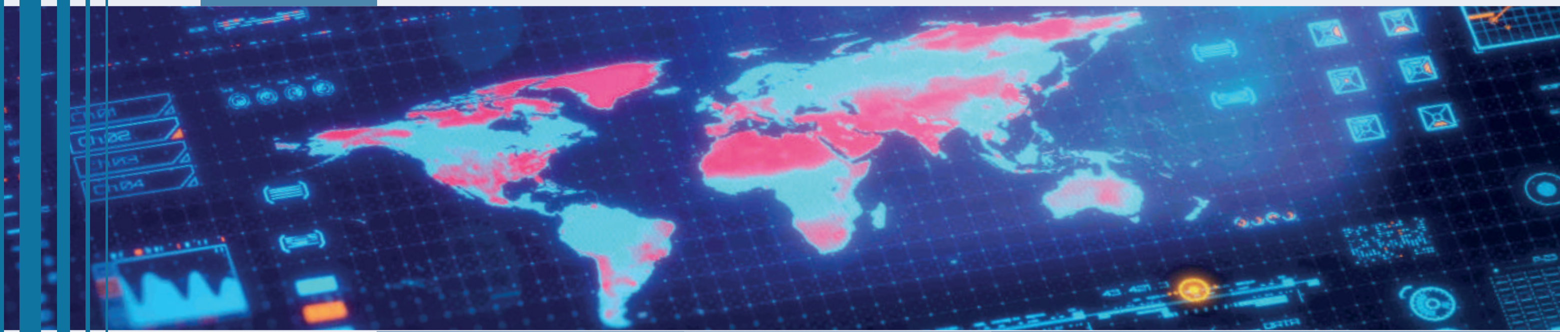

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EXCITE: The Physics and Modelling Background

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Abstract

EXCITE (EDHEC Cross-Model Climate Institute Temperature Emulator) is a webhosted tool developed by the EDHEC Climate Institute. It provides a user-friendly platform for scientists, experts, professionals, and ordinary users to explore and visualise how the Earth surface temperature responds to various emissions scenarios. This document outlines the scientific background underpinning EXCITE, including the foundational climate model functions and the generation of emissions scenarios. By leveraging the most recent CMIP6-calibrated model parameters, EXCITE enables users to easily visualise the latest progress in climate science. We show how EXCITE can provide useful information for policy-makers, investors, regulators, and the broader public.

1 Purpose of This Document

The purpose of this document is to provide the physics and modelling background behind the EXCITE (EDHEC Cross-Model Climate Institute Temperature Emulator) software. EXCITE is a web-hosted tool developed by the EDHEC Climate Institute designed to allow users to explore and visualise how global warming responds to various emission scenarios. A companion document (*EXCITE: The How-To Guide*) explains how to use the investigation tool, ie, how to provide the inputs to the model and how to interpret the outputs. The EXCITE tool is designed to provide information on the temperature profiles at various horizons (to the end of the century) associated with a user-defined carbon emission schedule. This information can inform the decision-making process of policy-makers, regulators and investors, and should also be of interest to broader public. In this document we explain the scientific basis of the models (Climate Emulators) used to obtain the output presented in EXCITE.

2 Introduction

A Climate Emulator is a simplified climate model that allows researchers and non-experts to quickly explore the potential global surface temperature response to various anthropogenic emissions scenarios (Folini et al., 2025). Although it relies on reduced-complexity methods, it can be calibrated to reproduce key climate variables generated by much more sophisticated climate models such as Earth System Models (ESMs) and General Circulation Models (GCMs). Because of its simple form and low computational demands, Climate Emulators are widely used as a crucial module in Integrated Assessment Models (IAM) to study the interplay of climate science with economic and social systems. A major application of Climate Emulator is the analysis of the feedback loop between economic growth and temperature anomalies in Integrated Assessment Models such as DICE (Nordhaus, 2017), PAGE (Hope, 2011), FUND (Waldhoff et al., 2014) and as described in Golosov et al. (2014) and Lemoine and Rudik (2017). Climate emulators are also used to explore potential energy deployment pathways that align with predefined temperature goals such as FaIR (Leach et al., 2021) and MAGICC (Meinshausen et al., 2011a,b) within the scenario analyses conducted by IPCC.

A Climate Emulator consists of two core modules. The first is a carbon cycle module, which translates anthropogenic emissions to atmospheric carbon concentrations. Increasing carbon concentrations lead to an imbalance of incoming and outgoing radiative energy (forcing). The second module, temperature equations, translates this imbalance in radiative forcing into a temperature increase. Different Climate Emulators vary in the formulation of their carbon cycles and temperature equations. For instance, the carbon cycle in DICE (Nordhaus, 2017) only models the carbon concentration change due to CO_2 emissions. In contrast, the carbon cycle in FaIR (Leach et al., 2021) and Joos et al. (2013) accounts for carbon concentration change that arises not only from CO_2 but also from other agents such as methane and nitrous oxide, etc. Temperature equations usually model heat exchange between either two reservoirs (Nordhaus, 2017; Geoffroy et al., 2013b,a; Tsutsui and Smith, 2024) or three reservoirs (Leach et al., 2021). There is no single "best" configuration of Climate Emulators. Rather, proper model calibrations are key to ensuring an emulator benchmarks well against state-of-the-art sophisticated climate models (Dietz et al., 2021; Folini et al., 2025). In Section 3, we introduce the carbon cycle and temperature equations used in EXCITE and its parameter calibrations.

