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ADEME's analysis of the French pilot climate stress test

Analysis note

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SUMMARY

POINTS TO REMEMBER

- The climate pilot exercise conducted by the French Prudential Supervision and Resolution Authority (ACPR) is an exercise of unprecedented scope. It required the mobilization of a large panel of French and foreign actors, the development of new tools and specific metrics as well as the coordination of almost all French banks and insurances by the supervisor for one year. ADEME welcomes this work, whose main results are in line with its own prospective studies (National Low-Carbon Strategy, ADEME Visions). ADEME encourages the continuation of these stress tests by supervisors.

- Transition risk does not emerge as a strong systemic risk for French financial institutions, given their moderate exposure to the sectors that would be most affected in the proposed scenarios. The NGFS scenario framework of coordinated policies with gradual effects produces significant sectoral shocks over time, but without generating major financial shocks over the time horizons corresponding to the maturity of the portfolios.

- Although the starting point is carbon price trajectories corresponding to the standards of transition policies, the macroeconomic effects of the scenarios are rather limited since carbon prices have little influence on the trend trajectory of GDP and the French economy does not see any very significant sectoral recomposition.

- For future exercises, additional hypotheses such as the anticipated materialization of stranded asset shocks, changes in access to financing following public policy announcements or coalitions of private actors, or a sharp macroeconomic correction linked to a disorderly action would deserve to be studied to complete the analysis.

- The carbon price as the main transition lever is an economically optimal tool, insofar as it is the most targeted and least distorting. Future stress-tests could also include more varied and potentially more economically adverse levers: regulations, standards, bans, etc.

- Socio-economic and technological projections significantly influence mitigation efforts (and therefore risks) and condition the capacity of institutions to bear future losses. Consistent with the NGFS framework, the pilot exercise uses rather central socio-economic assumptions. Future exercises could include more extreme scenarios: a fragmented world, declining productivity, and the delayed maturity of renewable energy and carbon capture and sequestration technologies.

- The main financial risk remains that of climate change damages. The pilot exercise highlights the considerable impacts on insurance liabilities. ADEME encourages the evaluation of these costs for the whole economy and the measurement of the damage caused by a limited action.

1. Introduction and context of the analysis

The French Prudential Supervision and Resolution Authority has initiated in 2020 the first world-wide climate supervision exercise, called "pilot exercise". (ACPR, 2020) . This exercise follows long-term concerted work, preceded by a risk analysis of the banking and insurance sectors, as well as an interview exercise with the main French groups in 2018. Finally, this work was followed by the publication of a guide for supervisors, associated with an initial proposal for reference scenarios at the global level (NGFS, 2020)

By analyzing the resilience of financial institutions to climate risks, climate stress tests should allow actors to anticipate the risks associated with their current investment strategy and to reallocate financial investments towards assets aligned with carbon neutrality trajectories. They are thus a key element of future financial tools to help achieve the Paris agreements. Climate risks include, according to the definition proposed by Mark Carney, physical risks (direct impact of climate and weather events on people and property), assessed in a trend manner, and transitional risks (adjustment process towards a decarbonized economy), reflecting more or less elaborate political planning.

This exercise is not, however, formally, and according to the authors' own typology, a "stress-test" exercise. This term refers to periodic exercises by supervisors and central banks aimed at reproducing the effects of a "severe but plausible shock" on one or a group of financial institutions. In this case, the pilot exercise does not simulate a recession, but a growth projection affected by different economic and political assumptions. It does not measure the solvency of financial institutions and does not impose regulatory capital requirements on them: it is more like a scenario analysis exercise. For the banks participating in it, it is therefore not at this stage a regulatory exercise within the framework of the Supervisory Review and Evaluation Process (SREP), since there is no consideration of climate risks in the evaluation of the capital buffer of financial institutions. Moreover, this exercise was carried out on a voluntary basis[1]. However, there are three specific objectives associated with the exercise:

- An objective to raise awareness among financial institutions and to encourage them to integrate, in their long-term strategies, a vision of the evolution of their activities and an evaluation of their climate-related risks;
- An objective to evaluate the economic cost that would occur if the strategy of the financial institutions moved away from the Paris agreements; these would result, in the pilot exercise, in the implementation of a so-called "orderly transition" which serves as the central scenario of the exercise;
- An objective of methodological development and operational integration, both on the side of supervisors and on the side of financial institutions (modeling tools, available data).

The Banque de France has invited a group of French and foreign institutions to comment on the results published in May 2021 as well as on the methodology applied during this exercise. ADEME has responded favorably and shares its thoughts in this study. First of all, ADEME supports the ACPR in this initiative, which constitutes, along with the British biennial exercise of 2021, the first *"bottom-up"* exercise (i.e. with the direct participation of banks and insurance companies) of such a scope conducted by a central bank. ADEME hopes that this exercise will be progressively extended among the members of the NGFS and could serve as an example for the generalization of this type of exercise throughout the world and proposes to the supervisor some development avenues for future exercises.

[1] The ACPR notes, however, that the participating groups represent a very significant share of the banking and insurance business in France: 9 banking groups (85% of the banking balance sheet) and 15 insurance groups (75% of the insurance balance sheet).

2. Methods and main results of the exercise

Established in 2017, the *Network for Greening the Financial System* (NGFS) brings together willing central banks and supervisors to integrate climate-related financial risk management. One of its actions aims to promote the use of climate scenarios as a risk analysis tool. In June 2020, the network published its "high-level reference scenarios", associated with four possible representations of the socio-economic and climate future. Two axes emerge to classify these scenarios:

- the degree of planning of the transition (ordered or disordered) ;
- the ambition of the public action (whether or not the Paris agreements' goals have been reached).

Three representative scenarios were run using three integrated assessment models (IAMs) used by the IPCC scientific community (GCAM[2], MESSAGE[3], REMIND[4]), namely:

- "hothouse world", a no-transition, business-as-usual scenario, leading to significant global warming and marked exposure to physical hazards;
- "orderly transition", a scenario of progressive and anticipated transition;
- "Disorderly transition", a scenario of delayed, disruptive and unanticipated transition.

Based on this analytical framework, the Banque de France has chosen to represent three scenarios of complete transition (common to banks and insurance companies) and one physical scenario (limited to insurance but including feedback effects on the banking system through a "second round" effect).

These three scenarios are macroeconomic, financial and sectoral trajectories including a central scenario of orderly transition and two adverse scenarios reflecting a disorderly transition:

- The central scenario and variant one (delayed transition) are calibrated to the representative ordered and disordered NGFS scenarios and replicate the carbon price and GDP trajectories.
- The variant two (rapid transition) only reproduces a disordered carbon price trajectory and combines lower productivity assumptions to represent a lack of maturity of renewable energy.

Finally, the physical scenario, aligned with the IPCC RCP 8.5, is a scenario of meteorological losses (natural catastrophe scenario established by the Caisse Centrale de Réassurance based on projections from Météo France) and health related to vector-borne diseases and air pollution (scenarios from the reinsurance broker AON for France). For exposures outside of France, insurance companies used NGFS climate data. Physical risk is assumed to affect only insurance liabilities.

To disaggregate the macroeconomic and sectoral scenarios, the Banque de France used a suite of models (Allen, et al., 2020) [5] and a static multisectoral general equilibrium model (Devulder & Lisack, 2020) which compute the macroeconomic (GDP, inflation, unemployment, public deficit and debt), financial (interest rates, spreads, exchange rates, oil prices) and sectoral (production and value added for 55 sectors of activity) assumptions for four major zones (France, Europe, the United States and the rest of the world).

The participating banks assessed the impact of these scenarios on a range of financial risks and portfolio segments, including credit risks (corporate and household) and market risks (portfolio revaluation, sovereign and counterparty risks) but excluding operational and liquidity risks. From 12.5% in 2019, the cost of risk (ratio of past provisions to total exposures) would reach 15.8% (orderly transition), 16.4% (delayed) and 17.2% (accelerated) in 2050, i.e. a lower impact than those measured in the European stress tests. Between the two most extreme scenarios (orderly and accelerated transitions), losses would be concentrated on the corporate portfolio (+11.6%, contribution of 75%) and bonds (+87.5%, contribution of 22.5%). The retail portfolio would contribute little (+0.5%). On the insurance side, a two- to fivefold increase in natural disasters would force institutions to raise premiums by 130% to 200% between now and 2050 (i.e. 2.8% to 3.7% per year).

[2] Global Change Assessment Model (PNNL).
[3] Model for Energy Supply Systems And their General Environmental Impacts (IIASA).
[4] REgional Model of Investment and Development (PIK).
[5] National Institute Global Econometric Model (NIESR).

3. General comment on the exercise and supervision of climate risks

(i) No systemic transition risk, but financial planning required

The results published by the Banque de France are in line with the economic projections carried out periodically by ADEME. According to the models of the National Low-Carbon Strategy (Ministry of Ecological and Solidarity Transition, 2020) According to the modelling of the National Low Carbon Strategy, an orderly transition scenario could generate 3 to 4 points of additional activity by 2050 and would only marginally modify the projected business-as-usual trajectories.

The economic risks associated with the transition could therefore materialize as deviations from this optimal theoretical trajectory. Whatever adverse shocks materialize (timing and magnitude of the action), they would not weigh significantly on the French economy and are not likely to cause a systemic risk to the financial system.

However, individual financial institutions may experience significant losses in credit and market activities. These losses will depend both on the economic trajectory actually achieved and on their investment strategy, but also on the sectoral disruptions that will accompany the transition and may lead to a turnover of players, particularly in exposed sectors. Micro-prudential supervision of climate risks must therefore be pursued by central banks, as an incentive but also as a regulation.

