Q1. How does the role of CSA vary based on the objectives listed above, and are there other prudential objectives where CSA could be relevant?

Q2. What are the key challenges in the application of CSA and how can they be overcome?

Climate scenario analysis is necessary and useful both for the private sector in their risk management and the supervisor for prudential purposes. Present climate scenarios (by the NGFS, IPCC, etc) are a good first step for these purposes. However, they are still in the rather early stages of their development for the purpose they are being used, and as such they have some room for improvement. The key challenge in using the CSAs lie in their outputs: they are generally underestimating the damages and financial losses that climate change can bring. For instance, one consulting agency to the private UK pension fund suggested that the damages from 3 degrees Celsius of warming might be as low as 0.5% of the world's GDP in 2050 and that 2 degrees of warming might not have negative investment outcomes (Keen, 2023). An FSB publication indicated that a 2 degree temperature increase would to global financial asset value loss of between 0.7% and 4.2%, and between 2.9% and 9.7% for 4 degree increase (FSB, 2020; Keen, 2023).

The reason for this might be that they are based on integrated assessment models (IAMs). These are complex models that integrate climate and economy modules and have as an input a damage function that relates temperature and GDP loss. Unfortunately, for many IAMs that damage function is not corresponding with the best climate science we have. More technically, these damage functions are often insufficiently non-linear in nature, resulting in very low damages for even high temperature increases (above 3 degrees C) (Keen, 2021, 2023; Pindyck, 2017; Stern, 2022; Stern et al., 2022).

The selection of the discount rate is another parameter within IAMs. The discount rate in effect establishes the value of welfare of future generations compared to our own, and thus determines the costs present generations need to pay in order to mitigate future damages. The higher the discounting, the lower the present damages, and vice versa. The discount rate is a freely set parameter by the IAM modeller, however, it also to a large extent determines the costs of mitigation. The dependence of IAMs on this rate, and in turn the modellers presuppositions and biases, has been another point of criticism (Pindyck, 2017; Stern et al., 2022; Van Den Bergh & Botzen, 2015).

In terms of transition risks, models often represent the costs of carbon in a simplistic way. They in effect subsume various types of climate mitigation under a simple carbon price. However, this ignores political difficulties with introducing a carbon price, as well as a plethora of other options for climate action, such as regulation and public investment, that are not equivalent to a carbon price mechanism (Keppo et al., 2021; Monasterolo et al., 2023).

On a more technical note, the IAMs are usually general equilibrium models. As such, they feature various simplifying assumptions: rational representative consumers, optimizing behavior, perfect foresight, return to equilibrium, etc. However, there are reasons to believe these assumptions might not always hold (Keppo et al., 2021; Stern, 2022; Stern et al., 2022). In addition, other, non-equilibrium models might be more appropriate for modelling a world with climate change where a return to former equilibria might not be possible (Hafner et al., 2020). As climate change progresses, various Earth systems might pass irreversible tipping points. This might have consequences for the economy which would not be best described with a return to equilibrium.

Aside from such fundamental methodological issues with model development, data gaps and data accessibility were named as some of the main issues in using CSAs for stress testing and other purposes (FSB-NGFS, 2022)

An example of these simplifying assumptions in IAMs is the treatment of finance. Finance in IAMs is often not explicitly modelled or is presented in a rudimentary manner only. This counters the insight that finance can have both stimulating and hampering effect on the transition (Battiston, Monasterolo, et al., 2021; Keppo et al., 2021; Monasterolo et al., 2023). The omission of the financial system in IAMs is also unfortunate, given the relevance of the outputs of these models and the scenarios for the broader financial sector and the supervisory purposes (Sanders et al., 2022).

Q3. What are the key areas where CSA methodologies and capabilities need to be further developed to be useful and relevant for the different objectives listed in this paper?

We have never encountered climate change before, so having complete data and providing accurate predictions based on historical data is impossible. However, IAMs could be made more realistic by keeping closer track to the available science of climate change.

For instance, the choice of the curve for the damage function can be improved. Instead of using linear functions, quadratic and log functions, that show higher damages for the equivalent temperature rise, might be more accurate (Keen, 2021; Trust et al., 2023). These functions would show damages more aligned with the expectations of climate scientists.