The core function of EXCITE is to allow users to explore and visualise how global warming responds to various emissions scenarios. The input of EXCITE is a trajectory of projected carbon emissions from the present until the end of this century. Since the projected emissions pattern closely depends on the assumptions of economic growth, technology development, and mitigation policies, each trajectory of emissions represents a distinct future scenario. A detailed discussion of the inputs is provided in the companion document *EXCITE: The How-To Guide*. However, in order to make this document self-contained, and to facilitate the presentation of the physics background, we briefly explain how the emissions are specified. EXCITE offers three options of emissions scenarios for users. The first option takes as input the projections produced by the SSP-RCP scenarios (O'Neill et al., 2017) and by the NGFS scenarios (NGFS, 2024). These scenarios are developed by identifying the optimal energy deployment pathways that meet the predefined temperature goals, given assumptions on economic growth, technology progress and mitigation policies. The second option allows users to customise their own emissions trajectory. Users can design a path of carbon emissions by inputting a few individualised parameters such as the peak level of emissions and the emissions at 2100, etc. Then, a tailored emissions trajectory will be generated via smooth interpolation. The third option relies on the EDHEC scenario simulator, a variant of DICE (Nordhaus, 2017), by the EDHEC Climate Institute (Rebonato et al., 2023, 2025b). In particular, a one-to-one relationship between the social cost of carbon and the abatement policy is established in Rebonato et al. (2025b). Given economic growth and other policy parameters, an emission path is uniquely determined by the chosen abatement policy. In EXCITE, once the user specifies the social cost of carbon, a trajectory of carbon emissions is automatically simulated via the EDHEC scenario simulator (Rebonato et al., 2023). All three options of emissions scenarios enable users to explore and visualise the significant uncertainty inherent in climate change analysis. Detailed explanations of these scenarios are provided in Section 4.

The rest of the paper is organised as follows. Section 3 describes the carbon cycle and the temperature equations that underpin EXCITE. We also discuss the parameter calibrations accounting for the "Hot Model" issue (Hausfather et al., 2022; IPCC, 2023). Section 4 details the three options of emissions scenarios: the benchmark scenarios–based on SSP-RCP scenarios (O'Neill et al., 2017) and NGFS scenarios (NGFS, 2024), and the customised scenarios generated by the EDHEC scenario simulator (Rebonato et al., 2023, 2025b). Section 5 discusses the potential future evolution of EXCITE.

3 From Carbon Emissions to Global Surface Temperature

In this section, we describe the core modules of EXCITE: the carbon cycle and the temperature equations. We then detail the parameter choices of EXCITE, with particular attention to the "Hot Model" issue (Hausfather et al., 2022; IPCC, 2023).

3.1 The carbon cycle

The carbon cycle in EXCITE is a three-box model that simulates the diffusion of carbon mass between the atmosphere (AT), upper ocean (UO) and lower ocean (LO). Let $\mathbf{M}_t = (M_t^{AT}, M_t^{UO}, M_t^{LO})^\top$ be the carbon mass (GtC) in the atmosphere, upper ocean and lower ocean at time *t*. The dynamic of the carbon cycle is given by

$$\mathbf{M}_{t+1} = (\mathbf{I} + \mathbf{B}) \cdot \mathbf{M}_t + \mathbf{E}_t, \tag{1}$$

where **I** is an identity matrix, **B** is the matrix of diffusion parameters between layers, and $\mathbf{E}_t = (e_t, 0, 0)^\top$ is a carbon emission vector with e_t representing the yearly injected carbon emissions into the atmosphere. For example, the annual global carbon emissions at 2020 are around 10 GtC.

The diffusion matrix is given as follows:

$$\mathbf{B} = \begin{pmatrix} b_{11} & b_{21} & b_{31} \\ b_{12} & b_{22} & b_{32} \\ b_{13} & b_{23} & b_{33} \end{pmatrix}, \tag{2}$$

with the entries representing the speed of carbon diffusion between reservoirs. Let $\mathbf{M}_{EQ} = (M_{EQ}^{AT}, M_{EQ}^{UO}, M_{EQ}^{LO})^\top$ be the carbon mass at equilibrium.

In addition, let $r_1 = \frac{M_{EQ}^{AT}}{M_{EQ}^{UO}}$ and $r_2 = \frac{M_{EQ}^{UO}}{M_{EQ}^{LO}}$. The entries in **B** enjoy the following properties.

1. The entry b_{ij}, i ≠ j denotes the fraction of carbon mass from layer *i* to layer *j* in one year; For example, $b_{12} = 0.054$ denotes that 5.4% of carbon mass from the atmosphere will enter the upper ocean in one year;

2. The entry b_{ii} denotes the total carbon mass diffused from layer *i* to other layers in one year; For instance, $b_{22} = -0.0752$ denotes that 7.52% of carbon mass from the upper ocean will enter the atmosphere and the lower ocean in one year; a positive (negative) b_{ii} means that there is a net positive (negative) flux of carbon mass into (out of) the *i*th layer.