While transition is a gradual, medium-term process, ADEME argues that transition risk could also manifest itself through short-term shocks, affecting both credit portfolios and market activities. We are thinking in particular of the materialization of stranded asset costs: risk of sudden closure of large energy-intensive production units (thermal power plant, blast furnace, refinery, airport, chemical plant...) even before investors have been able to amortize fixed costs, following regulatory or fiscal measures; risks of a sudden drop in demand for certain products (packaging or disposable plastic products, phytosanitary products, thermal vehicles), investment demand (halt in public works investments such as the construction of roads, bridges etc...); the risks of skills mismatches in the labor market and the capacity of low-emitting sectors to absorb labor from carbon-intensive sectors.

Finally, the main climate risk to be covered remains the physical risk: in the absence of additional mitigation action, the average temperature in France could, according to Météo France, increase by 4°C by 2100 and the economy (and therefore the financial system) would then be very seriously affected in a systemic way.

(ii) Choosing between a risk-based or incentive-based approach

For this first climate exercise, the objectives and conditions of the exercise were a non-mandatory framework (voluntary participation of the participating financial institutions) and an absence of regulatory capital requirements. It is thus more of an exercise in appropriating climate neutrality scenarios, with no practical incentive for the (necessary) transition of the financial sector. The so-called "dynamic balance sheet" hypothesis, which allows institutions to modify the composition of their portfolio after 2025, makes it possible to make institutions aware of the endogenous nature of climate change, by making them integrate the consequences of their investment decisions. This hypothesis is essential over long time horizons, since portfolios must be reloaded, but it raises questions about the possibility that actors may underestimate the risks to which they are exposed.

ADEME supports the call of the different actors to pursue and strengthen the regulatory implications of the next exercises. Integrating capital constraints seems to be an important step to encourage the transition of the financial sector, but such an exercise seems difficult as long as its consequences are supposed to materialize in long time horizons and the tools and methodologies are not sufficiently

mature. However, such long-term exercises will remain indispensable to take the full measure of a complete transition and of a planet that will have warmed significantly.

The observations also concern the choice of the reference scenario. The central choice of an orderly and successful transition appears to many observers to be open to discussion because it would not correspond to the most likely future or would lead to an optimistic assessment of the transition, since it is based on an inter-temporal optimization that is quite remote from (geo)political, economic and social constraints. It should be noted, however, that this approach is consistent with the NGFS framework of the representative "orderly transition" scenario and has been co-constructed with the institutions voluntarily participating in the exercise. On this issue, ADEME develops a more pronounced opinion in the note and proposes not to explicitly define a central scenario. However, it should be noted that this choice has no practical consequences: the financial institutions project their losses independently of the central scenario. As such, more than the reference scenario, it is the choice of the set of scenarios, their narrative and the methodology used that will have direct practical consequences for the financial sector.

First, ADEME notes that most of the criticisms expressed may stem from the multiplicity of stated objectives, some of which may appear difficult to reconcile. The exercise here aims to integrate both a risk-based approach to the scenarios (measuring the vulnerability of institutions to several transition scenarios) and an incentive-based approach (encouraging institutions to align their financial strategy with a decarbonized economy). In the first approach, the very wide range of possible futures should push supervisors to propose a large number of scenarios, reflecting most of the possible extremes and retaining rather adverse assumptions. In a bottom-up exercise, however, it is recognized that this number is limited in practice by the capacity of institutions to decline a large number of series on all segments of their activities, which can become time-consuming if the panel is too large.

The choice of a central scenario would then tend to bias the assessment of risks by favoring a more probable and/or less adverse future than the others, and could then lead to sending the wrong signals to actors. On the contrary, in the second approach, the supervisor explicitly chooses to evaluate the cost of not aligning with the Paris agreements, i.e. to measure the risks of achieving an imperfect transition ("disordered" transition), incomplete, or even non-existent ("unchanged policy"). Instead, the pilot exercise ranks according to this precise approach and selects a targeted range of risks.

A next step could be to develop the first approach, for example by including transition scenarios in the usual regulatory exercises (with horizons of 2 to 3 years). However, ADEME recognizes that such a step is subject to new methodological challenges and encourages the NGFS to pursue its methodological initiatives in consultation with all stakeholders (supervisors, ministries, environmental agencies, NGOs, academic partners and the general public).

(iii) The climate scenarios materialize long-term consequences, the effects of which can occur in a more anticipated way

The pilot exercise proposes scenarios based on a relatively linear and progressive carbon price trajectory that produces sectoral shocks without affecting economies as a whole; it does not measure the resilience of a financial institution to an unanticipated extreme shock. Although the main effects of climate change will materialize over long time horizons, we believe that it is useful to propose shocks that are not too time-lagged and to consider the materialization of the risk on existing portfolios. Incentives are more direct and effective if the risk starts at an immediate horizon, as is the case for the simulation of a financial crisis during a stress test. On the other hand, the probability of violent shocks in the very short term cannot be ruled out: shocks linked to the social sustainability of environmental actions (for transition risks), changes in market expectations regarding the achievement of the transition or intense climatic episodes (e.g. in France: low level of the Rhine in 2018, drought in 2019, frost episode in April 2021) The rapid reaction of financial actors (EU-ETS market, rating agencies, CDS spread[6] on carbon sector companies) is likely to generate market risks, which are taken into account in the exercise, but also a modification of the financing conditions and the credit rating of actors. The internal rating models of financial institutions do not necessarily include all the parameters that would allow this type of reactivity

[6] *Credit Default Swaps.*

to be taken into account, by anticipating the effects (progressive and threshold) of the carbon tax trajectory.

Rating and valuation changes in the markets could occur well in advance of the long-term horizons of the energy transition, as players anticipate in practice the future consequences of the low-carbon transition. Thus, although the effects of climate change will become more sensitive in the long term, the effects on credit and financial metrics have a high probability of materializing earlier. While actors can anticipate the long-term effects of certain measures (such as the rise of the carbon trajectory, the gradual tightening of standards in the automobile industry, the increasing obligation to renovate buildings, etc.), rating models have not been designed for this purpose and may rely more exclusively on balance sheet data and historically observed behaviour. Thus, although agents are not "myopic" about the future, the integration of the consequences of the scenarios could be limited to the short term in their credit models. It would therefore be advisable to deepen the modeling of the effects of the transition in the credit models, for the carbon neutrality horizon but also in the short term.

(iv) The players do not share the same frame of reference for transition risk

In the framework proposed by Mark Carney, transition risks include, in a general way, all the risks "linked to the process of adjustment towards a decarbonized economy" and to "the revaluation of assets resulting from political and technological changes and physical risks"[7]. Many actors can interpret the definition of transition risk in different ways. Which scenario should be measured and against what is it measured, given that no future is more certain than another? Is it the risk of making the transition instead of doing nothing? Is it the risk of making the transition badly (or, to follow the NGFS frame of reference, of making it in a "messy" way)? Or the risk of not making the transition, insofar as the actors would then miss the emergence of new economic opportunities?

Transition risk has a particular scope since, in this definition, it essentially aims to highlight the risks of financial institutions financing a carbon economy. In another approach, it could also be understood as all the economic consequences of a transition action[8]. Transition risk can then both serve in a risk-based approach or provide incentives to achieve a policy objective. Here, the pilot exercise aims to assess the financial risks of an incomplete translation of the objectives of the Paris agreements and more specifically measures the risk of "disorderly transition", where the trigger is linked to the degree of environmental public action and its long-term economic and financial consequences.

Should we therefore consider the transition as a future achievement? The question arises in particular with regard to the time horizon studied. A player who wrongly anticipates the transition could suffer losses, but should we then speak of transition risk, at the risk of discouraging him from accompanying it? In any case, it appears that transition risk is as much a scenario risk as a financial strategy risk.

[7] *"Finally, transition risks: the financial risks which could result from the process of adjustment towards a lower-carbon economy. Changes in policy, technology and physical risks could prompt a reassessment of the value of a wide range of assets as costs and opportunities become apparent."*

[8] The NGFS reference scenarios (phase I) tend to make the orderly transition appear more adverse than the status quo (excluding physical risks). At the French level, however, ADEME considers that the NGFS scenario would generate an economic gain. In any case, a properly planned transition is assumed not to significantly influence the trend path of the economy.

(v) The choice of tools conditions the position and the adversity of the scenario

Macroeconomic models dedicated to the study of climate change, in particular multisectoral models, produce very heterogeneous results on the effects of a transition action. This is due to the high number of parameters, specific hypotheses that do not reflect a precise political reality (e.g. redistribution of revenues, monetary policy), but also to the theoretical foundations for representing the equilibrium of markets or the behaviour of agents (Jacquetin, 2021) . The same transition action can then be evaluated in several ways depending on the circumstances and conditions of the exercise. For example, an orderly transition action can be considered both as adverse on domestic GDP, as in the Canadian exercise with a general equilibrium model, or as opportune, as in the Hungarian exercise with a macroeconometric model (*see* Figure 1).

