



Net0 Pathways through improved IAMs across Sectors, dimensions, and scales

Mid-term project report

Related Tasks: 7.1

Deliverable 7.5

[Lead: CMCC]

December 2024



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This project has received funding from the European Union's Horizon Europe programme under grant agreement No 101081604.

PRISMA (Net-Zero Pathway Research Through Integrated ASsessment Model Advancements)

Deliverable Title	Mid-term project report
Deliverable number	7.5
Brief Description	The Mid-term Report includes key achievements of the project.
WP number	7
Lead Beneficiary	FONDAZIONE CMCC
Author(s)	All
Deliverable Due Date	31/12/2024
Actual Delivery Date	30/12/2024
Nature of the Deliverable	R – Document, report
Dissemination Level	PU - Public
Version	1



1. Overall progress over the first half of the project

During the first half of the project, PRISMA has achieved the goals set in the Grant Agreement. Ten deliverables and nine Milestones have been submitted (see Tables 1 and 2). PRISMA has addressed the 3 key project objectives of developing new modeling capabilities while rooting them in new empirical work and making models more robust and decision-relevant (see Section 1.1).

The project's unique feature is matching a vast and diverse suite of modeling tools with new sources of data, both qualitative and quantitative, and making models trustworthy and relevant.

To do so, during the first half of the project models have begun to develop new capabilities tailored at real-world solutions. These include a better representation of the financial sector, a key enabler of the transition, which has received limited attention; better representation of circularity, lifestyle, inequality, and structural change. And a better inclusion of sustainable development goals beyond climate, such as biodiversity. These model developments have been implemented directly into the single models but also using cross-modeling tools, such as the LIFE model for endogenous simulation of lifestyle change which has been coupled with several IAMs. Research productivity has already been very significant, with 26 papers already published, three in leading interdisciplinary journals (Nature, and PNAS), and 33 presentations in international conferences.

The model development has been informed by parallel advancements on the empirical front. A new datasets on cost of capital, material intensities, and other key variables for IAMs has been established and provided to the modelers. Social scientists working on lifestyle have used new data sources and surveys on human behaviour to calibrate a lifestyle change model. Meanwhile, intense stakeholder engagement activities have taken place, in order to ensure that the model developments are guided by a continuous confrontation with the key users of models. A launch event and five thematic workshops have taken place on subjects such as 'Climate Finance', 'Citizens and behavioural change', 'Impacts of climate (in)action', 'Biodiversity and biophysical impacts', and 'Sector-specific green transformations'.

Although model development is yet to be completed, PRISMA's work has already been embedded in the policy process. The focus has been put on the EU climate targets for 2040, which is a key policy decision for the EU and also internationally in the context of the Global Stock Take. Decarbonization scenario work was presented at a high-level event in Brussels before the Commission released its own impact assessment. Two policy briefs have been published in 2024.

Del. No	Deliverable title	WP no.	Lead beneficiary	Delivery date
D1.1	Non-technical brief: What can our models deliver?	1	BRUEGEL	Jun 2023
D1.2	Detailed nomenclature (list of variables including definitions and recommended units) for comparison of IAM scenario assumptions and reference data	1	IIASA	Jun 2023



D4.1	Open-source lifestyle change model and IAM linkage source code	4	UOX	Jun 2024
D7.1	Critical risks analysis	7	CMCC	Mar 2023
D7.2	Dissemination, Communication & Exploitation Plan	7	CMCC	Apr 2023
D7.3	Data Management Plan	7	CMCC	Jun 2023
D7.4	Ethics Management Plan	7	CMCC	Jun 2023
D3.1	Open Database of region- and technology- specific cost of capital	3	ETH Zürich	Dec 2024
D3.2	Database of up-to-date probabilistic technology cost forecasts	3	UCAM	Dec 2024 - to be submitted
D7.5	Mid-term project report	7	FONDAZIONE CMCC	Dec 2024

Table 1: Project deliverables in the first half of the project

Milestone no.	Milestone Title	WP no.	Lead beneficiary	Due date
MS1	Kick-off project meeting	7, 1	CMCC	Mar 2023



MS2	Establishment of the Advisory Board	7	CMCC	Apr 2023
MS3	Website with link to PRISMA explorer set-up	7, 1	CMCC	Jun 2023
MS4	First round of the five research stream workshops	1	BRUEGEL	Dec 2023
MS5	Preliminary results on cost of capital heterogeneities and technology cost trajectories	3	CMCC	Dec 2023
MS6	Preliminary LCA data of bulk and speciality materials	4	CMCC	Dec 2023
MS7	Preliminary data and models on granular sectors, distributions, financial sectors, and digitalization for IAM implementation	2	PIK	Jun 2023
MS8	Scenario protocol for new pathways and Net zero implementation for policy analysis	6	CMCC	Jun 2024
MS9	Model-based insights from integrated SDG scenarios as input for synthesis scenarios	5	PBL	Dec 2024

Table 2: Project milestone in the first half of the project



1.1.1. WP1: Co-design, stakeholder engagement, and model usability [Months: 1-48]

Lead partners: Bruegel; PIK

WP1's objectives are: a) ensuring relevance and legitimacy of the project's work through stakeholder engagement, b) improving research quality and tool usefulness by engaging closely with its user community, incl. capacity building, c) improving transparency of IAM research through open access and clear documentation.

