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CLIMATE-RELATED RISKS FOR ITALY: AN ANALYSIS BASED ON THE LATEST NGFS SCENARIOS

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Abstract

The paper presents an overview of the pathways of the main Italian climate and macroeconomic variables according to the updated NGFS Phase IV long-term scenarios. Our analysis shows that: 1) climate risks translate into GDP losses and higher inflation; the macroeconomic impacts due to transition risks are broadly in line with those of the EU, while those relating to physical risks are slightly greater; 2) significant government investment is needed to achieve the more ambitious climate targets, a result that is shared with the rest of the EU and, more generally, at the global level; and 3) keeping inflation under control would require higher policy rates over fairly long horizons, although deviations from the baseline level of policy rates generally tend to be fairly contained across all scenarios, except in the most ambitious climate scenarios. Such climate scenarios are one of the key policy tools for assessing the overall resilience of the economy and the financial sector for forward-looking climate scenario analysis and stress testing purposes.

JEL Classification: C60, E50, G32, Q40, D58.

Keywords: NGFS scenarios, climate change, climate stress test, scenario analysis, environmental policy.

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1. Introduction[+]

There is a growing need to understand how climate risks will unfold in the future. That is: What should we expect if climate change is not mitigated (physical risk)? What would be the effects of less or more stringent climate policies (transition risk)? NGFS climate scenarios help to address these questions by providing a common starting point for analyzing the climate risks for the economy and financial system. These scenarios illustrate possible economic trajectories through the middle of the century based on different assumptions about the evolution of climate policy and about how it influences emission concentrations and temperature dynamics. The NGFS scenarios are not forecasts; instead, they serve to explore a spectrum of plausible outcomes - generally reported as deviations from baseline values[1] - with the aim to identify long-term economic and financial vulnerabilities (NGFS, 2023).

Notably, NGFS climate scenarios possess distinctive qualities that render them particularly suitable for analyzing climate-related financial risks: i) they generate internally consistent results that integrate transition, physical, and macro-financial risks; ii) they are applicable globally, regionally, and in some cases also at the country level; and iii) they are openly accessible through an online public platform (NGFS, 2024).[2] Since they are developed for risk assessment purposes, the NGFS scenarios differ from other scenarios, such as those provided by the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA); nevertheless, at the global level they are well aligned on a number of dimensions, in particular as future emission pathways are concerned.[3]

The scenarios vary in the combination of various degrees of transition and physical (acute and chronic) risks (Figure 1), which depend on the timing and stringency of the climate policies and on the availability of decarbonization technologies; they reflect, in particular, four possible futures (which, in turn, combine into seven different scenarios; Figure 2):

i) a “hot-house world”, with no or very mild transition (climate policies are implemented in some jurisdictions, but efforts are insufficient to halt significant warming at the global level);

ii) an orderly transition (climate policies are implemented at an early stage and progressively tightened over time);

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[1] The baseline scenario rests on common assumptions about GDP and population with no climate-related risk. Also, changes in efficiency parameters over time are tuned such that the baseline scenario meets exogenous economic growth pathways and final or useful energy pathways in line with socio-economic assumptions sourced from the database on Shared Socioeconomic Pathways (SSPs) (O’Neill et al., 2015). In particular, the SSPs reflect five different developments of the world that are characterized by varying levels of global challenges (see Riahi et al., 2017 for an overview). They include: a world of sustainability-focused growth and equality (SSP1); a “middle of the road” world where trends broadly follow their historical patterns (SSP2); a fragmented world of “resurgent nationalism” (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5). NGFS scenarios use SSP2 as an input.

[2] Data are available on the NGFS websites (https://www.ngfs.net/ngfs-scenarios-portal/use) and are also reported in the IMF Climate Change Dashboard (https://climatedata.imf.org/pages/ngfs).

[3] Thus, for example, while the NGFS and IEA scenarios differ in many aspects (especially in terms of output variables and geographical detail), climate targets underlying the NGFS Net Zero 2050, Current policies and NDCs scenarios are very close to the IEA’s Net Zero Emissions by 2050 (NZE), Stated Policy Scenario (STEPS) and Announced Pledges Scenario (APS) scenarios.

iii) a disorderly transition (climate policies experiencing delays or discrepancies across countries and sectors);

iv) a "too little, too late" transition (a delayed and poorly coordinated transition that proves ineffective in mitigating physical risks).

The transition risks reflect policy reactions, technological changes (for example the availability of carbon dioxide removals that enables keeping a higher share of fossil fuels in the energy mix) and regional policy variation. Such risks, in turn, may impact on the financial sector, as they affect investment incentives, business profitability, and household wealth. All these factors, moreover, might lead to the build-up of stranded assets.

The physical risks can affect the economy in two ways: i) through acute impacts, because of the increase in the frequency and intensity of climate-related extreme events (such as heatwaves, floods, cyclones and wildfires) that can lead to business disruption, property damage; ii) via chronic impacts (from increased temperatures, rising sea level and precipitation changes) that can lead to a progressive reduction in factor productivity (agricultural yields, labour and energy productivity, etc.).

Orderly scenarios are characterized by overall low or moderate combinations of transition and physical risks, while the "too little, too late" scenario is characterized by high risks.

This note aims to provide an overview of how climate risks could affect Italy in the coming decades, according to the Phase IV NGFS scenarios described by the NGFS (2023).

The main insights are the following.

- **At the global level, reaching net zero GHG emissions by 2050 will require large-scale efforts across all sectors of the economy**, mainly in terms of policy reactions (i.e. increase in carbon prices), technological changes and carbon dioxide removal: an immediate coordinated transition will nevertheless be less costly than a disorderly one or no action in the long run.
- **Focusing on Italy, in all scenarios the share of primary energy derived from low-carbon sources**, which include biomass, nuclear, solar, wind, geothermal, and hydro, **is expected to increase significantly compared with actual values. An orderly transition, in particular, would require a fast uptake of renewable energies and an unprecedented pace in the electrification of final energy uses (in buildings, transport, etc.).** [4]
- Italian **GDP falls** across all scenarios in the short term. **Government investment has to rise dramatically** to partly offset the **contraction in private sector investment due to higher carbon taxation**.
- **Inflation would increase in Italy and, more broadly, across the euro area countries in the short run, driven by higher energy prices, which in the scenarios considered would require higher monetary policy rates**.

Notwithstanding that these scenarios are a key tool for assessing the macroeconomic impacts of climate risk, certain issues and critical aspects warrant attention. In particular, the following critical

[4] Energy is classified into a variety of types. Primary energy (also referred to as energy sources) is the energy embodied in natural resources (e.g., coal, crude oil, natural gas, uranium) that has not undergone any anthropogenic conversion. It is transformed into secondary energy by cleaning (natural gas), refining (oil in oil products) or by conversion into electricity or heat. When the secondary energy is delivered to the end-use facilities it is called final energy (e.g., electricity to the wall outlet), where it becomes useful energy (e.g., light). Renewable energy is obtained from the continuing or repetitive currents of energy occurring in the natural environment and includes non-carbon technologies such as solar energy, hydropower, wind, tide and waves and geothermal heat, as well as carbon-neutral technologies such as biomass (https://www.ngfs.net/ngfs-scenarios-portal/glossary/).

aspects might represent obstacles to the use of NGFS scenarios by different stakeholders (e.g. Central Banks, Supervisors and the private financial sector).

- Optimizing agents in NGFS models are myopic with respect to physical risks and, as such, the costs related to these risks are not reflected in their savings and investment decisions. This modelling feature likely contributes to underestimating chronic damages and their related impact on the macroeconomic variables.
- NGFS scenarios only model the impacts of policy changes in the form of a unique carbon price, which evolve differently to achieve the CO2 target. Thus, since the models do not differentiate between various fiscal measures such as carbon taxes, subsidies, and environmental standards, the differing impacts on a country's GDP, unemployment, and energy mix are not fully taken into account.
- While assumptions about the availability of carbon storage technologies might lead to overly optimistic impacts (not fully embedding the related uncertainties), no adaptation is envisaged in the scenarios; this feature likely leads to an overestimation of the losses due to the chronic physical risk.
- The current set of scenarios fails to consider some channels, such as the impacts of tipping point events, extreme tails risks, and second-round effects, and includes only a limited – though expanding – subset of acute climate events (e.g. no impact on biodiversity is envisaged). To take the missing impacts into account, users need to incorporate additional adjustments and judgements.

The work is structured as follows. In Section 2, we describe the main features of Phase IV long-term scenarios; in Section 3, we discuss the main results for Italy. Section 4 reviews a few critical aspects of the NGFS scenarios, while Section 5 looks at their possible uses.

2. Phase IV NGFS scenarios

As described by the NGFS (2023), compared to the previous releases, the updated NGFS scenarios (Phase IV) have been improved and updated with the latest data and models' versions. The updates include the new country-level policies to reach net-zero (e.g. as part of the EU Fit-for-55, the US Inflation Reduction Act, etc.);[5] the latest GDP and population data;[6] the current geopolitical context, including consequences of the war in Ukraine on energy prices, the latest trends in renewable energy technologies[7] and limitations on the availability of Carbon Capture and Storage (CCS). Further, acute physical risk modelling was improved to include more hazards, and to more accurately capture their transmission to the economy at the country-level. **With these updates the macroeconomic and climate outcomes are worse than in previous vintages across all scenarios.**

The combination of physical and transition risk in the different scenarios can be represented in four quadrants (Figure 2). Within each quadrant one or more scenarios have been developed, totaling a set of seven different scenarios.

1) **Orderly** (low physical risk, low transition risk).
    a) *Low Demand*: introducing a novel Paris-aligned scenario that charts a course towards achieving the +1.5°C end-of-century warming limit. This scenario necessitates additional measures in end-use sectors such as behavioral changes, reduced energy demand,

[5] With a cut-off date of March 2023.
[6] Using the latest snapshot from the IMF World Economic Outlook 2022.
[7] For example, capital costs for solar PV will decrease faster according to the new projections.

accelerated electrification, and greater reliance on renewables. These elements distinguish it from the Net Zero 2050 scenario.

b) *Net Zero 2050* (1.5°C): a scenario designed to cap global warming at 1.5°C through stringent climate policies and technological innovations, aiming for global net zero greenhouse gas (GHG) emissions by around 2050. No significant behavioural changes are anticipated in this scenario.

c) *Below 2°C*: a scenario characterized by a gradual escalation in the rigor of climate policies, aiming to provide a 66 per cent probability of limiting global warming to below 2°C by the middle of the century. Disorderly (low physical risk, high transition risk).

