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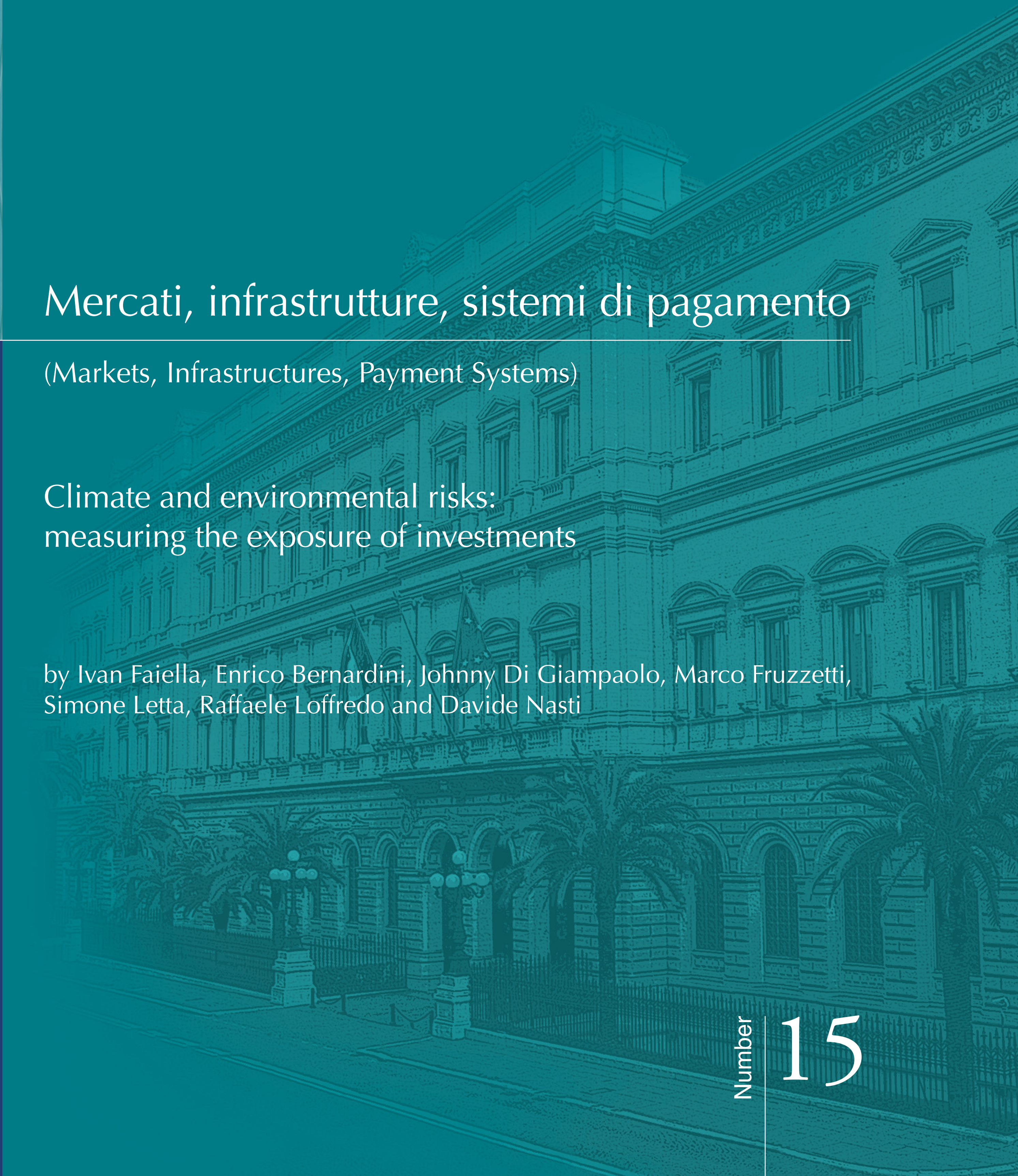

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Climate and Environmental Risks: measuring the exposure of investments

by Ivan Faiella,* Enrico Bernardini,** Johnny Di Giampaolo,** Marco Fruzzetti,**
Simone Letta,** Raffaele Loffredo*** and Davide Nasti**

Abstract

This paper presents a number of methodologies for assessing the climate risk exposure of several financial asset classes. Regarding government bonds, the paper proposes using public information; in order to develop forward-looking measures of countries' risk exposure, the paper uses historical trends combined with governments' climate commitments and the scenarios developed by the Network for Greening the Financial System. With regard to private sector issuers, the paper finds quite a high coverage and correlation amongst the carbon emissions data from different providers, while the divergences in the data for other environmental indicators are still significant. Finally, the paper shows that the application of sustainability criteria in the Bank of Italy's investment strategy delivered a non-negligible reduction in the exposure to the climate and environmental risks of the portfolios.

JEL: E58, G11, Q56 Sustainability.

Keywords: sustainable finance, investments, climate risks, environmental risks.

Sintesi

Il lavoro presenta alcune metodologie per la valutazione dell'esposizione delle attività finanziarie ai rischi climatici. Per quanto riguarda i titoli governativi, si fa ricorso a informazioni pubbliche; le analisi prospettiche fanno leva sul confronto tra gli impegni climatici assunti dai governi e i dati storici, integrati con gli scenari elaborati dal Network for Greening the Financial System. Per gli emittenti privati, l'analisi mostra che la copertura e la correlazione tra i dati delle emissioni carboniche offerti da diversi fornitori specializzati sono elevate, mentre per altri indicatori ambientali le divergenze rimangono rilevanti. Il lavoro mostra infine che l'applicazione dei criteri di sostenibilità ha consentito una non trascurabile riduzione dei rischi climatici e ambientali del portafoglio della Banca d'Italia.

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1 Introduction

The latest report by the Intergovernmental Panel on Climate Change (IPCC, 2021) confirmed that some effects of climate change are unprecedented, irreversible over periods of hundreds of years, and unequivocally linked to human activity; only rapid and sizeable reductions in greenhouse gases can limit some of these effects. A greater awareness about the impact of climate change on economic and financial variables is confirmed by the growing attention to the various sustainability profiles of financial investments. This phenomenon is particularly due to the commitments to tackle climate change undertaken by many governments that signed the Paris Agreement on Climate and to the growing awareness that corporate value creation can only be durable if it is oriented to the long term and careful of the claims of the various stakeholders: shareholders, customers, suppliers and other actors in the social, institutional and regulatory context in which corporates operate. In particular, the focus on the measurement and management of climate risks has increased among participants in the financial system. In the last few years, central banks have increased their efforts in measuring and disclosing their exposure to climate and environmental risks with regard to the investments (NGFS, 2019b and 2020b) and institutional functions (NGFS, 2018, 2019a and 2021a; Bolton *et al.*, 2020). On a larger scale, attention to climate and environmental sustainability has also recently turned to sovereign debt issuance.

Exposure to climate risks mainly materializes through two channels: a) damage to infrastructures and the properties of firms and households, caused by climate-related events (physical risk); and b) the consequences for the economic and financial system stemming from the transition to a low-carbon economy (transition risk). Although the environmental risks are closely connected to climate-change risks, they derive from wider phenomena and stem from the economic and financial effects relating to an overuse or degradation of natural resources (e.g. resource depletion, deforestation and pollution), to biodiversity loss and to the degradation of ecosystem services (NGFS, 2021b; Dasgupta, 2021). In the case of environmental risks as well, the transmission channels are represented by both physical damage to economic activities and structures, and by the consequences associated with mitigation policies, technological changes or the behavior of economic agents in response to environmental events. In 2020, the COVID-19 pandemic confirmed that extreme events can have unexpected and asymmetrical effects on several economic sectors, with impacts similar to those relating to transition risk, and reinforced the arguments in favour of an appropriate identification of 'tail risks', namely those events that have a low probability of occurrence but significant impacts (NGFS, 2020a).

This paper contributes to the ongoing debate on the methodologies to be applied for assessing exposure to climate risks by providing an extensive framework for the possible solutions. Through an international comparison of data and methodologies, the paper reviews the indicators that can be used to assess the exposure of public and private entities. The paper also shows the results from applying the proposed metrics for measuring the exposure to climate- and environment-related risks to the Bank of Italy's investments in Eurozone equities, government and corporate bonds and government bond investments of the foreign exchange reserves.

The assessment of how the various financial instruments are exposed to climate risks is a complex exercise due to the uncertainty relating to the multiple interactions between the risk sources to consider, mainly connected to physical and transition risk. If the evaluation is carried out for a portfolio of securities, the complexity is increased by the possible interactions between the different effects of risks on several asset types and instruments in the portfolio. In line with market practice, this paper does not address the issue of estimating how the climate risks of individual countries or companies are correlated with each other. This has not been explored in the literature yet, due to the complex relationships involved, which mean considering the interactions among economic, financial and climate- and nature-related transmission channels and refer to phenomena governed by non-linear trends with tipping points, which are difficult to integrate into traditional statistical and financial model settings. The measurement presented in the paper, following the common practice, is carried out separately for each asset class considered. Some precautions are taken to avoid the well-known problem of double counting in the measurement of emissions: the portfolio indicators are calculated separately for public and private sector issuers and, for the latter category, the measurement takes into account all sources of capital for a company. Furthermore, the focus is mainly on transition risks, not because physical risks are not material, but because at present there are not enough data available to/on/for? investors about which and how deeply the securities are exposed to physical risks[1] and to what extent these risks are covered by insurance.

An initial assessment of climate risks can be based on a review of the backward-looking metrics, under the assumption that these metrics can also provide a useful basis for a forward-looking assessment. However, the usefulness of such data can/may be limited if future climate policies (or the effects of climate change, when analysing physical risk) have a different extensiveness and intensity than in the past. At the same time, the uncertainty about the future evolution of climate

[1] For example, it is extremely complex to assess the exposure of a country to physical risks, because it tends to be localized in specific areas of a country. The international comparison is even more complex. For a European comparison, see Peseta IV; for an international comparison, see Notre Dame Global Adaptation Initiative.

policies, the socio-economic behavior of companies and investors, as well as technological innovation, make it difficult to draw up these assessments. For this reason, forward-looking indicators usually make use of climate scenarios that hypothesize different future combinations of climate risks depending on the policies undertaken to combat the increase in emissions and on socio-economic evolution (Bernardini *et al.*, 2021). For the assessment of individual companies, two simple methods do not need to use scenarios and are based on forecasts of the alignment path of emissions compared with climate policies' targets. The first method analyses the corporate's emissions over time; the second one assesses whether future emissions trends are consistent with the reduction commitments to which the company/corporate is directly or indirectly subject, considering the sector and/or the country it belongs to.

The measurement of greenhouse gas (GHG) emissions only provides information on exposure to transition risks and is limited to historical data on a corporate's emissions. Even with this simplification, measuring exposure to climate risks implies solving a number of issues:

1. What is the perimeter of emissions? [2] Are only those relating to production activities (direct or scope 1) or also those deriving from energy uses (indirect or scope 2) considered? Or do we? also include those that are generated by the entire value chain of the firm, including those relating to the uses of the final products (scope 3)? [3]

2. Which GHGs are considered in the calculation of emissions? Only CO_2 or all gases, e.g. those considered in the Kyoto protocol? [4]

3. How are emissions considered, in absolute terms or normalized to take into account the different size of companies and countries (carbon intensity, as emissions per employee, per unit of turnover, value added, enterprise value, per inhabitant, per unit of GDP and so on)?

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[2] The emissions classification standard is defined by the World Resource Institute's Greenhouse gas protocol, supported by various organizations and data providers. Based on this protocol, GHG emissions are divided into three categories: direct emissions, i.e. produced by proprietary or controlled sources, are classified as scope 1; indirect emissions, deriving from the purchase and consumption of energy (electricity, steam, heating, air conditioning) are classified as scope 2; and all remaining indirect emissions (other than scope 2) along the value chain, downstream and upstream, are classified as scope 3. Consequently, the overall emissions of a product / service are given by the sum of scope 1, 2 and 3 emissions Typically, the scope 3 emissions of a single company make up the majority of its total emissions: however, they may overlap with the scope 1 emissions of another company, resulting in double counting.

[3] Estimating and using these emissions is anything but simple. The available studies indicate that this information, even when available, has serious quality issues. See for example Busch *et al.* (2020).

[4] Global Warming Potential (GWP) is a measure of how much a given greenhouse gas (in addition to CO_2, CH_4, HFCs, NF_3, SF_6, N_2O and PFCs) contributes to global warming, using CO_2 as a reference, and considering the combined effect of the residence time in the atmosphere and the ability to absorb the infrared radiation emitted by the earth (and therefore retain heat). The overall unit of measurement of greenhouse gases (indicated with the acronym GHG) is the CO_2 equivalent (CO_2e) in which each greenhouse gas is converted into CO_2 by means of its GWP.

