 77$ in 2018 first to 102.40$ in 2020, an increase of 33%, and then to 107.20$ at the end of 2021, a total increment of almost 40%. The drop at the beginning of 2020 is mainly due to the COVID-19 pandemic crisis and could distort the chart analysis, even if this could be also a signal of weakness of Duke Energy because it addresses its strong exposure to fossil fuels and in particular to the oil price, which drop almost to zero in March 2020. The stock price seems to rise more gradually than the one of NextEra Energy but to give a more consistent analysis it is necessary to look at its fundamentals trend in the same period (data from *Morningstar*):

- Revenues: from approximately $24,5bn in 2018 to almost $23,9bn in 2020, a decrease of 2.5%.
- EBIT: from $3,07bn in 2018 to approximately $0,84bn in 2020, a decrease of almost 73%.
- Net Income: from approximately $2,7bn in 2018 to $1,37bn in 2020, a decrease of almost 50%.
- FCF: from $-2.2bn in 2018 to $-1.05bn in 2020, an increase of almost 53%.

Also for Duke Energy the fundamentals seem not be cointegrated with stock price in trends, but differently from NextEra Energy it has a better up-trend in cash flows which could be considered consistent with the price increase in the same period. Therefore, the use of a DCF[102] Model for stock pricing address as its intrinsic value approximately $100 and as we can see from the chart (Figure 23) its actual price is close to that. As consequence, the last two trading months reflect a different investors behaviour toward Duke Energy stock price and if we look at its actual KPIs the firm has a P/E of almost 27 times its expected profit, in line with the average, and it is using financial leverage, Debt/Equity ratio at 1.24, on average.

[102] Discounted Cash Flow (DCF) Models. FCFF (free cash flow to the firm), FCFE (free cash flow to the equity).

In conclusion Duke Energy Corp. appear as a more stable *grey* firm than others and with more ability to achieve future sustainable perspectives.

4.4.3 Pacific Gas and Electric Corp.

The last example comes from another major utilities holding in the U.S, the PG&E Corp, with a market capitalization of over $27.3bn and more than 9 million of costumers across 47 states of the U.S. This case is interesting to analyse because it has features very different from the others and in a sense can be used as key example in the research of possibile price bubble. As we will see, the firm was under turmoil between 2019 and 2020 due to a huge wildfires in 2017/2018 started in some of its old equipment, and thus it has had to sell almost all its assets under bankruptcy with a dangerous triggering impact on stock price (see Figure 24 below). This is a clear signal of not having take into account of physical risk in pricing the securities and thus it has had critical consequences.

Figure 24. PG&E Corp. stock price. *Source Yahoo Finance.*

As shown in Figure 24, the stock was already in turmoil at the end of 2017 due to other previous wildfires at its plant and equipments.

In any case, taking into consideration the same time frame used before, the price drop from 45$ in 2018 to 7$ at the end of 2020, a total decrease of almost 85%, and then start gradually recover up to 10$ at the end of 2021. It is fair to say that PG&E price will probably never recover in the short/medium time horizon and its intrinsic value is drastically changed, under the DCF model it is 12$ up to now. The fact that physical changes can cause dramatic consequences for the firm seems no more marginally and the cut of production output could be not at its end, thus now investors are aware of the physical risk tied to the PG&E Corp and they incorporate it in the stock pricing. Looking to fundamentals we find confirmation of this phenomenon (data from *Morningstar*):

- Revenues: from approximately $16,8bn in 2018 to almost $18,5bn in 2020, an increase of approximately 10%.
- EBIT: from $-10,1bn in 2018 to approximately $-0,94bn in 2020, an increase of almost 91%.
- Net Income: from approximately $-6,84bn in 2018 to $-1,3bn in 2020, an increase of almost 81%.
- FCF: from $-1,76bn in 2018 to $-26,74bn in 2020, a decrease of almost 1420%.

The critical trend in fundamentals is in PG&E cash flows and if we look at its actual KPIs the P/E ratio is 76 times its expected profit, above average, and the Debt/Equity ratio is at 1.83, highly over average. Therefore the street for PG&E Corp to become a green firm and to return at its initial production regime seems to be quite long and untangled.