3. There is only carbon diffusion between two adjacent layers; therefore $b_{13} = b_{31} = 0$;

4. Because of the mass conservation, we have that $\Sigma_j\, b_{ji} = 0$, for $j = 1, 2, 3$.

5. The ratio of the diffusion speed is reciprocal to the ratio of the equilibrium mass, i.e, $b_{12}/b_{21} = 1/r_1$; $b_{23}/b_{32} = 1/r_2$.

The above conditions further give that : $b_{11} = -b_{12}$, $b_{22} = -b_{21} - b_{23}$ and $b_{33} = -b_{32}$.[1] Because of these constraints, there are only five free parameters to be calibrated for the carbon cycle, which are the diffusion speed from the atmosphere to upper ocean, b_{12}; the diffusion speed from upper ocean to lower ocean, b_{23}; and the equilibrium carbon mass $\mathbf{M}_{EQ}$. The choice of these parameters for EXCITE is given in Table 1.

Table 1: The parameter calibrations follow Folini et al. (2025). The unit of b_{12} and b_{23} is the fraction of mass per year and the unit of $\mathbf{M}_{EQ}$ is GtC.

b_{12}	b_{23}	M_{EQ}^{AT}	M_{EQ}^{UO}	M_{EQ}^{LO}
0.054	0.0082	607	489	1281

We adopt the parameter calibrations for the carbon cycle from Folini et al. (2025). In Folini et al. (2025), the same carbon cycle is calibrated to match the performance of the multi-model-mean (MMM) of all CMIP5 climate models in Joos et al. (2013). In addition to the MMM-calibration, Folini et al. (2025) also provides two alternative calibrations that represent extreme cases: a super fast and a super slow carbon diffusion scenarios. However, as argued by the AR6 (IPCC, 2023), the uncertainty in the carbon cycle feedbacks is unlikely to have a significant impact on the projections of global warming in this century. For simplicity, we only provide one calibration for the carbon cycle of EXCITE. Nevertheless, the uncertainty in the carbon cycle can be an interesting dimension to improve EXCITE in the future.

To initialise the carbon cycle simulation, we also need the initial values of the carbon mass. In EXCITE, the starting point is set at 2020 and the initial carbon mass vector is given by

$$(M_{2020}^{AT}, M_{2020}^{UO}, M_{2020}^{LO}) = (880, 628, 1323).$$

Note that the atmospheric carbon mass in 2020 is about 880 GtC or equivalently 414 ppm in carbon concentration, significantly higher than the preindustrial level of 280 ppm in 1850.

1 - Note that the time step of the carbon cycle is deliberately fixed at one year. Although, in theory, it is possible to scale the carbon cycle with a larger time step as in Folini et al. (2025), our numerical experiments suggest larger time steps lead to worse performance. Therefore, users are not allowed to freely choose the simulation time step.

The equilibrium atmospheric carbon mass is estimated to be around 607 GtC. The difference between today and the equilibrium value will lead to an imbalance in radiative forcing, which is modelled as follows:

$$F_t = F_{2xCO_2}\frac{\ln(M_t^{AT}/M_{EQ}^{AT})}{\ln(2)} + F_t^{EX}, \tag{3}$$

where F_t is the radiative forcing at time t, F_t^{EX} represents the forcing from agents other than CO_2, and F_{2xCO_2} is the equilibrium forcing once the temperature has reached equilibrium after an instantaneous doubling of the CO_2 concentration. An imbalance of radiative forcing will induce heat exchange between reservoirs, leading to a temperature increase. This process is modelled via the temperature equations, which are discussed in the next section.

3.2 The temperature equations

The temperature equations in EXCITE is a two-layer energy balance model. Because of its simple form, the two-layer model is a popular choice in Climate Emulators such as in DICE (Nordhaus, 2017). Tsutsui and Smith (2024) advocates that the two-layer model captures well the behaviours of most IPCC-selected climate models. The two-layer energy balance model simulates the heat exchange between the upper layer: the atmosphere and the upper ocean, and the lower layer: the deep ocean. Let T_t^{UP} and T_t^{LO} denote the temperature in the upper layer and lower layer at time t, respectively. The theoretical temperature dynamics (cf. Geoffroy et al. (2013b)) are given by

$$\begin{aligned} C^{UP}\frac{\mathrm{d}T^{UP}}{\mathrm{d}t} &= F_t - \lambda T_t^{UP} - \gamma(T_t^{UP} - T_t^{LO}),\\ C^{LO}\frac{\mathrm{d}T^{LO}}{\mathrm{d}t} &= \gamma(T_t^{UP} - T_t^{LO}), \end{aligned} \tag{4}$$

where C^{UP} and C^{LO} denote the heat capacities in the upper and lower layers, respectively. Heat capacity indicates the amount of energy required to increase the temperature of a system by 1 Kelvin. In addition, λ is the ratio of the equilibrium forcing and equilibrium temperature and $F_t - \lambda T_t^{UP}$ represents the net imbalanced forcing. The last term $\gamma(T_t^{UP} - T_t^{LO})$ denotes the heat exchange between the two layers because of the temperature difference.

