REQUEST FOR AN EMI R&D PROJECT 2027–2029

Country/Organisation:	ITALY/CNR-ISAC
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Project Title:	Hydrogen-Economy cLImate projectiOn Scenarios (HELIOS)

To make changes to an existing project please submit an amended version of the original form

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ………….	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2027	
Would you accept support for 1 year only, if necessary?	YES	NO X

Computer resources required for project year:		**2027**	**2028**	**2029**
High Performance Computing Facility	[SBU]	25 million	10 million	
Graphics Processing Unit Cluster-A	[GBU]			
Graphics Processing Unit Cluster-B	[GBU]			
Accumulated data storage (total archive volume)[2]	[GB]	42000	58000	

[1] The Principal Investigator will act as contact person for this EMI R&D Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

EWC resources required for project year:		2027	2028	2029
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

Principal Investigator: Emanuele Di Carlo

Project Title: **H**ydrogen-**E**conomy c**LI**mate projecti**O**n **S**cenarios (**HELIOS**)

Extended abstract

All EMI R&D Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the EMI R&D Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous EMI R&D Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 5,000,000 SBU should be more detailed (3-5 pages).

1. Project overview

Assessing future climate change requires combining physically based Earth System Models (ESMs) with socio-economic scenarios describing plausible development pathways. While ESMs reproduce the response of the climate system to external forcing, Integrated Assessment Models (IAMs) describe the evolution of energy systems, technology, land use and greenhouse-gas emissions. Their combined use has become the standard framework for producing climate projections that support international climate assessments and mitigation strategies (O'Neill et al., 2016).

The rapid development of low-carbon technologies is creating transition pathways that are only partially represented within existing climate-scenario frameworks. Among these technologies, hydrogen is expected to play an increasingly important role in decarbonising hard-to-abate sectors. Depending on the adopted socio-economic pathway, hydrogen may remain confined to industrial applications or become widely deployed in transport, electricity storage and high-temperature industrial processes. The potential large-scale deployment of H_2 may contribute to a substantial reduction of CO_2 emissions, provided that a consistently low carbon footprint is guaranteed in the H_2 production process (specifically, by favouring “blue” and “green” hydrogen, which involve reduced or zero carbon-dioxide emissions; Ocko and Hamburg, 2022).

A factor that could significantly undermine the potential benefits of a transition to a hydrogen-based economy is the issue of H_2 leakage throughout the entire value chain. Although molecular hydrogen is not itself a greenhouse gas, atmospheric leakages perturb atmospheric chemistry through interactions with hydroxyl radicals, modifying methane lifetime, tropospheric ozone and stratospheric water vapour. These indirect effects alter Earth's radiative balance and therefore need to be considered when assessing hydrogen-based energy systems (Ocko and Hamburg, 2022).

In summary, H_2 emissions can exert a significant climatic influence, which must be thoroughly quantified to provide policymakers with a comprehensive understanding of the environmental implications associated with the widespread adoption of H_2 in the energy sector.

HELIOS addresses this challenge by coupling hydrogen-explicit transition pathways generated with the WILLIAM Integrated Assessment Model to the EC-Earth4 Earth System Model. Rather than investigating isolated perturbations, the project evaluates complete socio-economic transition pathways, providing physically consistent projections of future climate under alternative hydrogen deployment strategies. The resulting simulations will constitute a valuable resource for climate-impact studies, evaluating the climatic implications of future energy-transition strategies, to the design of next-generation scenario-based climate assessments.

2. Objectives

The HELIOS project aims to quantify the climate response associated with alternative hydrogen-transition pathways. Specific objectives are to:

• investigate the sensitivity of large-scale circulation, hydrological cycle and temperature patterns to different levels of hydrogen deployment;

• assess the contribution of hydrogen-based decarbonisation strategies to future climate evolution under Green Growth narratives;

• provide a coordinated ensemble of EC-Earth4 simulations supporting future climate-assessment activities.

These objectives will be tackled through a modelling approach, following well-established methodologies detailed in Section 3.

3. Methodology

3.1 Numerical experiments

Climate simulations will be performed with EC-Earth4, combining OpenIFS cy48r1, NEMO4, SI3 and H-TESSEL. Compared with the CMIP6 configuration, the model incorporates substantial updates in both numerical performance and physical parameterizations, making it the reference modelling framework for forthcoming EC-Earth climate applications. The T255L91–eORCA1 configuration provides an effective compromise between physical realism and computational efficiency for century-scale coupled simulations, providing a nominal atmospheric resolution of approximately 80 km coupled to a 1° ocean grid. Atmospheric chemistry and the carbon cycle are not explicitly simulated; instead, hydrogen-induced effects enter through prescribed greenhouse-gas concentration pathways derived from dedicated Chemistry Transport Model (CTM) simulations driven by WILLIAM hydrogen-emission scenarios. The impact of H_2 emissions on atmospheric composition (CH_4, O_3 and water vapour; see Section 1) enters the model exclusively through prescribed GHG concentration pathways. These pathways are derived from Chemistry Transport Model (CTM) simulations forced with H_2 emission scenarios produced with the Integrated Assessment Model WILLIAM. Both the design of the H_2 emission scenarios and the corresponding CTM simulations are delivered by parallel efforts and are not part of HELIOS.