Obviously in the global financial markets there is a wide range of companies, firms and financial entities that are tied to the energy sector and not only directly but even more indirectly due to the heavly dependence between industry sectors, where all the firms are in a sense commercial partners in conducting their businesses.

Therefore, many other examples similar to the ones previously described can be found in the markets and each one with different intrinsic features and markets response; but united by being exposed to the climate-related risk, with relative sensitivities to the physical or/and transition risk. The risk concerning a possible creation of green bubbles in the financial markets is tied to the actual uncertainty around the proper credit risk assessment derived by the climate changes evolution and the consequent possible markets inefficiency in fairly pricing stocks value.

As previously described, it is essential to implement a common global taxonomy in the climate-related risk management process and robust standards for the relative credit ratings (ESG scores) of financial entities to avoid the *greenwashing* phenomenon and a drug market.

Findings and conclusions

In a global framework where almost all the financial entities are interconnected and banks with supervisors play a central role in mitigating the financial risks, the persistency of the climate change risk has to be treatened very carefully. The last dedades have seen a critical environmental deterioration which is leading the real economy to change its behaviour toward climate changes. A wide range of firms start to be heavily influenced by climate events directly at their fundamentals, both from physical and transition risk drivers, and the consequences looking forward are even worse. Banks, insurance companies and funds are changing their approach to green finance, taking an eye to all their possible exposures toward NFCs and CPRS. Up to now, the consequences of this high use of green lending seems to be covered by a consistent degree of uncertainty, which could lead in misleading information and unfair valuation of green-labeled securities. From the Supervision perspective it is quite clear how sensible become the climate change debate and in the last months important steps have been made to increase the real economy awarenes. However, this is just the beginning and the actual framework reflects more than one difficulty to realize in a timely manner the emissions targets.

The climate change risk is something never seen before and has unique features that necessitate an untangled risk management process to achieve an effective mitigation. From the point of view of the banking system this is an essential task to enhance the financial equilibrium. However, the lack of a common taxonomy is charging possible inappropriate behaviours around agents and the greenwashing phenomenon is far from been wiped out from the markets. With more than one classification within financial risk categories and with an important number of trasmission channels, the climate change risk is addressed as the ultimate systemic risk, which could lead to triggering events and increases financial vulnerabilities.

The necessity to take immediate actions and the persistency of this uncertainty around climate-related risks is a trade-off that the whole financial economy is facing and toward which the markets are changing their behaviour.

The possible formation of a financial bubble in the green finance field is not necessarily something bad, as long as market-makers and investors are aware of it and act accoricaly. This was not the case, for example of well-known ESG fund of Blackrock[103] at the beginning of 2022. The ETF iShares ESG MSCI EM Leaders (Ldem) lost almost the 91% of its assets in only two trading section, dropping from $803 ml to just $70 ml under management (see Figure 25).

Figure 25. *iShares ESG MSCI EM Leaders*. *Source Bloomberg.*

This ETF was first traded at the beginning of 2020 and its main investor was Ilmarinen[104], which has usually a long-term investment horizon and its disinvestment appears quite significant.

[103] The largest investment company in the world, with more than $10 trillion under management.
[104] The largest private pension fund in Finland.

It is strange that a pension fund decides not to rely on ESG funds, given the common time-horizon, and this could address that the fund does not believe on future sustainable projects of the firms under the ETF, or even that the possibility to achieve them is far from the actual markets response.

Obviously, this is only a case and the real reasons of such a drastic decision by Ilmarinen could never be disclosed. However, it is a first significant event within the green finance field and it should be used by banks to analise the changes in market sentiment. As previously stated, there are more than one alarm bell that rules out the necessity to threat the climate change risk no more marginally; banks are fundamental for a correct financial economy response. However, the actual persistency of not enough clear standards and common taxonomy in the climate-related risk management process, could induce market inefficiency in securities pricing and a distortion of investors behaviour.

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