Consequently, the discrete temperature equations with one-year time step are given by:

$$\begin{aligned} T_{t+1}^{UP} &= T_t^{UP} + 1/C^{UP}(F_t - \lambda T_t^{UP} - \gamma(T_t^{UP} - T_t^{LO})),\\ T_{t+1}^{LO} &= T_t^{LO} + 1/C^{LO}\cdot\gamma(T_t^{UP} - T_t^{LO}). \end{aligned} \tag{5}$$

There are four parameters to be calibrated for the temperature equations Eq. (5): the heat capacities C^{UP} and C^{LO}, the ratio of forcing to the temperature at equilibrium, λ, and the heat exchange coefficient γ. We adopt two sets of parameter calibrations for EXCITE. One set is from Geoffroy et al. (2013a,b), which calibrates the two-layer temperature equations to benchmark against 15 climate models from CMIP5. The other set is from Tsutsui and Smith (2024), which calibrates the same equations to benchmark against 43 climate models from CMIP6. Unlike CMIP5, the climate models in CMIP6 exhibit a "Hot Model" problem (detailed soon in the next section). Hence, we further divide the 43 groups of the CMIP6-calibrated parameters into three groups: a hot model group (18 calibrations), a cold model group (9 calibrations), and a likely group (16 calibrations). In the next section, we explain what is the "Hot Model" problem and our strategy for choosing parameter calibrations for the temperature equations.

3.3 The "Hot-Model" issue and our filter criterion

A group of the newest generation of climate models in CMIP6 projects a substantially higher level of global warming response to a given trajectory of carbon emissions, which are considered "too hot" (Hausfather et al., 2022). In particular, their equilibrium climate sensitivity (ECS)– the equilibrium temperature response to a doubling of CO2 concentration is much higher than other models. The highest ECS of the climate models in CMIP5 is 4.7°C. Among the climate models in CMIP6, 25% have an ECS above 4.7°C, and more than 20% have an ECS above 5°C. Those climate models with a very high ECS (> 5°C) are shown to have a poor performance in replicating the historical temperature data. For details on the "Hot Model" issue, we recommend reading Hausfather et al. (2022); IPCC (2023) and the references therein.

To enhance the credibility of our temperature equations, it is important to filter the parameter calibrations that account for the "Hot Model" issue. For this, we follow the practice suggested by Hausfather et al. (2022) and the AR6 (IPCC, 2023), that is to recognise a hot model by its ECS. We list the ECS criterion in Table 2. The ECS of all 43 calibrations for our temperature equations is illustrated in Figure 1.

Table 2: The ECS range criterion

	Cold	Likely	Hot
ECS range	< 2.5°C	[2.5°C,4°C]	> 4°C
# of calibrations	9	16	18

Users who wish to exclude the "Hot Model" influence can focus on the likely group. For completeness, we retain all three groups of calibrations in EXCITE. Note that the other criterion to identify a hot model could be comparing its transient climate response (TCR)– the temperature response to a linearly increasing carbon concentration. The likely group of models include models with a TCR falling between 1.44-2.2°C.[2]

Figure 1: The ECS of the 43 calibrations for our temperature equations. The hot model group is in red, the cold model group is in blue and the likely group is in green.

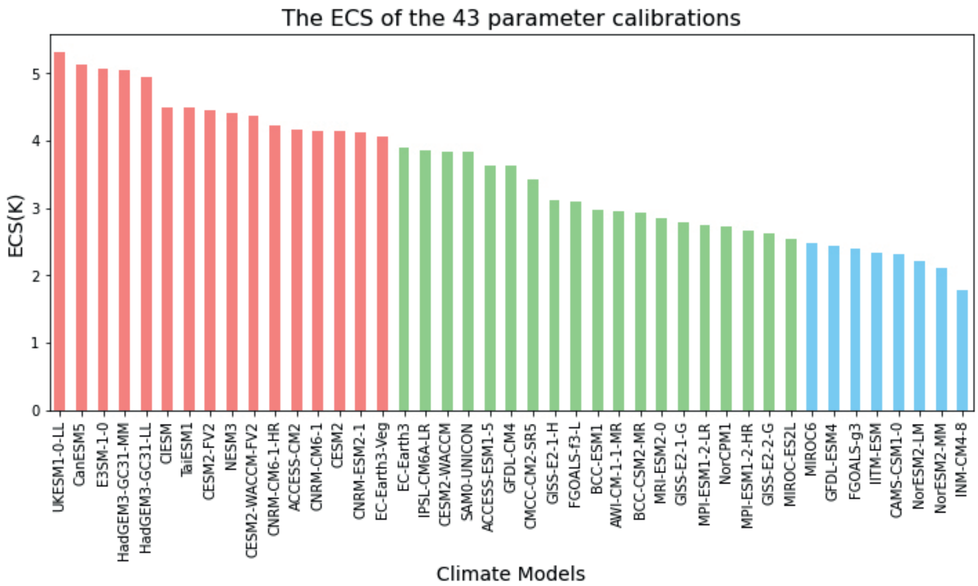


Figure 2 displays the temperature projections generated by EXCITE given a specific trajectory of carbon emissions. For illustration, we use two emissions scenarios—SSP2-45 and SSP5-85 (detailed in the next section). The projections obtained from the hot model calibration group are consistently higher than those from the other