2) **Disorderly** (low physical risk, high transition risk).

   a) *Delayed transition*: this scenario assumes that annual emissions will not decline until 2030, necessitating robust policies to keep warming below 2°C, particularly as the availability of negative emissions technologies is limited.

3) Hot house world (high physical risk, low transition risk).

   a) *Nationally Determined Contributions (NDC):* this scenario incorporates all pledged policies, even if not yet put into effect. It assumes that the moderate and varied climate ambitions outlined in the conditional NDCs as of early 2021 persist throughout the 21st century, resulting in low transition risks. Despite emission reductions, global commitments are deemed inadequate to halt global warming.

   b) *Current policies*: a scenario depicting a hot house world, where existing policies remain unchanged.

4) **Too little, too late** (high physical risk, high transition risk).

   a) *Fragmented Word:* this new scenario explores the more severe impacts that may arise if climate mitigation policies are not promptly and globally implemented. Countries without net-zero targets adhere to current policies, while others with such targets only fulfill 80 per cent of their commitments. Despite the possibility of meeting the Paris Agreement, the scenario is fraught with both high physical and transition risks, making it most suitable for climate stress-testing purposes.

The NGFS scenarios are produced by a suite of models aligned in a coherent way (Figure 3).

- **Transition risk models** comprise three Integrated Assessment Models (IAMs) – REMIND-MAgPIE, GCAM and MESSAGEix-GLOBIOM – which are used to simulate the impacts of different policy ambitions on the energy sector, emissions, and land use. The main policy lever driving the transition in the NGFS narratives is represented by the price of carbon. It is the marginal abatement cost of an incremental ton of greenhouse gas emissions and a proxy for overall climate policy ambition and effectiveness, accounting for a variety of real-world climate policies (carbon tax, subsidies, environmental standards, etc.). In particular, the emission price is sensitive to: (a) the level of ambition to mitigate climate change (higher ambition implies higher emissions prices); (b) the timing of policy implementation (higher emissions prices are necessary in the medium to long-term if action is postponed); (c) technology assumptions such as the availability and viability of CDR. *Ceteris paribus*, a higher emission price implies a more stringent policy.
- **Physical risk models** rely for chronic physical risks on the Potsdam Institute (PIK) and for acute physical risks on Climate Analytics. Acute physical risks are assessed for four hazards (floods, heatwaves, tropical cyclones, and droughts) at the country level with various channels of transmission, such as capital stock damages for floods and tropical cyclones, crop yield

losses for droughts, and population impacted for heatwaves. Chronic physical risks are more severe than the acute ones and are associated with long-term shifts in climate patterns; they are assessed via a damage function that quantifies the effect of a change in climate-related variables (e.g., temperature) on economic output.[8] Both sets of models project physical risk based on the Global Mean Temperature Paths (GMTs) provided by the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC).

- The **macroeconomic model** used to trace out the impacts of transition and physical risks on macroeconomic and financial variables is a version of the NiGEM model which also includes a climate module. NIGEM uses as inputs and constraints some of the output variables from the IAMs and the physical risk models, which are used to derive transition and physical risk shocks to the downscaled macroeconomic variables and data provided by the NIGEM model.

Each NGFS scenario consists of a set of climate-related and macro-financial variables available for each model and geography (Figure 4). A comprehensive list of output variables for the different models can be found in the IIASA and IMF portals.

3. The main results for Italy

In this section we present the NGFS projections of global temperatures and the main variables for Italy.

***Global temperatures*.** The scenarios exhibit distinct characteristics based on varying assumptions regarding transition and physical risks, leading to divergent global temperature trajectories (Figure 5a). These temperature pathways are formulated on a global scale, aligning with the objective of constraining the rise in the global average temperature to well below 2°C, and potentially to 1.5°C above the pre-industrial benchmark established in the Paris agreements. Annual average temperatures are projected to rise across scenarios, albeit to a different extent. Up to the year 2030, there are negligible distinctions among temperatures in different scenarios, indicating the time required for the risks and the benefits associated with alternative assumptions to manifest; the temperature converges to approximately 1.5°C above the pre-industrial level. Noticeable differences across scenarios are already in place in 2050. By 2100, the temperature peaks at above 2.75°C in the Current Policy scenario. Conversely, in the Low-demand scenarios, the temperature starts to fall after 2040, settling at below 1.25°C by the century's end. In the other scenarios temperatures range between these two extremes.

***Emissions*.** Despite the fact that global temperatures are monitored on a global scale, emissions and the shadow carbon price are calculated at the country level and vary depending on the national energy mix, economic structure, and investments in green technologies. **In the orderly scenarios (Below 2°C, Net Zero 2050 and Low Demand), CO2 emissions initially remain at elevated levels but afterwards diminish faster than in the other scenarios** (Figure 5b).[9] CO2 emissions from energy and industrial process contribute the most to the reduction of the national GHG emissions in the orderly scenarios (Figure 6). Around 2040, the national CO2 emissions reach zero levels and subsequently become negative, a requisite step to attain the global target. **Conversely, in the Current**

[8] Chronic physical risks include risks associated with long-term increases in temperature, changes in average precipitation patterns, rising sea levels, and ocean acidification. These risks affect labour and land productivity, capital depreciation, scarcity of natural resources, forced migrations, increased adaptation costs, etc.

[9] The results refer to the REMIND output model. We employ this model as it is the one that will be used in the currently ongoing one-off Fit-for-55 climate risk scenario analysis. Note that, as discussed below, the REMIND presents results that are qualitatively similar to the other models.

Policies scenario, emissions decline at a slower pace, remaining consistently positive and notably high. In the Nationally Determined Contribution scenario, emissions remain about flat after 2040-2050.

Carbon Dioxide Removal (CDR). Negative emissions can be achieved thanks to the availability of CDR technologies. CDR comprises different ranges of methods to remove CO2 emissions from the atmosphere and store it over climate-relevant time horizons (from decades to millennials), such as augmenting forest cover and soil sequestration (referred as "land use"), cultivating crops for bioenergy (referred as "BioEnergy with Carbon Capture and Storage" - BECCS) or Direct Air Carbon Capture and Storage (DACCS).[10] Even though the IPCC has established that the removal of CO2 from the atmosphere is essential and necessary to achieve the global target of net zero emission, **the NGFS scenarios assume low to medium availability of CDR** (Figure 6).[11] Under the Net Zero 2050 scenario, CCS technologies are expected to be in place already in 2030 and their role increases over time so that approximately 80 Mt CO2 per year should have been removed via CCS by 2050; the value almost halves under the Low Demand scenario.

Comparing emissions and CDR availability with other sources. Emissions pathways in the **Net Zero 2050 scenario are substantially more optimistic than those presented in the June 2023 Italian National and Energy and Climate Plan (NECP),** the critical strategic document guiding Italy's energy policy to 2030. The NECP's predictions indeed, are closest to the NGFS Current policy scenario. According to the NECP, under the policies identified, national GHG emissions will be equal to 312 Mt CO2eq in 2030 (and 252 Mt CO2eq in 2040), while the NGFS scenarios foresee emissions to range between almost 250 Mt CO2eq (in the Net Zero 2050) and 350 Mt CO2eq in 2030 (in the Current Policy). **Substantial differences between the NECP and the NGFS scenarios are recorded in the relevance of the CDR and CCS technologies in the emissions projections.** The CCS are mentioned in the NECP as crucial to offset the emissions deriving from industrial processes and the national climate targets, as acknowledged by the IEA (2023); however, the emission removal capacity of the CCS and the land use, land-use change and forestry (LULUCF) sector is still envisaged to be limited in the current NECP projections. According to the NECP, CCS will not contribute to the emission pathways up to 2030, while the LULUCF will remove about 34 Mt CO2eq in 2030 against about 70 Mt CO2eq in the NGFS Net Zero 2050 scenario. The contribution of the LULUCF and CCS increases in the projections provided by the Italian Long Term Strategy for the Reduction of Greenhouse gas emissions (LSRGHG, 2021) under the scenario that assumes that Italy will achieve net zero emissions by 2050 and which foresees that they will capture about 65-85 Mton CO2 eq.

Price of carbon. **The largest increase in carbon price is projected under the Net Zero 2050 scenario**, reaching over 800$$_{(2010)}$/ton in 2050 (Figure 5, panel c). The increase for Italy is higher than the one projected at the global level which is about 600$$_{(2010)}$/ton in 2050, under the same scenario; this result also reflects the fact that prices tend to be lower in emerging economies as there tends to be a greater number of low-cost abatement options still available. **In the Low Demand scenario, despite the target temperature is similar to the Net Zero 2050 one, the price increase is much more muted reflecting behavioural changes.** Models suggest that by 2035 a carbon price[12] of 400$$_{(2010)}$/ton would be needed in Italy to foster a transition towards a sustainable economy, which

[10] In the NGFS scenarios, Direct Air Carbon Capture and Storage (DACCS) technologies were switched off in all scenarios, in particular because of the uncertainty with regards to their development.