The first objective was delivered through a stakeholder launch event, a policy brief explaining PRISMA's contribution to integrated assessment modelling in the context of the EU's 2040 target, and five thematic stakeholder workshops. These stakeholder engagement sessions not only ensured the legitimacy and relevance of PRISMA's work, but contributed to the second objective of engaging with the user community and building knowledge regarding integrated assessment modelling. Strong progress was made on the last objective of improving open access and clear documentation, with actions underway to shift the IAMC wiki to a new platform and, once complete, further steps will be taken to automate in-code documentation.

Deliverables:

D1.1 Non-technical brief: What can our models deliver? [Bruegel, M6] - submitted

D1.2 Detailed nomenclature (list of variables including definitions and recommended units) for comparison of IAM scenario assumptions and reference data [IIASA, M6] - submitted

Milestones:

1 Kick-off project meeting [CMCC, M3] - achieved

3 Website with link to PRISMA explorer set-up [CMCC, M6] - achieved

4 First round of the five research stream workshops [Bruegel, M12] - extension granted to M17; achieved

Task 1.1: Stakeholder Engagement (Lead: BRUEGEL/UNIGE; Partners: all; M1-48)

With the aim of connecting policy practitioners and integrated assessment modellers, this task focused on the organisation of several stakeholder events and meetings, as well as the publication of a policy brief for stakeholders, explaining how PRISMA's work can help to inform European energy and climate policy. The work on the citizen survey has also started.

The stakeholder engagement work began with a launch event entitled "Climate Targets 2040: Bridging Modelling and Policy". This event took place at the Bruegel premises in Brussels in September 2023. The event discussed the EU's binding 2040 emissions reduction target, bringing together senior scientists from the PRISMA consortium with key policymakers from the European Commission. The European Commission ultimately published its proposed target of 90% in February 2024. The stakeholder event was well attended, with over 50 people in person and almost 300 viewing online.

Publication of D1.1 'Non-technical brief: What can our models deliver?', which was then entitled 'Informing Europe's 2040 Climate Targets', followed the stakeholder event. The policy brief used insights from the discussion at the event to set out the process underpinning the European Commission's 2040 target impact assessment and highlight how PRISMA's modelling developments can provide important contributions to policymaking going forward.

The final Task 1.1 activity in the first half of the project were five stakeholder sessions, categorised thematically to cover the major research streams in PRISMA. These workshops were held either in-person or online, depending on the requirements of the relevant stakeholder group. The 'Climate Finance' workshop took place on 16/11/2023 as a side event at the IAMC 2023 conference. A half-day workshop for the 'Citizens and behavioural change' workshop took place on 14/03/2024 at the Bruegel offices in collaboration with the CircEular project. The 'Impacts of climate (in)action'



(22/01/2024), ‘Biodiversity and biophysical impacts’ (22/11/2023), and ‘Sector-specific green transformations’ (05/03/2024) took place online, with the insights from the latter used as the basis for a PRISMA policy brief assessing the European Commission’s 90% 2040 target.

The work towards the D1.3 “Publication with the results of the citizens’ survey” has started at UNIGE, where the survey has been designed to elicit the preferences of the European citizens for mitigation options modelled in IAMs. The survey with an expected sample of around 400 respondents in six European countries (France, Germany, Italy, Spain, Netherlands, Poland) will focus on four highly uncertain mitigation measures: bioenergy with carbon capture and storage, green hydrogen, afforestation and reforestation, and sustainable diets. The survey will follow the methodology of informed citizen panels: it will measure initial acceptance and policy support by the citizens towards these measures, and then the evolution of these preferences as the citizens are provided with more information about the mitigation potential and uncertainty. In the next reporting period, the survey will be launched and its results analyzed.

Task 1.2: Documentation (Lead: PIK; Partners: CMCC, E3M, IIASA, PBL, SMASH; M1-48)

With the focus of Task 1.2 on a structured and transparent documentation of the participating integrated assessment models PBL and PIK initialized discussions on the technical basis of the underlying IAM documentation wiki (<https://www.iamcdocumentation.eu>). PBL as host of this service is currently in the process of moving the wiki to a different hosting server and to a different software backbone. This new version will likely be Github based as an alternative to Mediawiki which is currently used. The different options were presented and discussed on the last PRISMA consortium meeting. For an automatized link of In-code documentation and the IAMC wiki discussions between PIK and PBL started but were put on hold for the moment given that the technical implementation strongly depends on the particular choice of software used to host the documentation. It will be taken up again as soon as a decision on this matter has been taken.