The importance of emission-based indicators has long been known in the climate risk literature for both sovereign and corporate bonds. This paper aims to contribute to this strand of research by broadening the focus in addition to historical GHG emissions data by: 1) simulating the emissions profiles relating to the future commitments of countries; 2) integrating backward-looking emissions patterns with the forward-looking ones implied in the NGFS scenarios; and 3) combining information on emissions with a set of indicators for the energy system that identify which countries have greater room for manoeuvre to manage the transition.

Below, Sections 2 and 3 present the indicators that can be used to assess the climatic and environmental risks of public sector[5] and private sector issuers respectively, also briefly illustrating for the latter the indicators relating to social sustainability and corporate governance profiles. Section 4 illustrates the methodology for calculating the exposure to climate and the environmental risks of financial portfolios, containing sovereign or corporate securities, using the carbon indicators presented. Section 5 outlines the environmental sustainability profile of the Bank of Italy's euro-denominated investment portfolios and foreign currency reserves. Section 6 draws some conclusions.

2 The exposure of the government bonds to climate and environmental risks

The link between the climate risks of a country and those of its government bonds is analysed by many academic papers - e.g. Voltz *et al.* (2020), Battiston *et al.* (2019), Klusak *et al.* (2021), Zenios (2021), Cevik and Tovar Jalles (2020), Kling *et al.* (2018) [6] - and by research papers of financial institutions, such as FTSE Russel (2019) and Bank of America (2021), based on the existence of different transmission channels of both physical and transition risks. The rating agencies as well have started considering climate risks of the government bonds and taking the countries' carbon emissions as relevant risk metrics.[7] To summarize, the transition towards a low-carbon economy - which can entail the adoption of market-oriented or fiscal measures (e.g. carbon pricing with a cap-and-trade system or the introduction of a carbon tax), or new regulations modifying the relative prices of the

---

[5] A survey of the literature on how climate risks can affect the value of government bonds is beyond the objectives of this paper. Among the main studies measuring the effects of climate risks, Volz *et al.* (2020) identify six transmission channels of climate risk on country risk: 1) fiscal effects of environmental disasters; 2) tax effects of adaptation and mitigation policies; 3) macroeconomic implications; 4) risks to the financial system; 5) effects on international trade and capital flows; 6) effects on political stability. Battiston and Monasterolo (2020) find that countries with a higher share of the less carbon-intensive sectors benefit from lower government bond yields. Cevik and Tovar Jalles (2020) examining 98 countries also find that vulnerability and resilience to climate risks affect - negatively and positively, respectively - the cost of government funding.

[6] For a description of macroeconomic impacts of the climate factors on the developed countries, see also Burke *et al.* (2015).

[7] Angelova *et al.* (2021) criticized the methodologies currently used by rating agencies for the integration of climate risks into the assessment of the government bond risks.

energy sources to penalize fossil fuels - can cause reallocation effects among the economic agents, with consequences also on the economy growth rate and eventually on the country financial soundness; furthermore, the technological breakthroughs in the power generation and more energy-efficient production processes could impair the creditworthiness of the net fossil fuels exporting countries, or affect those countries dependent on obsolete production processes with implications on their competitiveness, industrial policy and eventually on their economic and fiscal stability. At the same time, countries more exposed to the physical risks of extreme climate events, such as floods, wildfires and droughts, could be forced to face huge public and private expenses for individual or coordinated adaptation initiatives (for example water resources management, dikes, insurance costs) and mitigation projects (for instance afforestation, substitution of internal combustion engines vehicles with electric ones, electric vehicles charging stations), or to bear expenses for fixing up the damages caused by climate changes, with consequences on the financial solvency, carefully scrutinized by the investors. The link between the country risk and the government bond risk is confirmed by analysis of Burns *et al.* (2016), Bank of America (2021) and Pinzòn *et al.* (2020), which found a correlation between the climate, environmental and ESG profile and the yield spreads of government bonds.

2.1 Backward-looking indicators: emissions and the energy system

The carbon emissions of a country represent a first indicator of the exposure to the transition risks. An unexpected tightening of climate policy indeed would imply new quantitative constraints to the emissions (for example a ban on the use of the most polluting energy sources like coal) or economic disincentives such as carbon pricing (for example by introducing a carbon tax or by making more stringent conditions for the EU ETS that allocates the emissions' permits in Europe). Both measures would aim to make the emissions more costly, penalizing the most polluting entities. In the economic system, such measures would exacerbate the costs for companies and households with negative spillovers on the national economy (in terms of reduced economic activity and worsening of the public finances). This is particularly evident in those countries whose economies are strongly dependant on the fossil fuels industry (for instance the states of the Persian Gulf, Russia, Australia, Canada and, more recently, the USA) which would suffer, besides the aforementioned effects, an abrupt trade balance deterioration as they are net exporter of energy sources. For those countries the impacts of an acceleration of the transition on the public finances are straightforward; they are less obvious for the energy importing countries (like Italy), whose higher transition costs would be compensated by the improvement of the trade balance (the energy bill of Italy in 2019 represented 2.2 per cent of the GDP).

The country emissions originate from the production (of the firms) and the consumption (of the firms and households) of the resident entities.[8] This information for the UE states is available on the *Air Emission Accounts* provided by Eurostat (with sectoral breakdown).[9] According to this data, the 2019 emissions in Italy were equal to 431 million of tons of GHGs: 111 million from households (due to heating, electricity consumption and transportation) and 320 million from firms.

An alternative data source is represented by the official data transmitted to the United Nations Framework Convention on Climate Change (UNFCCC), which are also disseminated by Eurostat.[10] These statistics refer to the emissions produced by residents and foreign entities within the country's borders (in Italy they are provided by Ispra). For Italy the two indicators are similar.[11]

The scope of the emissions to consider. The total emissions encompass different GHGs. Indeed, besides the carbon dioxide (CO_2), other greenhouse gases exist; they are measured in terms of CO_2 equivalent (CO_2e).[12]

Figure 1 shows the CO_2e CO_2 emissions in Italy. The latter are emissions due to the fossil fuels combustion which are often the only information available at the country level, in particular when considering extra-UE states. An analysis that focuses only on these emissions have shortcomings, such as the underestimation of the contribution of some sectors (producing mainly GHG different from CO_2) to the total emissions. For example in 2019, in Italy the contribution of the agricultural sector to the CO_2 emissions was 3.6 per cent, while the share of the CO_2e attributed to the same sector was 12.2 per cent, principally related to methane emissions.

Emissions and carbon intensity. Among the major European countries, Italy shows some of the lowest emissions levels (Fig. 2a). The absolute emissions do not allow for comparison amongst countries of different dimension (in terms of either population or economy). For comparison

[8] The so-called scope 3 emissions, which include all indirect emissions that occur in a company's value chain, are not considered. Even if they provide useful information (for example because the emissions reductions in the developed countries are partly due to relocation strategies increasing the imported goods from developing countries) it does not exist a standard measure of this type of emissions; only some papers assess the carbon emissions attributed to net imports (see for example Peters *et al.*, 2011).

[9] The data is provided by Eurostat based on the firms' residence, included airline and shipping companies, and according to the Statistical Classification of Economic Activities in the European Community (NACE). The data refers to the emissions of the so-called Kyoto basket that encompasses the following six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the so-called F-gases (hydrofluorocarbons and perfluorocarbons) and sulphur hexafluoride (SF_6).

[10] Eurostat provides UNFCCC data about National Inventories, where the emissions are assigned to the country where they are produced. Eurostat releases a link-table that accounts for the differences between the two systems.

[11] For example in Italy the 2017 emissions were equal to 427.7 million of tons of CO_2 according to the UNFCC methodology, while the emission attributed to residents were 445.5 million.

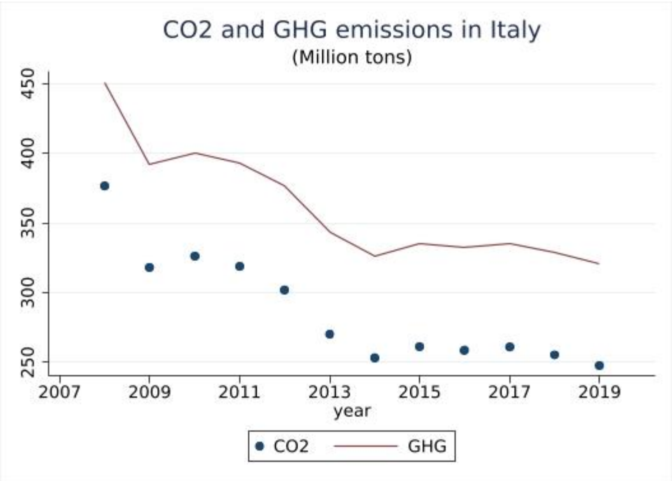
[12] See footnote 4.

purposes, the emissions need to be normalized with a scale factor translating into **carbon intensity metrics**.

Figure 2b shows the emissions per capita of a sample of European countries; Figure 2c illustrates the GHG emissions per unit of value added at constant 2010 prices. In both cases, Italy is well below the European average: in 2018 each Italian citizen was accounted for 5.4 tons of CO_2e emissions, 1.5 less than the UE average and 3.2 less than those of a German. Similar results are obtained when one considers the carbon intensity: the production of 1 euro of added value in Italy required 224 g of CO_2e emissions, 50 less than both the UE average and the German level.

Even when other extra-European countries are included in the comparison, Italy confirms its better performance in terms of emissions. In this case, it is worth remembering that the data is limited to CO_2 emissions of the energy sector, meaning those generated by fossil fuels combustion (about 80 per cent of the total CO_2 emissions).[13] Figure 3a shows the CO_2 emissions per capita of Italy compared to non-European countries, such as Canada, Japan, Australia, China and USA; again Italy is the country with the lowest emissions. The same holds true for emission per unit of GDP (in grams of CO_2 per 2011 PPP[14] USD GDP).

Figure 1 - CO_2 and GHG emissions in Italy



Source: our computation on Eurostat data

[13] See *Statistical Review of World Energy* of BP for a complete, updated and freely accessible database of the emissions.

[14] The official exchange rates do not provide an accurate assessment of the purchase power of two currencies for those goods that are not involved in international trades (non-tradable goods). Therefore, to compare the standard of living among different countries, it is appropriate to take into account the general price level of each country. To this end, the exchange rates against the US dollar are adjusted to consider the different country price indices and the GDP is expressed in PPP (Purchasing Power Parity) in USD terms.

Beyond the emissions: efficiency and carbon intensity of the energy systems. The decarbonization process requires modifying the traditional energy system by progressively phasing-out fossil fuels, which in 2018 accounted for about 80 per cent of the primary energy demand.[15] In particular, the decarbonization of the economic system may occur through three possible channels: 1) limiting economic activity (*Y*); 2) decreasing energy intensity (*E/Y*, the energy required per unit of product that is the inverse of the energy productivity); 3) reducing the carbon intensity of energy uses (CO_2/E, the quantity of emissions emitted per unit of employed energy).