Moreover, tipping points (social and natural) could be accounted for in a more accurate way. Natural tipping points entail irreversible changes in the environment that come about as a result of increased GHG emissions in the atmosphere. Moreover, it is not clear when these tipping points might come about or if the threshold for the emergence for some of them has been crossed. These tipping points include, for example, loss of the ice sheet, leading to see level rise, and slowdown and loss of the Atlantic circulation, leading to large scale weather pattern changes in Western Europe specifically (Lenton et al., 2019).

Social tipping points describe situations where the effects of climate change lead to cascading social changes with potentially devastating consequences. An example of this effect might be the Arab Spring, where crop failures and ensuing high food prices led to large scale social unrest, spreading to several countries (Juhola et al., 2022; Kelley et al., 2015).

Additionally, alternative kinds non-equilibrium models could be used as a basis for CSA (Hafner et al., 2020; Keppo et al., 2021; Mercure et al., 2016, 2019). These models often do not assume a return to the equilibrium state, assume agent satisficing instead of optimizing, rely on bounded instead of perfect rationality, consider money as endogenous and not fixed, and often explicitly model the financial system.

Alternatively, various kinds of models could be used for various purposes in the financial sector. For example, catastrophe modelling could be used for more acute physical risks as these are often not completely represented in IAMs (Botzen et al., 2019).

Q4. Are the key features listed above appropriately calibrated for a range of CSA exercises, and should other features be considered?

These features are only satisfied in the current scenarios up to a point.

Transparency

While the development of the NGFS scenarios, for example, has been mostly public and is open sourced, the underlying models these scenarios use are opaquer. IAMs are by their nature very complex, consisting of various elements, that are often not well documented or of which it is not clear why certain parametrisation choices are made. This makes the output of the models hard to interpret and leave a lot of leeway to the modellers for free input. End users thus have trouble interpreting these results and putting them to use (Keppo et al., 2021; Pindyck, 2017).

Completeness

In addition, many (physical) risks are missing from the NGFS scenarios, including only heatwaves, droughts, river floods and tropical cyclones (Monasterolo et al., 2023; NGFS, 2023). Also, the full climate effects of GHG emissions are lacking, leading to underestimates in total GDP damages. This reduces the usefulness for the intended use of these models in various parts of the world. In the financial sector this might manifest as a blind spot for various kinds of localized physical risks, thus underplaying the material asset value loss.

Plausibility

Another blind spot in the design of IAMs is the overreliance on past data in constructing future forecasts. This leads not only to ignoring tipping points, but also miscalculating tail risks (Trust et al., 2024). As the probabilities of large-scale damages are increasing in the world of climate change, previous tail-risk events become more likely. However, this fact will be missed looking only at past data. IAMs by their nature also ignore (deep, Knightian) uncertainty, as differentiated by extreme risk. This refers to events to which a risk probability cannot be assigned, i.e. the ones about whose likelihood we simply do not know (Pindyck, 2017; Stern, 2022; Stern et al., 2022; Van Den Bergh & Botzen, 2015)

Comprehensiveness

As discussed, IAMs are often designed and parametrised by economists. This often leads to unexpected and overly optimistic results. A wider inclusion of geoscientists and other natural scientists in the discussion has led to more appropriate outputs of IAMs. Therefore, broadening the scientific base beyond the economic profession to include various other disciplines could bring more realism to climate scenarios (Keen, 2021, 2023). Aside from scientists, this also includes social scientists who could shed light on the topics of migration, social tipping points, geopolitics, etc. This would bring about a more comprehensive picture of plausible risks beyond solely the GDP impact.

Q5. How does the design of CSA exercises vary depending on the objectives? Please elaborate on the main usage-specific considerations for each of the different objectives.

Severity of scenarios

It is commendable that NGFS is developing a suite of short term-scenarios. Their intended purpose is more accurately described as having more current (annual) data, so that climate scenarios are more relevant for supervisors and the users of these scenarios. In addition, tail risks are relevant for all stress test exercises, but especially for climate stress tests, due to the non-linear effects of climate change, such as tipping points and endogeneity (Battiston, Dafermos, et al., 2021)

Baseline selection

Baseline selection is key in performing CSAs. The issue with most current baselines is that they are frequently based on past data and ignore the fact that some countries have already established climate policies (Battiston & Monasterolo, 2024).