[11] Nevertheless, climate experts are divided over whether CRD are necessary requirements or a dangerous distraction from limiting emissions (see Anderson et al., 2023) for more information on this issue.

decreases to about 200$$_{(2010)}$/ton in a scenario with behavioural responses. The delayed transition scenario is characterized by the implementation of more rigorous policies occurring only after 2030, at which point the carbon price begins to rise. Finally, **under current policies the carbon price does not deviate from the baseline scenario without transition and physical risks.** The differing profiles of carbon prices consistent with the climate targets underlying the various scenarios can be translated into future market prices. Following the methodology used in NGFS (2022), which accounts for the average emission intensities of the various fossil fuels (oil, gas and coal), the resulting market prices for fossil fuels would be higher in 2050, compared to market prices in 2020, by approximately four times for oil, more than seven times for gas and thirty times for coal (Figure 16).[13] Note that, while these increases appear to be staggering they depend on the fact that 2020 has been chosen as the initial year, when prices for oil, gas, and coal were much lower compared to current market valuations. Also, if instead of market prices one would consider final gross prices, as suggested by Faiella and Lavecchia (2021), the corresponding increase by 2050 would be much more contained.[14] Finally, another note of caution is warranted. If transition were to occur in an orderly fashion, resulting, as shown in Figure 7, in sizeable increases in the share of green energy sources, carbon prices would probably follow more muted paths, as the share of energy from brown energy sources (and the underlying demands for these fossil fuels) would be negligible by 2050, compared to current levels.

Primary and final energy.[15] In line with the EU and Italian climate and energy policies, the Net zero 2050 scenario foresees that the decarbonization will occur through the expansion of renewable energies and electrification, as well as the reduction of energy consumption. **In all scenarios, the shares of primary energy derived from low-carbon sources, which include Biomass, Nuclear, Solar, Wind, Geothermal, and Hydro, increase reaching the maximum in the Net Zero 2050 scenario** where the share of green energy is above 40 per cent in 2030 and above 90 per cent in 2050, while this share remains at a minimum in the Current Policy scenario where it is about 30 per cent in 2030 and only slightly above 50 per cent in 2050 (Figure 7). Most of the rise is driven by the expansion in the solar, wind and geothermal energy that will account respectively for 22, 20 and 16 per cent of the total primary energy in 2050 in the Net Zero 2050 scenario. At the same time, in all scenarios, final energy consumption decreases: among the components, electricity increases up to 2050, while the relevance of natural gas shrinks rapidly, especially in the Net Zero 2050 and Delayed Transition scenarios (Figure 8). **A substantial increase in the use of renewable energy accompanied by the relevant drop in the reliance on oil and gas by 2030, which will be replaced with hydrogen and other synthetic fuels, is also predicted in the NECP.** Notably, the prediction of the Net Zero 2050 scenario and those reported in the NEPC, under the policies currently identified, are very similar in terms of final energy consumption as well as electricity and gas share in 2030.[16]

[13] Cf. also Graph 1 in NGFS (2022), "Not too late – Confronting the growing odds of a late and disorderly transition", September. This graph is based on trajectories for carbon prices consistent with the previous Phase III scenarios.

[14] For oil and gas, accounting for current final gross prices – prices including taxes currently amount to approximately 1.5/1.6 EUR/litre, i.e. 39 USD 2020/GJ, while gross gas prices currently stand at 26 USD 2020/GJ – increases by 2050, including carbon prices, would result approximately in a doubling of prices for both oil and gas.

[15] Primary energy is the energy as it is available as resources before it has been transformed while final energy consumption refers to what end users actually consume (see the definitions provided by the Eurostat). The difference between the two is a proxy of the relative energy efficiency of the energy conversion process (including the losses on transporting and distributing energy).

[16] In 2030 final energy consumption will be about 5.3 Exajoule/Yr in both scenarios, Electricity will account for about 1.4 Exajoule/Yr and natural gas for about 1. 1 Exajoule corresponds to 10^{18} joules.

At the same time, also the Italian Long term Strategy for the Reduction of Greenhouse gas emissions (2021) foresees an uptake of the renewable energy and a drop in fossil fuels by 2050 in the scenario in which Italy will reach net zero emissions. Nevertheless, it is important to note that all **these projections imply an unparalleled uptake of renewable energies and electrification** (Figure 9). **The most significant energy savings are expected to come from the transport and buildings (residential and commercial) sectors** (Figure 10), as envisaged by the NECP, which foresees that the instruments to achieve these savings will include tax incentives for building renovation and purchasing zero-emissions vehicles.[17] Similar patterns in terms of renewable energy and final consumption at the sector level are observed when looking at the OECD and EU countries.

GDP. **Italian GDP falls across all scenarios**, driven mostly by increased physical risks, both acute and chronic (Figure 11a). **Long-term economic costs are overall rather contained, but greater in scenarios that are lacking in policy ambition and coordination across countries**.[18] In 2050 the GDP cumulative deviations from the baseline level range between -4 percentage points (Fragmented World) and less than -1 (Net Zero 2050 and Below 2°C).[19] Comparing across scenarios, GDP losses are more upfront in the Net Zero 2050 scenario, as carbon prices rise immediately, in order to smoothly reach the net zero climate target; GDP short-term costs are instead more contained in the Fragmented World and Delayed Transition scenarios, which either foresee a much smaller increase in carbon prices (Fragmented World) or a steep increase in carbon prices at a later stage (Delayed Transition). GDP costs in these two scenarios tend to increase over time, also reflecting transition risks that are more markedly negative as the speed of the transition is combined with investment uncertainty which negatively affects consumption and investment.[20] In the more ambitious orderly scenarios (Net Zero 2050 and Below 2°C) GDP essentially returns close to baseline by 2050.

***GDP components*.** All scenarios foresee a **contraction in private sectors' investments** with respect to the baseline scenario without transition and physical risks (Figure 11b). **In the Net Zero 2050, investment reductions are steeper** and upfront, reflecting rapid increases in carbon prices in this scenario. However, this scenario embodies at the same time the steepest rise – compared to baseline – in government investments, financed by carbon revenues. **Government investments rise more than 40 per cent above baseline between 2025 and 2030 before returning to baseline by around**

[17] The European Commission in its assessment of the NEPC evaluates positively the comprehensive set of measures that Italy adopted or intends to adopt to support the development of renewable energy and the phasing out of fossil fuels subsidies and assesses the Italian contribution to the EU targets on renewable energy as slightly above the one resulting from the EU legislation. On the other hand, it instead assesses as insufficient the measures described in the NEPC to improve the buildings' energy efficiency. See: https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#national-energy-and-climate-plans-2021-2030

[18] The costs from physical risks are non-linear, as the different climate-related impacts (e.g. flooding, drought, wildfires) can be spatially correlated and their frequency and intensity tend to grow over time (with the increase in GHG concentration).

[19] The baseline scenario refers to a hypothetical scenario with no transition and physical risk, but also incorporating most recent impacts, such as the post-pandemic recovery and the consequences of the Russian war in Ukraine (cut-off date: February 2023). See also footnote for a more detailed description of the baseline scenario.

[20] In the disorderly transition scenarios (Delayed transition and Fragmented world), it is assumed that policy uncertainty leads to a higher investment premium for two years, with the premium gradually returning to the baseline thereafter. This occurs in a period ranging between 2030 and 2031 in both the Delayed Transition and the Fragmented World scenarios. These additional investment premium shocks accentuate the sharper and more persistent macroeconomic costs in these two scenarios compared to the more orderly ones (Net Zero 2050, Below 2Cº, and Low Demand).

2040 (Figure 11c).[21] Government investments compensate the fall in private investment also in the Below 2°C scenarios, albeit rising by slightly less than 10 per cent compared to the baseline level. All the remaining scenarios entail both a contraction in private and public investments. The fall compared to baseline is more adverse in the Fragmented World and Delayed Transition scenarios.

GDP impacts due to physical risks. With respect to physical and transition risks one can observe that (Figure 12):[22]

a) **Acute physical risk is the most relevant source of risk in the short and long term**.[23] Since physical risk is unaffected by mitigation efforts in the short-run, acute physical risk is similar across scenarios until 2040, with a strong surge in losses in Current Policies thereafter. Overall losses will exceed 90 billion of euros in 2050 under the Net Zero 2050 scenario, 110 in the Delayed transition and 185 in the Current policy scenario. In all scenarios losses are due to droughts and heatwaves. These figures are considerable if compared with the estimates of the damages due to extreme climate events in Italy between 1980 and 2022 provided by the European Environment Agency which amounted to 110 billion of euros.[24]
b) **Chronic physical risk becomes gradually more important over time** and causes the largest negative impact on GDP in the Current Policies scenario, with associated economic losses in 2050 being almost double than what is implied by the Net Zero 2050 scenario.[25]
c) **Transition risk leads to a negative short-term impact** on GDP in the Net Zero 2050 scenario. However, the cost-saving later on more than offsets these initial losses compared to a Delayed Transition or a Current Policies scenario.

***Inflation*.** The implementation of carbon pricing in transition scenarios tends to raise energy costs in the short-term, leading to higher consumer prices (since both lower demand and financial market losses affect output). Subsequently, **higher carbon prices result in modest increases in inflation** (Figure 13 panel a) and unemployment before returning to previous trends. The rise in inflation rates is particularly visible in the more ambitious Net Zero 2050 scenario. After the initial spike compared to the baseline level, inflation tends to undershoot from approximately 2027-2037 as more and more new cleaner energy capacity is installed, leading to a fall in energy prices and a moderation in production costs and consumer prices. Inflation rates tend not to deviate instead significantly from the baseline in the other scenarios, except for the Delayed transition and Fragmented World scenarios.

[21] In the scenarios run with NiGEM it is assumed that the IAM carbon tax revenue is recycled differently depending on the various scenarios. More specifically, the orderly scenarios use a recycling option where 50 per cent of the revenue is used for government investment, while the remaining 50 per cent is used to pay off government debt. All other scenarios recycle all revenue through taxes. The recycling simulations also turn the energy sector in NiGEM off. This is to ensure that all energy movements, including world price of fossil fuels etc., are directly related to the IAM transition shock rather than because of fiscal stimulus.

[22] Note that only one potential chronic physical risk transmission channel (productivity) has been modelled, as it has been decided that more research is needed on the potential for climate impacts to raise inflation (e.g., through supply-side shortages) and/or unemployment (e.g., due to displacement). The methodology used, which rests on the damage function developed by Kalkuhl and Wenz (2020), does not include impacts related to extreme weather, sea-level rise or wider societal impacts from migration or conflict. For given countries these would likely strongly increase the physical risk. These estimates also do not fully capture adaptation, which would reduce impacts but require significant investment.