In symbols, we can express the emission levels with the following identity, called the Kaya identity (Kaya and Keiichi, 1997):

$$\overbrace{\mathrm{CO_2}}^{Emissions} = \overbrace{\mathrm{Pop}}^{Population} * \frac{\overbrace{\mathrm{Y}}^{Product}}{Pop} * \frac{\overbrace{\mathrm{E}}^{Energy}}{\mathrm{Y}} * \frac{\mathrm{CO_2}}{E},$$

which can be written in terms of variations, given the population, in the following way:

$$\dot{\mathrm{CO_2}} \cong \underbrace{\dot{Y}}_{Economic\ activity} + \underbrace{\dot{\mathrm{E/Y}}}_{Energy\ intensity} + \underbrace{\dot{\mathrm{CO_2/E}}}_{\substack{Carbon\ intensity\\ of\ energy\ uses}} .$$

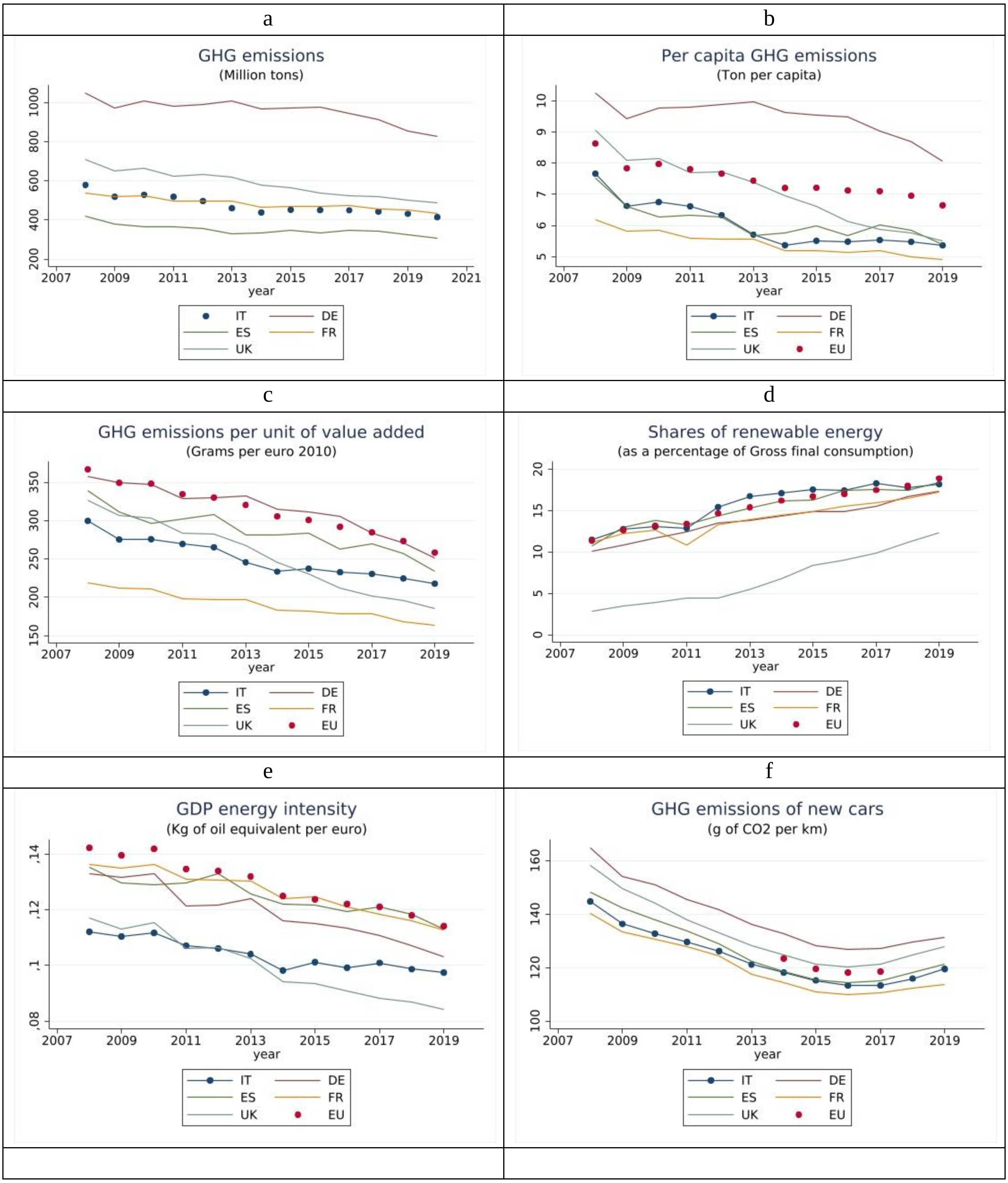
The first channel, by which the emissions decrease because of a limitation of the economic activity (or population), happened in 2020 due to the containment measures introduced after the COVID-19 pandemic outbreak (it would be a manageable channel only in a Malthusian approach or in a degrowth setting). The second channel is related to the increase of the energy productivity and it requires policies that reduce the energy intensity of the economic system (for example by reducing the specific consumption of buildings, cars and electric devices). The third channel needs the diffusion of technologies that decrease the carbon intensity within energy usages and transformation, such as the employment of renewable resources for the energy production for heating and electric or the use of nuclear energy.

Figures 2e and 3c show how Italy makes an efficient use of energy (measured in Gigajoule-GJ) compared to other countries, both per unit of GDP and per capita. According to the last indicator, in 2019 an Italian consumed on average 105 Gj of energy, a quantity slightly higher than that of a Chinese, 30 per cent less than that of a Japanese and much more lower than that consumed by an

[15] The primary energy demand equals the total energy demand of a country excluding losses during transformation in other types of energy and energy carriers used for non-energy purposes (for example used for the refining of the oil products).

Australian, a US citizen or a Canadian (41, 37 and 28 per cent, respectively; Fig. 3c). In addition to the higher energy efficiency, Italy has a lower carbon intensity of the energy usage, as it can be seen from the greater percentage of renewable sources employed, compared to European countries (Fig. 2d) and, even more, to extra-European countries (Fig. 3d).

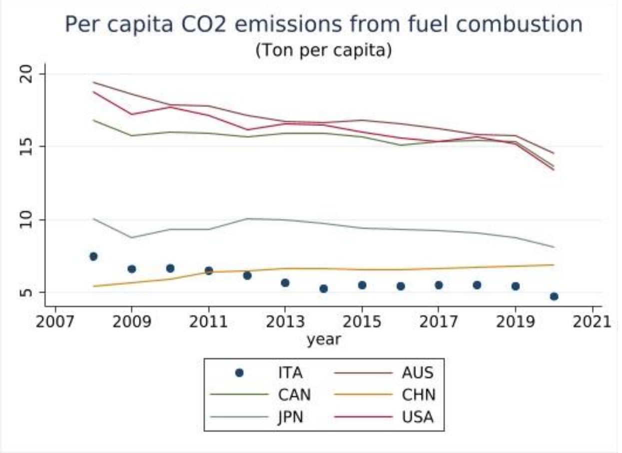
Figure 2 - Statistics on emissions and energy use (Italy vs European countries)



Source: our computation on Eurostat data. EU=Data of the 28 UE countries as of 2019.

Figure 3 - Statistics on emissions and energy use (Italy vs extra-European countries)

a



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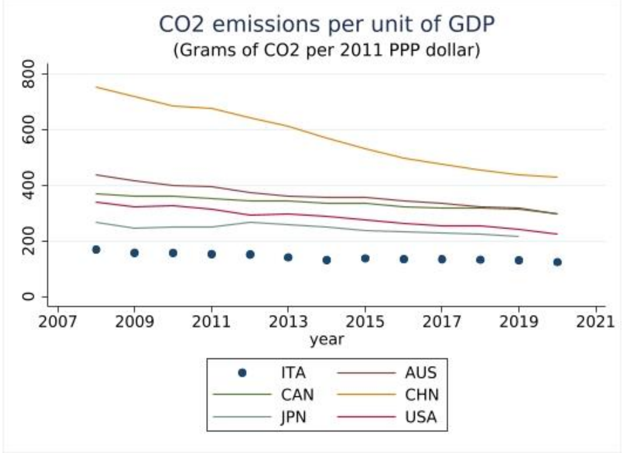

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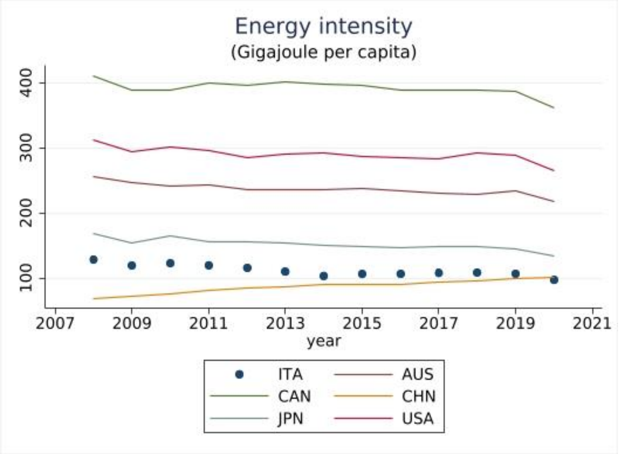

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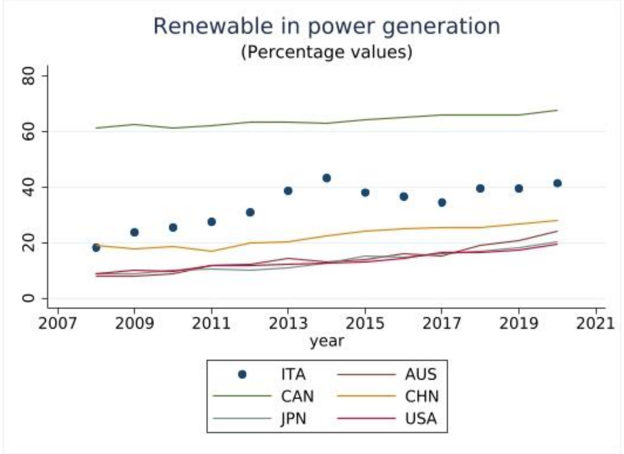


Source: our computation on *BP Statistical review of world energy* and World Bank data.

2.2 Forward-looking indicators: from historical emissions to decarbonization scenarios

Backward-looking information gives a comforting picture of Italy's position so far, confirmed by the fact that Italy has achieved all the European targets by 2020[16], but the transition process is still marginal and linked to the growth of renewable energies in the power sector. Furthermore, as already happened for the Lisbon 2020 objectives, the transition will be accompanied by a probable increase in the energy expenditure for businesses and households (see Bernardini *et al.*, 2021, in particular chapter 3). The trend in historical emissions is not enough to understand the capacity of a country in

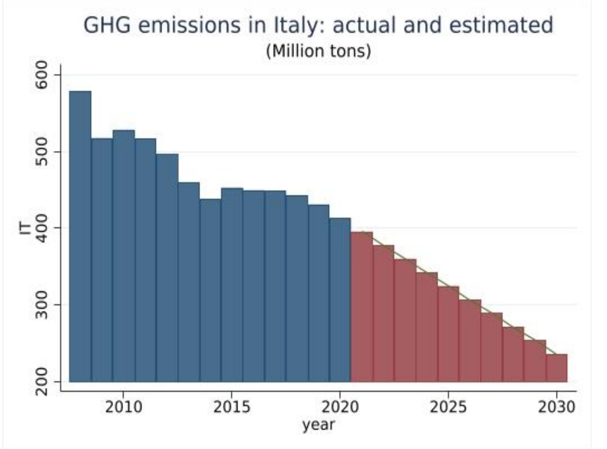
[16] Italy is one of the few EU countries that achieved all three of the Europe 2020 objectives, in terms of containing greenhouse gas emissions, reducing energy demand and increasing renewable energy deployment (EEA, 2020).

achieving the new European targets that envisage a sharp reduction in emissions in the next decade to achieve carbon neutrality by 2050: the new agreed targets foresee that by 2030 EU emissions will decrease by 55 percent compared to 1990 values[17]. The need to keep record and monitor the national commitments to decarbonization or to net-zero has been highlighted in the aftermath of the COP26 (UNEP, 2021).

Historical emissions and future commitments. Figure 4a shows, in the blue histograms, the historical trend of Italian emissions and in the red histograms the trend of emissions necessary to reach the new target by 2030. These values are calculated by setting the emissions of 2030 at 45 per cent of the value 1990 and interpolating the intermediate years. [18] The pace of emission reductions is expected to accelerate significantly and requires emissions to be almost halved over the next decade. Figure 4b shows the same estimate and includes a comparison with other European countries as well. The figure highlights the drastic decarbonisation that should be implemented in Germany, that in the next decade should eliminate a volume of emissions equal to the total annual emissions of Italy.

Figure 4 - Actual and projected emissions * (Italy vs selected European countries)

a



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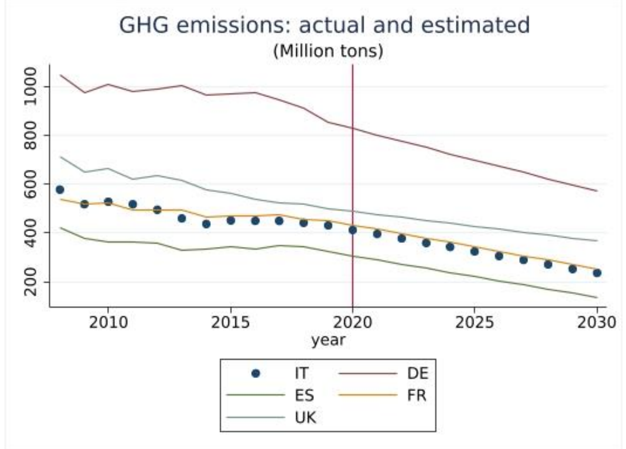


Source: our computation on Eurostat and EEA data.

* Projected emissions are estimated assuming that emissions in 2030 are 45 percent of those in 1990 (based on IPCC inventories). The data between 2020 and 2030 are interpolated with a simple trend.