2 - In EXCITE, the default climate model groups follow the ECS criterion suggested by Hausfather et al. (2022); IPCC (2023). However, advanced users who have expert knowledge about climate science can also customise their own "Cold", "Hot" and "Core" model groups by designing the ECS and TCR range.

groups. Moreover, the notable difference between the multi-model mean (MMM) of all calibrations and the MMM of the likely group alone further underscores the influence of the "Hot Model" effect.

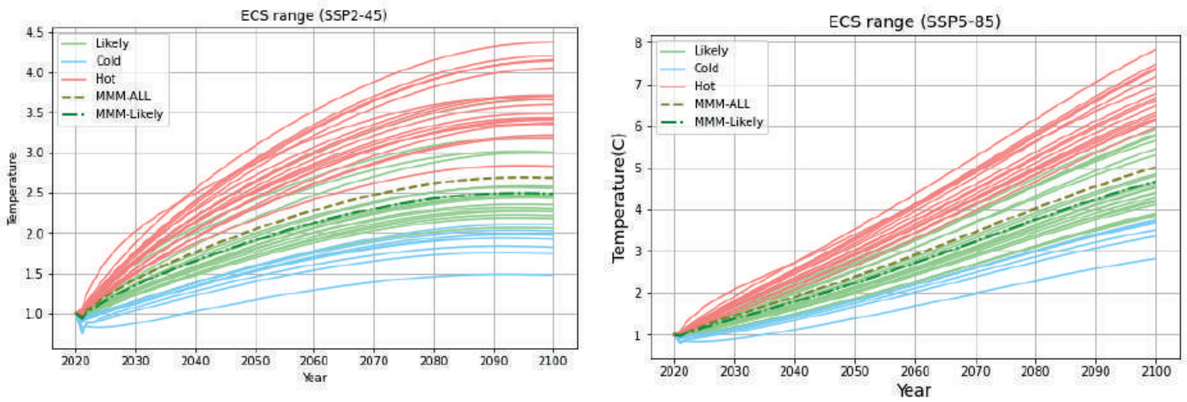
Given a trajectory of carbon emissions, the spread of end-century temperature projections is considerable. For example, under SSP2-45, the projected temperature increase ranges from 1.5°C to 4.5°C. Even when focusing solely on the likely group, the range remains between 2°C and 3°C, which is still broad. This demonstrates the substantial uncertainty inherent in climate models. Consequently, it is vital to regularly update the parameter calibrations to ensure that EXCITE remains benchmarked against state-of-the-art climate science.

In addition to the uncertainty in climate models, another major uncertainty in climate scenario analysis lies in the projections of carbon emissions. Figure 2 illustrates this point: the multi-model mean (MMM) temperature from the likely calibration group is around 2.5°C in SSP2-45 at 2100, whereas it increases to approximately 4.8°C in SSP5-85. The key differences between SSP2-45 and SSP5-85 arise from variations inassumptions about economic growth, technological development, and mitigation policies. Thus, understanding the uncertainty in carbon emissions is as important as understanding the uncertainty in climate science. Further explanations of the emissions scenarios are provided in the next section.

4 The input to EXCITE: emissions scenarios

As a first step in EXCITE, users select an emissions scenario—a trajectory of carbon emissions. This trajectory is processed by the climate emulator (detailed in Section 3), which then generates temperature projection trajectories. In this section, we introduce the emissions scenarios input options embedded in EXCITE. We begin by presenting the two sets of standard scenarios based on publicly available datasets, and then describe the customised scenarios that represent a unique feature of EXCITE.

Figure 2: The temperature projections given a trajectory of carbon emissions. The left plot uses the carbon emissions in SSP2-45 and the right plot uses the carbon emissions in SSP5-85. In addition, MMM-ALL denotes the multi-model-mean of all 43 calibrations and MMM-Likely denotes the MMM of the likely group calibrations.



4.1 The SSP-RCP scenarios

The Shared Socioeconomic Pathways (SSPs) are a set of narratives outlining potential developments in human society (O'Neill et al., 2017). The five SSPs differ along several dimensions, including economic and population growth, lifestyle and well-being, technological progress, and the availability of natural resources etc. The Representative Concentration Pathways (RCPs) provide alternative trajectories of atmospheric greenhouse gas concentrations, which directly influence global warming. Together, the SSPs and RCPs form the foundation for the scenario analyses conducted by the IPCC in the context of climate change.