3.2 Future scenarios

Concentration-driven projections for the period 2015–2100 will be performed with the fully coupled atmosphere–ocean configuration of EC-Earth4. To explore the effect of different degrees of hydrogen deployment, five scenarios will be run, ranging from a green-growth pathway without hydrogen to an ambitious hydrogen implementation covering multiple sectors of human activity, from industrial use to passenger transport. The full set of scenarios is summarised in Table 1.

ST scenarios	Sustainability narrative	H2 in sectors	Trade	Synthetic fuels
Baseline	Trends	0	0	0
ElecRES_noH2	Green Growth	0	0	0
ElecRES_low-H2	Green Growth	Industrial us as feedstock	0	0
ElecRES_medium-H2	Green Growth	Industrial use as feedstock Freight transport Industry high temperature	Small/Medium	Small/Medium
ElecRES_high-H2	Green Growth	Industrial use as feedstock Freight transport Industry high temperature Passenger transport	Medium/Large	Medium/Large

Table 1. Future climate-projection scenarios explored in HELIOS, spanning increasing levels of H_2 deployment across socio-economic sectors.

The GHG concentration pathways driving each scenario are derived from CTM simulations forced with the H_2 emission scenarios produced with the WILLIAM Integrated Assessment Model. Following the recommendations of the ScenarioMIP Scientific Steering Committee (van Vuuren et al., 2023), each scenario will be run as a 3-member ensemble to obtain a reasonable minimum signal-to-noise ratio and to sample internal climate variability.

Unlike traditional concentration pathways adopted in CMIP exercises, the HELIOS scenarios are directly linked to energy-system transitions simulated with the WILLIAM Integrated Assessment Model. Consequently, the experiments explore internally consistent combinations of energy demand, hydrogen deployment, technological development and international trade, providing a more policy-relevant framework for climate assessment.

The scenario design has been intentionally conceived to isolate the climatic response to progressively increasing hydrogen deployment while maintaining internally consistent socio-economic assumptions. This enables attribution of simulated climate differences directly to alternative energy-transition strategies rather than unrelated changes in background forcing.

4. Workflow

As illustrated in Section 3, the project consists of a single stream of coupled scenario simulations. Given the available computational resources and the maturity of the EC-Earth4 configuration, most of scenario simulations will be performed during 2027, with model evaluation, data archiving and analysis proceeding in parallel and extending through the project lifetime.

The project is organised in three consecutive phases.

Phase 1: preparation of forcing datasets, configuration of EC-Earth4 experiments and validation tests.

Phase 2: production of the complete ensemble of coupled simulations for all hydrogen-transition scenarios.

Phase 3: quality control, post-processing, archiving and scientific analysis of the model outputs.

5. Resources and technical implementation

Based on the most recent EC-Earth4 runs on the Atos HPC2020 system, one model year of the OpenIFS–NEMO coupled configuration at T255L91–eORCA1 resolution costs approximately 25,000 SBU. Each simulation spans 85 years (2015–2100). With 5 scenarios and 3 ensemble members each, a total of 15 model runs is required, corresponding to 15 × 85 = 1,275 model years.
The resulting computational cost is 1,275 model-years × 25,000 SBU/year ≈ 32,000,000 SBU. An additional 10% contingency is requested to accommodate potential simulation reruns, production overheads and post-processing activities, leading to a total request of approximately **35 million SBU**.

Regarding storage, the requirements are approximately 45 GB per model-year, implying 1,275 × 45 GB ≈ 58,000 GB (58 TB).

Model configuration	Activity	Model years	Total resource cost
T255L91–eORCA1 (coupled)	5 scenarios × 3-member ensembles	1,275	~32 million SBU

Table 2. Synthesis of HELIOS simulations and estimated computational cost. The total amount of requested resources is approximately 32 million SBU and 58 TB of archive storage.

The requested computational resources are almost entirely devoted to production simulations. The EC-Earth4 configuration has already been extensively tested on the ECMWF infrastructure, ensuring that the requested allocation will be efficiently exploited with minimal overhead associated with model development and debugging.

Reference

Döscher, R., and Co-authors: The EC-Earth3 Earth system model for the Coupled Model Intercomparison Project 6, Geosci. Model Dev., 15, 2973–3020, https://doi.org/10.5194/gmd-15- 2973-2022, 2022.

Ocko, I. B. and Hamburg, S. P.: Climate consequences of hydrogen emissions, Atmos. Chem. Phys., 22, 9349–9368, https://doi.org/10.5194/acp-22-9349-2022, 2022.

O'Neill, B. C., Tebaldi, C., van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., Knutti, R., Kriegler, E., Lamarque, J.-F., Lowe, J., Meehl, G. A., Moss, R., Riahi, K., and Sanderson, B. M.: The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6, Geosci. Model Dev., 9, 3461–3482, https://doi.org/10.5194/gmd-9-3461-2016, 2016.

Van Vuuren, D. et al., 2023: ScenarioMIP workshop: Pathway to next generation scenarios for CMIP7, 10.5281/zenodo.8186116.