Task 1.3: Data handling (Lead: IIASA; Partners: CMCC, PIK, PSI, PBL; M1-48)

Task 1.3 started a “variable template”, a list of variables and regions used for reporting in the modelling activities to ensure consistency across work packages.

Several previous projects (NAVIGATE, IPCC AR6, openENTRANCE, NGFS) diverged in the variable and region naming conventions, so this task started by combining shared elements (see Deliverable 1.2) and then expanded in a structured manner, reconciling differences and inconsistencies. The codelists are available at <https://github.com/iamconsortium/common-definitions> under a Creative Commons CC0 license to facilitate reuse, in line with the FAIR principles.

Since November 2023, the coordination of the development of the variable template was conducted in close cooperation with the IC Scientific Working Group on Data Formats to ensure consistency across modelling projects and usability for a broad range of use cases.

Task 1.4: Open Source & Open Access (Lead: PIK; Partners: IIASA, PBL, CMCC, PSI, SMASH, E3M; M1-48)

Aiming for increased accessibility of model components and tools in PRISMA, Task 1.4 started collecting information on the used models and tools in the project with contributions from PIK, IIASA, CMCC, PBL, PSI. PIK created a metadata documentation guide to be used by the teams to annotate models and software based on the well established citation file format (<https://citation-file-format.github.io/>). The citation R package (<https://github.com/pik-piam/citation>) has been extended so that it now can extract software reports from these metadata files to create a report of software and models attached to a project.

The first steps of making open-source the IMACLIM-R software have been carrying on by SMASH: 20 years of model developments have been analysed to define the property share of the software among 5 public and private institutions, who exchanged regarding the choice of an open license and the



terms of use of the software.

Task 1.5: Capacity Building (Lead: BRUEGEL; Partners: PIK, CMCC, E3M, PSI, UNIGE; M1-44)

During this first half of the project, we organized several events that align closely with our capacity-building goals (reaching relevant stakeholders and aspiring modellers in Europe). The "Climate Targets 2040: Bridging Modeling and Policy" event on September 13, 2023, facilitated direct engagement between policymakers and modelers, fostering a mutual understanding of 2040 climate targets. The webinars held on November 22, 2023, January 22, 2024, and January 25, 2024, addressed critical topics such as climate impacts on biodiversity and GDP, adaptation and maladaptation, and lifestyle changes. They have provided practitioners with valuable insights on implementing these features in integrated assessment models. Additionally, the session at the 2023 conference of the Integrated Assessment Modeling Consortium, focused on the relevance of climate scenarios for the finance and private sectors, enabling a dialogue that identified user needs for new scenario types. These activities have promoted the dissemination of our modeling tools, gathered constructive feedback, and enhanced the transparency and accessibility of IAM-based research.

Significant Results:

- Stakeholders launch event at Bruegel premises in September 2023 with over 300 online and in-person attendees.
- D1.1 "Informing Europe's 2040 targets" policy brief.
- D1.2 Detailed nomenclature (list of variables including definitions and recommended units) for comparison of IAM scenario assumptions and reference data
- Five stakeholder workshops/webinars.

1.1.2. WP2: Entry-points to just and efficient transitions to net zero [Months: 1-42]

Lead partners: PIK; E3M

Climate change mitigation does not happen in isolation, but is rather embedded in broader trends of macro-economic structural changes as well as rapid technological change in the energy sector. The activities in this WPs help to improve our understanding of these transitions, to understand implications for equity and justice. Ultimately, the results are used to derive improved policy analysis for the transition towards a just and efficient net zero energy system in Europe. The work programme is on track, with model improvements and applications under way by individual teams, as well as development of datasets on near-term trends and inequality prepared for use by all teams.

Deliverables:

None

Milestones:

*7 Preliminary data and models on granular sectors, distributions, financial sectors, and digitalization for IAM implementation [PIK, M18] - **achieved***

Task 2.1: Improving the representation of economic structural change and its interplay with climate policy (Lead: E3M; Partners: CMCC, AGROPARISTECH, PIK; M1-42)

The transition to low or zero-emission economies by mid-century requires profound structural macroeconomic changes. The task aims to improve the representation of structural change in climate change scenarios as well as the macroeconomic modelling of structural change and its interplay with



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ambitious climate policies. In the first period of PRISMA, we worked intensively in several work streams and activities to achieve the task objectives. First, all participating modelling teams improved the sectoral granularity of participating models (GEM-E3, IMACLIM, WITCH, REMIND), while the comparability of model data and results with economic data sources (e.g., Eurostat, GTAP) has been improved. As part of this task, E3M and AGROPARISTECH explored the interplay between climate policy and macroeconomic structural change using advanced multi-sectoral macro-economic models GEM-E3 and IMACLIM to assess the mitigation impacts across sectors and regions. In particular, the two teams collaborated to develop a multi-model study on “Assessing the socio-economic impacts of different ways to recycle revenues from carbon pricing” which was presented in the 2023 annual conference of the Integrated Assessment Modelling Consortium (IAMC), <https://hal.science/hal-04477526/>. This study aims to assess the impacts of different ways to use the revenues from carbon pricing and the potential trade-offs between equity and economic efficiency.