[23] Future acute impacts are computed by means of stochastic simulations. The international disaster database Emergency Events Database (EM-DAT) is used to approximate historic damages from weather-related extreme events to derive stochastic shocks as inputs to the NiGEM model. In particular, historical equation residuals are replaced with future climate projections from Climate Analytics.

[24] https://www.eea.europa.eu/en/analysis/indicators/economic-losses-from-climate-related.

[25] Note that in the Current Policies scenario there is no transition risk.

In these latter two scenarios inflation tends to rise above the baseline level as soon as carbon prices tend to rise (see Figure 5, panel c and Figure 13, panel a).

Central bank policy rates. Monetary policy, being aimed at inflation and output stabilization, responds endogenously to the deviations of inflation rates and output from baseline.[26] For these reasons, **central bank policy rates tend to rise mostly in the Net Zero 2050 scenario** and to a lesser extent in the other scenarios (Figure 13 panel c). The Delayed transition and Fragmented World scenarios are two exceptions: in both scenarios policy rates are first reduced as GDP tends to fall below its baseline level while inflation rates remain close to baseline.[27] At a later stage inflation rates overshoot the baseline level and policy rates rise. Long term interest rates, being the convolution of short term interest rates in NiGEM, follow closely the dynamics of policy rates, albeit in a much smoother way. Finally note that chronic and acute shocks are run with exogenous trade linkages (i.e. turned off) and both monetary and fiscal policy off, in order to assess the impact of acute climate events on individual countries.[28] As such central bank policy rates do not respond to physical shocks in the scenarios.

Comparison of GDP projections across models**.** The pathways obtained by the three different models, GCAM, MESSAGE and REMIND (see the appendix for further details) for the Italian GDP combined – i.e., that consider both transition and chronic physical risks – **are qualitatively similar** (Figure 14).[29] However, there are **some quantitative differences**, especially for the Net Zero 2050 scenario (for this scenario, there are also differences in the recovery timing). The differences are mainly driven by the transition risk, while there are only minor deviations in the impacts of the chronic physical risks. Similar pathways are also observed for the components of the GDP discussed above, including consumption and both private and government investments.

Comparison of GDP projections across countries**.** As shown in Figure 15, **the narrative observed for the European Union is similar to the one described for Italy**, although with some differences in the magnitude of the shocks. Acute physical risk is the most relevant source of short- and long-term risk in all scenarios for the Italian GDP. The drop in GDP due to acute and chronic physical risks is more significant for Italy than Europe. In both areas, chronic physical risk becomes gradually more critical over time and causes the largest negative impact on GDP in the Current Policies scenario in 2050; the effect of transition risk on GDP is negligible in the Net Zero 2050 scenario, while it is material in the Delayed Transition. **Similar pathways are also observed for the global GDP, although the projected losses are usually larger than those predicted for Europe and Italy.** Acute physical events remain the more prominent source of risks, followed by chronic physical risks. The main differences relate to: i) the impact of the transition risks in the Net Zero 2050 scenario, which

[26] In NiGEM monetary policy can be chosen by the user so as to follow a standard Taylor rule or other specifications. For the euro area the chosen policy rule in the simulation runs follows a so called “two-pillar” strategy according to which the short-term interest rate is set as a function of the ratio of the nominal GDP target to nominal GDP and the difference between inflation expectations and the inflation target. This rule, which closely mimics the more standard Taylor rule, ensures more stability in model runs as it reduces the variability of the price level, and stabilises the price level more quickly over time. Cf. also R. Barrell and K. Dury (2000).

[27] In these two scenarios policy rates spike downward between 2030 and 2035. This abrupt reduction in policy rates stems from the fact that in the disorderly transition scenarios when both physical and transition risk shocks are considered, additional policy uncertainty is assumed by imposing a higher investment premium for two years (see also footnote 23).

[28] GDP damages due to chronic physical risk are provided by the Potsdam Institute (PIK), while the impacts of acute physical risks are provided by Climate Analytics.

[29] The NGFS scenarios are produced by a suite of models used to account for transition and physical risks. The transition variables are separately produced by three Integrated Assessment Models (IAMs). Climate and physical risk variables are produced by separate modelling. Then, the macro-financial variables are produced by the econometric model NiGEM, based on the IAM and Physical risk inputs. See also Section 2 and Annex B for further details.

is negative over all the horizons, possibly due to the fact that for some countries the transition will take longer and will require more efforts than for Europe and ii) the impact of the acute and physical risks in the NDCs scenario, which is much more extensive for the World than for Europe and Italy, reflecting the fact that the emissions' cuts currently pledged will not be sufficient to limit the negative effects of climate change at the global level.

4. Main critical aspects

Although these scenarios are a key and novel tool to assess the macroeconomic and financial impacts of climate risks, certain critical aspects warrant attention.

- It should be noticed that **optimizing agents in NGFS models are myopic with respect to physical costs** and, therefore, the latter are not reflected in the savings decisions, investment, etc. This modelling feature likely contributes to **underestimating chronic damages and their related impact on the macroeconomic variables.**
- **Physical risks** (both acute and chronic) **exhibit very frontloaded effects**, i.e. already by 2030 the impacts on GDP are close to their long-run levels. This is due to the fact that acute data/parameters itself do not take into account any previous damages so there is an immediate effect in NiGEM simulations in the starting period. Additionally, output from acute risks (apart from floods) are a result of stochastic simulations and the 90 per cent confidence bound was chosen by the NGFS.[30] Finally, for chronic risks, a lot of temperature models have 2010 as a starting point so when starting the reporting in 2023, there are already 13 years of impact built up.
- **The models incorporate a unique price of carbon, evolving differently to achieve the CO2 target**. However, this carbon price fails to differentiate between various fiscal measures such as carbon taxes, subsidies, and environmental standards. Specifically accounting for the implementation of these diverse measures could imply differing impacts on a country's GDP, unemployment, and energy mix. Further, since such price of carbon is not directly linked to a specific measure it cannot easily be employed by national Governments to calibrate their measures, such as carbon taxes. Furthermore, NGFS scenarios only model the impacts of policy changes in the forms of carbon price and do not take into account other possible spillover effects deriving from the unavailability/shortage of human and material resources to reach climate targets.
- **Achieving the emission target necessitates the removal of CO2 from the atmosphere** through actions like expanding forest cover and soil sequestration, cultivating crops for bioenergy or CCS technologies. Currently, the utilization of these technologies is limited, casting doubt on the realistic attainment of the emission reduction targets. Experts differ in their view of the required volumes of the CDR by 2050, ranging from 1.5 billion of tonnes to maximum 10 billion of tonnes per year. The NGFS scenarios make an optimistic assumption on their availability within the range identified in the literature assuming that CCS technologies will cover about 5 billion of tonnes in 2050. See Anderson et al. (2023) for a recent discussion on this issue.
- **The NGFS climate scenarios (as all climate scenarios) are not forecasts, describing possible alternative futures. Still other scenarios could materialize in the future.** For instance, none of the current NGFS scenarios assumes that committed countries step back and stop the transition nor capture potential carbon lock-in and an increase in near-term GHG emissions (see Gardes-Landolfini et al. (2023) for further details).

[30] This decision was taken by the NGFS consortium in order to point out the large impacts due to these shocks, which based on interactions with end-users are considered very relevant and of particular interest for stress testing etc.

- **No adaptation is envisaged in the scenarios** meaning that humans will not change their behaviours even in the presence of substantial temperature increases. This feature likely leads to an overestimate of the losses due to the chronic physical risk.[31]
- **The current set of scenarios provides a non-exhaustive estimate of the potential damages from climate change** as it misses to consider some channels such as, the impacts of tipping point events and extreme tails risks, second round effects, and includes only a limited – though expanding – subset of acute climate events. To take into account the missing impacts users need to incorporate additional adjustments.
- **The orderly scenarios imply an uptake of renewable energies and electrification never seen before which are necessary to achieve the ambitious climate targets.** The Phase IV scenarios are updated to take into account latest trends in renewable energy technologies (e.g., solar and wind) and key mitigation technologies; for example, capital costs for solar PV will decrease faster according to the new projections. **Still, high policy rates, the decreasing likelihood of continued cost reduction in renewable energy technologies (IMF, 2023) and supply chain constrains on critical minerals might slow down the deployment of renewable energy technologies.**
- **The long-term scenarios might not be easily integrated into climate scenario analysis (CSA) and stress test scenarios (CST) for two main reasons. First, they describe alternative possible futures rather than adverse events usually considered in stress test analysis. Second, the long time horizon (up to 2050) represented one of the main challenge for end-users** for a direct integration of NGFS scenarios within their CSA and CST modelling frameworks. Against this backdrop, the NGFS is currently working on the definition of a set of short-term scenarios, whose release is foreseen in 2024 (see Appendix A for a general overview and the conceptual note published by the NGFS (NGFS, 2023)). By covering a time horizon up to 5 years, these scenarios are deliberately adverse and can be used to test the resilience of economic or financial systems to such negative developments.
- **Despite progresses, the scenarios still have a limited sectoral granularity. Sectoral data include exclusively a few high emitting sector that are relevant from an energy viewpoint**, i.e. coal, oil and gas, power, buildings, industry and transportation. A broader sectoral granularity will improve the scenarios' overall usability and help design and implement CST. To address the challenges related to the still limited sector granularity, the NGFS is currently working on a sectoral downscaling methodology, which will be implemented in the Phase IV scenarios to cover more economic sectors and a much more granular breakdown of activities.
- The short-run increase in inflation is quite pronounced and requires a tightening of the monetary policy. However, **fiscal policies and/or macro-prudential policies could also be contemplated to keep inflation in check. In the simulations, fiscal policy assumptions do not contemplate inflation concerns.** Moreover, **macro-prudential policies are not considered,** given that none of the models employed for implementing the scenarios contain the banking sector. The tightening of the monetary policy could be excessive, if other instruments are taken into account.
- While some of the critical aspects mentioned are intrinsic to the definition and models chosen by the NGFS, such as the use of a shadow carbon price and the choice to avoid assigning probabilities to each scenario, **other issues will be possibly addressed in the subsequent releases of the scenarios**. The NGFS Workstream Scenario Design and Analysis will indeed continue working to update and further develop the available scenarios; for instance, they aim to increase the limited sectoral granularity, develop short-term scenarios and, if necessary,

[31] The Low Demand scenario represents an exception since it models human behavioural changes. However, NiGEM macroeconomic and financial outputs are not available for this scenario.

revise assumptions on CSS and the costs and development of renewable energy technologies. These improvements and revisions will widen the use and possible applications of the scenarios. In this vein, the NGFS initiatives aimed at developing a proper communication strategy, also by organizing outreaches in order to disseminate the scenarios, are key to expand the number of end-users and collect their feedbacks.