[17] The Integrated Climate-Energy Plan submitted to the Commission at the end of 2019 was prepared considering a strategy based on achieving by 2030 30 percent of renewables in gross final energy consumption, a reduction by 43 percent in energy use compared to the trend and a 40 percent decrease in GHG emissions compared to 1990. The plan will be revised to integrate the new targets.

[18] In September 2020, as part of the European Green Deal, the Commission proposed raising the target and reducing greenhouse gas emissions by 2030 to 55 per cent. The Commission has started the process of formulating detailed legislative proposals in July 2021.

Table 1 shows the annual percentage changes in emissions for the period 2008-2019 (observed) and those necessary to achieve the goal in the period 2019-2030 (estimated on our own calculations).

Table 1- Actual and projected emissions in 2008-2019 and 2019-2030
(yearly percentage change)

CAGR	DE	ES	FR	IT	UK
2008-2019	-2.0	-2.6	-1.8	-2.9	-3.4
2019-2030	-3.9	-8.2	-5.6	-5.8	-3.0
Difference (in p.p.)	-1.9	-5.6	-3.8	-2.9	0.4

Source: our computation on Eurostat and EEA data.

Except for the UK, all countries are expected to significantly increase their annual reduction rates of emissions. Italy and Germany should double it; France and Spain have to triple it. Even if the economic crisis caused by the pandemic will temporarily make these objectives less difficult to achieve, once the product will starts to grow again, the "activity" channel of Kaya's identity will provide a positive contribution that needs to be compensated with structural reduction measures of energy and carbon intensity.

Historical emissions and climatic scenarios. Historical emissions can also be compared with those of the scenarios published by the Network for Greening the Financial System (NGFS). [19]

Figure 5 combines the historical emissions profile of China, the United States and Europe (overall the main contributors to GHG emissions) with what they should enact according to the different NGFS scenarios. In the "Current Policies" scenario, emissions continue to grow and there is no mitigation; only China reaches a plateau after 2080 (Fig. 5a); in the scenario "NDCs", which assumes that countries reduce emissions according to the commitments declared by signing the Paris Agreement, emissions are reduced but not enough to keep the temperature rise within 2°C (temperatures at the end of the century would increase of 2.5° C) (Fig. 5b). In the scenario "Delayed transition", a trend close to maintaining the 2°C is assumed but with a disorderly transition in which emissions increase before abruptly decreasing (they must become negative after 2060 in order not to affect the carbon budget, [20] Fig. 5e). In the two scenarios "Orderly" (Net-zero 2050 and Below 2 °C),

[19] The NGFS is a global network of central banks and supervisory authorities that promotes the sharing of experiences and best practices in the management of environmental risks (with specific attention to climate risks) in the financial sector.

[20] According to some estimates based on the assumptions of the United Nations Intergovernmental Panel on Climate Change (UN IPCC), to have half the probability of staying within a 2°C increase by the end of the century, the carbon budget would be equal to 1,200 billion tons (Gt) of emissions, compared to the 2,910 Gt of emission embedded in the reserves of fossil fuels: therefore 59 per cent of these reserves would be unburnable. The budget would be even more stringent (464 Gt) in the case of a global temperature target of 1.5°C, making 80 percent of the reserves unburnable.

the transition is instead orderly and emissions are reduced to keep the temperature rise within 2 and 1.5°C respectively (Figs. 5c and 5d).

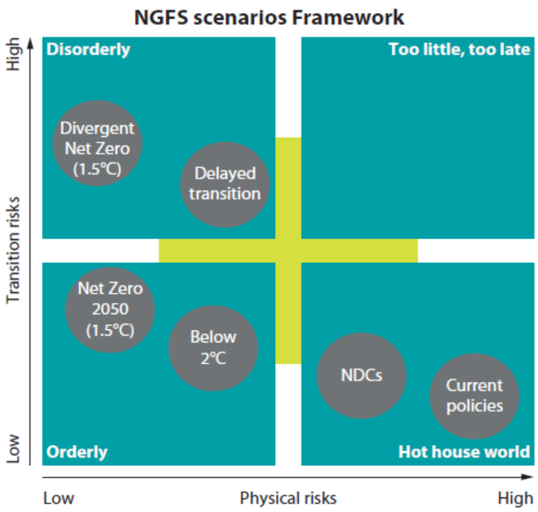
NGFS scenarios

Since 2020, central banks can rely on climate scenarios published by the Network for Greening the Financial System (NGFS) that provide a common framework for forward-looking analysis. In June 2021, the NGFS baseline scenarios were updated to take into account more recent and granular information, which also includes the pandemic effects on GHG emissions (NGFS, 2021c). The update now considers three groups of scenarios (a fourth group is not considered at this stage) which assume different trend profiles of future emissions (see Figure A).

1. The first group assumes the adoption of immediate mitigation policies and a rapid transition towards climate neutrality (Orderly). The increase in global temperature remains below 2°C, in line with the Paris Agreement. There are two scenarios in this group: Net-Zero 2050 and Below 2°C.
2. In the second group, an uncoordinated and late action is assumed in which the transition is not implemented immediately and must then accelerate later but without achieving the goal of containing the temperature increase within 2°C (Disorderly). There are two scenarios in this group: Divergent Net-zero (1.5 °C) and Delayed transition.
3. In a third group no new policies are adopted and emissions and their concentrations increase towards values compatible with an increase in temperatures that exceed 3°C compared to pre-industrial levels (Hot house world). There are two scenarios in this group: Current policies and NDCs.

Each scenario represents different combinations of physical and transition risks. Physical risk is maximum in case of no policy or late and insufficient policy (scenarios on the right hand side of Figure A). This risk is lower if transition policies are implemented but the transition risk increases: this risk is highest when the transition is implemented in an unplanned way (scenario group in the upper left quadrant). Without climate policies there is no transition risk.

Figure A - NGFS scenarios

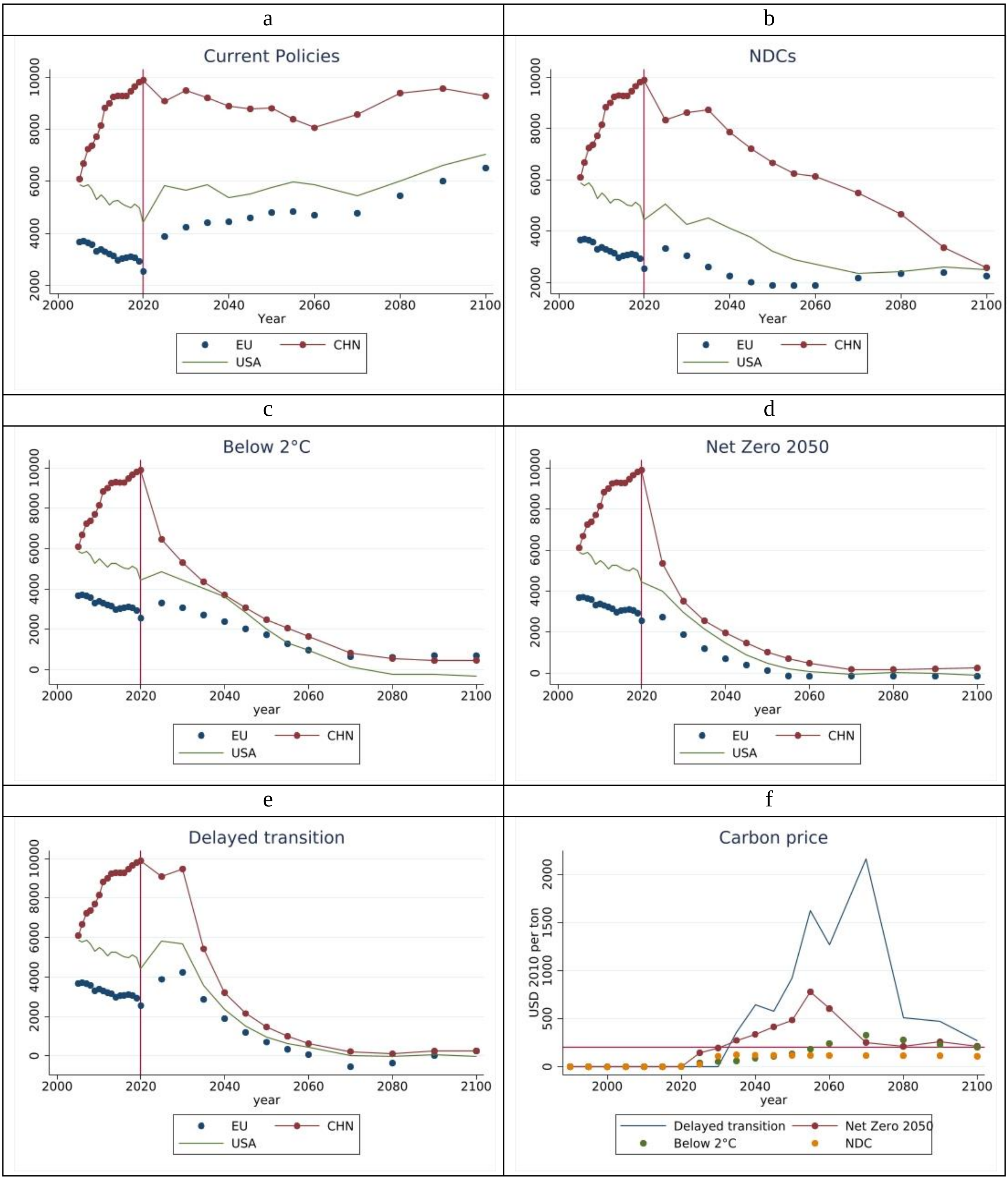


The forecasted time series of variables of the NGFS scenarios, which derive from simulations of different climate models, can be consulted and downloaded from an archive hosted by the IIASA (https://data.ene.iiasa.ac.at/ngfs), an independent international research institute that regularly contributes to IPCC climate reports.

What are the underlying costs of these future emission trends? The value of the CO_2 price (in 2010 dollars per ton) needed to reach the different decarbonization scenarios (which would be zero in the *Current Policies* scenario) ranges around 200 dollars in the orderly transition scenario (represented by the red line in Figure 5f); towards the end of the century it temporarily exceeds $ 2,000 per ton in the *Delayed transition* scenario.

Figure 5 - Actual emissions and NGFS scenarios

(*millions of ton of CO2 and USD 2010 per ton of CO2*)



Source: our computation on *BP Statistical review of world energy* and NGFS Scenario Explorer vers. 2.2. (modello MESSAGEix-GLOBIOM 1.1) data.

The methods for integrating future emissions path in financial portfolios have so far been less investigated, given the greater complexity compared to historical emissions: when good quality data are available, analysis on carbon footprint evolution will be viable such as those presented in paragraph 4.

However, a branch of "Transition Finance" is acquiring growing interest from the financial community both in terms of valuation methods (with stress tests and portfolio alignment tools) and creation of new financial instruments for investors interested in reducing risks and taking the opportunities of the carbon transition (TCFD, 2021; OECD, 2021).

Qualitative assessments. In addition to the quantitative assessments reported above, it is also possible to rely on qualitative assessments. For the EU countries, for example, it is possible to analyze the Commission's assessments on the climate-energy plans of individual countries. Also in this case, the situation of Italy can be considered optimistically. The Commission assessed positively the Italian plan presented in 2019 and overall considered it aligned with its recommendations: "Overall, the final NECP largely addresses most of the Commission recommendations" (EC, 2020). Further sources for this qualitative analysis are the IEA databases on national policies regarding energy efficiency and renewable energy.[21] Further evaluation will be possible in the future once the European Union taxonomy of sustainable investments is finalized, for example by comparing how many sectors are aligned with the taxonomy and their relevance to GDP.

2.3 Enviromental risk exposure indicators

Climate change is the environmental issue considered most urgent and critical also because it is directly linked to many other negative impacts on the environment (from the water scarcity to the biodiversity loss). For extending the assessment of the exposure to environmental risks, a useful indicator is the Human Development Index (HDI) of the United Nations Development Programme (UNDP), which has recently introduced a metrics that considers also the environmental footprint of the countries (Planetary pressures-adjusted Human Development Index).[22] This inclusion has improved by twelve positions the ranking of Italy. After the adjustment, for example, Norway has moved down from the first to the fifteenth position and other countries that use and export natural resources have been downgraded as well (for instance Australia, Canada, United States and other exporters of fossil fuels). Besides Italy, other European countries - especially France, Spain, United

[21] See www.iea.org/policies.

[22] The environmental footprint of a product or policy is a multidimensional metrics that summarises the environmental impacts through specific indicators, such as greenhouse gas emissions, water consumption and resource depletion.

Kingdom and Ireland - have improved their rankings thanks to the relatively low percentage of fossil fuels employed in their energy mix and to a lower use of raw material.