AGROPARISTECH has explored the trajectories of job losses in the coal mining sector in India and China using the Imacim multisectoral general equilibrium model. Several methodological innovations were introduced to produce these assessments: downscaling methods and the creation of a module representing the future of employees in the sector, in order to refine the estimates. This work has been presented at conferences (ECEMP, IAMC 2023) and a scientific article is in preparation.

In the context of task 2.1, E3M develops a new study based on a comprehensive scenario analysis of achieving net-zero emissions globally, employing two distinct mathematical macroeconomic models characterized by disparate theoretical underpinnings (GEM-E3 and E3ME). The study compares the macroeconomic impacts of net-zero policies (in terms of GDP, employment, trade and investment) and analyses the main differences and similarities in modelling results and policy implications depending on which model is used. The study also compares the mitigation costs (as calculated by the models) with the range of economic costs of climate change impacts (based on damage function research) and finds that the mitigation costs are much lower and much less uncertain than the potential losses due to climate damages, which highlights the importance of acting urgently to reduce emissions and mitigate climate change.

PIK further develops the multi-sectoral growth model. A first major improvement applies to the modelling of mitigation capabilities. This allows the model to endogenously represent the trade-off between investments in the expansion of production and investments into mitigation. First results show that with the mitigation option available, the importance of sectoral reallocation for future emission reduction is limited. But on the other hand, it is in particular the manufacturing sector that suffers less from a drop out of labor, what in turn helps developing regions to sustain economic development. A second major improvement applies to the representation of international trade in manufacturing and agricultural goods, which is implemented based on a Ricardian-type model supplemented with an Armington-type composition of domestically produced and imported goods. While international trade accelerates structural change in general, reallocation patterns in reaction on climate change damages known from autarky models, for example the shift of labor back to the agricultural sector, is still prevalent. Johannes Koch had presented the model and first results at last year's IAMC conference and at the international Energy Workshop this year.

CMCC has completed and published two studies, on technological spill overs and structural change from brown to green technologies. Moreover, the implementation of three sectors in RICE50+ is ongoing and will include structural change dynamics of the Net zero transition. The task activities give a better understanding how economic structural change, and resulting growth, employment, productivity and trade effects shape future mitigation opportunities and vice versa.

Task 2.2: Near-term sector transitions (Lead: PIK; Partners: E3M, PBL, UNIGE, WISE; M1-42)

As part of this task, individual modeling teams from PIK, E3M, PBL, UNIGE and WISE are working on improving granularity and accuracy in the modeling of the energy supply, transport, buildings and industry sectors. PIK has worked on improving the granularity and representation of drivers of sector-level transitions in the REMIND model, and applied the improved model for a sector-detailed assessment of the EU's transition towards climate neutrality and relevant mid-term targets. This work provided crucial input to the evaluation of EU mitigation targets for 2040 (Rodrigues et al., in review). E3M has worked on incorporating the latest Eurostat and GTAP data in the GEM-E3 model to ensure



accuracy of the model's base year and realistic short-term projections. WiseEuropa develops a large-scale DSGE model with energy sector detail. The PBL team has implemented improvements to the IMAGE model's residential and commercial sectors, including an improved representation of the uptake of heat pumps, and including the heat-island effect in urban areas.

An overarching focus of the task lies on improving consistency of near-term transition. To further facilitate model improvements, a database of historical reference data was established. We are currently working on bottom-up estimates of plausible near-term deployment projections for photovoltaics, wind power, nuclear, carbon capture and storage as well as hydropower, based on project pipelines or market outlooks. IAM results can be benchmarked against these results. This analysis system also provides crucial insights for the ongoing improvement of sectoral modeling in the IAMs.

Task 2.3: Distributional and social impacts of mitigation policies (Lead: CMCC; Partners: PIK, E3M, PBL, UNIGE, WISE, ENPC; M1-42)

The process to provide first a set of inequality data based on three dimensions (income inequality by deciles, urban/rural settlement patterns, and gender) has been started and the first three countries have been processed and made available on the open access github repository <https://github.com/witch-team/inequality-dataset-for-iams>. We will have around end 2024 52 countries most likely to be able to address inequality, and energy and food consumption related impacts of mitigation policies across these three dimensions, empirically and for ex-ante modelling.