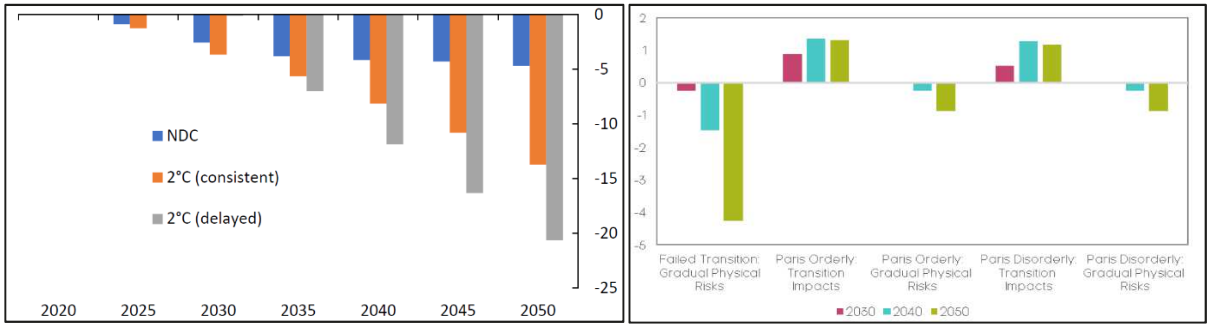

Figure 1: Adversity of transition scenarios according to the Canadian (left) and Hungarian (right) exercises

Source: Ens and Johnston (2020), Cambridge Econometrics (2021).

In the context of the synthesis of a climate scenario, two new sources of uncertainty (IPCC, 2013) can therefore be taken into account, both for physical and transition risk:

- The risk related to technical sensitivity, which in a broad sense includes all the technological and climatic parameters that vary the results of the model (for example: the discount rate, the preference for the present, the inter and intra-sectoral substitution elasticities, the sensitivity of temperature to atmospheric concentrations, etc.)
- The risk linked to inter-model differences, resulting from structural modeling choices (for example: the level of sectoral granularity, the level of disaggregation of production functions, the source of financing of the economy, the behaviour of agents, etc.)

These two dimensions of uncertainty are inherent to any modeling exercise but are more limited in a classic stress test (short horizon, aggregated models). This is why this dimension can be completed in risk assessment exercises by, for example, robustness and sensitivity tests underlying the choice of tools and their calibrations. Given the state of the still pioneering work on climate exercises, and in parallel with the implementation of "bottom-up" exercises allowing institutions to take ownership of climate risks, we encourage supervisors to study and, if possible, publish "top-down" analyses of the sensitivity of portfolios to these assumptions.

(vi) The specificities of credit risk in the face of transition scenarios

Assessing the consequences of a macroeconomic transition scenario on credit risks is a complex task. At the level of sectoral aggregates (output and value added), the transition may or may not benefit a sector, without knowing whether the actors have become more or less vulnerable. Indeed, sustained activity may be carried out with the same actors in the sector or with new entrants (creative destruction). For a bank's credit risk, the default rate will increase with these sectoral changes likely to lead to the default of existing players (e.g.: energy transition, electrification of transport, digitalization, e-commerce, circular economy, etc.).

Thus, the top-down construction of a transition scenario, starting from an assessment of winning and losing sectors, can be adapted to equity portfolios where gains will compensate for losses. On the other

hand, in the case of credit risk (nearly 90% of RWAs in European banks), the winners in a sector will not compensate for the failures of the losers, and the increase in the cost of risk for banks in this sector will be proportional to the dispersion of profits/losses linked to the transition within the sector. A potentially key sector that illustrates this is the construction industry: it is expected to see a decrease in public road works and large concrete infrastructures with a parallel growth in numerous renovation projects. The growth of the sector in transition scenarios could be based on a decline in the activity of developers in new construction, and a strong rise in unlisted SMEs and SMIs in renovation of existing buildings. According to the results of the pilot exercise, this sector will see a decline in its cost of risk depending on the changes in credit parameters anticipated by financial institutions in the context of this bottom-up exercise. A more detailed analysis would ensure that the variation in sectoral indices does not uniformly benefit all the players in a sector and that the challenges of the transition are well integrated into the institutions' internal models.

(vii) Transition risk is as much a scenario risk as a financial strategy risk

In a simplified way, financial risk exists when the evolution of the asset portfolio composition does not correspond to the evolution of the weighted profitability of the sectors (if we assume, as Gordon does, that the expected profitability of an asset is equal to the discounted sum of its yields and thus of the ratio of profits to stock). Thus, in a no-action scenario excluding the cost of damages, the financial risk remains limited if institutions favor the purchase of assets from energy-intensive industries (and in the absence of an exponential rise in the price of fossil fuels generating a recession). On the contrary, in a transition scenario, there is financial risk if they favor the purchase of assets from energy-intensive industries. The risk will be less if the transition is delayed, unless there is a recession and stranded costs down the road.

Contrary to the usual macroeconomic evaluation exercises, it would not only be a question of analyzing the macroeconomic differences between a reference scenario and an alternative scenario, but also of analyzing for each transition scenario, whether ordered or not, the financial risk that financial institutions run in the case where they would have anticipated the transition (or not). The exercise could then consist, not only of a scenario analysis, but of an analysis of financial strategies in a given scenario, which ADEME presents in a hypothetical way:

i. To assess the economic and financial effects of an orderly transition with perfect anticipation by financial institutions (institutions buy assets/credit to green industries and decrease the share of energy-intensive industry assets in their portfolio) relative to the effects of an orderly transition with imperfect anticipation (they change their portfolio composition too little and/or too late)
ii. To evaluate the economic and financial effects of a disordered transition where institutions have a precursory role (they buy assets/offer credits to green industries and decrease the share of assets of energy-intensive industries in their portfolio) relative to the effects of a disordered transition with myopic or imperfect anticipation with a refractory attitude (they do not modify or belatedly modify the composition of their portfolio).

In the ordered case, the trajectory of the carbon price is linear and moderate (as shown by the Quinet Commission) and the risks of recession are low if the carbon sink is substantial and if the rest of the world adopts a cooperative behavior. In the disordered case, the carbon trajectory is quasi-exponential and the risks of recession are all the greater with stranded costs and/or restricted carbon sinks. In both cases, the supply of credits to green industries is expected to grow as they expand (unless we assume that they will be financed by government, self-financing and/or direct purchase by households without intermediation, which is unlikely).

In the orderly case, the financial risk could be significant if institutions do not anticipate the transition (credit default risk of energy intensive sectors, loss of profitability of equity and bond portfolios). In the disordered case, the financial risk could be limited in the short run if institutions do not anticipate, but it should be more important in the long run since the risk of credit default and loss of profitability could be further amplified by the recession. One could compare these results to a no-action scenario, to check whether the financial profitability of an orderly transition scenario is superior to it (the case of the double dividend), although it appears unsustainable (exponential rise in fossil fuel prices and irremediable climate damage costs).

4. Macroeconomic transition scenarios

(i) The SSP2 narrative does not show the most pronounced transition risks

ACPR uses the NGFS baseline scenarios as the basis for its macroeconomic scenario narratives: socio-economic assumptions (long-term activity projections and labor force) and public policy assumptions (carbon prices, coupled with an abatement target constrained by, among other things, technology assumptions and the future importance of CO2 removal technologies, incorporating the development of carbon capture and sequestration (CCS) technologies and afforestation and reforestation of land.

The long-term projections reproduce the assumptions of the SSP2 *"middle of the road"* scenario, a conservative scenario that reproduces observed historical [9]economic trends. This scenario occupies a relatively central position among the various IPCC projections, both in terms of economic projections (*see* Figure 2) and in terms of mitigation issues (*see* Figure 3). In particular, the productivity assumptions seem optimistic, given the generalized slowdown in labor productivity observed since the 2008 crisis. This is why most of the long-term assumptions made by international institutions may have overstated the gains actually achieved over the 2010-2020 period, excluding the Covid shock (*see* Table 1). This slowdown is also marked in France (Cette, Corde, & Lecat, 2017) (Sode, 2016) as it is in all developed countries (Conseil d'orientation des retraites, 2020) and emerging countries (Aubry, Boisset, François, & Salomé, 2018) . There are many reasons for this, and they are the subject of debate among economists: the structural effects of economic crises, weakening innovation, sluggish technological diffusion, investment shortfalls, lower factor mobility in emerging countries, etc. This uncertainty weighs on long-term projections and prompts various institutions to take precautions, such as the COR, which uses several productivity variants in its retirement projections up to 2070[10].

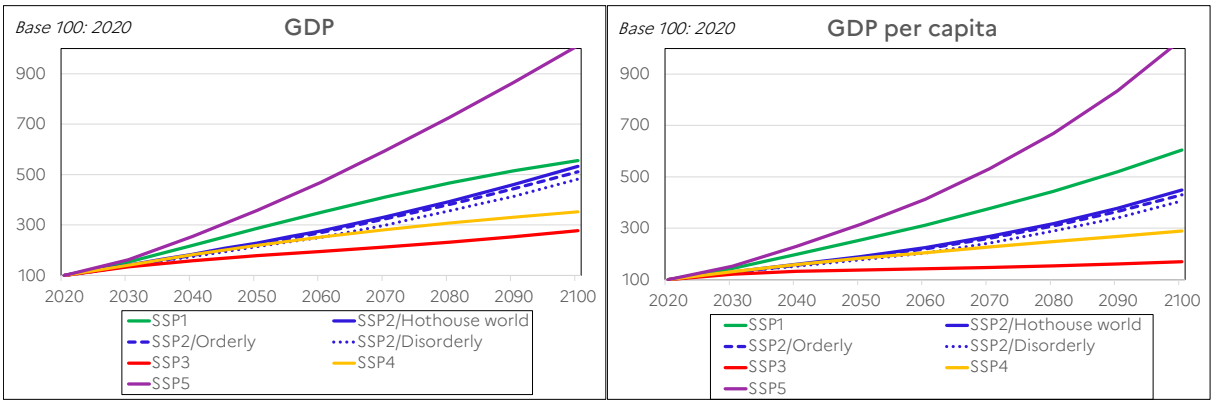

Figure 2: Socio-economic assumptions of the IPCC and NGFS scenarios

Reading: The trajectories are derived from their respective marker models[11]. The socio-economic assumptions of the "hothouse world" scenario are calibrated to the IPCC reference path (SSP2). In the remaining scenarios (orderly/disorderly), they are "semi-endogenous" (originally calibrated, but modified ex-post by the political transition assumptions of the new scenario).