Although the SSPs and RCPs are developed independently, the practice in current scenario analyses is to map various SSPs to different RCPs to form integrated scenarios. These scenarios are constructed through complex optimisation processes that identify optimal energy deployment pathways. As a result, each scenario produces a rich, multi-dimensional dataset—including information on energy, emissions, agriculture, and more.[3] For our purposes, we extract the resulting carbon emissions from these datasets.

Figure 3 illustrates one potential use of EXCITE. In this example, we select five emissions scenarios that share the same SSP (SSP2) but map to different RCPs. The resulting carbon emissions patterns vary significantly, which in turn leads to a wide spread in the temperature projections obtained using the MMM-likely calibration (see Section 3). EXCITE offers twenty-six SSP-RCP scenarios, allowing users to explore a wide range of socioeconomic pathways and their corresponding climate change trajectories.[4]

Figure 3: This figure plots one output by EXCITE. The left figure selects five emissions scenarios and the right figure plots the resulting temperature projections by the MMM-Likely.

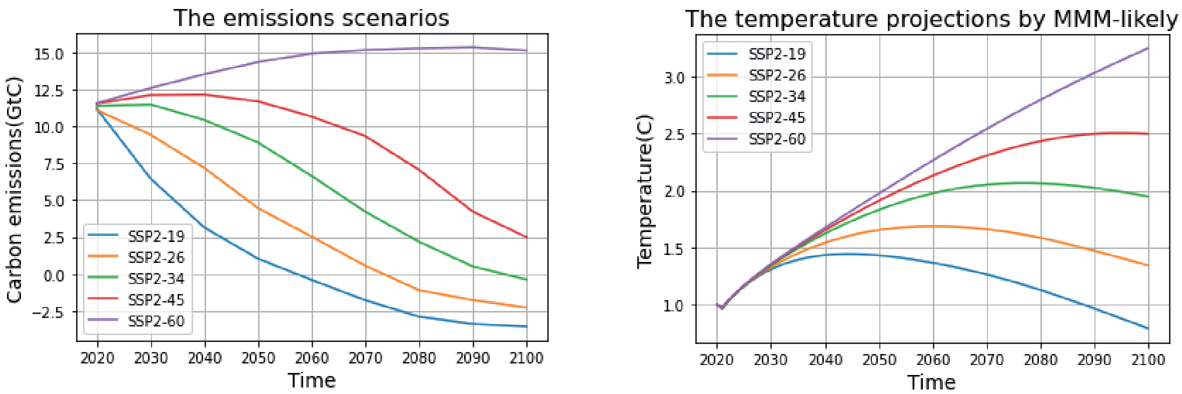
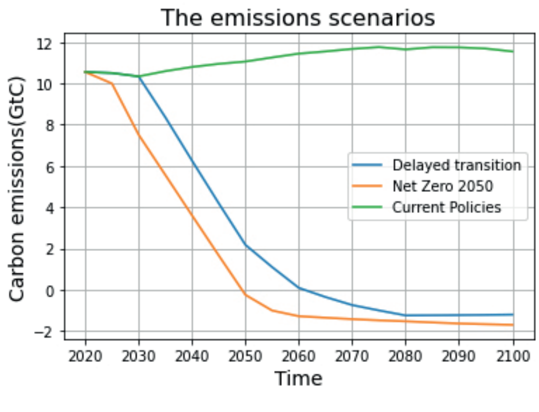


Figure 4: Carbon emissions under three selected NGFS scenarios. The carbon emissions under Delayed Transition start to fall from 2030 onwards. Before that, the emissions just follow Current Policies. In contrast, the emissions under Net Zero 2050 start to fall immediately.



4.2 The NGFS scenarios

The Network for Greening the Financial System (NGFS) has developed a set of scenarios that follow a similar philosophy to the SSP-RCP framework. One key difference is that all NGFS scenarios are based on the same SSP (specifically, SSP2) while incorporating more detailed variations in mitigation policy assumptions. For instance, the "Delayed Transition" scenario models a situation where mitigation efforts are postponed until 2 030, in contrast to a more aggressive scenario, such as "Net Zero 2050," in which comprehensive policies are implemented immediately. Figure 4 illustrates this difference.

3 -The original data set is available: SSP Database. For more detailed descriptions of the SSP-RCP scenarios, we recommend Van Vuuren et al. (2017); Fricko et al. (2017); Fujimori et al. (2017); Calvin et al. (2017); Kriegler et al. (2017).

4 - The original database offers more than a hundred variants of SSP-RCP scenarios developed by different IAMs. The selected SSP-RCP scenarios in the AR6 (IPCC, 2023) focus on the scenario produced by its marker IAM for SSP. Following this practice, EXCITE embeds all the variants of the SSP scenarios generated by their marker IAMs. Further information on the marker IAMs is provided in the appendix.

We note that seven NGFS scenarios ("Net Zero 2050", "Delayed Transition", "Current Policies", "Low Demand", "Fragmented World", "Below 2°C", and "Nationally Determined Contributions") have been developed using three different IAMs—GCAM, MESSAGEix-GLOBIOM, and REMIND-MAgPIE. In other words, each NGFS scenario is available in three variants, depending on the underlying IAM. These IAMs differ in aspects such as assumptions about renewable energy availability, technological progress, and optimisation methods. For further details, please refer to NGFS (2024) and the references therein.