Table 2- Planetary pressures-adjusted Human Development Index (PHDI)
(*2019*)

Country	HDI	PHDI*	Position HDI	Position PHDI	Direction of the rank change
Australia	0.944	0.696	8	80	↓
Austria	0.922	0.771	18	29	↓
Belgium	0.931	0.800	14	10	↑
Canada	0.929	0.721	16	56	↓
China	0.761	0.671	85	101	↓
Germany	0.947	0.814	6	7	↓
Spain	0.904	0.795	25	14	↑
France	0.901	0.801	26	10	↑
United Kingdom	0.932	0.825	13	3	↑
Ireland	0.955	0.833	2	1	↑
Japan	0.919	0.781	19	17	↑
Netherlands	0.944	0.794	8	14	↓
USA	0.926	0.718	17	62	↓
Italy	**0.892**	**0.783**	**41**	**29**	↑

Source: our computation on UNDP data.
* Planetary pressures-adjusted HDI.

2.4 Comparison of climate and environmental indicators for some countries

The previous paragraphs presented a set of indicators useful to assess the transition risk of government bonds. For most of the metrics, Italy shows a low carbon footprint and a limited climate/environmental risk in comparison with other countries, based on emission per capita and per unit of GDP. This is the result of the good performance of Italy both in terms of energy intensity (quantity of energy per capita or per unit of GDP) and of carbon intensity of the energy system, also related to the widespread use of renewable resources in the electric system (Table 3). These indicators are used to compare the climate risk exposure of the Bank's government bond portfolio with a market index (see Par. 5.2).

Table 3 - Carbon intensity, energy intensity and Italy's position in a sample of developed countries (*2019*)

	Carbon intensity		Energy intensity		Carbon intensity of the energy	
	Emissions per capita	Emissions per unit of GDP	Energy per capita	Energy per GDP	Emissions per unit of energy	Electricity from renewable sources
	ton of CO_2 per capita	g of CO_2 per 2011 PPP USD	Gj per capita	Mj per 2011 PPP USD	ton of CO_2 per TJ	Percentage values
Australia	17.0	338.7	254.3	5.1	66.8	20.9
Austria	7.2	129.7	167.5	3.0	43.1	73.9
Belgium	10.8	208.7	235.1	4.5	45.9	20.2
Canada	14.9	301.8	379.9	7.7	39.1	65.3
China	6.9	436.2	98.8	6.3	69.3	26.7
Germany	8.2	152.5	157.3	2.9	52.0	39.9
Spain	6.0	144.6	122.4	3.0	48.7	37.2
EU28	6.5	167.5	134.2	3.5	48.4	34.1
France	4.6	96.6	148.6	3.1	30.9	20.4
United Kingdom	5.7	124.1	116.1	2.5	49.4	36.9
Ireland	7.7	87.9	135.8	1.5	56.8	37.4
Japan	8.9	214.7	147.2	3.6	60.1	18.8
Netherlands	11.2	194.6	205.4	3.6	54.7	18.5
USA	15.1	241.9	287.6	4.6	52.5	17.3
Italy	**5.4**	**127.0**	**105.3**	**2.5**	**51.0**	**39.7**
Italy position	**2**	**4**	**2**	**2**	**8**	**4**

Source: based on data of *BP Statistical review of world energy* and World Bank.

3 Climate and environmental indicators for private sector entities

The information about the environmental sustainability are crucial to redirect the resources necessary for the transition toward a low-emission economy. To this purpose, in addition to indicators related to carbon emissions, absolute or relative, as those described before, it is common to employ ESG scores, which jointly assess environmental, social and governance factors of firms, states, supranational organizations and collective investment undertakings (OICR and ETF).

The climate and environmental metrics are therefore just a subset of the factors considered by analysts and their relative importance varies significantly among industrial sectors. For example, the relevance of climate and environmental factors is greater for firms belonging to utility, energy and basic material sectors, whilst in financial and technology sectors the corporate governance and social indicators are more relevant. The lack of a direct link between ESG scores and climate and environmental factors is also corroborated by a research showing that high ESG scores are combined in some cases with high carbon emissions (OECD, 2020).

The ESG scores assess the environmental and climate factors along different viewpoints, as they summarize the multifaceted analysis of: the corporate exposure to those factors; its ability to manage the related risks; the firm's capability to exploit the relevant opportunities. The scores are provided by companies, which have developed their own assessment methodologies and ancillary services. A consolidation process by the major ESG providers is ongoing on the global market; the major ones take over smaller firms often specialized on specific fields and geographical areas. The relevance of the ESG scores for the climate analysis is due to their large use in the sustainable finance for the selection of financial assets, the investment portfolio construction, the definition of market indices and the reporting. Their use has to be complemented by the awareness of their current limits, in particular with regard to the methodological heterogeneity and to the information completeness and quality. Some studies have highlighted that, given an issuer, the providers assign very different scores; their correlation is relatively low, corresponding to 40-50 per cent on average. In the absence of consolidated benchmark models, like those used for financial evaluations or credit ratings, providers have based their competitive advantage on the method differentiation. The causes of this disagreement are mainly attributable to the selection of sustainability factors in the score elaboration (for example the use of natural resources, waste management, workplace safety, consumer protection, board competence and composition) and the indicators used for the score calculation.[23] The relevant ESG factors change with sectors, enterprise models and whether one assumes the point of view of the entrepreneur, who is interested only in the factors with financial consequences for the firm (i.e. financial material), or the point of view of other stakeholders, sensitive to all factors having a significant impact on the environment and society (sustainability materiality). Furthermore, the relevant factors evolve over time, because of technological progress, policy changes and social phenomena (dynamic materiality).[24] For the selection of factors, providers do their own analyses whose details are not disclosed to protect their intellectual property. Regarding the differences in the used indicators, the main cause is the heterogeneity of the corporate reporting, related to the lack of a regulation on the disclosure of non-financial information.[25] This lack of information forces providers to replace missing or incomparable data with model-based data or to resort to alternative non-corporate sources.[26] In the next future, the ongoing review of the Directive 2014/95/EU on Non-Financial Reporting (NFRD) should improve the quantity and quality of information on corporate

[23] See Berg *et al.* (2019).
[24] See Rogers and Serafeim (2020).
[25] See Kotsantonis and Serafeim (2019).
[26] Specifically, it has been observed that the information are often qualitative, the time horizon of the analysis and the forecasts is of short and medium term and still few companies fix quantitative sustainability targets. See 2nd Investing Initiative (2017), "Limited visibility. The current state of corporate disclosure on long-term risks", Discussion Paper, September.

sustainability and therefore make it easier to find data for ESG assessments.[27] A further contribution to a convergence of ESG assessments will be provided by the European taxonomy of environmentally sustainable economic activities (Regulation EU 2020/852) which, once the approval process of its technical annexes has been completed, will provide a set of objective criteria for assessing the sustainability of businesses.[28] The Regulation in particular states that the companies themselves will communicate the proportion of their turnover derived from products or services associated with "green" activities, and the proportion of their capital expenditure and the proportion of their operating expenditure related to assets or processes associated with "green" activities.

The factors with a greater availability of information are those related to the carbon emissions, in particular the direct and indirect emissions (scope 1 e scope 2), while data on scope 3 emissions are poorer. Some specialized providers are able to guarantee even a coverage close to 100 per cent thanks to the use of own estimation models. The fields with the second-most coverage are waste generation and energy consumption (both 69 per cent), while the coverage decreases for data on the use of renewable energy sources (Table 4).

We carried out a correlation analysis on the same indicators (Table 5), based on data provided by four specialized companies, which has highlighted, for data on carbon emission (especially Scope 1 and 3), a very high correlation among three providers, greater than 90 per cent. This circumstance suggests a potential for a combined use of data from different providers, in order to get a larger coverage of the investable universe and to detect abnormal data. Similar results are observed for other indicators on energy consumption, waste generation and recycle (among the four providers analyzed). Therefore, there is often a higher correlation for these indicators than that observed so far for the ESG scores, hence some of these indicators can be used directly in the financial models, as it happens frequently for the carbon emission data, if one wants to undertake a sustainability impact investment strategy.

[27] The European Commission on 21 April 2021 published a proposal for a directive on sustainability communication (*Corporate Sustainability Reporting Directive* - CSRD) to supplement and update the current directive on non-financial communication. Sustainability information will be reported according to the standards developed by the European Financial Reporting Advisory Group (EFRAG). According to the current forecasts on the approval process of the CSRD, large enterprises could be required to comply from 2024, while for small and medium-sized enterprises the obligation would start from 2027.

[28] Activity to be considered environmentally sustainable under the European taxonomy must comply with three main conditions: a) provide a substantial contribution to the achievement of at least one of six environmental objectives of the European Union; b) do not cause significant damage to any of the other environmental objectives (so-called do not significant harm principle - DNSH); c) ensure compliance with minimum ethical and social principles (so-called minimum safeguards), verified with the compliance with specific international standards and conventions.

Table 4 - Coverage of the main environmental and climate corporate factors

Environment	Coverage
Carbon emissions	
Scope 1 emissions	81%
Scope 2 emissions	80%
Scope 3 emissions	62%
Energy	
Energy consumption	69%
Renewable energy consumption	49%
Water	
Water withdrawal	53%
Water consumption	56%
Water pollution	13%
Waste	
Waste generated	69%
Hazardous waste	50%
Waste recycled	54%

Source: based on ESG data provided by four leading suppliers on companies included in the MSCI EMU index, the FTSE Italy All-share index and two Bloomberg-MSCI euro area and USA corporate bond indexes.

Table 5 - Correlation of the main environmental and climate indicators among providers

	Provider A/ Provider B	Provider A/ Provider C	Provider A/ Provider D	Provider B/ Provider C	Provider B/ Provider D	Provider C/ Provider D
Environment						
Scope 1 emissions	1.00	1.00	0.95	1.00	0.95	0.95
Scope 2 emissions	0.20	0.77	0.98	0.16	0.20	0.78
Scope 3 emissions	1.00	0.99	0.52	0.99	0.52	0.52
Energy consumption				0.89		
Water withdrawal				0.95		
Water consumption			0.93			
Waste generated				0.95	0.77	0.78
Hazardous waste				0.89		
Waste recycled				0.99	0.99	0.99

Source: based on ESG data provided by four leading suppliers on companies included in the MSCI EMU index, the FTSE Italy All-share index and two Bloomberg-MSCI euro area and USA corporate bond indexes.

With respect to the completeness and quality of the information contained in the ESG scores, they provide valuable clues about the past situation and the ongoing controversies, whilst they are less effective to assess future sustainability and controversy risks. These limitations depend on various reasons: the corporate communication is mainly based on backward-looking indicators; corporate strategies and commitments are often generic and not supported by quantitative goals; lastly, the risk analysis is often referred to the short-medium term.

To overcome this limit, some providers have developed methodologies to measure, through the analysis of climate scenarios, the firm exposure to the climate risks and the potential impact on its equity and debt capital defined as climate value at risk (Dietz *et al.*, 2016).

4 Carbon footprint and exposure metrics for financial portfolios

Within the scope of its sustainable investment activity, the Bank of Italy has started to estimate the exposure to climate and environmental risks of its foreign reserves and euro-denominated investment portfolio; the metrics introduced in par. 2.1 and 3 has been used to this aim. Government and private securities have been considered separately in order to avoid double counting issues. Backward looking metrics, such as portfolio GHG emissions' allows to: a) assess and track the carbon impact of investments; b) obtain a proxy of the transition risk through comparisons between portfolios and benchmark indices.

Assessing a carbon metrics of a diversified portfolio of equities and bonds requires to consider a measure of the company's total value, the enterprise value including cash (EVIC), in order to allocate company's GHG emissions and revenues to either shareholders and lenders of the company, avoiding double counting issues. For government bonds, countries' GHG emissions and public debts are weighted by the share of public debt held within the portfolio. Countries' GHG emissions include those from resident companies; consequently, it is not appropriate to calculate carbon metrics for a diversified portfolio of government and private securities in order to avoid double counting of GHG emissions. Therefore, we have treated government and private securities separately.