5. Possible uses of NGFS Scenarios

The utilization of NGFS scenarios extends across central banks, financial sectors, firms, and academia, serving various purposes.

- **NGFS scenarios have been crafted specifically for initial deployment in CSA to provide a common benchmark for central banks and the global financial system**. Indeed, these scenarios can be used to test the resilience of economic or financial systems in alternative futures, promote better preparation and motivate policy makers and private actors to facilitate and support the transition to a net-zero economy.
- **Numerous central banks and supervisors also conducted CST exercises, bottom up or top down, for both micro and macroprudential purposes** (e.g. ECB, 2021, 2022 and 2023). However, so far they **needed to modify or adjust NGFS scenarios to make them suitable for these kind of analysis** to make the scenarios more adverse in the short term.[32] The short-term scenarios to be released during 2024 will help to test the resilience of economic or financial systems to adverse climate-related events. Primary applications of these scenarios include micro- and macro-prudential CST to assess the impact of adverse events that could create systemic risk; more generally, these scenarios will allow for a better understanding of the macroeconomic impacts of various transition paths, their channels and potential trade-offs and could be also useful in the monetary policy decision-making process.
- Recognizing the imminent nature of climate risks, it is imperative to assess them in **conjunction with other macroeconomic shocks**, such as interest rate or GDP fluctuations. In essence, these scenarios should be incorporated into broader stress tests to evaluate their impact on the overall economic system.
- **The NGFS scenarios can serve as a valuable reference to assist firms and banks in establishing the emission reduction goals;** a growing number of these entities will be compelled to forecast their future emissions trajectory as part of transition plans. A broader sectoral granularity will improve the scenarios' usability to this aim and, at the same time, help design and implement CST.
- Policymakers can leverage these scenarios to **gauge the necessity of policy interventions** required to attain climate targets and to compare alternative possible futures.

[32] As reported in ECB (2023), three short-term scenarios were developed, over the time-horizon 2023-2030, combining NGFS scenarios and macroeconomic projections underlying the 2023 EU-wide stress test, as well as latest data on energy. While the first economy-wide climate stress test (2021) has shown the importance of a timely and effective transition directly using NGFS long-term scenarios, the objective of the second exercise was to use short(er)-term scenarios to assess the impact of three different transition pathways on the real economy and the financial system.

Figures

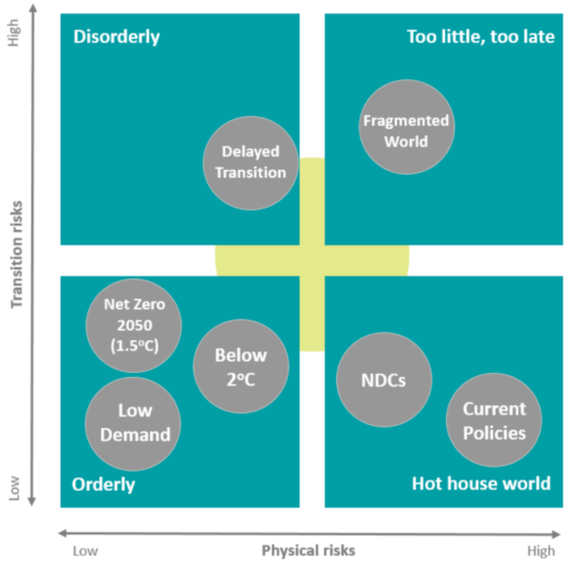

Figure 1: NGFS scenarios framework in Phase IV, four quadrants
Source: NGFS scenarios for central banks and supervisors, October 2023

Quadrant	Scenario	End of century warming	Policy reaction	Technology change	Carbon dioxide removal	Regional policy variation
Orderly	Low Demand	1.4°C (1.6°C)	Immediate	Fast change	Medium use	Medium Variation
	Net Zero 2050	1.4°C (1.6°C)	Immediate	Fast change	Medium-high use	Medium Variation
	Below 2°C	1.7°C (1.8°C)	Immediate and smooth	Moderate change	Medium use	Low variation
Disorderly	Delayed Transition	1.7°C (1.8°C)	Delayed	Slow/ Fast change	Medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.4°C (2.4°C)	NDCs	Slow change	Low use	Medium variation
	Current Policies	2.9°C (2.9°C)	None - current policies	Slow change	Low use	Low variation
Too-little-too-late	Fragmented World	2.3°C (2.3°C)	Delayed and Fragmented	Slow/ Fragmented change	Low-medium use	High variation

Figure 2: NGFS scenarios framework in Phase IV, details
Source: NGFS scenarios for central banks and supervisors, October 2023.
Note: The end of century (peak) temperature are model averages.

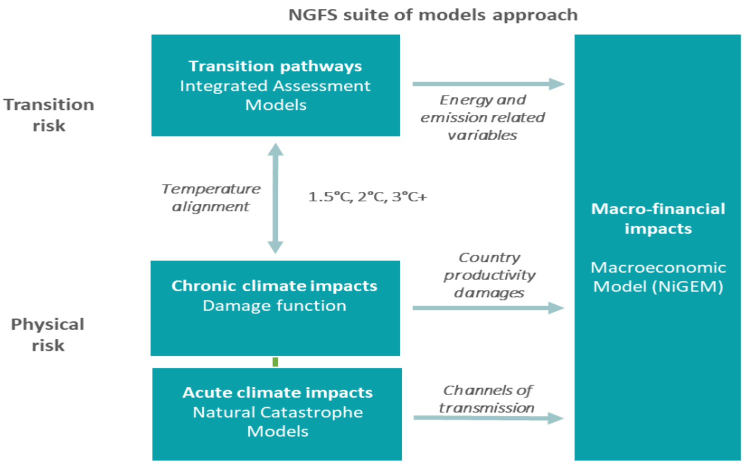

Figure 3: NGFS modelling approach

Source: NGFS scenarios for central banks and supervisors, October 2023

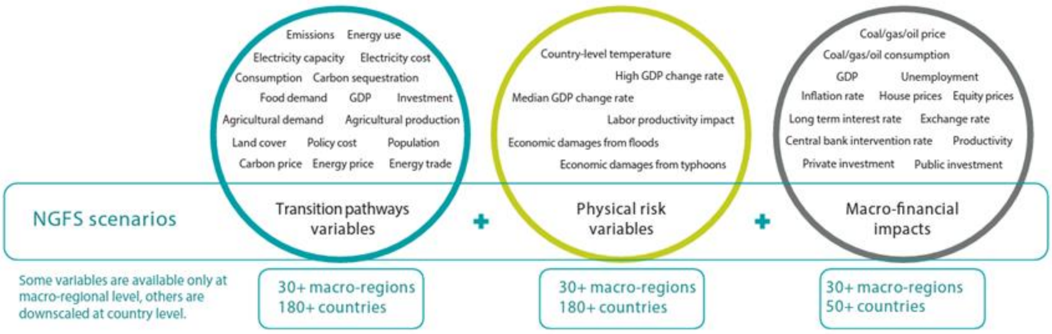

Figure 4: Overview of the range of data provided by NGFS scenarios

Source: NGFS scenarios for central banks and supervisors, October 2023

Note: this visual does not contain the full list of variables and is for illustrative purposes only. The names of the variables do not necessarily correspond to the ones used in the databases. The number of countries/regions available varies significantly depending on the variable. Downscaled climate-related and macro-financial variables are available for 180+ and 50+ countries, respectively.

a) Global Temperatures	*b) CO2 Emissions*	*c) Price of Carbon*

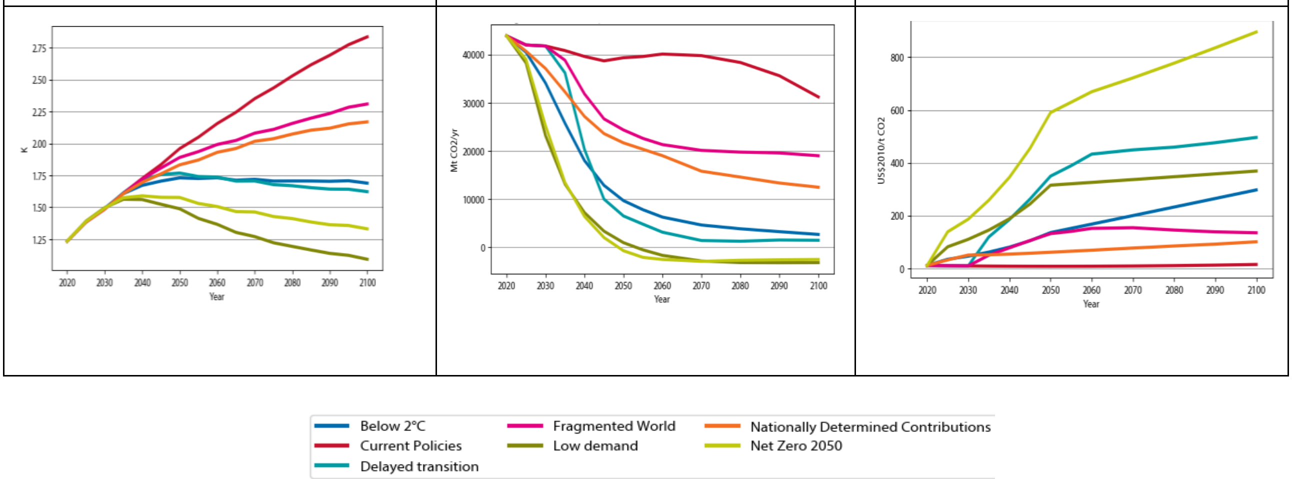

Figure 5: Main climate variables

Note: Model used REMIND. Panel a) Global temperatures, unit: degrees Celsius. Panel b) CO2 emissions for Italy, unit: Megatonnes of CO2 per year. Panel c) Price of carbon for Italy, unit: US $ 2010 per ton of CO2.