4.3 Customised scenarios

The more innovative feature of the emissions scenarios in EXCITE is its customised scenarios. The customised scenarios allow users to design their own carbon emissions pathway.

4.3.1 Customised scenarios by designing a trajectory of carbon emissions

The first way to customise a scenario is to directly design the trajectory of carbon emissions. The initial carbon emissions at 2020 are set at 10 GtC. Users can then design a path of carbon emissions by specifying a few parameters: the levels for the peak emissions and emissions at 2100, as a percentage of 2020 emissions; at which year the emissions will attain its peak level, and when the emissions will become flat. Based on these information, the embedded function will generate the carbon emissions path via smooth interpolation.

Directly designing the path of emissions provides users with a naive but straightforward way to explore the impact of various emissions trajectories on temperature projections.

4.3.2 Customised scenarios by specifying a social cost of carbon

This section introduces the customised scenarios constructed by the EDHEC scenario simulator developed by the EDHEC Climate Institute (Rebonato et al., 2023). The simulator is a variant of DICE (Nordhaus, 2017)–one of the most widely used IAMs in the research community of climate analysis.

Dynamic Integrated Climate-Economy model (DICE) is an IAM developed by the 2018 Nobel Laureate, W. Nordhaus. As an integrated model, it has three modules. The first one is an economic module that generates economic production and associated anthropogenic CO_2 emissions. The second module is a climate emulator that translates the CO_2 emissions to temperature increases. The third module relies on a damage function that converts the temperature increase to economic damage. By integrating these components, DICE enables researchers to study the complex feedback between economic growth and the consequential climate response in a straightforward manner.

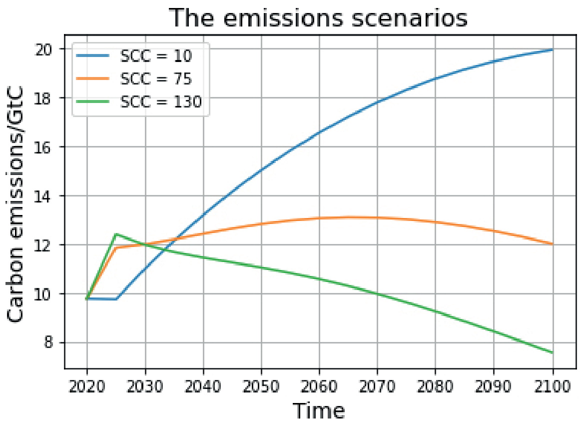
Despite the many advantages of DICE, it also receives some criticism from experts. In particular, the climate emulator in DICE (Nordhaus, 2017) is argued to be flawed, that the carbon cycle moves too slow and the temperature equations warm too fast (Dietz et al., 2021; Folini et al., 2025).

The EDHEC scenario simulator follows the same philosophy as DICE and also embeds three modules. However, we replace the flawed climate module in DICE (Nordhaus, 2017) with the same climate emulator underpinning EXCITE (detailed in Section 3). Rebonato et al. (2023) outlines the differences between the EDHEC scenario simulator and DICE (Nordhaus, 2017) in other aspects such as incorporating a stochastic economic growth function and a stochastic damage function. For details of the EDHEC scenario simulator, see Rebonato et al. (2023).

Rebonato et al. (2025b) establishes a one-to-one functional relationship between social-cost-of carbon (SCC) and abatement aggressiveness. SCC is the marginal cost of abatement given an optimal abatement pathway, meaning that a higher SCC reflects a greater willingness of a society to curb emissions growth. From a large set of numerical experiments running with the EDHEC scenario simulator under different parameter configurations, Rebonato et al. (2025b) establishes a one-to-one functional relationship between SCC and the abatement function.[5] That is to say, once users select a value of SCC, which uniquely determines one mitigation scenario, a trajectory of carbon emissions is automatically generated by the EDHEC scenario simulator. This customised scenario enables users to have a straightforward understanding of the impact of carbon price policy on the future temperature response. Figure 5 illustrates the customised emissions scenarios by the EDHEC scenario simulator. We pick three values of SCC (USD per GtCO2).[6] Obviously, the trajectories of carbon emissions diverge significantly. Note that the current carbon price in Europe is about 125 USD/GtCO_2, in USA is about 20 USD/GtCO_2 and in China is less than 10 USD/GtCO_2.

We remark that the current customised scenario option in EXCITE is implemented with the simplest form. All modules of the simulator are in a deterministic fashion with predefined parameters. However, the EDHEC scenario simulator is sufficiently flexible to incorporate more variations as explained in Rebonato et al. (2023). In the future, users could be allowed to define a more individual scenario by selecting e.g, economic growth parameters, etc. We discuss in the next section the possible extensions of EXCITE.

Figure 5: The emissions scenarios generated by the EDHEC scenario simulator. The unit of SCC is USD per Gigatonne of CO_2.



5 Future evolution of EXCITE

In the last section, we discuss potential dimensions to advance further EXCITE in the future.