For a given portfolio containing *n* private securities (shares and/or corporate bonds) or *m* government bonds the following carbon footprinting and exposure metrics can be considered[29]:

- **portfolio emissions**: sum of GHG emissions, expressed in tons of CO_2 equivalent (tCO_2e), associated with each security using different weights: a) for private securities, the ratio

[29] The term *carbon footprint* is often referred to the amount of GHG emissions produced by a good, a service or an organization; in this case, GHG emissions of companies and countries financed by the portfolio have to be measured in an absolute or normalised way. The *Task Force on Climate-related Financial Disclosures* (TCFD) of the *Financial Stability Board* (FSB) has defined as carbon footprint of a financial portfolio a specific metrics (sometimes also referred to as *capital carbon footprint*); such metrics normalises GHG emissions of a portfolio by its market value in a single currency.

between the market value of the security and the enterprise value including cash (EVIC); b) for government bonds, the ratio between the nominal value of the bond in the portfolio and the nominal value of country's public debt (PD);

$\sum_{i=1}^{n}\left(\frac{Market\ Value_i}{EVIC_i}\cdot\ GHG\ Emissions_i\right)$ for shares and corporate bonds;

$\sum_{i=1}^{m}\left(\frac{Nominal\ Value_i}{PD_i}\cdot\ GHG\ Emissions_i\right)$ for government bonds;

- **carbon footprint**: portfolio emissions (expressed in grams di CO_2e) for EUR 1 invested:

$\frac{Portfolio\ Emissions}{Portfolio\ Market\ Value}$;

- **carbon intensity** of *i-th* issuer: ratio between GHG emissions and a) revenues for corporates, b) GDP for countries:

$CI_i = \frac{GHG\ Emissions_i}{Revenues_i}$ for shares and corporate bonds;

$CI_i = \frac{GHG\ Emissions_i}{GDP_i}$ for government bonds;

- **portfolio carbon intensity:** ratio between the total emissions and a) revenues associated to portfolio for corporates (based on EVIC), b) GDP associated to portfolio for countries:

$\frac{Portfolio\ Emissions}{\sum_{i=1}^{n}\left(\frac{Market\ Value_i}{EVIC_i}\cdot Revenues_i\right)}$ for shares and corporate bonds;

$\frac{Portfolio\ Emissions}{\sum_{i=1}^{m}\left(\frac{Nominal\ Value_i}{PD_i}\cdot GDP_i\right)}$ for government bonds;

- **WACI** (*weighted average carbon intensity*): average of carbon intensities of the issuers weighted by the securities' weights in the portfolio (at market values):

$\sum_{i=1}^{n}\left(\frac{Market\ Value_i}{Portafolio\ Market\ Value}\cdot\ CI_i\right)$ for shares and corporate bonds;

$\sum_{i=1}^{m}\left(\frac{Market\ Value_i}{Portafolio\ Market\ Value}\cdot\ CI_i\right)$ for government bonds.

These indicators reformulate those reported by the *Task Force on Climate-related Financial Disclosure* in the annex to its recommendations (TCFD, 2017)[30], to extend their use to diversified portfolios of stocks and bonds and to government bonds.

Some of the indicators described above make it possible to compare in relative terms the exposure to transition risk; others depend on the absolute size of the portfolio and may be relevant for the link with climate policies (see par. 2.1) or in relation to certain sustainability objectives. An estimate of climate risks would require forward-looking measures and, in particular, an analysis of the effects that technology, regulations, taxation, etc. (transition risk) and extreme climatic events (physical risk) can have on industrial sectors and on the value of companies.

The Kaya identity, shown in par. 2.1, shows that the emission changes of a company or a state depend on the energy efficiency (revenue or GDP per unit of energy used) and the carbon intensity of energy uses (GHG emissions per unit of energy used) of the issuer. Therefore, emissions can be reduced through technologies that improve energy efficiency or through non-fossil energy sources. Carbon intensity is therefore useful for classifying companies (and sectors) or countries according to their respective energy-environmental efficiency.

The indicators that take into account the efficiency in the terms indicated above (carbon intensity and WACI) or that normalize emissions by the amounts invested (carbon footprint) allows to follow the climate impact of a portfolio over time, as well as to compare portfolios of different sizes.

As already noted, the carbon intensity of the portfolio is calculated by expressing emissions per unit of revenues (or GDP) in proportion to the share held in the assets of a company (or the public debt of a country); in this way, dimensional differences are taken into account and an indication of the energy and carbon efficiency of the portfolio as a whole is obtained. This measure also provides an indication of the exposure to transition risk.[31]

Table 6 summarizes the main advantages and disadvantages of each indicator.

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[30] As of October 2021 a new version of the annex has been released, which adopts the EVIC approach for listed private securities (TCFD, 2021).

[31] The financial risk arising from the energy transition required to keep the global temperature rise below 2°C can materialize through several channels, such as: a) government decisions about the imposition of taxes or restrictions on CO_2 emissions that they would cause a significant increase in costs for less efficient organizations; b) a sudden technological innovation that disrupt some sectors including, potentially, those related to fossil fuels (which have the highest intensity values); c) more or less rapid changes in the expectations and/or preferences of economic agents. It is reasonable to assume that transition risk could affect low-energy efficient and/or high carbon-intensive sectors through all these channels.

Table 6 - Climate risk indicators of a portfolio in terms of GHG emissions

Indicators	Pro	Cons
Total portfolio emissions (tCO2e)	Useful for following the dynamics of the a portfolio of constant size over time	It cannot be used to compare portfolios that differ in size
Carbon footprint (gCO2e/EUR invested)	Allows comparisons between portfolios	It does not consider energy and carbon efficiency
Carbon intensity (gCO2e/EUR of revenues or GDP)	Evaluate the energy and carbon efficiency of a portfolio	- More complex to calculate
WACI (gCO2e/EUR of revenues or GDP)	- Easier to calculate - Independent of the economic value / size of the company	- Indicator highly sensible to the exposures to carbon intensive sectors

For companies, direct and indirect GHG emissions (scope 1 and scope 2) are usually considered.[32] These data are available from numerous providers such as Refinitiv, Bloomberg, MSCI, Trucost and Sustainalytics, Vigeo Eiris. Data on revenues and EVIC can be obtained from financial data providers, including MSCI, Refinitiv and Bloomberg.

For carbon emissions, in relation to the countries of the European Union, it is possible to use the data from Eurostat's Air Emission Accounts (see paragraph 2.1), which represent the national emissions of GHGs by resident entities (businesses and families). Eurostat data on 2020 emissions are not yet available; however, estimates from other sources indicate that the Covid-19 pandemic caused an important reduction in national emissions between 2019 and 2020.[33] Eurostat data can be used for the public debt and GDP of EU countries.[34]

For non-EU countries, given that no harmonized Eurostat data is available, the British Petroleum (BP) database (British Petroleum, 2020) was used to obtain data on emissions,[35] while GDP and public

[32] See footnote 2.
[33] Based on the data available for 2020, in February 2021 the Italian EPA (ISPRA) estimated a reduction in Italy's GHG emissions of 9.8 percent; this reduction is greater than that drop in GDP (-8.8 percent) estimated by the European Commission in its economic forecasts. This trend, which confirms the decoupling between emissions and GDP already observed in previous years, is due to a set of pandemic-related facts: a) the reduction of emissions from power generation (-12.6 per cent) for lower energy demand; b) the reduction of energy consumption also in other sectors, such as industry (-9.9 per cent) and transport (-16.8 per cent), due to the reduction of private transport in urban areas, and of heating (-5.8 percent) for the partial or total closure of public buildings and commercial activities.
[34] In the following, we consider consolidated gross public debt and real GDP in euro at constant 2008 prices.
[35] These data cover the annual CO_2 emissions of individual countries and not those of all greenhouse gases as in the case of Eurostat data.

debt data were obtained from the World Bank's database and normalized using the US dollar as the base currency.

Generally, the calculation of the carbon footprint of a bond portfolio does not differ according to the type of bond; therefore, this measure is not reduced by the presence of green bonds, even if these allow to finance projects with characteristics of environmental sustainability (water and waste treatment, pollution prevention and control initiatives, transport infrastructures including railways, systems for energy efficiency and energy production from renewable sources). To take into account in a distinct way the positive contribution to the environment of these projects, therefore, it is useful to calculate the percentage of green bonds of a bond portfolio or a specific class of assets; this percentage is the only measure that will be calculated for supranational securities present in the portfolios considered in this work.

5 Climate and environmental risks exposure of Bank of Italy's investment portfolios

In this paragraph, we apply the climate and environmental risk exposures indicators to the Bank's investment portfolios and analyse the results, which are largely driven by the Bank's investment policy which has integrated ESG principles since 2019. The integration of sustainability criteria into the investment policy aims to improve the financial risk management and to signal the Bank's commitment to sustainable development, mindful of society and the environment. The new investment policy was initially applied to the equity portfolio, with a focus on the European market where there is a wider availability of ESG data (NGFS, 2019 b). In 2020, the ESG strategy was extended to US and Japanese equity investments held via funds and ETFs and to corporate bonds. Purchases of green bonds issued by supranational agencies were also started.

5.1 The Bank of Italy's foreign reserves and investment portfolios: objectives and composition

The Bank of Italy, in addition to the monetary policy portfolios, manages the foreign reserves and the investment portfolio, the latter mainly invested in euro. These portfolios, according to their relevant institutional purposes, have different objectives and geographical allocations.

Foreign reserves can be used for foreign exchange market interventions to preserve currency stability. The management of reserves contributes to the Bank's annual net income and to preserve the financial soundness of the Bank against the risks it is exposed in following its mandate. The management of the reserves is primary aimed at preserving their value and liquidity. Furthermore, given the growing importance of foreign exchange reserves as an integral part of assets, their management pursues the maximization of returns within the risk-limits. The portfolio is geographically diversified according to the major global currencies (US dollars, Japanese yen, British pounds, Canadian and Australian dollars, Chinese renminbi). In the remainder of the analysis, only the foreign reserves invested in government securities are considered, which amounted to over EUR 31 billion at the end of 2020 (Table 7).

The objective of the **investment portfolios** is to contribute to the coverage of Bank's operational costs and to preserve its capital robustness in facing the most adverse scenarios, by diversifying investments with respect to the typical risk factors of a central bank. Approximately 10 per cent of the portfolio is invested in shares, funds and ETFs. Equity shares are represented by securities listed in the euro area; funds and ETFs are denominated in foreign currencies and replicate equity market indices for the US and Japan. Investments in banking and insurance sectors are excluded due to the institutional role of the Bank of Italy. The remainder of the investment portfolio consists mainly of government and private bonds. Overall, the financial portfolio considered amounted to EUR 160 billion at the end of 2020 (Table 7).

Table 7 - Bank of Italy's investments considered in the sustainability analysis
(market values in billions of euro and percentage changes)

	31.12.2019	**31.12.2020**	**% chg**
Investment portfolios			
Equity	*9.2*	*12.1*	*31.1*
Corporate Bonds	*0.8*	*0.8*	*1.8*
Government (1)	*138.8*	*147.1*	*6.0*
Total	**148.8**	**160.0**	**7.5**
FX reserves			
Government (1)	30.9	31.4	1.8

(1) Government debt includes supranational bonds.

Paragraphs 5.2 and 5.3 show carbon and climate indicators for government and private securities held by Bank of Italy (in euro and other currencies), also including a comparison with benchmark indices for each asset class.

5.2 Government bonds

Investment portfolios consist of a significant share of government bonds, mainly issued by the Italian Government. It also includes government bonds issued by other euro area countries and supranational issuers, comparable to governmental entities.

Indicators presented in Paragraph 4 were calculated for this portfolio with reference to the end of 2019 and 2020, using the carbon intensity of the individual countries (ratio between national GHG emissions and GDP) at the end of 2019 to highlight the effect deriving from the change in the size and composition of the portfolio between the two years (Table 8).

To make a comparison with a possible market allocation, a benchmark index was estimated modifying the *ICE BofA All Maturity All Euro Government Index*, considering the top 7 countries of the euro area by size of their public debt. [36]

Table 8 - Carbon indicators of EUR government bond investments

	Portfolio (1) 31.12.2020	Portfolio 31.12.2019	var. %	Benchmark (2) 31.12.2020
Portfolio emissions *(thousand tCO_2e)*	20,580	20,289	*1.4*	28,757
Carbon footprint *(gCO_2e per EUR invested)*	142	149	*-4.9*	198
Carbon intensity *(gCO_2e per EUR of GDP)*	262	263	*-0.1*	278
WACI *(gCO_2e per EUR of GDP)*	262	262	*0.0*	255

Source: based on Eurostat.
(1) National GHG emission and GDP based on 2019 level.
(2) index ICE BofAML *All Maturity All Euro Government Index* (ECAS) considering the top seven EU countries by size of public debt.