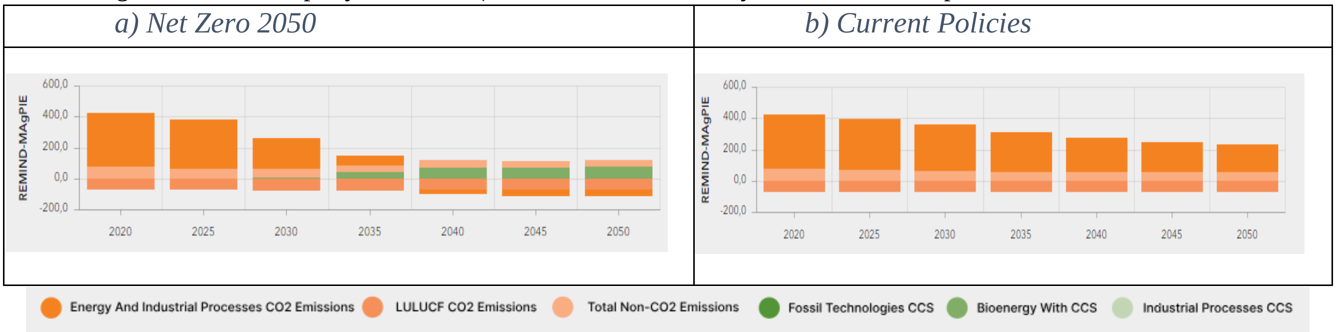

Figure 6: GHG Emissions and Carbon capture and Storage (CCS)

Source: https://climatedata.imf.org/pages/ngfs/#ngfs4. Data for Italy. Unit: Megatonnes of CO2-equivalents per year.

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Figure 7: Primary energy, downscaling by energy sources (percentages)

Note: brown energy sources include Coal, Oil, and Gas; green energy sources include Biomass, Nuclear, Solar, Wind, Geothermal, and Hydro. Model used: IAM with REMIND inputs. Data for Italy.

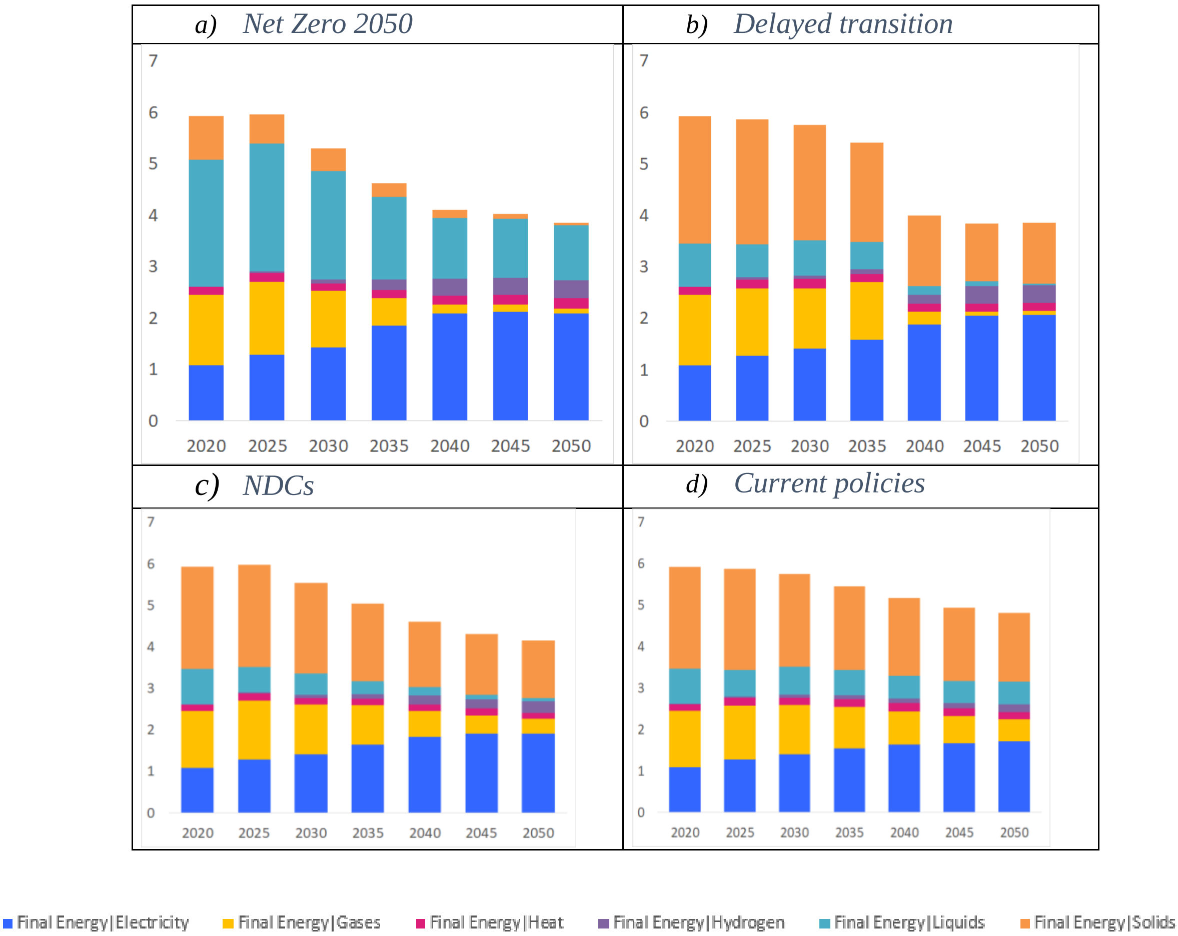


Figure 8: Final energy, downscaling by energy sources[33]

Note: Models used: NiGEM with REMIND inputs. Data for Italy. Unit: Exajoule /year.

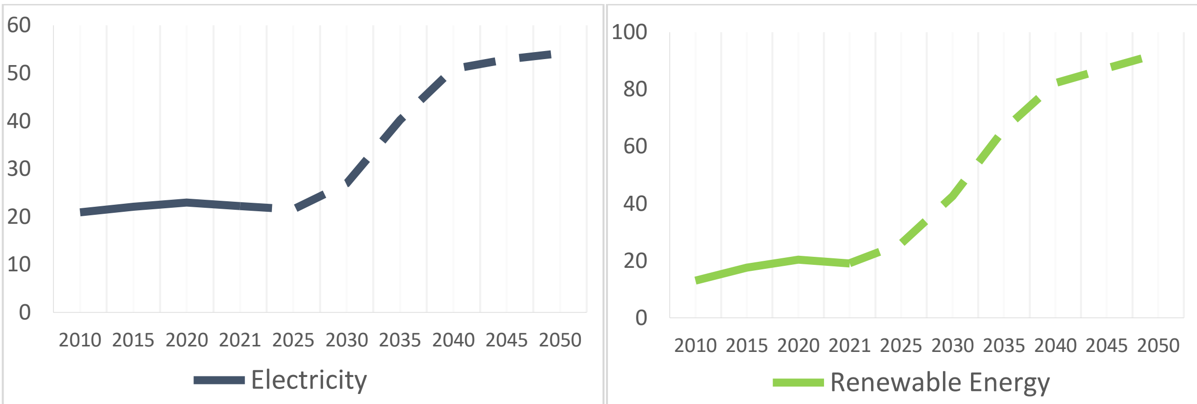


Figure 9: Electricity and renewable share of energy

Source: Historical data are from the Eurostat, while projections are the Net Zero 2050 NGFS scenario.

Note: the figure reports the electricity share of final energy (in percentage) and the renewable share of primary energy.

[33] Gases include all gaseous fuels such as natural gas; solids represent coal and biomass; liquids include oil products, biofuels and fossil synfuels.