Sources Riahi et al (2017), NGFS (2020).

[9] The different SSPs offer an extremely diverse set of narratives: Sustainability (SSP1), Middle of the Road (SSP2), Regional Rivalry (SSP3), Inequality (SSP4) and Fossil-Fuel Development (SSP5).

[10] See the annual report of the COR (2020): *"The long-term targets of the 1%, 1.3%, 1.5% and 1.8% scenarios define a range of possibilities that is considered sufficiently broad to assess the outlook for pensions in France. The most favorable assumption corresponds to hourly productivity growth over the long term (1980-2018), the least favorable corresponds to the post-crisis period (2010-2019). The intermediate assumption (1.3%) reflects productivity growth over the period 1990-2019.*

[11] IMAGE (SSP1), MESSAGE (SSP2, NGFS Hothouse world), AIM (SSP3), GCAM (SSP4, NGFS Orderly transition), REMIND (SSP5, NGFS Disorderly transition).

Calibrating socio-economic assumptions in a macroeconomic model is often a perilous exercise and one that does not enjoy consensus. In general, labor productivity gains are endowed with a constant deterministic trend that is supposed to reproduce past historical trends. This trend is often calibrated ad-hoc by economists: at first glance, it does not significantly bias the macroeconomic results, especially when the economist evaluates the relative difference between two scenarios.

Long-term scenarios	Average annual growth (%)
SSP (IPCC)	4,1-4,3 %
Reference scenarios (NGFS)	4,2 %
Observed (excluding year 2020)	**2,6%**

Table 1: Comparison of different global activity projections over the period 2010-2020

The three ACPR transition scenarios (and in particular the ordered scenario and variant 1) do not represent any significant macroeconomic shocks and in particular no recession, which is the central element of a usual financial stress-testing exercise. This new property may be appropriate for a long-term "climate" scenario, since in any case the economy could not suffer a prolonged recession over such a long time period, leading to the default of all portfolio counterparties. It should be noted, however, that overly optimistic assumptions may always lead institutions to underestimate intrinsic risks, whereas simple scenario-based forecasting exercises can accommodate more variable productivity assumptions (the differences between scenarios being, at first order, little dependent on common socio-economic assumptions).

Finally, very different productivity and activity assumptions can significantly influence the abatement costs needed to achieve carbon neutrality[12]. A more energy-efficient narrative would limit the mitigation action required and the risks associated with a transition scenario (e.g., SSP1). On the contrary, a more sustained development hypothesis would be accompanied by dynamic growth but could be more exposed to the risk of a transition, especially a disordered one (SSP5). Finally, in the absence of cooperation, the SSP3 narrative shows both the lowest projected activity but also the highest mitigation efforts. While it appears central and conservative among the shared socioeconomic trajectories (neither too optimistic nor too adverse), the SSP2 narrative does not sufficiently explore the most extreme risks where autonomous improvements in the energy intensity of technologies and their carbon content would be frustrated (Riahi, et al., 2017) . These assumptions would further constrain public policy and its temporality.

(ii) The transition is taking place in a more or less favorable technological framework

Public action is characterized here by the evolution of carbon prices, associated with the technological hypotheses mentioned above as well as the hypotheses of carbon capture and sequestration. Regarding the latter, the NGFS scenarios make assumptions that ADEME considers relatively ambitious. Although they are in line with the work of the IPCC, they are associated with the most successful transition scenarios (SSP2 2.6 and 1.9, respecting respectively the limits of a 2°C and 1.5°C increase) and are based on a high level of maturity of these technologies as well as the most favorable learning curves. Such assumptions could tend to minimize the financial risks associated with the transition [13]and the effort required. In practice, the tutelary value of carbon is very sensitive to the estimated carbon sinks, as demonstrated by the work of the Quinet Commission (*see* Table 2). Concerning the technological maturity, variant 2 allows to capture part of these effects.

[12] For example, Heutel (2012) points out that during an expansion, capital is more productive and the opportunity cost of abatement relative to investment would therefore be large.

[13] See Riahi (2017): '*CCS plays an important role in many of the mitigation scenarios even though its deployment is subject to large uncertainties'*.

Models		2030		2050	
Technico-economic	TIMES	322	288	1 365	2 451
	POLES	253	351	1 958	3 513
Macro-economic sectors	IMACLIM	168	168	1 453	3 122
	IMACLIM (myopic)	228	-	3 328	-
	ThreeME	143	143	511	2 389
	NEMESIS	185	185	-	-
	Average	221		2 233	
	Minimum-maximum	143	351	511	3 513

Table 2: Carbon Trigger Value for Sinks between 75 (orange) and 95 MtCO2e (blue)

Source: France Stratégie (2019), The Value of Climate Action.
Note: Carbon price expressed in €2016/tCO2e.

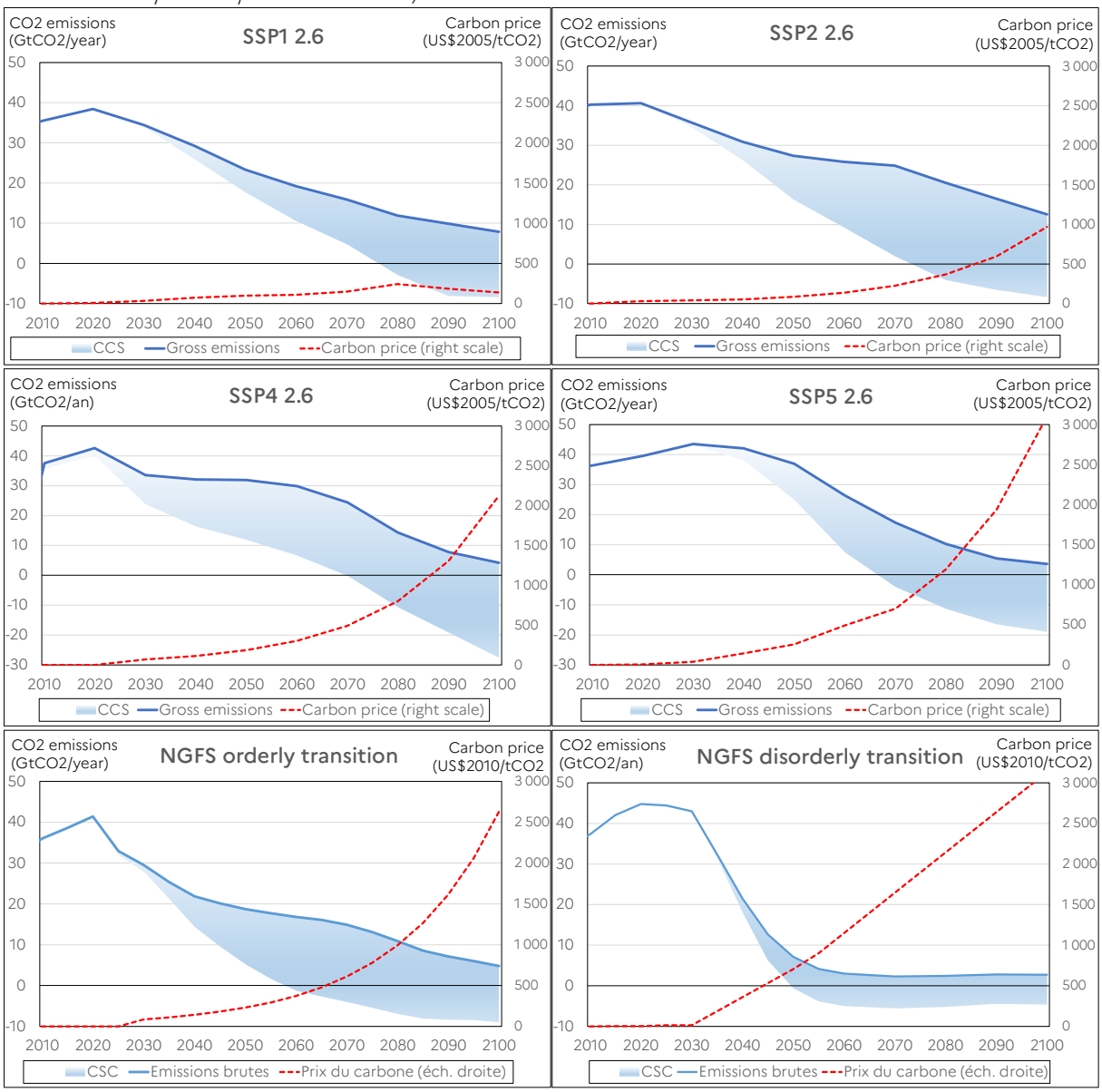

Figure 3: Mitigation efforts associated with the IPCC and NGFS scenarios

Note: Trajectories consistent with CPR 2.6 and keeping warming below 2°C. These are associated with their marker model. The RCP 2.6 is not considered achievable by the SSP3 scenario. Carbon prices should be compared with caution as they are derived from different models.

(iii) The choice of a central scenario of orderly transition may suggest that it is both the least adverse and the most likely in the future

Climate-related financial risks face radical uncertainty: uncertainty related to the implementation of collective action and its consequences, uncertainty related to climate change and its consequences. This is why most models, which are partly or entirely based on past data, are unable to correctly assess the effects of mechanisms that have not yet been fully observed. No actor can yet define the most likely path with certainty or what will be the economically optimal future path. The cost-benefit analysis work carried out by academic research and marked by the work of Nordhaus, has far too many theoretical limitations to be conclusive.