Granularity

Granularity is indeed key in designing CSAs. Data aggregation or using or using firm-level data is shown to lead to large underestimation of financial losses compared to using asset-level data, sometimes even up to 70% (Battiston et al., 2017; Bressan et al., 2024).

Q6. What additional usage-specific considerations are relevant for each of the different objectives of CSA listed in this paper and why?

Q7. Which scenario and scenario features are used for the different objectives listed (ie internally developed, those from scenario builders or a combination of the two)?

Q8. What features and measures could be adopted in the future to enhance the utility of currently available scenarios (eg NGFS, IEA, IPCC)?

Transparency and better comparison between scenarios should be improved. As discussed, these scenarios are based on models that can be very opaque in their design, rendering them of little use for end-users at best and misinforming them at worst. These scenarios also often yield similar outcomes, but without deeper insight into their methodology it is hard to discern why that is (Monasterolo et al., 2023).

A better pipeline between the modelers/designers and end users should be established. End users and their advisors often use these scenarios without understanding how to interpret their output, leading to errors in understanding and use. Better explanation of uncertainties, fitness for purpose, appropriateness and potential downsides of these scenarios should be made available to end users (Keppo et al., 2021).

Current scenarios would also benefit from more diverse choices of and updates to SSPs and RCPs. NGFS scenarios are based on a very narrow band of assumptions to social and economic change, leaving out more extreme scenarios (Monasterolo et al., 2023). This is another reason NGFS scenarios produce overly optimistic results.

Q9. What alternative or novel approaches could supervisors consider for CSA and how might these be used for prudential purposes?

Supervisors could use alternatives to the standard equilibrium-based models. As discussed, these alternatives rely on more realistic assumptions and explicitly include money and finance as key elements. This realism is crucial for the proper use of the scenarios based upon these models in the financial sector and their supervisors.

As climate change could change economies and societies in unprecedented ways, putting specific numbers on potential losses might be unrealistic or even impossible (Chenet et al., 2021; Kedward et al., 2020). More narrative scenario analysis could help here (Trust et al., 2024). While not being able to precisely quantify risks often necessary for everyday use in the financial sector, it can open horizons to potential risks that are not captured within current models.

Relatedly, experts from multiple scientific disciplines could be involved in these exercises. As climate change will have multidimensional impacts on societies, having a multidisciplinary approach to assessing risks is key.

However, perfecting any model to account for all sources of risk could take time and will in any case never be complete. Supervisors have it within their mandate to maintain the stability of the financial system. As the damages of climate change rapidly intensify, they might not have the luxury of waiting for a perfectly accurate model with complete climate data. They might be compelled to act in a precautionary way, staving off the worst climate change effects (Chenet et al., 2021; Grünewald, 2024; Kedward et al., 2020).

Q10. How could the effectiveness and efficiency of supervisory exercises be improved?

Supervisory exercises should be complete. The recent ECB's stress test (Alogoskoufis et al., 2021) covered only bank loans which does not capture the totality of the financial system. In addition, stress tests should be dynamic and also take second-order effects into account instead of doing static balance sheet analysis. They should use up-to-date and realistic scenarios that cover all the relevant impacts to be as inclusive as possible of possible risk channels and economic, social, and climate development. The results of these exercises should be clearly and carefully explained to all stakeholders, especially including limitations. Central banks often have access to a wealth of data, making these exercises comprehensive. However, due to their complexity many stakeholders might not understand the nature of these exercises and especially their limitations.
Moreover, supervisory scenarios should involve investors' expectations and risk perceptions regarding the pricing of high- and low-carbon assets. Low investor expectations in a credible transition path (through, e.g. carbon tax or EU Taxonomy implementation) might postpone credit reallocation from high- to low-carbon investments. This could be addressed by expanding the presently used IAMs with climate financial risk modules (Battiston & Monasterolo, 2024)

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