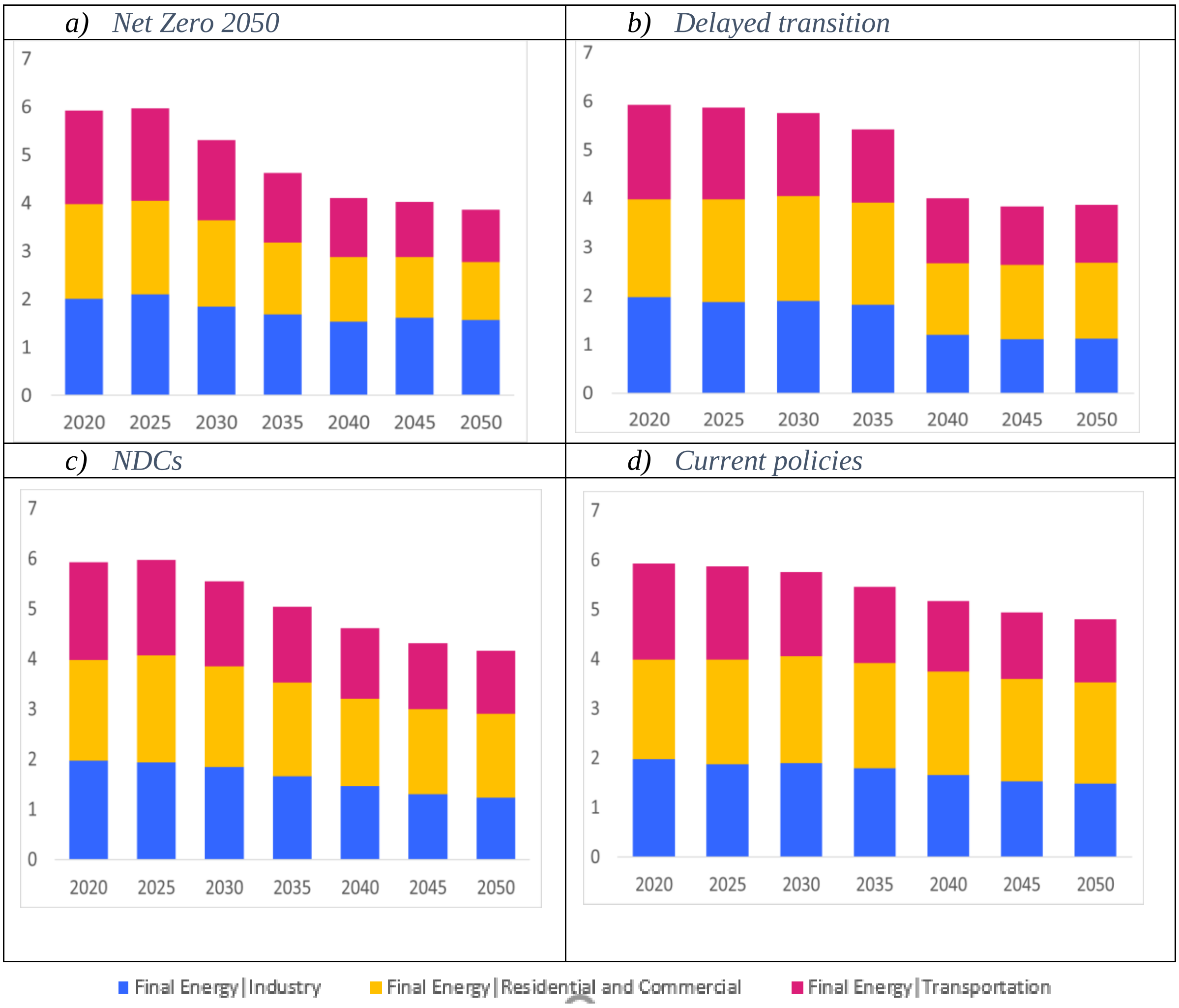


Figure 10: Final energy, downscaling by sectors

Note: Models used: NiGEM with REMIND inputs. Data for Italy. Unit: Exajoule /year.

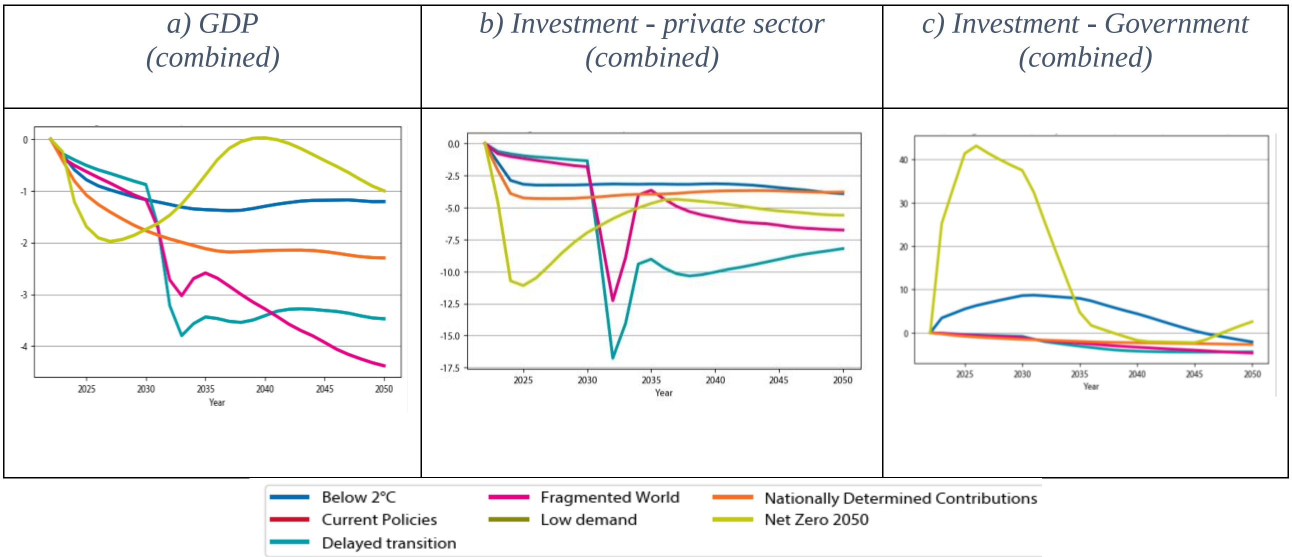


Figure 11: GDP and components

Note: Model used: NiGEM with REMIND inputs. Panel a) GDP (combined considers both transition and chronic physical risks); Panel b) Investment – private sector; Panel c) Investment – Government sector. Data for Italy in percentage deviation from the baseline.

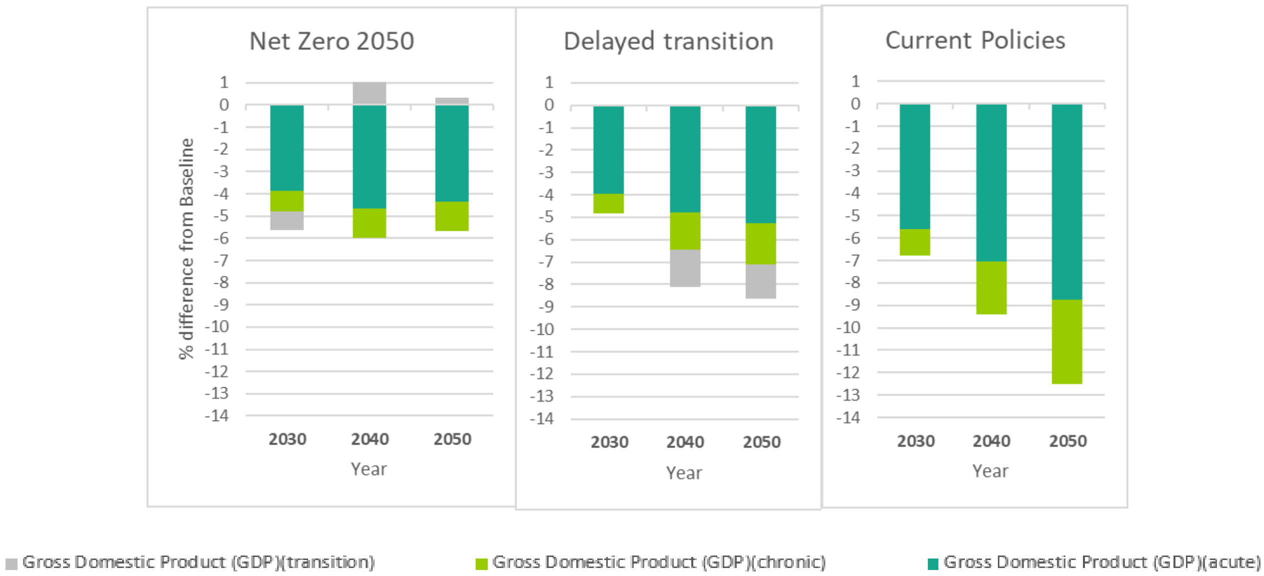


Figure 12: GDP deviation due to transition, chronic and acute risks

Note: Models used: NiGEM with REMIND inputs. Data for Italy in percentage deviation from the baseline.

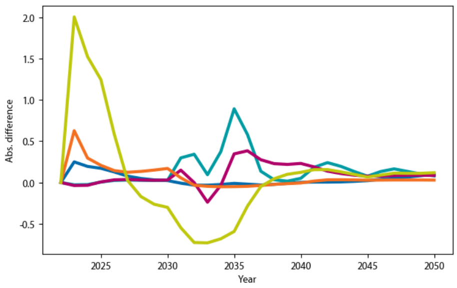
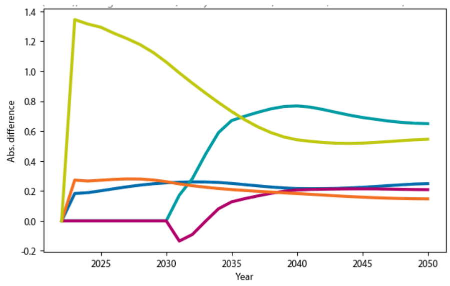
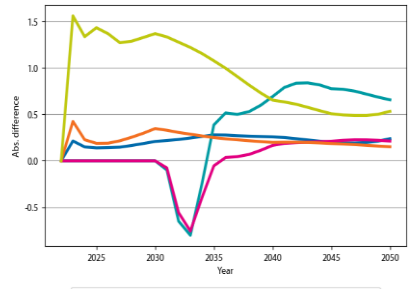
a) Inflation rate (%) (combined)	*b) Long term rate (%) (combined)*	*c) Central bank rate (%) (combined)*
		

Figure 13: Inflation and CB policy rates

Note: Models used: NiGEM with REMIND inputs. Data for Italy in absolute differences from the baseline.