This is why the definition of "climate-related risks" does not enjoy consensus among stakeholders. Both because it is not clear which of the transition risks and the physical risks will predominate on a given horizon. On the transition risk alone, the actors do not share the same frame of reference either. For example, during the evaluation of the National Low-Carbon Strategy, ADEME and CIRED concluded that the new neutrality trajectory would generate, compared to a previous less ambitious SNBC, a similar gain in GDP, of the order of 3 to 4 points by 2050 (Ministry of Ecological and Solidarity Transition, 2020) .

Instead, the pilot exercise chooses to place the orderly transition scenario (considered to be a trajectory compatible with the SNBC) as the central scenario. This choice has no practical consequences for financial institutions[14], but will certainly have one in terms of communication and incentives. Macroeconomic impacts and losses are expressed both in terms of changes in each scenario but also in terms of deviations from this orderly transition, and losses (or gains) will be expressed in terms of the reference portfolio that materializes. For this reason, the scenarios appear relatively unadverse: the trajectories differ essentially in their temporality.

The risk dimension of the pilot exercise is then mainly captured by the magnitude of the tax shock, in particular the "delayed" variant 1 (*see* Figure 4): in the short run, the ordered scenario is more adverse (since with immediate public action), while in the long run, the delayed scenario takes the upper hand (since catching up requires more abrupt action). Depending on the model used and the recycling assumption, other institutions might reach the opposite conclusion; this debate echoes the "double dividend" theory in environmental macroeconomics. ADEME recognizes that this theory does not enjoy consensus among stakeholders and will remain open to debate in the absence of sufficient historical perspective, but stresses that this uncertainty should be represented in the work of supervisors. The Three-ME model used by ADEME and OFCE, for example, makes it possible to obtain an economic and environmental gain from an environmental tax, in particular when the recycling of revenues is targeted to alleviate distortionary taxes (Callonnec & Combaud, 2019) and industries subject to the ETS remain exempt.

Moreover, unlike the usual financial shocks that [15]are supposed to negatively impact all institutions, the energy transition highlights certain sectors as winners. A financial institution could turn out to be a winner, even in a scenario that the supervisor would present as adverse. Consequently, if we seek to measure the risks in their broadest context, the notion of a central scenario seems less relevant, especially since it could lead to an erroneous interpretation of this orderly transition scenario as being both the least adverse and the most likely. However, choosing another, more conservative scenario (such as a no-action or *business-as-usual* scenario) could also prove even more counterproductive: in its analysis of the NGFS work, the associations *Oil Change International* and *Reclaim Finance* fear that projections of investments in non-sustainable activities could give the impression to economic actors that these remain necessary or even inevitable (Ioualalen & Schreiber, 2021) .

[14] The assessment of losses for financial institutions is based on scenarios expressed "in level", not in relative deviation from a reference path.
[15] These shocks are generally reproduced from past events: economic recessions, financial bankruptcies, downgrading of a government's rating, increase in spreads...

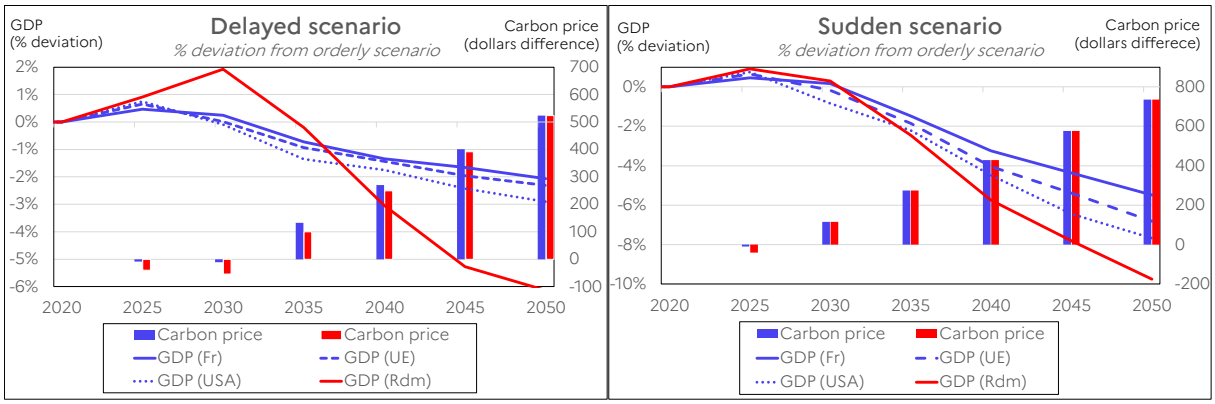

Figure 4: ACPR macroeconomic scenarios

Source: ACPR scenarios
US carbon prices differ marginally from FR/EU prices.
Reading: In 2030 (2050) GDP is 0.3% higher (2.1% lower) in the delayed scenario than in the ordered scenario, while carbon prices are $11 lower ($533 higher).

In order to compare macroeconomic impacts and impacts on portfolios, ADEME therefore proposes not to explicitly define a central scenario, especially since this one seems unsuitable for an exercise in assessing climate-related financial risks (see next section).

A greater diversity of scenarios should thus make it possible to position financial actors in relation to transition or non-transition scenarios: in which scenario(s) is each actor the most vulnerable? Is it well positioned to support a more proactive policy to decarbonize the economy?

(iv) The three transition scenarios are not representative of all possible futures and do not include the most extreme risks

The pilot exercise was based on two boxes of the NGFS matrix: those of the ordered transition and the disordered transition. These families can be associated with "forward-looking" scenarios, where the macroeconomic trajectory is conditional on the achievement of an environmental objective (Jacquetin, 2021) . Finally, the scenarios here correspond to relatively linear and conservative deterministic trajectories. Future risk assessment exercises will necessarily have to evaluate scenarios where the risk materializes "at the tail end of the distribution" (*fat-tail risks*). These scenarios have a low probability of materialization but will have the most severe economic and social consequences.

ADEME suggests that supervisors propose other types of scenarios, *at least* a no-action scenario[16] ("no policy change") and scenarios based on more severe narratives (e.g., SSP3/SSP5), which would not necessarily be calibrated to respect a predefined path and would result, for example, in an incomplete transition. Financial institutions could then assess the state of their future losses under a wide range of futures as well as more adverse options, which remains the subject of a stress test.

It is difficult to evaluate precisely the probability of transition scenarios that are not based on the reproduction of historical events that have already been observed, except by developing micro-founded and "stock/flow consistent" models that escape Lucas' criticism. We can therefore speak more of plausibility than of probability of occurrence for them. Another way of qualifying them is by the range of possibilities covered and the severity of these scenarios for the economy. ADEME considers that, in the context of this pilot exercise, the field is quite limited with three scenarios of achieving carbon neutrality in 2050 through continuous and coordinated carbon price paths at a global level. Less ideal approaches, such as *stop-and-go* climate policies, failure to meet targets or lack of international cooperation, should make it possible to explore scenarios that are equally plausible but of greater severity.

[16] In their respective forward-looking exercises, the Bank of Canada, the Bank of England or the Bank of Hungary have chosen to include this no-action scenario (with or without physical risks depending on the exercise).

(v) Aggregate sectoral shocks comparable to our assessment of the NCBS, but arguing for finer segmentation in the future

The sectoral scenario (here the ordered transition scenario), associated with the achievement of carbon neutrality in 2050, does not reveal any major sectoral shock for the French economy. This aggregate result is broadly similar to ADEME's assessment of the SNBC (see Figure 5). A more detailed view, however, reveals more marked changes in the ADEME model: a decline in French energy intensity, the virtual disappearance of the oil and natural gas sector, massive spillover effects in services related to energy renovation investments, and the relocation of activity from exporting countries to fossil fuel importing countries. The reasons for this are mainly related to the choices and assumptions of sectoral modeling (see next section), but also possibly to a higher carbon price trajectory in the ADEME scenario.