A model comparison paper on the first dimension (income inequality) with eight participating IAMs has been started under the NAVIGATE project and being continued within PRISMA. It has now been published in Nature Climate Change.

Task 2.4: Policies for a just and efficient net zero transition in Europe (Lead: E3M; Partners: PIK, CMCC, PBL, WISE, BRUEGEL, UCAM; M19-42)

The task starts in the second reporting period. However, some relevant activities have been implemented in the first PRISMA period, including contributions to the the PRISMA-ECEMF workshop on the 2040 EU climate targets and a paper was published based on PRIMES-Buildings scenarios to provide insights about the strategies and options that EU countries can use to decarbonise their building sectors. PRISMA work also fed into the [scenario assessment](#) for deriving the EU 2040 greenhouse gas emission reduction targets.

Significant results:

- Working paper “Assessing the socio-economic impacts of different ways to recycle revenues from carbon pricing” (available here <https://hal.science/hal-04477526/>).
- Journal article “Decarbonising the EU Buildings|Model-Based Insights from European Countries” (available here <https://www.mdpi.com/2225-1154/12/6/85>).
- Inequality dataset including different settlement patterns at <https://github.com/witch-team/NAVIGATE-inequality-dataset>
- Paper “2040 greenhouse gas reduction targets and energy transitions in line with the EU Green Deal”, Rodrigues et al. (under review).
- Emmerling, Johannes, Pietro Andreoni, Ioannis Charalampidis, Shouro Dasgupta, Francis Dennig, Simon Feindt, Dimitris Fragkiadakis, et al. “A Multi-Model Assessment of Inequality and Climate Change.” *Nature Climate Change*, October 4, 2024, 1-7. <https://doi.org/10.1038/s41558-024-02151-7>.

1.1.3.WP3: Climate finance and innovation [Months: 1-42]

Lead partners: E3M; CMCC

Technological progress and the availability of low-cost finance to enable the further development and deployment of low-carbon technologies are key factors in paving the way to decarbonization. This is true both for demand-side and supply-side transformations, as technologies enabling



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sustainable lifestyles and the necessary structural changes in national economies must be further developed and financed. To gain a better understanding of these challenges, this WP produces major developments in the representation of the financial sector and technological innovation in Integrated Assessment Models, incorporating state-of-the-art empirical research on (regionally and technologically differentiated) cost of capital and future technology cost estimates.

Deliverables:

- D3.1 “Open Database of region- and technology- specific cost of capital”.
- D3.2 “Database of up-to-date probabilistic technology cost forecasts”.

Milestones:

5 Preliminary results on cost of capital heterogeneities and technology cost trajectories [CMCC, M12]
- *achieved*

Task 3.1: Modelling the financial sector in IAMs (Lead: E3M; Partners: CMCC, ETH, WISE; M1-32)

The modelling of the financial sector in IAMs is currently under-developed and thus IAMs provide little insight on how necessary investments and innovations to enable a low-carbon transition can or should be financed. The work in this task involves improving the representation of finance both in conventional and agent-based IAMs based on the (often non-climate-related) literature on agent-based macroeconomic models, macro-financial/flow-of-funds models as well as empirical work by ETH on financing needs, financing sources (e.g., private or public sector) and types of finance (e.g., debt or equity) for different technologies. In the first period of PRISMA, the E3M team analysed the key issues to be addressed when modeling the financial sector in large-scale Computable General Equilibrium models and identified the main challenges to integrate the financial sector with the real economy and how these can be addressed. E3M also developed a small model maquette showcasing the integration of the financial sector into the GEM-E3 model with the incorporation of banking sector, stock-flow modelling, and differentiation of finance supply by agent.

The CMCC team is linking in its agent-based IAM the energy sector to the banking sector through loan access, allowing central bank interest rates to influence banking climate finance. Additionally, an equity market is being implemented to price various energy technologies based on performance and risk, impacting credit access for each technology. These developments facilitate the exploration of dynamics involving de-risking as well as external finance through loans and equity issuances. A soft coupling WITCH-DSK paper has been submitted to Nature Climate Change.

The WISE team has been developing the financial sector in its DSGE model by experimenting with few alternative mechanisms in order to find the best set-up for applications associated with the climate policy oriented models. In most of these alternatives we distinguish between borrowers and lenders and introduce the friction through market imperfections. This is done by introducing to the model the new class of agents called entrepreneurs (special type of households), investment good producers (special type of firms) and financial intermediaries / banks. Entrepreneurs purchase capital from investment good producers and rent it to the good and service producing sectors. In order to finance this purchase they must acquire a bank loan as they can only finance part of it from their own resources. There is a financial friction associated with this loan as bank do not know the exact financial position of a given entrepreneur. In consequence the conclusion of the loan contract is costly and requires collateral especially as entrepreneurs face the risk of idiosyncratic bankruptcy. Similar mechanisms are considered for the consumer and real estate purchases in order to better reflect the reality of economic activity financing and understand how it may impact the deployment of renewable energy and the decarbonization process in the EU and in the world.