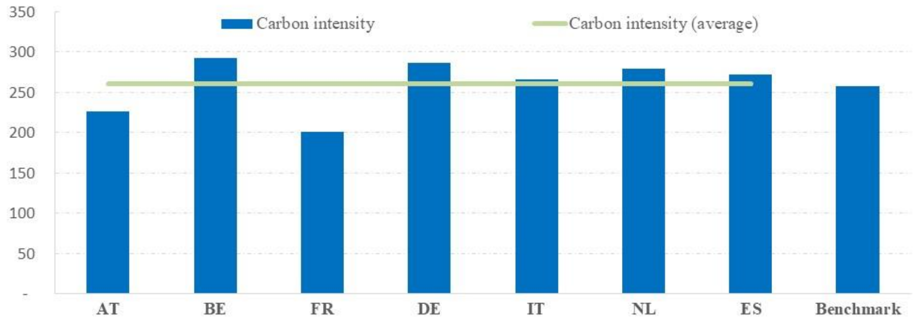
The government bond portfolio at the end of 2020 (Table 7) increased by 6 per cent, this is partly due to the market value appreciation of the portfolio.[37] The growth of portfolio GHG emissions was less than proportional (+1.4 percent, Table 8); consequently, carbon footprint has decreased in the period (-4.9 percent). The carbon intensity and the WACI have remained substantially unchanged because the portfolio composition and the share of countries' public debts held by the Bank have recorded modest changes. The WACI shows values close to the carbon intensity of Italy (266 gCO2e per euro of GDP), as Italian government bonds represent by far the major share of the portfolio.

The benchmark index shows higher emissions than the portfolio, since it is characterized by a higher weight of countries with GHG emissions larger than Italy (i.e. Germany); consequently, the carbon footprint and carbon intensity of the Bank of Italy's portfolio are lower. WACI of the benchmark

[36] Austria, Belgium, France, Germany, Italy, Netherlands and Spain.
[37] In the same period (between the end of 2019 and the end of 2020), the abovementioned general ICE BofA market index appreciated by 4.6 percent.

index is instead lower due to the greater weight of French securities: the carbon intensity of France (201 gCO_2e per EUR of GDP) is significantly lower than that of Italy and the average of the countries considered in the index (Fig. 6).

Figure 6 - Carbon intensity of government bonds
(in grams of CO_2e per EUR of GDP)



Source: based on data from Eurostat.

Concerning green bonds, at the end of 2020 a sovereign issue which finances projects to reduce GHGs has been included in the portfolio, while among the supranational securities green bonds worth approximately 5 per cent of this asset class have been purchased.

The government's foreign exchange (FX) reserve portfolio was composed mainly of US Treasuries and to a lesser extent of Japanese, British, Australian, Canadian and Chinese bonds. As in the case of the EUR portfolio, the reference index used for the comparison was obtained using the *ICE All Maturity* indices for the government bonds of the six countries in which the Bank invested. The indices for each currency include government bonds issued by their respective government with a residual maturity of at least one month, a maturity at issue of at least 18 months and a minimum issued amount of 1 billion, USD, AUD and CAD, 200 billion of JPY, 500 million GBP and 10 billion CNY. Carbon indicators of the FX reserve portfolio were calculated on the basis of holdings at the end of 2020 and with the carbon indicators at the end of 2019 (latest data available), similarly to the EUR portfolio (Table 8).

Although the Bank of Italy does not currently have in place an investment strategy based on sustainability criteria for the FX portfolio, the indicators outperform the benchmark (Table 9).

For a better comparison of the environmental sustainability of the government bond portfolios, both investment portfolios and FX reserves portfolio with their relative benchmarks, the analysis has been enriched with further environmental indicators:

- energy per unit of GDP (Mj per USD 2011): energy consumed (expressed in megajoule) divided by 2011 PPP USD GDP;

- Sovereign Warming Potential in the business as usual (BAU) scenario and in the nationally determined contributions (NDCs) (in Celsius degrees): it assesses a country's alignment to a global stabilization goal, based on the country's commitments to reduce its emission profile with current policies (BAS) and considering the NDCs to reduce national emissions that each country declared under the Paris Agreement;
- Environmental Vulnerability Index (EVI): it reflects the extent to which the natural environment of a country is prone to damage and degradation. This index contains indicators on weather and climate, geology, geography, ecosystem resources and services, high winds, dry periods, endemics, frequency of earthquake, tsunamis, volcanic eruptions, etc.[38] Score indications are: below 215 (resilient), above 215 (at risk), above 265 (vulnerable), above 315 (highly vulnerable) and above 365 (extremely vulnerable).

Table 9 - Carbon indicators of FX reserves' government bond investments

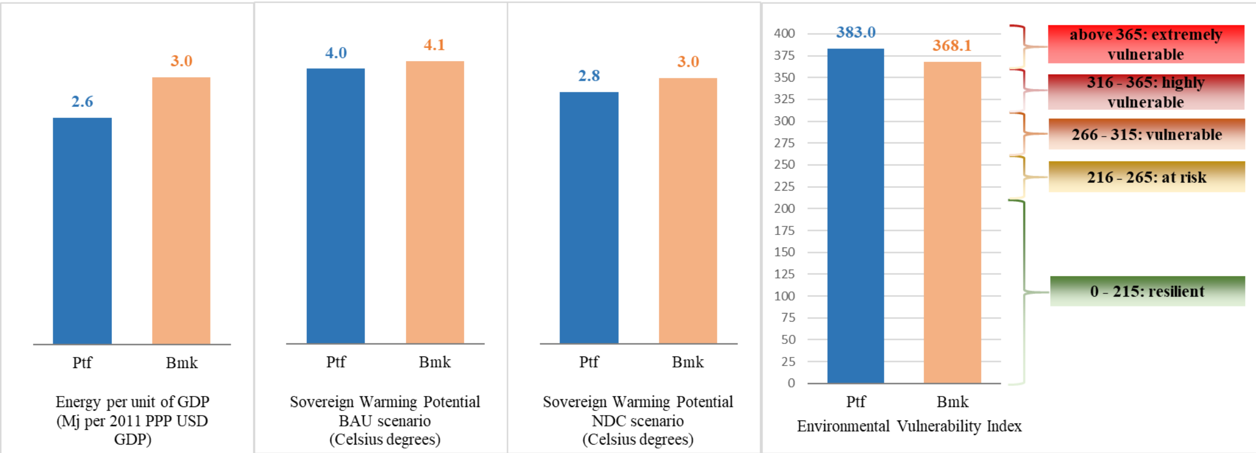
	Portfolio (1) 31.12.2020	Benchmark (2) 31.12.2020	% chg
Portfolio emissions *(thousand tCO_2)*	7,765	10,459	*-25.8*
Carbon footprint *(gCO_2 per USD invested)*	357	481	*-25.8*
Carbon intensity *(gCO_2 per USD of GDP)*	263	307	*-14.2*
WACI *(gCO_2 per USD of GDP)*	244	242	*0.8*

Source: based on BP data.
(1) National CO_2 emission and GDP based on 2019 level.
(2) ICE All Maturity index.

As of 2020, the EUR portfolio shows better indicators than the benchmark (Fig. 7) - thanks to the large exposure to Italy that, as evidenced in the paragraph 2.4, is one of the best-performing country from the standpoint of the environmental and energy metrics - except for the EVI.[39] With regard to the EVI, both the portfolio and the benchmark are classified as 'extremely vulnerable'.

[38] This metrics is provided by MSCI ESG Research.
[39] This metrics included seismic risks, which, though very relevant for Italy, are not related to climate change.

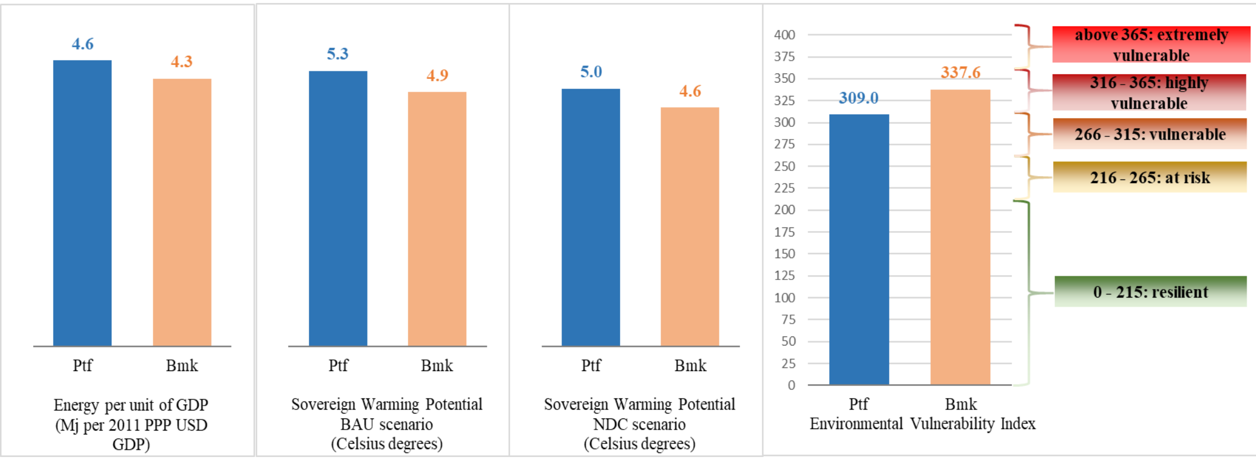
Figure 7 - Environmental and energy sustainability of the Bank of Italy euro government bond portfolio



Source: based on data from ICE, BP, MSCI and World Bank as of 2019. Portfolio and benchmark data as of 12/31/2020.

The FX portfolio does not overperform the benchmark in terms of energy consumption and sovereign warming potential (Fig. 8). With respect to EVI, the portfolio is classified as 'vulnerable', while the benchmark is considered as 'highly vulnerable'. These results are explained by the higher exposure, compared to benchmark, to USA, a country that presents on average worst indicators compared to the other countries. The Bank of Italy has not currently adopted sustainability criteria for the management of FX reserves.

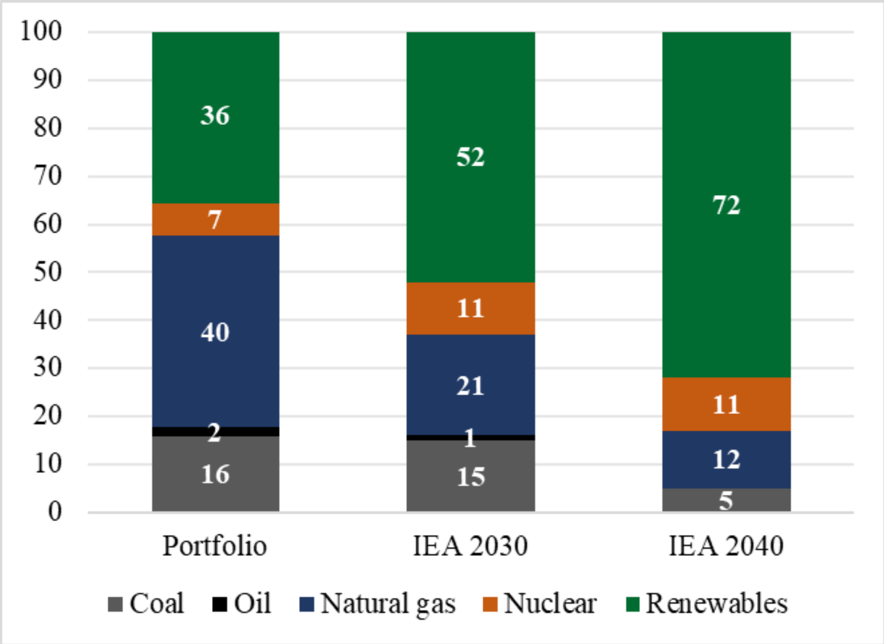
Figure 8 - Environmental and energy sustainability of the Bank of Italy foreign currency government bond portfolio



Source: based on data from ICE, BP, MSCI and World Bank as of 2019. Portfolio and benchmark data as of 12/31/2020.

To obtain a forward-looking metrics for the entire government bond portfolio, it has been carried out a comparative analysis of the energy mix employed for the power production by the states whose government bonds are bought by the Bank (in euro and in foreign currencies), weighted by their share in the portfolio (Fig. 9). Specifically, we compare the current power mix with the one compatible, according to the International Energy Agency scenarios for 2030 and 2040, with a temperature increase within the two degrees (IEA, 2020). The differences between the portfolio and the IEA projections are primarily due to the high percentage of natural gas in the portfolio. This is a consequence of the large exposure to Italy, which makes an intense use of gas power plants (more efficient in term of unit of energy produced than other fossil fuels and one of the reason for the high efficiency of the Italian energy system). Finally, Italy is also one of the countries with the highest share of renewable energy sources employed in the power mix.

Figure 9 - Power mix: portfolio vs IEA projections
(percentage values)



Source: IEA data as of 2019. Portfolio data as of 12/31/2020. The 2030 and 2040 power mix are projections of the Sustainable Development Scenario (IEA, 2020).