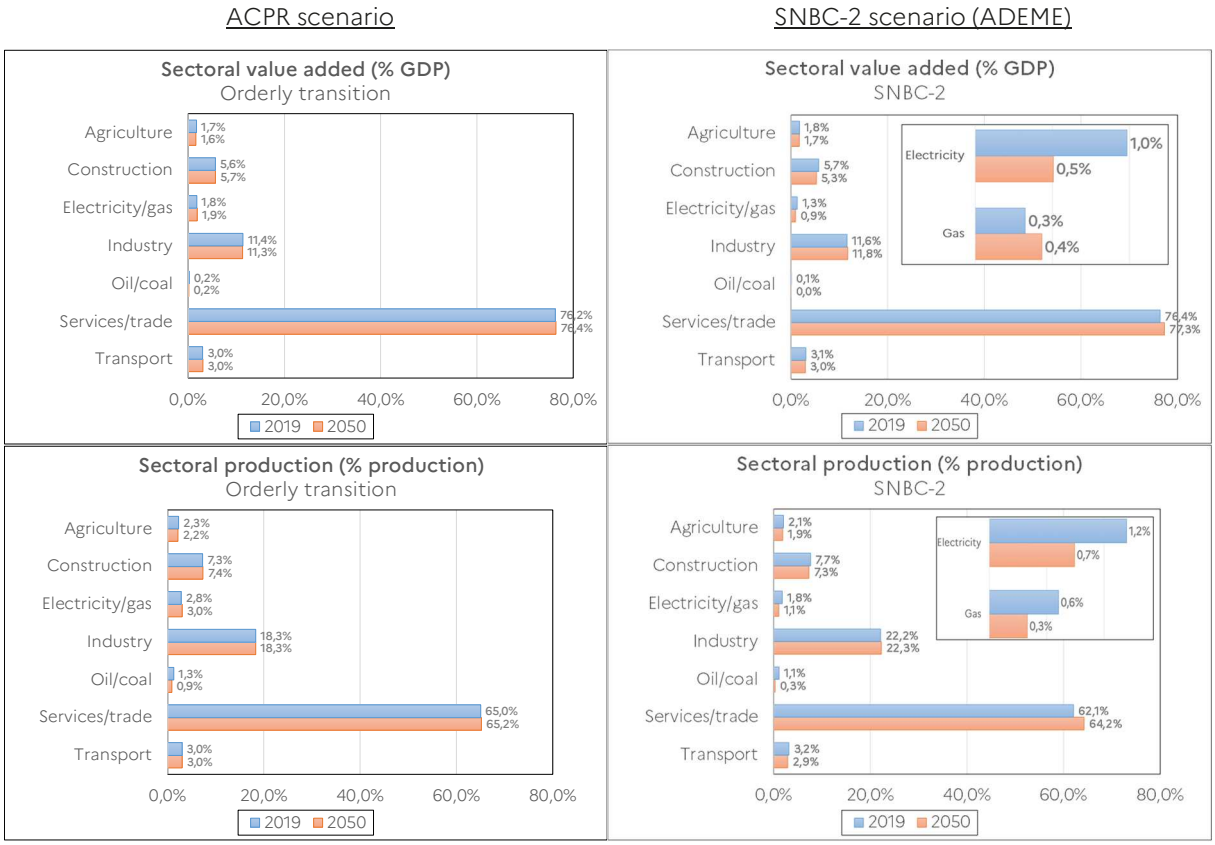

Figure 5: Evolution of French sectoral activities in the ACPR and ADEME scenarios

Sources: ACPR scenarios and ADEME simulations.

Note: the simplified sectoral disaggregation comes from different nomenclatures, sources and calibration years, which explains the small differences in 2019 on sectoral outputs.

In the SNBC scenario modeled by ADEME (2020), most sectors experience a significant increase in their capital intensity due to investments in renovation and energy efficiency (*see* Appendix 1) Fossil fuel importing sectors (notably gas and oil) also benefit from significant relocation effects and domestic job creation due to higher energy prices (*see* Appendix 2). Within the gas/steam/heat sector, the use of natural gas is assumed to disappear by 2050 in favor of an increase in renewable energies (biogas and geothermal in particular) and the electrification of uses.

5. Modelling tools and assumptions

(i) The mechanisms of the energy transition require multi-sectoral macroeconomic modeling

As the ACPR notes, the analysis of climate risk scenarios requires the use of tools specifically adapted to the exercise:

- a very long time horizon (1), necessary to represent the long-term materialization of climate-related financial risks;
- an international (2) and sectoral (3) dimension, linked to France's highly internationalized financial activities and to taking into account the heterogeneity of sectors' exposure to climate risks.

This exercise is therefore relatively new. Socio-economic projections related to climate are usually not as advanced. The French National Low-Carbon Strategy is assessed using models focused on the national economy. On the other hand, international institutions (IPCC, IEA) propose very aggregated trajectories, notably for economic and political planning purposes. This is mainly due to the fact that macroeconomic models, which are necessary tools for the synthesis of these scenarios, are generally not as granular. Models that combine sectoral and geographic disaggregation are rare, often have limited access, and their use is limited to experts in large research institutions. In order to master all aspects of these tools, which are considered by many to be "black boxes," supervisors will have to continue to reflect on and consult with the various modeling actors in order to develop the methodology.

The choice of the NiGEM model makes sense insofar as it is a reference among financial institutions; it is already widely used and its theoretical foundations are sufficiently transparent; moreover, it is one of the few international macroeconomic models, a necessary characteristic for taking into account the exposures of French financial groups. Its representation of trade between countries also makes it a particularly interesting tool for representing the consequences of a global transition scenario linked to changes in activity and the price competitiveness effects of a tax, and for defining plausible financial scenarios based on these imbalances. However, it does not propose sectoral disaggregation and represents only one energy production factor associated with a highly aggregated production function (known as "Cobb-Douglas"). This representation makes it a still limited tool for fine modelling of transition risks, which are limited here essentially to the risks of sobriety[17], of recession in the face of a rise in energy taxation, and of a possible impact on total factor productivity. A transition scenario would reveal other mechanisms: energy[18] efficiency effects and effects of substitution and transfer of activity towards products and activities that emit less greenhouse gases, consequences of economic measures such as a carbon tax, but also of technological developments or new standards and regulations. While the aggregate impact is globally consistent (see §4(v)), the multiple effects of the transition may be properly represented by more granular sectoral models and more extensive production functions. As part of the pilot exercise, the ACPR is using a sectoral model to take into account some of these effects, including the sectoral interactions given by an input-output matrix.

According to this model, the *retail* portfolio seems to be little affected by the transition risk: the variables retained (GDP and unemployment) show a favorable trajectory. In fact, in the absence of an effective inter- and intra-sectoral training policy, a portion of the workforce could be exposed to the risk of unemployment. Finally, in the exercise, revenues from the carbon tax are redistributed to households. In the presence of less dynamic purchasing power gains, a less effective redistribution policy and regulatory constraints (mandatory renovation work), the increase in carbon prices could also significantly weigh on household solvency.

The main models dedicated to the study of climate change are based on the theory of Walrasian general equilibrium. Originally static, these models have undergone multiple developments and have many advantages for the study of environmental policies (fine representation of sectoral interconnections in

[17] Energy sobriety consists in reducing the need for energy services and limiting production and/or consumption.
[18] Energy efficiency consists of reducing the amount of energy needed to provide a given energy service by investing in more energy-efficient equipment (home insulation, less energy-consuming vehicles, etc.).

the economy, market equilibrium, international trade). However, these models are restrictive in terms of financial risk assessment. It is assumed that supply determines demand and that demand has no retroactive effect on production. The evolution of the capital stock is determined by a stock of savings, which itself depends on exogenous parameters (population and labour productivity). Money is assumed to be neutral and monetary policy has no impact on investment or activity. This type of model seems less appropriate for dealing with financial crises.

To assess the impact of finance on the economy, it would be necessary to take into account money creation by assuming that interest rates balance the supply of and demand for money (or that the supply of money adjusts to demand according to rates) and not savings and investment. Neo-Keynesian models therefore seem the most appropriate. Several candidate models have been tested by central banks on an exploratory basis (*see* Table 3). In "top-down" exercises, the Bank of Canada, for example, used the CGE EPPA (Ens & Johnston, 2020) model, while the Bank of Hungary relied on the macroeconometric model E3ME (Cambridge Econometrics, 2021) . The Banque de France, using NIGEM, uses a neo-Keynesian model incorporating nominal rigidities and a Taylor rule.

	EPPA	E3ME
Full name	Emissions Prediction and Policy Analysis	Energy-Environment-Economy Global Macro-Economic
Institution	Massachussets Institute of Technology (USA)	Cambridge Econometrics (UK)
Category	Walrasian general equilibrium model	Neo-Keynesian macroeconometric model
Monetary policy	Currency neutrality	Taylor's rule (money supply adjusts according to rates)
Investment and financing of the economy	Savings finance the economy and investment	Money creation finances investment

Table 3: Other candidate models for a climate stress test

(ii) The diversity of tools makes it more difficult to understand and ensure the coherence of trajectories

The representation of the scenarios required the use of three models, very different in nature, allowing the three successive steps to be carried out:

- The IAM models have made it possible to determine, both the common socio-economic assumptions (GDP of the different regions) and the public action assumption for each scenario, a target carbon value associated with achieving the objectives of the Paris agreements,
- The NiGEM model makes it possible to represent, from these two trajectories, macroeconomic scenarios at the national level (GDP[19], inflation, raw materials, interest rates, exchange rates);
- Finally, the static multisectoral model makes it possible to disaggregate the national macroeconomic scenarios to the sectoral level (production and value added).

Several series appear to be common to these three models, notably: GDP, carbon price and productivity gains. To maintain consistency over the course of the exercise, the Banque de France decided to align each of the macroeconomic trajectories with the other. This alignment is achieved in practice by adjusting labor productivity gains, an exogenous variable often calibrated by the user, to a reference value intended to reproduce past trends.

This method allows for consistency between the main trajectories (carbon price and GDP). However, it does not correct for structural differences between the models and may limit their full understanding.

[19] Only variant 2 does not explicitly follow the NGFS reference path.

For example, it is assumed that the IAM carbon price trajectory (which here corresponds to the main transition lever) allows for carbon neutrality at the global level. In practice, this value is subject to many uncertainties, and its evaluation depends on the methodology and the families of models used. Thus, a certain carbon trajectory may lead to neutrality in one model, but be insufficient in another. The working group on the shadow value of carbon indicated a value of between €143 and €351 for the year 2030 (France Stratégie, 2019) . Finally, the carbon value would benefit from being regionalized according to the respective mitigation efforts of countries.

The consistency of the three tools is ensured here by the fact that no economic series (other than GDP and carbon prices) or environmental series (emissions) appear more than once. For example, the NiGEM model does not represent emissions and therefore does not allow to verify the achievement of neutrality. In practice, different assumptions about productivity gains can significantly modify the properties of the trajectories: these are no longer the same as those of the MRIs[20]. The calibration of productivity gains thus appears to be an important factor that serves as an adjustment variable. In practice, it is difficult to give economic meaning to these new productivity gains: they influence the macroeconomic trajectory (prices, activity, foreign trade) but do not correspond to an economic hypothesis or a specific transition shock. If they are dynamic, they make it possible to limit economic losses by supporting a fall in production costs and gains in purchasing power; in this case, they ensure consistency with a global GDP trajectory, given by the MFIs, [21]but they also influence the overall macroeconomic and sectoral dynamics.