Finally, as part of task 3.1 the modeling teams enhanced their representation of cost of capital differentiated by technology and region and developed a multi-model scenario analysis assessing how reducing the cost of capital can finance the energy transition in developing countries as well as the impact of policies decreasing the investment risk in developing countries. This work has been



published in Nature Energy (Calcaterra et al., 2024), and finds that a reduction of investment risk leads to substantial climate and equity benefits in the Global South.

Task 3.2: Assessing the importance of heterogeneity in cost of capital for green transitions (Lead: ETH; Partners: E3M, UNIGE, PIK, CMCC, ENPC, PBL; M1-32)

The cost of capital is an important factor for the low-carbon transition, but this cost is different by technology and region. So task 3.2 aims to empirically assess differences in the cost of capital across regions as well as technologies, as these have important implications for the design of cost-efficient transition strategies and policies aimed at de-risking green investments - especially given the high capital intensity of low carbon technologies.

To assess model structures concerning the representation of cost of capital, ETH and PIK have derived learnings from energy system models (where cost of capital heterogeneity is more common compared to IAMs) and published them as a perspective in Joule (Lonergan et al., 2023). In addition, we have conducted semi-structured interviews with all modeling teams involved in PRISMA to identify model-specific representations of investment risk and technology granularity. These interviews informed our efforts to provide cost of capital estimates that are tailored to the models involved in PRISMA.

To this end, ETH has leveraged auction data to derive estimates for solar photovoltaics in emerging countries where data is usually sparse (Egli et al., 2023). Moreover, we have conducted a systematic meta-analysis of cost of capital estimates for renewable energy technologies to compile a novel database for renewable energy technologies overall. We are currently drafting a publication around this dataset, which will be submitted to Scientific Data early 2025 and was showcased in Milestone 5. Based on the results of our interviews with the modeling teams, we are also expanding the database beyond the power sector to capture demand-side technologies based on various data sources, which resulted in the deliverable D3.1 (due in M24).

All modeling teams can incorporate the resulting cost of capital estimates to explore their effects on socio-economic outcomes, such as transition speeds and regional burden sharing. For example, in a forthcoming paper, UNIGE conducted a hindcasting-based electricity system modeling in Europe to show that inclusion of differentiated costs of capital to reflect investment risk is one of the most important efforts to improve the realism of modelled pathways (Fisch-Romito et al., forthcoming). In addition, ETH and modelling teams of PIK, PBL, CMCC and E3M are working on a first implementation of financing cost estimates for the major climate-relevant sectors beyond the power sector to derive learnings for modelers and policy implications. Aside from our work on providing cost of capital estimates, we are also prioritizing sectors and technologies based on their representation in models and their relevance for model outcomes to ensure that our empirical efforts focus on high-impact sectors and technologies.

Task 3.3: Probabilistic technology cost forecasting (Lead: UCAM; Partners: UOX, ETH, PBL, UNIGE; M1-32)

This task aims to provide forecasts of technology costs, technology-specific innovation rates and upscale potential, validating them on empirical data where possible or relying on expert elicitations. In the first half of the project, UCAM has been working on developing new and updating existing probabilistic technology cost forecasts for low-carbon technologies. As part of these efforts, we have undertaken the audit of existing and newly collected technology cost and deployment data to identify data series suitable for the probabilistic forecasting procedure described in Way et al. (2022). The audit revealed major issues with many published data series, including time series that are too short or non-sequential, experience ambiguity, and problematic past data series and learning rate calculations that uncritically migrate between literature sources. The use of such data in technology cost forecasting threatens the validity of such forecasts and their application in the models. To address this issue, we are developing an open database of updated and validated technology learning curve data, aiming to automate the probabilistic forecasting procedure and develop data standards for this process. Updated preliminary technology cost trajectories produced by this procedure for solar photovoltaics (PV) and onshore wind were included in Milestone 5. With further data collection and validation efforts undertaken throughout 2024, we have produced new, up-to-date probabilistic technology cost forecasts for solar PV, onshore and offshore wind, lithium-ion batteries, PEM electrolyzers, and white LED lighting, all included in the deliverable D3.2 (due in M24).



The UCAM team is also working on incorporating technology-specific characteristics into the probabilistic cost forecasting procedure. We developed and are currently populating a set of metrics for cross-technology comparison of learning patterns, with the metrics chosen to be complementary to the characteristics explored by the ETH team and based on knowledge, engineering, and economic complexity of low-carbon technologies. The metrics found to be associated with particular technology learning patterns can be potentially incorporated into the probabilistic technology cost forecasting models validated with expanded technology data sets.