5.3 Private sector securities[40]

Bank of Italy's investment portfolio is composed by several asset classes, therefore we computed carbon and climate indicators for all private securities (Table 10) and afterwards separately for equities (Table 11) and for fixed income (Table 12). The investment portfolio considered had a value of EUR 12.9 billion at the end of 2020.

The indicators considered for private securities are based on the previous year's issues, revenues and EVICs, according to the practices applied by data providers and investors who publish this information.

[40] The Bank of Italy does not invest in private securities issued by financial companies or the media sector (both characterized by low emissions).

At end 2020, sustainable investment criteria have also been extended to the fixed-income asset class (Table 12). The increase in the size of the equity portfolio (+31.1 percent, Table 7) has led to an increase of GHG emissions (+25.6 percent, Table 10); however, the application of the sustainability criteria to the new purchases has stabilised the carbon footprint over time. Carbon footprint was already at a very low level due to the integration of ESG criteria into the equity portfolio in 2019. Carbon intensity and WACI decreased (-10.1 and -11.5 per cent, respectively), highlighting a progressive shift of the portfolio towards more carbon-efficient companies.

Table 10 - Carbon indicators of private securities, investment portfolio

	2020	2019	% chg
Portfolio emissions *(thousand tCO_2e)*	1,717	1,366	*25.6*
Carbon footprint *(gCO_2e per EUR invested)*	134	137	*-2.5*
Carbon intensity *(gCO_2e per EUR of revenue)*	264	294	*-10.1*
WACI *(gCO_2e per EUR of revenue)*	243	275	*-11.5*
High emission sector *(percentage)*	28.5	28.4	*0.1*

Source: based on data from MSCI ESG Research LLC and Bloomberg.

In order to analyse the drivers of the improvements, the results by asset class have been broken down. This shows that the reduction of both the carbon footprint and the WACI was higher for corporate bonds, for which 2020 was the first year of adoption of sustainability criteria, which had already been applied to the equity portfolio since 2019. Furthermore, the static comparison between the two asset classes shows that the differences in the carbon emission indicators, which are better for the bond portfolio than for the equity one, are partly explained by the lower exposure of the former to carbon-intensive sectors (Table 11 and 12).

Lastly, the investment portfolio at the end of 2020 included green bonds (2.3 per cent).

The Bank's **direct equity investments**, i.e. those managed internally without making use of collective investment instruments, consist of two separate portfolios, one of Italian securities and one of securities of other euro area countries. The management of the two portfolios is based on the replication of market capitalization equity indices, adapted to exclude financials and the Italian media for reasons connected with the Bank's institutional functions. Since 2019, the integration of ESG criteria in the portfolio management has followed a dual approach: (a) the exclusion of companies producing controversial weapons[41] and tobacco; (b) the preference for companies with the best ESG profile and the lowest carbon emissions (*best-in-class approach*)[42].

In 2020, equity investments overall showed a profile of environmental sustainability, measured with carbon emissions indicators, better than the reference indices (Table 11).

Table 11 - Carbon indicators of equity investments

	Portfolio 2020	Benchmark 2020	Portfolio 2019	Δ% Port 2020 - Bench	Δ% Port 2020 - 2019
Portfolio emissions *(thousand tCO_2e)*	1,664	2,181	1,281	-23.7	29.9
Carbon footprint *(gCO_2e per EUR invested)*	137	180	139	-23.7	*-0.8*
Carbon intensity *(gCO_2e per EUR of revenue)*	272	330	303	*-17.7*	*-10.4*
WACI *(gCO_2e per EUR of revenue)*	251	290	283	*-13.4*	*-11.6*

Because of the ESG strategy integrated with the target of reducing carbon intensity, in 2020 the absolute GHG emissions of equity portfolio are 23.7 percent lower than the benchmark. Compared to the 2019 portfolio, absolute emissions increased by 29.9 percent as a result of the aforementioned increase in the portfolio size (+31.1 percent). In several cases the investment flows favour companies with a high ESG profile, which at the same time emit meaningful amounts of GHG, such as the power-generating companies. This supposed contradiction, as previously explained (par. 3), is due to the fact that the sustainability profile proxied with ESG scores is not only referring to the climatic aspects of companies, but also to their social and corporate governance profile, therefore in many cases the environmental and overall ESG profile can diverge.

Carbon intensity and WACI are lower than the benchmark (-17.7 and -13.4 per cent) and the 2019 portfolio (-10.4 and -11.6 per cent); this indicates the effectiveness of a portfolio strategy favoring companies that emit lower quantities of GHGs, with respect to their turnover.

The direct investments in **corporate bonds** of the Bank are managed internally and consist in the portfolio of EUR bonds. Management of portfolio is based on the optimized replication of bond indices, adapted to exclude, as for equities, financial stocks and the Italian media. Since 2020, the

[41] Controversial weapons are banned by special international conventions as they indiscriminately and massively affect the civilian population and cause damage to health even in the long term. The exclusion adopted by the Bank comprises anti-personnel mines and cluster munitions (the production of which precludes companies from joining the United Nations Global Compact), chemical weapons, biological weapons, invisible fragmentation weapons, white phosphorus, blinding lasers and nuclear weapons.

[42] The ESG profile is measured by scores provided by a specialized company.

management of corporate bonds has been integrated by environmental, social and governance sustainability criteria, applying the same strategies used for the equity class - the exclusion of companies operating in controversial activities and the preference for companies with the best ESG profile (*best in class*).

In 2020, bond investments show overall an environmental sustainability profile, measured with the indicators listed in par. 4, better than both the market index and the 2019 portfolio (Table 12).

The comparison with a market index and not with the one actually used - which already integrates ESG criteria - allows us to analyze the differences in transitioning from a traditional management to one that considers ESG profiles.

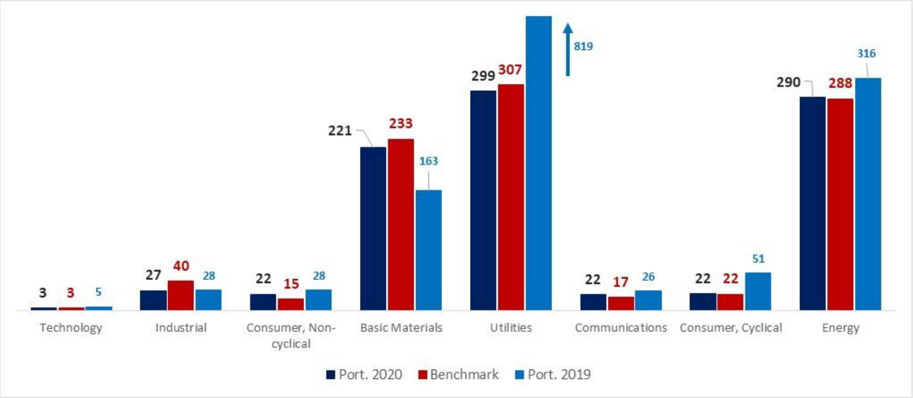
Table 12 - Carbon indicators of EUR corporate bonds investments

	Portfolio 2020	Benchmark 2020 (1)	Portfolio 2019	Δ% Port 2020 - Bench	Δ% Port 2020 - 2019
Portfolio emissions *(thousand tCO_2e)*	52	82	85	*-36%*	*-39%*
Carbon footprint *(gCO_2e per EUR invested)*	70	109	118	*-36%*	*-41%*
Carbon intensity *(gCO_2e per EUR of revenue)*	139	226	172	*-39%*	*-19%*
WACI *(gCO_2e per EUR of revenue)*	118	196	161	*-40%*	*-27%*

(1) ICE BofA AAA-A Euro non-financial

All indicators are significantly lower than the market index and the 2019 portfolio (which did not integrate ESG considerations), in particular for the carbon footprint.

Figure 10 - Sectorial Carbon footprint of corporate bonds



To identify the drivers of the improvement in the carbon footprint, the sectoral distribution of the portfolio values at the end of 2019 and 2020 is shown and compared with the market benchmark (Fig. 10). While there are no significant differences between the 2020 portfolio and the benchmark at the sector level, the improvement in the portfolio's carbon footprint in 2020 mainly depends on the sharp reduction of the indicator for the Services and Energy sectors.

6 Conclusions

In the last decade, the focus on investments' sustainability profiles has grown, in particular as regards the measurement and management of climate risks. The methodologies for estimating and assessing the exposure to these risks have been enriched, in order to integrate them with the management of traditional market risks for the purpose of portfolio choices.

This work contributes to the ongoing debate on the selection and use of indicators for measuring climate risk exposure, offering a review of the indicators available for different categories of financial assets (shares, corporate and government bonds). Although the number of consistent and comparable indicators is still limited, the paper shows how investors can make progress towards measuring and managing climate risks using a wealth of public information that is little explored as yet, although it is systematically used by private data providers in their sustainability assessments.

Public sources are particularly useful for government bond valuations and can be complemented by additional data from specialized providers. For a forward-looking analysis of countries' climate risks, the work emphasizes the usefulness of combining historical trends with the government commitments and the scenarios developed by the Network for Greening the Financial System. Due to the limitations in the availability of data on the climate-related physical risk assessment, the analysis only marginally investigates this topic (through the environmental vulnerability index), in spite of it being an area of growing attention for investors.

For corporates, the work finds quite a high coverage and correlation amongst the carbon emissions data offered by various specialized providers; this evidence supports the idea that such data can be integrated into financial models. The divergences in the data for other environmental indicators (e.g. the use of energy and water, as well as waste management) across different providers are still significant. The joint use of data from different providers can contribute to achieving a broader coverage of the investment universe and to identifying potential data anomalies.

The paper also addresses the methodological issues for measuring the indicators at portfolio level and shows a concrete application to the Bank of Italy's financial investments in euros and in foreign exchange reserves. The analysis shows a significant reduction of the exposure to the climate and environmental risks of the Bank's investments obtained through the integration of ESG principles into the strategies adopted for the management of financial portfolios not related to monetary policy. After the integration of ESG criteria into the directly managed equity portfolio in 2019, the scope of sustainable investment criteria was further extended in 2020 to equity investments carried out through collective instruments in the United States and Japan and to bond portfolios, which include bonds issued by private sector companies, supranational bodies and agencies to finance projects with environmental sustainability characteristics (green bonds).

In February 2021, the Eurosystem agreed on a common stance for the disclosure by central banks, starting from 2023, of risk measures for investment portfolios not related to monetary policy. In addition, the Eurosystem is currently carrying out an analysis on the implications of climate-related risks as part of the review of its monetary policy strategy; the first results were published last September.

In July 2021, the Bank of Italy published its Responsible Investment Charter, to set out its vision of sustainable finance, to communicate the core principles inspiring the management of financial investments and to define the lines of action to improve sustainable investments.

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GLOSSARY

Carbon footprint/intensity

The carbon footprint is the ratio of the greenhouse gas emissions caused by a product, service, organization, event or individual, generally expressed in tons of CO_2 equivalent (i.e. taking as a reference for all greenhouse gases - GHG - the effect associated with CO_2, assumed equal to 1) and the value of the related investments (value of the company, referred to the equity and debt capital). When GHG are divided by the turnover, the ratio is referred as carbon intensity.

CO_2

Carbon dioxide.

ESG

Acronym of *environmental, social and governance* dimensions of the corporate practices not closely related to economic and financial practices. These three dimensions are increasingly considered within the corporate management and investment decision making.

ESG score

The ESG rating is the summary judgment expressed on a scale of letters or numbers by an independent party on the environmental, social and governance profiles of an issuer, a financial instrument or an investment fund. The assessment, in its broadest sense, takes into account exposure to ESG risks and the ability of the assessed entity to manage them and seize any opportunities. It differs from the traditional rating, which assesses the creditworthiness of a company based on its economic-financial variables.

GHGs

Acronym of *green house gases*, that are gases considered by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the so-called F-gases (hydrofluorocarbons and perfluorocarbons) and sulphur hexafluoride (SF_6). These gases are able to retain the heat produced by solar radiation on the earth's surface and prevent from being dispersed into the atmosphere, resulting in an increase in the average temperature of the earth's surface.

TCFD

Task force on climate related financial disclosure promoted by the Financial Stability Board and established in 2015 by the private sector to develop a broad and flexible framework for the disclosure by companies and investors of information on exposure to sources of climate-related financial risks. In 2017, the TCFD developed recommendations for the disclosure of information covering four areas of interest: corporate governance, strategy, risk management and metrics/targets related to climate risks.

WACI

The weighted average carbon intensity is a portfolio indicator computed as the average of carbon intensities of the issuers weighted by the securities’ weights in the portfolio (at market values).

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