ADEME encourages further work to move towards a unified framework that makes the narrative chosen by the supervisor more readable and defines the assumptions applied, both on transition shocks and socio-economic assumptions (productivity gains). This would imply, for example, no longer relying specifically on the set of NGFS assumptions [22]and relying on the results of a single model without trying to reproduce a predefined path. If satellite models need to be applied to achieve a necessary scenario expansion (as for the fine-grained representation of different interest rates), the supervisor could ensure that the same assumption is not represented more than once. It is however conceivable to loop the three models mentioned above as long as NiGEM determines the dynamics.

(iii) Multisectoral and environmental modeling is a source of uncertainty

In contrast to the usual stress-testing exercises, the tools used are much more disaggregated and require a much more detailed theoretical and empirical foundation:

- From a theoretical point of view, the models come from several schools of thought and represent differently the reactions of agents to new public policies. In particular, so-called "Walrasian" models will tend to give a more pessimistic picture of an environmental policy[23], whereas so-called "Keynesian" models may give a less abrupt representation, especially in the presence of redistribution policies[24].
- Empirically, multisectoral models combine a very large number of economic equations, which considerably increases the need for historical series and the number of parameters to be set, particularly to account for interactions and intermediate consumption; some of these data are often difficult to estimate properly, while the models appear to be very sensitive to some of them[25].

In this new type of exercise, scenario analysis will have very real consequences for institutions and their solvency assessment. Since supervisory exercises are based on vulnerability analysis, the methodology and tools may be deliberately selected for their adverse nature. The choice of a model is therefore a crucial step and, while it appears difficult to date to share the same definition of transition between institutions and to avoid criticisms and potential biases in forecasting, it is important to be transparent about the properties of these tools and to assess the robustness of the assumptions, in particular in the

[20] Since IAMs are Walrasian, the introduction of a carbon tax (even if redistributed) leads to a deadweight loss. The trajectory of GDP may be underestimated, as is the tutelary value of carbon.
[21] Except for variant 2.
[22] The NGFS trajectories appear to be indicative and do not strictly apply to the specificities of the French economy.
[23] According to general equilibrium theory, the application of an environmental tax would generate an economic "deadweight loss", insofar as the new situation would no longer be optimal for the agents.
[24] The models can then correct pre-existing market distortions or imperfections.
[25] For example, the sectoral elasticities of substitution between factors of production, which condition transfers of activity.

face of the most sensitive parameters (monetary policy, calibration of production functions, initial state of the economy, etc.). We welcome the efforts made by the Banque de France in sharing methodologies and data. We also see the interest in continuing along this path by comparing the properties and results of the models used in the pilot exercise with other existing approaches for building transition scenarios.

Finally, transition risks are based on different levers of action (fiscal, technological, regulatory, behavioural shocks, etc.). Macroeconomic models are particularly well suited to represent the first two levers mentioned, and the Banque de France has chosen to rely on carbon price as the main action lever. It is indeed the most direct and optimal economic tool to reduce emissions and it has been the lever of choice in all climate monitoring exercises conducted so far. However, its use raises the question of the redistribution of the revenues generated, and the economic trajectories appear to be very dependent on the category of models used and on the redistribution chosen (in this case a tax credit for households, *see* Table 4).

Scenario	Effect on GDP (% difference)		Effect on employment (thousands of jobs difference)	
	2030	2050	2030	2050
Central scenario	0,2	0,1	35	21
100% household recycling	0,2	0,1	31	24
100% corporate recycling	0,1	0,1	24	21
Mixed recycling via social contributions	0,2	0,1	45	31
Mixed recycling on a pro rata basis of household and business revenues via corporate income tax	0,2	0,1	37	22
Revenue used for budgetary consolidation purposes	-0,1	0	-36	-14

Table 4: Macroeconomic impacts of a €100/tCO2 carbon tax by recycling (Three-ME model)

Source: Callonnec & Combaud (2019).

(iv) The multisectoral model would benefit from being integrated into the macroeconomic dynamics

The combination of the static multisectoral model developed by researchers at the Banque de France makes it possible to represent ex-post the sectoral disaggregation of impacts and the trade-offs made by agents between different goods according to their level of taxation. However, this "separate" modeling of NiGEM is limited insofar as the macroeconomic trajectory will not be affected by the spillover effects that could be exerted by the changes in aggregate demand induced by sectoral transfers. The latter is supposed to profoundly modify the economic fabric and provoke major transfers of activity (investments, employment, foreign trade) that will in turn influence the national economy. Separating the two tools may therefore lead to a bias in forecasting, and these mechanisms would benefit from being represented in a single tool through a macroeconomic loop. Finally, some properties of the (general equilibrium) model will influence the macroeconomic results here: the absence of capital in the production function (which limits the spillover effects of energy efficiency investments), an exogenous labor supply and an absence of unemployment (which limits the relocation phenomena between importers and exporters of fossil fuels), and an energy mix divided between two vectors, electricity/gas and oil/coal (which limits the substitutions between energy sources).

6. Representation of physical risk

The physical risk appears more difficult to apprehend by its nature and the Banque de France's exercise is also the first among supervisors to assess it directly. This field is still at the stage of study and academic research and the first methodologies will necessarily be exploratory and will need to be refined.

ADEME recognizes the difficulty of including this risk in economic scenarios, in particular by integrating "damage functions" whose theoretical and empirical relevance has been widely disputed in the literature. Yet the costs of climate change will certainly affect the entire economy. A review of the literature carried out by ADEME highlights numerous propagation channels for the French economy alone: agricultural, forestry and fish farming yields, labor productivity, capital losses, energy demands and yields, etc. These risks affect the productive activities of companies, and many of them do not appear to be covered by insurance to date. If they were, they would necessarily affect the insurance premiums and therefore *ultimately* the economic policyholders.

The pilot exercise took an important step in covering property damage, illness and death risks. However, the exercise does not take into account economic disruptions related to damages (whether insured or not). The impact of an increase in insurance premiums are taken into account in the exercise and could be further investigated. Thus, the industry's responses remain unsatisfactory: on the one hand, insurers considered that the entire cost of claims could be absorbed by clients, including the hypothesis of rebalancing the CATNAT plan in France, which is necessary to keep it in balance, and on the other hand, the exercise revealed the difficulty banks have in determining the precise location of their exposures.

The exercise did not cover at this stage the direct economic disruptions to productive activities (loss of worker productivity due to increased heat periods and sick leave, fluctuations in tourism income, disruptions to energy yields and demand, agricultural and fish farming yields). For future exercises, it might be relevant to include a macroeconomic, sectoral and, if possible, geographical dimension that would concern all actors, both for uncovered risks (damage costs) and covered risks (insurance costs).

The choice of representing a single scenario also makes sense, as the climate projections appear relatively close to each other in 2050. However, the climate inertia could be shorter than expected and some studies already estimate that mitigation efforts could be noticeable much sooner. On the other hand, there are many uncertainties around feedback loops and tipping points, which would limit the visibility of future risks, especially extreme risks. Finally, the latest temperature projections are more pessimistic and dismissing the climate counterpart of a disordered or incomplete transition could be counterproductive in the effort to reorient financial sector strategies. ADEME proposes on the basis of the English biennial exercise (Bank of England, 2019) to integrate the costs of damage in advance so as not to defer them to future generations.

7. Sensitivity of results to assumptions

The financial sector appears to be relatively unexposed to transition risks, compared to the risks traditionally simulated in financial stress tests: "The reason is that none of the transition scenarios considered is accompanied by a decline in GDP, contrary to the usual framework of regulatory stress tests". (Clerc, et al., 2021) . In a traditional stress test, it is assumed that all risk factors suffer a negative shock; the nature of the climate exercise is different since some sectors will benefit from the transition while others will lose out. The ACPR concludes that the financial sector would ultimately be moderately exposed to transition risk, which is also reflected in the macroeconomic scenarios periodically conducted by ADEME.

The results confirm that Variant 1 (delayed transition) is relatively unadverse, and that the risks materialize mainly in Variant 2 (accelerated transition) marked by technological lag effects and less dynamic productivity gains. This example tends to show that the transition risk could be much higher if more refined scenarios and narratives were applied and combined with additional measures or shocks to the only steady rise in carbon prices, which constitute a targeted and not very distorting transition lever.

For all that, banks seem to depend as much on economic assumptions as they do on mitigation actions, and in particular on the assumption of redistribution of revenues across different segments of credit risk[26]:

- The risk seems limited for the *retail* portfolio. More than the assumption of redistribution of carbon prices (via a tax credit to households), it is also the assumption of dynamic gains in purchasing power that compensates for the carbon tax and supports household solvency[27]. In this case, it is the distribution hypothesis that is the least favorable to the growth of activity that has been retained in a conservative logic;
- The bond portfolio also sees a significant increase in losses, driven by the deterioration in public finances that is more pronounced in the disorderly transition scenarios[28]; had the revenues been allocated to fiscal consolidation, the sovereign portfolio[29]might have been less affected (and the *retail portfolio* more), thus mitigating the financial shock.

On the insurance side, the costs of climate change on the liabilities side are mainly offset by higher rates and partly by an increase in asset valuation, in line with the assumption that accommodative monetary policies will continue throughout the projection horizon[30]. The effect of this low interest rate universe (*see* Figure 6) has multiple effects on the assets, liabilities and equity of insurance companies; this is an important assumption that conditions the results of the stress test and that would certainly deserve to be discussed in a context of transition and climate change.