ETH has focused their work for task 3.3 along two strands: system dynamic projection modeling of technology competition and characterization of technology complexity which can inform assumptions for technology learning rates. For the modeling work, ETH has developed a modeling framework for assessing technology competition in specific markets which uniquely takes into account interregional differences in innovation (i.e. experience curves) as well as spatial deployment spillover effects (published in PNAS, Noll et al. 2023). For this model we also explore the differentiation of global vs. local learning for certain technologies, which could be more readily applied within the larger integrated assessment models. This modeling work is ongoing, we hope to expand to other relevant sectors where low-carbon technologies compete for market shares against incumbent high-carbon technology, and we plan to integrate our findings where possible within the PRISMA consortium IAMs. This part of the project resulted in updated technology cost forecasts for lithium-battery packs and fuel cell systems for commercial road freight transport, both included in the deliverable D3.2.

For the characterization of technology complexity work, the general research direction is to understand how technology-inherent characteristics can explain innovation dynamics, and by extension theoretically inform learning rates. Specifically, we first looked at direct air capture combined with storage (DACCS) as a case study (published in Joule, Sievert et al. 2024) where we considered technology characteristics to both estimate technology-specific learning rates and project future costs of direct air capture. As DACCS is still a relatively nascent technology with limited historical cost data and therefore little empirical evidence for estimating experience curves, this study introduces a new methodology for technology cost forecasting based on an empirical analysis of technology-inherent characteristics that determine the cost reduction potential. Technology cost forecasts produced by this methodology for three variants of DACCS technology - with liquid sorbent, solid sorbent, and CaO ambient weathering - are included in the deliverable D3.2. A similar approach is currently in the works for advanced geothermal technologies. Lastly, to advance the theory behind technology complexity, which can directly inform experience rates and cost projections, ETH is presently drafting a methodological paper on quantifying technology complexity more formally.

Task 3.4: Modelling technological progress and development (Lead: CMCC; Partners: E3M, ETH, IIASA, PBL, UCAM; M1-32)

This task aims to strengthen the modelling of endogenous technological change in IAMs.

The UCAM team, working together with colleagues in the UK-funded EEIST project (<https://eeist.co.uk>), published an empirical paper analysing the representation of induced innovation and technological progress in a sample of 24 energy-economic models and IAMs, including one PRISMA model, DSK (Pasqualino et al., 2024). The paper empirically supports the premise of Task 3.4 by showing that only a quarter of the sampled models endogenize technological progress in some form, typically through learning curves, R&D, or spillover effects. A typology of different approaches to modelling induced innovation and technological progress based on model structure and features, which is developed in this paper, will be used to inform the work on integrating the results of Task 3.3 into the PRISMA models to strengthen the modelling of technological change in IAMs.

CMCC has estimated technological learning curves for key decarbonization technologies, including BECCS and DAC, and notably also included spill-overs between countries. A full bilateral spillover matrix for EU and OECD countries has been estimated and published as Kim and Verdolini (2023).

E3M has worked to endogenize R&D investments, both via public and private investments and represent knowledge spillovers between different technology paradigms in the GEM-E3 model. These modelling advancements will be coupled with the new empirical estimates for learning rates (task 3.3) to ensure the accurate representation of technological progress in the model.

The IIASA team developed an open-source Python-based tool to exogenously project technology costs



with regional specificity across scenarios. Future costs for the reference region are projected by applying a “progress rate”, and regional variation of technology costs can be derived in three ways within the tool: (1) static cost ratios, (2) convergence based on year, and (3) convergence based on economic development (GDP per capita). The modular nature of the tool allows for the flexibility to easily add or remove technologies, regions, and scenarios. The tool has been utilized for use in a 12-regional version of the IAM MESSAGEix-GLOBIOM and is currently being used within the IIASA MESSAGEix team as part of an internal process to update the model for the newly released SSP data. In collaboration with Rupert Way from the University of Oxford, we plan to benchmark the tool’s cost projections against empirically validated probabilistic cost forecasts. An abstract based on this work has been accepted to the IAMC Annual Meeting 2024 and a paper is currently being written with the intention to submit to a journal.

Task 3.5: Quantifying financing and innovation needs on the road to net zero (Lead: CMCC, Partners: E3M, ETH, UCAM, IIASA, WISE, ENPC, PIK; M19-42)

This task is only starting now with the goal to synthesize and implement the findings from the preceding tasks in a Net Zero context.