5.1 A more advanced climate emulator

As discussed in Section 3, the carbon cycle in EXCITE is a three-box model that only considers the CO_2 emissions. Following Folini et al. (2025), the forcing from other GHG agents such as methane is simply modeled as a proportion to the forcing from CO_2. In the future, we can consider a more detailed carbon cycle as in Joos et al. (2013) and Leach et al. (2021) to improve this part of the performance.

Note that FaIR (Leach et al., 2021) and MAGICC (Meinshausen et al., 2011a,b) are two climate emulators adopted by IPCC in climate scenario construction. Though they have more complex structures than the two-layer temperature equations we use in EXCITE, it would be interesting to compare the performance of these climate emulators.

5 - In order not to distract attention, we skip introducing the concrete function in this work. For readers who are interested in this relationship, please read Rebonato et al. (2025b).
6 - In EXCITE, the scenarios generated by the EDHEC scenario simulator are under the option "E-DICE".

5.2 Customised scenarios

The customised scenarios can also be constructed using the EDHEC scenario simulator. At the moment, this functionality is implemented in EXCITE in a relatively simple form. However, the EDHEC scenario simulator is quite flexible and can provide users with many other options to customise their individual scenarios. For example, the stochastic EDHEC scenario simulator can allow users to choose not only the abatement scenario (via SCC) but also an economic growth scenario, e.g., a high or a low growth scenario, combined with a demographic scenario and a carbon intensity scenario, etc.[7]

The current EDHEC scenario simulator is calibrated to generate global data (e.g., global consumption and climate damage on global GDP growth). However, as the three modules in the simulator are stand-alone, it is possible to replace the economic production and the damage module with more granular models. For instance, the economic production module can be replaced with region/country/sector-based models. *If* the damage module can be changed accordingly to produce regional/country/sectoral-like local damages, the simulator would be able to produce more granular data. Then, users could customise a scenario to observe more local impact of climate change.

5.3 Visualisation of the impact on asset prices.

The potential users from a broad financial industry would be interested in the final impact of climate change on stock markets. For this, we can also add one more section to EXCITE to illustrate the interplay of climate change and stock markets.

A previous work (Rebonato et al., 2025a) by the EDHEC Climate Institute explores the potential physical impact induced by climate change on the valuation of equity assets. The physical damages on the consumption flows are investigated with the EDHEC scenario simulator. As equity assets are closely impacted by the change in consumption flow, the indirect impact of temperature increase on asset prices is derived. Other similar works investigating the comparison of the impact of physical damage and transition costs using the EDHEC scenario simulator are in progress. Once we embed one dedicated finance section to EXCITE, users will be able to customise a scenario and visualise the impact on stock markets.

7 - Carbon intensity is defined as the amount of emissions produced per unit of GDP. Generally, highly industrialised economies tend to have lower carbon intensities due to advanced technologies and energy efficiency, whereas emerging economies often have higher carbon intensities, reflecting their reliance on fossil fuels and less efficient energy use. The trajectory of carbon intensity is also a key parameter to determine how much emissions are produced along the way.

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A Appendix

Table 3: The marker IAM for each SSP. Data source:SSP database

Scenarios	Marker IAMs
SSP1	IMAGE
SSP2	MESSAGE-GLOBIOM
SSP3	AIM
SSP4	GCAM
SSP5	REMIND-MAGPIE

About EDHEC Climate Institute

Institutional Context

Operating from campuses in Lille, Nice, Paris, London and Singapore, EDHEC Business School is ranked in the top ten European business schools. With more than 110 nationalities represented in its student body, some 50,000 alumni in 130 countries, and learning partnerships with 290 institutions worldwide, it is truly international.

EDHEC Business School has been recognised for over 20 years for its expertise in finance. Its approach to climate finance is founded on a commitment to equipping finance professionals and decision-makers with the insights, tools, and solutions necessary to navigate the challenges and opportunities presented by climate change. EDHEC has developed a significant research capacity on the financial measurement of climate risk, which relies on the best researchers in climate finance, and brings together experts in climate risks as well as in quantitative analysis.

The DNA of EDHEC's work has also resided, since its origin, in the ability to generate business ventures, by encouraging spin-offs based on the research work of its teams. EDHEC is currently involved in three ventures: Scientific Portfolio, Scientific Infra and Private Assets, and the soon-to-launch Scientific Climate Ratings.

Mission and Ambitions

The EDHEC Climate Institute (ECI) focuses on helping private and public decision-makers manage climate-related financial risks and make the most of financial tools to support the transition to a low-emission economy that is more resilient to climate change.

It has a long track record as an independent and critical reference centre in helping long-term investors to understand and manage the financial implications of climate change on asset prices and the management of investments and climate action policies.

The institute has also developed an expertise in physical risks, developing proprietary research frameworks and innovative approaches. ECI is also conducting advanced research on climate transition risks, with a focus on supply chain emissions (Scope 3), consumer choices, and emerging technologies.

As part of its mission, ECI collaborates with academic partners, businesses, and financial players to establish targeted research partnerships. This includes making research outputs, publications, and data available in open source to maximise impact and accessibility.

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