The question of these two assumptions (revenue redistribution and monetary policy) appears to be crucial, both to the adversity of the scenarios and to the perception of financial risk among different segments of the institutions. Some alternative hypotheses could modify certain conclusions of the exercise (*see* Table 5and Table 6). Since these choices are not necessarily subject to *best estimates*, the climate stress tests have a practical limit here, and the pilot exercise is a reminder of the inherent limitations of projecting to such long time horizons. Future exercises could benefit from establishing sensitivity tests on these choices.

[26] The effects appear to be less obvious for the assessment of market risk.
[27] In addition, institutions should limit the assessment of losses to GDP and unemployment assumptions alone, variables that are by construction little influenced by the sectoral transition in the pilot. Other factors could affect the risks related to households, for example the risk related to training and the need for new skills, or the cost of energy work.
[28] Certainly through the increase in the probability of default by sovereigns.
[29] However, the sovereign portfolio accounts for a small proportion of credit activities in the banking book.
[30] Bonds in the insurance portfolio are valued at market value, in contrast to the banks' balance sheet, where they are valued at historical cost. This is why banks experience losses on this segment of credit risk (linked to government deficits and higher default probabilities), whereas insurers benefit from a revaluation of their sovereign securities linked to the flattening of the risk-free interest rate curve.

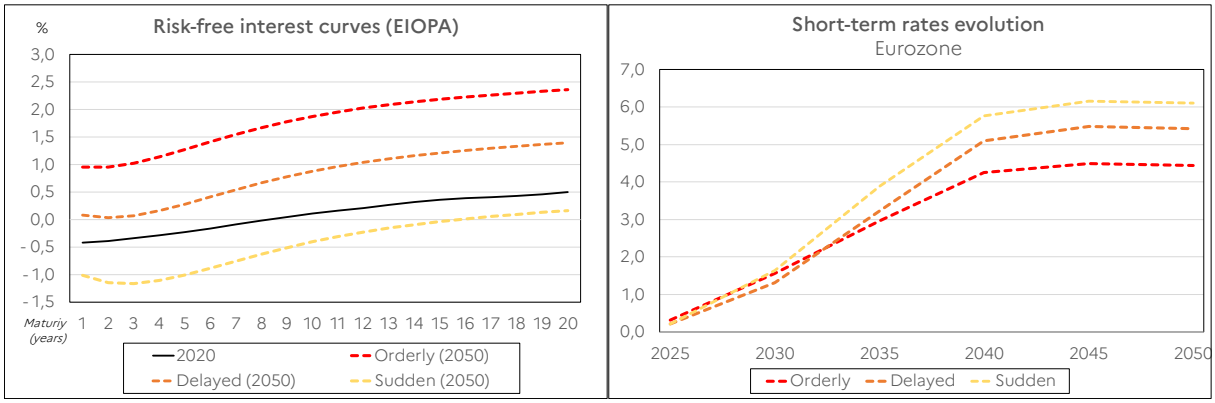

Figure 6: Evolution of interest rates in the pilot exercise

Source: ACPR scenarios.

		Pilot exercise: Ineffective recycling	Alternative hypothesis: Efficient recycling	Alternative hypothesis: Budget consolidation
Macroeconomics	GDP	The tax credit for households is not enough to offset the recessionary effect of the carbon tax. Public finances are deteriorating due to the slowdown in activity. The key interest rate is lowered to compensate for this slowdown.	Ripple effect	Higher recessive effect
	Public Finance		Less degradation	Consolidation
	Interest rates		Higher	Weaker
Financial consequences	Probability of household default		Weaker	Stronger
	Probability of sovereign default		Weaker	Much lower
	Insurance assets		Lower revaluation	Upward revaluation

Table 5: Indicative consequences of several carbon tax recycling assumptions

Note: Interest rates are kept low here because of the form of the Taylor rule used in the pilot exercise (combined inflation and nominal GDP targets).

		Pilot exercise: Expansionary monetary policy	Alternative hypothesis: Tight monetary policy
Macroeconomics	GDP	Policy rate decreases to compensate for the slowdown in activity.	Recessive effects
	Interest rates		Higher
Financial consequences	Insurance assets		Lower revaluation

Table 6: Indicative consequences of various policy assumptions

Note: the monetary policy assumption depends both on the choice of a rule for central bank behaviour and on the projected economic scenario. In the pilot exercise, the Taylor rule ensures both an inflation target and an activity target and tends to prolong a low policy rate universe, due to recessionary effects. The inflationary pressure linked to the carbon tax tends to dissipate due to the slowdown in activity.

8. Proposals for future exercises

In conclusion, ADEME suggests several avenues of development for future climate exercises.

(i) On the transition climate scenarios

- Identify more adverse socio-economic and transition assumptions that are more in line with recent macroeconomic developments and that are adapted to an assessment of the most significant risks (productivity assumptions, technological assumptions and carbon capture and sequestration assumptions).
- Include hypothetical risk scenarios, which would no longer be conditional on achieving carbon neutrality, as well as "tailing" scenarios, in order to highlight plausible but more adverse scenarios specific to a stress test (e.g., a fragmentation of transition policies in the regions of the world).
- Explore scenarios associated with different or complementary levers of action for carbon prices (steering the energy mix, regulatory, technological or behavioural shocks).
- Include physical risks in macroeconomic scenarios, where possible relating all future damages to the observed period, such as the Bank of England (2019).
- Propose the inclusion of short-term transition scenarios in the periodic European stress-testing exercises and the simulation of transition scenarios not anticipated by financial actors, implying a more abrupt revaluation of credit parameters and providing greater incentives for portfolio transition.
- For each scenario, simulate and compare the effects of adjusting the asset portfolios of institutions with perfect or imperfect anticipation. A balance sheet dynamic, defined by the supervisor, would allow a better comparison of the potential risks of the transition for financial institutions.
- Ensure that the sectoral changes generated by the transition (renovation, circular economy, development of use rather than purchase, digitalization, etc.) that are likely to lead to the exit of old players and the entry of new ones are taken into account in the modeling of rating changes in the institutions' internal models. A sectoral growth should not be uniformly applied to companies with different positioning with regard to the transition (e.g. construction vs. renovation in the case of the pilot exercise). If the method is not applicable to all portfolios, it would be appropriate as a first step to have the financial institutions work on a more precise assessment of the transition risks for the main contributors in each sector.

(ii) On modeling choices

- Favour the use of a single macroeconomic model, as in the exploratory exercise of the Bank of Canada (2020) or the Bank of Hungary (2021) or, failing that, carry out a loop between the models, ensuring that the GDP trajectory is determined in dynamic equilibrium according to a Global Supply-Global Demand approach.
- In the absence of a *hard link* between the models, the trajectory of the IAM GDP should be calibrated to that of the econometric models and not vice versa in order to avoid forecasting bias. The calibration of the IAM GDP path could be achieved by aligning the exogenous evolution of the IAM labor supply with the change in the employed population given by the macroeconometric models. This would ensure consistency between the two approaches. Productivity gains and the effective growth rate of GDP would be common to each module.
- Explicitly separate exogenous and endogenous economic assumptions; in particular, calibrate the exercise by a productivity trend rather than by a GDP trajectory, which is assumed to be the adverse consequence of transition risk.
- Explain the properties and limitations of the tools used in the exercise, particularly the multisectoral models, and propose sensitivity tests.
- Gradually extend the physical risk to actors other than insurance companies through common macroeconomic scenarios, for example by using empirically based sectoral damage functions.

Appendix 1: Sectoral recomposition in the SNBC

Source: Three-ME simulations.

Note: Capital intensity is defined here as the stock of capital relative to annual output (in volume).

Appendix 2: Origin of consumption in the SNBC

Source: Three-ME simulations.

Note: Consumption includes the final consumption of households and the intermediate consumption of companies.

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ABBREVIATIONS AND ACRONYMS

ACPR	French Prudential Supervision and Resolution Authority
ADEME	French Ecological Transition Agency
CGE	Computable general equilibrium model
CSC	Carbon capture and sequestration
EIOPA	European Insurance and Occupational Pensions Authority
ESG	Environmental, social and governance criteria
EU-ETS	EU Emissions Trading Scheme
IPCC	Intergovernmental Panel on Climate Change
IAM	Integrated assessment model
NACE	Nomenclature of economic activities in the European Community
NGFS	Network of central banks and supervisors for the greening of the financial system
NIESR	*National Institute of Economic and Social Research* (British Economic Research Institute)
NiGEM	*National Institute Global Econometric Model* NIESR macroeconometric model
CPR	Representative concentration profile
RWA	Risk-weighted assets
SNBC	French National Low Carbon Strategy
SSP	Shared socio-economic trajectories
THREE-ME	French Multisectoral Macroeconomic Model for the Evaluation of Environmental and Energy Policies

ADEME IN BRIEF

At ADEME - the French Agency for Ecological Transition - we are firmly committed to the fight against global warming and resource degradation.

On all fronts, we are mobilizing citizens, economic players and regions, giving them the means to move towards a resource-efficient, low-carbon, fairer and more harmonious society.

In all areas - energy, air, circular economy, food, waste, soil, etc., we advise, facilitate and help finance many projects, from research to sharing solutions.

At all levels, we put our expertise and foresight capacities at the service of public policy.

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ADEME analyzes the results of the climate pilot exercise conducted by the Banque de France in 2020-2021 and proposes several methodological developments for future climate risk supervision exercises.