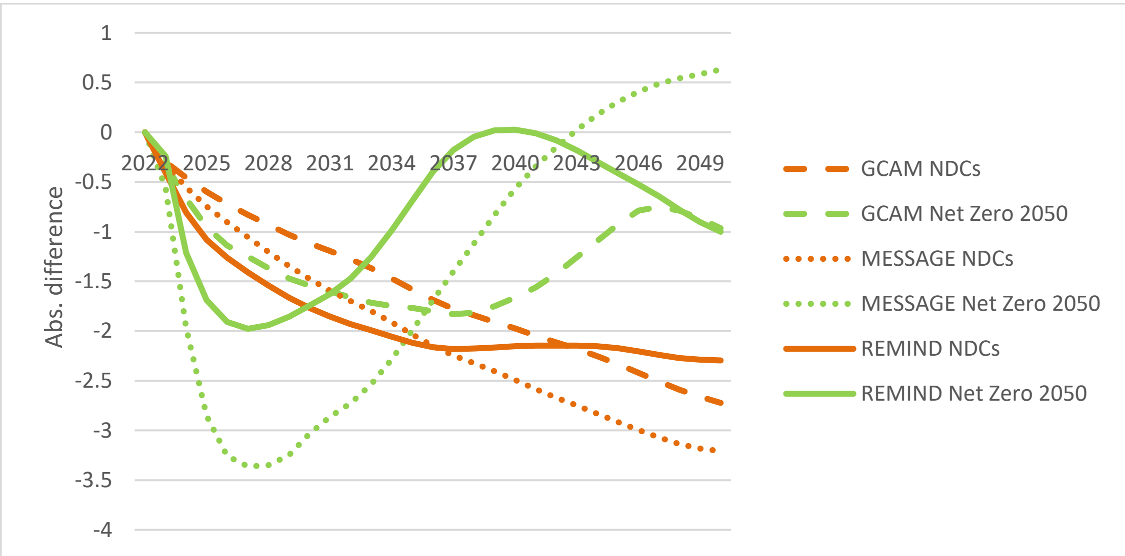
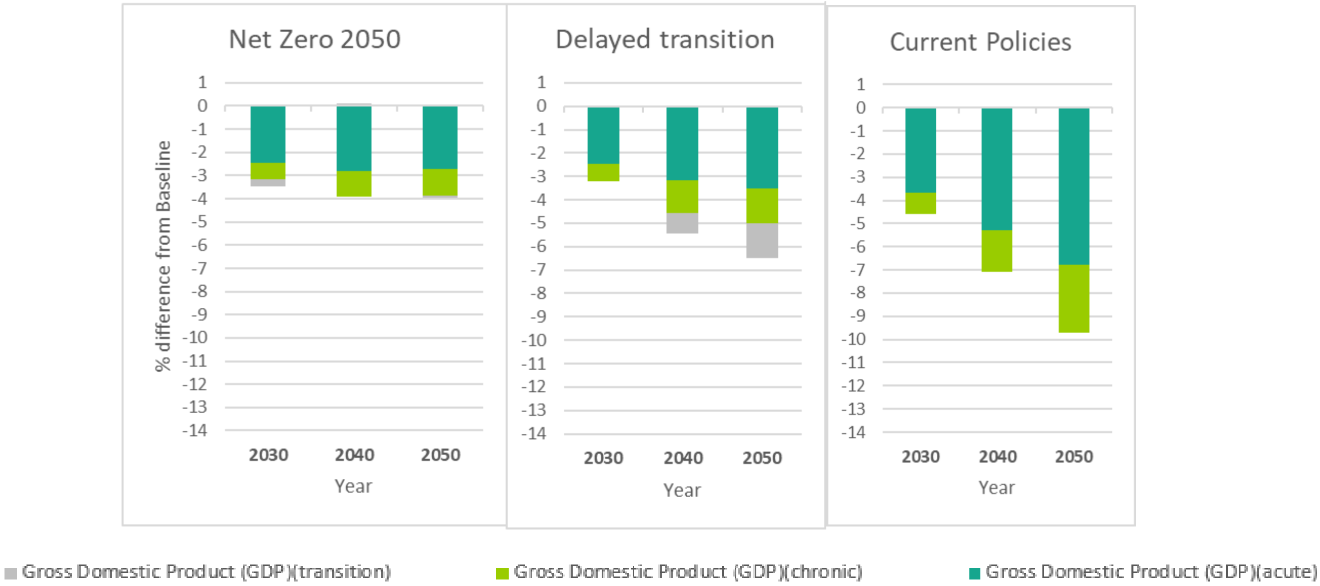


Figure 14: GDP (combined) comparison across models

Note: Models used: GCAM, MESSAGE, REMIND. Data for Italy in absolute differences from the baseline.

a) *Europe*



b) World

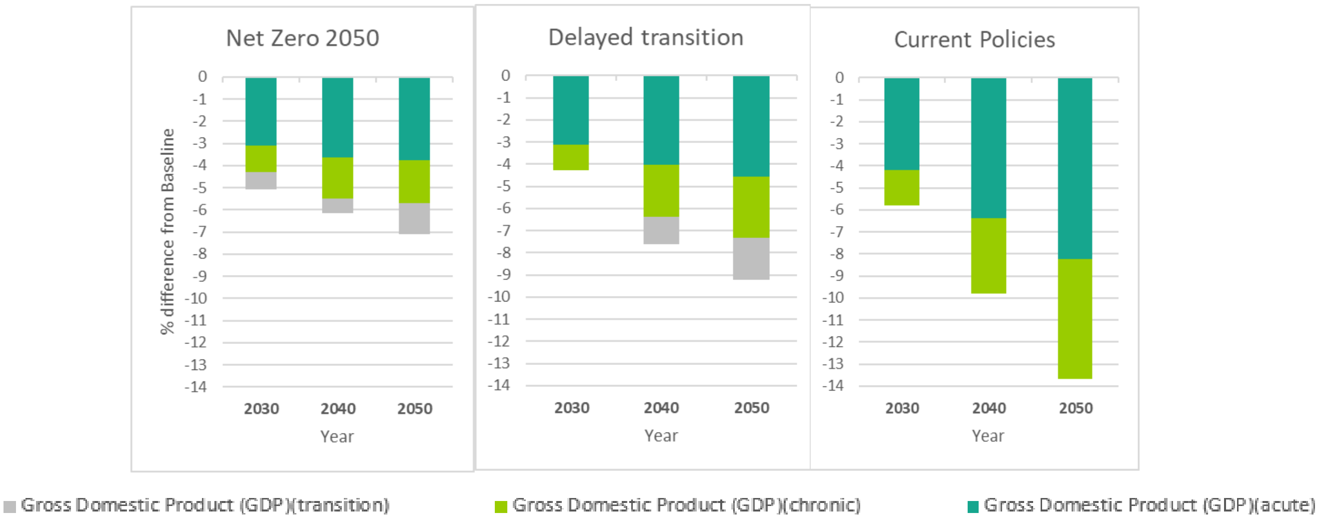


Figure 15: GDP deviation due to transition, chronic and acute risks comparison across countries

Note: Models used: NiGEM with REMIND inputs. Unit: percentage differences from the baseline.

Real prices and trajectories, 2020 = 100

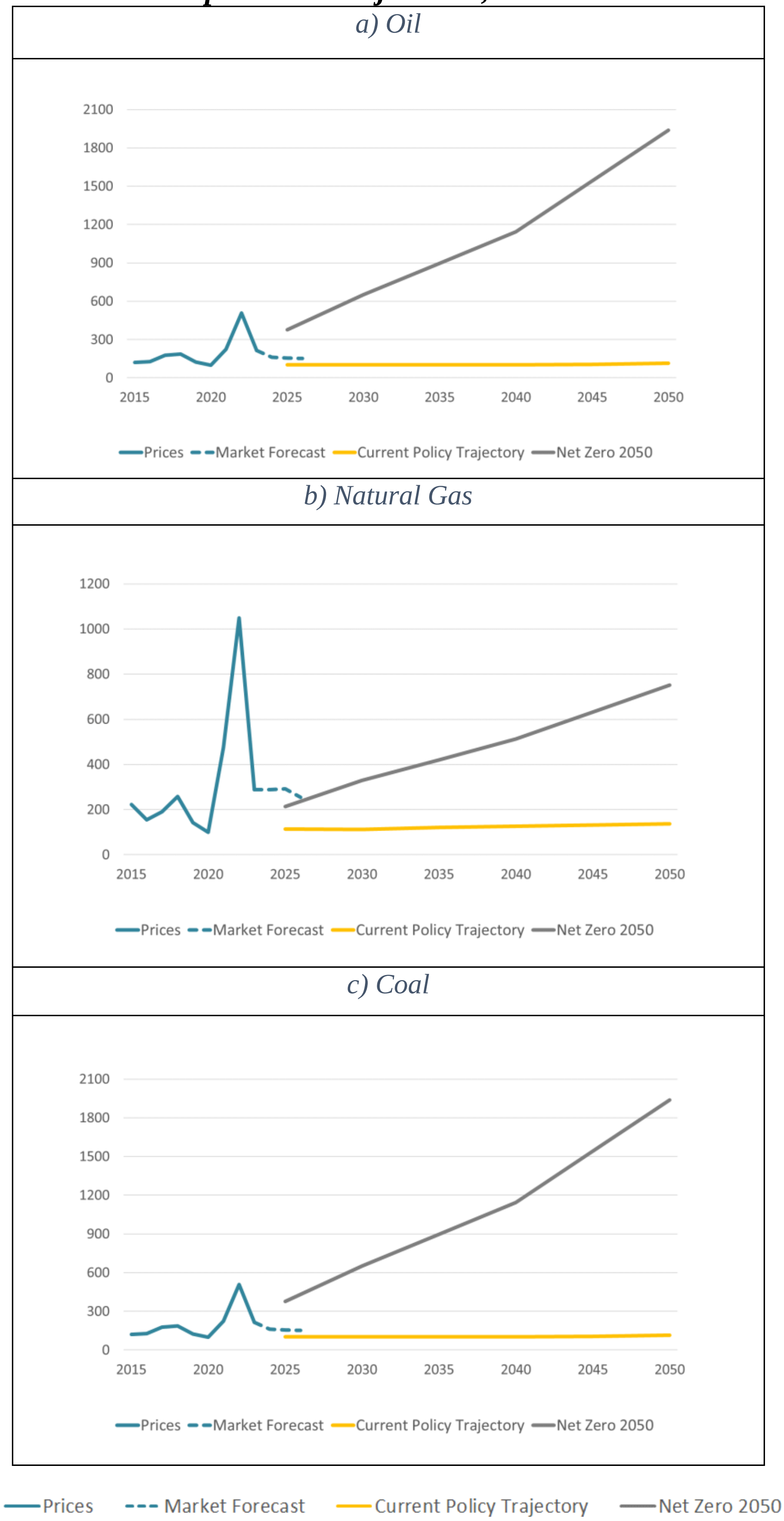


Figure 16: Price developments and NGFS transition scenarios

Note: For realised prices, quarterly average price; for market futures, latest futures prices. For Oil realised prices, ICE Futures Europe Brent Crude Futures. For Natural Gas realised prices, ICE Endex Dutch TTF Natural Gas Futures. For Coal realised prices, Rotterdam coal futures. Current Policy and Net Zero 2050 trajectories include the sum of primary energy price and carbon price projections based on average emission intensities.

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