Significant results:

- Kim, Y. J., & Verdolini, E. (2023). *International knowledge spillovers in energy technologies*. Energy Strategy Reviews, 49, 101151. (<https://doi.org/10.1016/j.esr.2023.101151>)
- Pasqualino, R., Peñasco, C., Barbrook-Johnson, P., Senra de Moura, F., Kolesnikov, S., Hafner, S., Nijse, F. J. M. M., Lamperty, F., Hinder, B., Melekh, Y., Sharpe, S., Jones, A. W., Anadon, L. D., Lenton, T. M., & Grubb, M. (2024). *Modelling induced innovation for the low-carbon energy transition: a menu of options*. Environmental Research Letters, 19, 073004. (<https://doi.org/10.1088/1748-9326/ad4c79>)
- Lonergan, K. E., Egli, F., Osorio, S., Sansavini, G., Pahle, M., Schmidt, T. S., & Steffen, B. (2023). *Improving the representation of cost of capital in energy system models*. Joule, 7 (3), 469-483. (<https://doi.org/10.1016/j.joule.2023.02.004>)
- Egli, F., Orgland, N., Taylor, M., Schmidt, T., S., & Steffen, B. (2023). *Estimating the cost of capital for solar PV projects using auction results*. Energy Policy, 183, 113849. (<https://doi.org/10.1016/j.enpol.2023.113849>)
- Calcaterra, M., Reis, A., Fragkos, P., Briera, T., de Boer, H. S., Egli, F., Emmerling, J., Iyer, G., Mittal, S., Polzin, F., Sanders, M., Schmidt, T. S., Serebriakova, A., Steffen, B., van de Ven, D. J., van Vuuren, D. P., Waidelich, P., & Tavoni, M. (2024). *Reducing cost of capital to finance the energy transition in developing countries: A multi-model analysis*. Nature Energy. (<https://www.nature.com/articles/s41560-024-01606-7>)
- Noll, B., Steffen, B., & Schmidt, T. S. (2024). *Domestic-first, climate second? Global consequences of the Inflation Reduction Act*. Joule, Volume 8, Issue 7, 2024, Pages 1869-1873, ISSN 2542-4351. (<https://doi.org/10.1016/j.joule.2024.06.001>)
- Noll, B., Steffen B. & Schmidt, T. S. (2023). *The effects of local interventions on global technological change through spillovers: A modeling framework and application to the road-freight sector*. Proc. Natl. Acad. Sci. 120 (42) e2215684120. (<https://doi.org/10.1073/pnas.2215684120>)
- Sievert, K., Schmidt, T. S., & Steffen, B. (2024). *Considering technology characteristics to project future costs of direct air capture*. Joule, 8(4), 979-999. (<https://doi.org/10.1016/j.joule.2024.02.005>)
- Fisch-Romito V., Jaxa-Rozen M., Wen X., Trutnevyte E. (2024): *Multi-country hindcasting evidence on societal factors to include in energy transition modeling*. Nature Energy 2024, forthcoming.
- Lonergan, K. (2024). *Justice-Informed Energy Systems Planning: Clarifying Concepts, Identifying Alternatives, Testing Claims, and Making Robust Decisions*. Doctoral Thesis, available at <https://doi.org/10.3929/ethz-b-000706774>.
- Fierro L. E., Reissl S., Lamperti F., Campiglio E., et al. (2024). *Macro-financial transition risks along mitigation pathways: evidence from a hybrid agent-based integrated assessment model*. (<https://doi.org/10.21203/rs.3.rs-5111841/v1>). Under review at Nature Portfolio.



1.1.4.WP4: Lifestyle, digitalisation, material efficiency, and circularity [Months: 1-48]

Lead partners: IIASA; PBL

Demand-side transformation is a critical enabler of progress towards net-zero emission targets. Goods and services consumed in residential, commercial, transportation, and food sectors require energy and material inputs. Resulting resource extraction has adverse social and environmental impacts. Significant opportunities exist to reduce these impacts by increasing material efficiency and reuse (circularity), by shifting from physical to digital forms of useful service (dematerialisation), by using digitalisation to improve the efficiency of energy and material use, and by shifting lifestyles towards low-energy and low-carbon practises (also in relation to the postgrowth discussion). WP4 systematically improves IAM capabilities to represent and simulate these drivers of demand-side transformation in order to enrich and broaden the policy toolkit on the road to net zero. The LCA module has been developed and already linked to three IAMs and further work is ongoing to include a fourth one.

Deliverables:

*D4.1 Open-source lifestyle change model and IAM linkage source code [UOX, M18] - **achieved***

Milestones:

*6 Preliminary LCA data of bulk and speciality materials [CMCC, M12] - **achieved***

Task 4.1: Digitalisation of lifestyles (Lead: Oxford; Partners: IIASA, PBL, E3M, CMCC, WISE Europe; M1-36)

Digital technologies are rapidly becoming intertwined into daily life. This trend has potential benefits for climate change mitigation. Benefits include substituting energy intensive physical activities (e.g., teleworking), optimising how a system operates to enhance performance (e.g., home energy management systems), controlling or managing how a user-service is provided (e.g., smart lighting) and accessing a service instead of owning a good (e.g., ride-sharing). Oxford is developing a deeper understanding of the relationship between digitalisation, lifestyle change and climate change mitigation. Using empirical methods we will explore the impact of changes in known drivers of lifestyle change (e.g., ICT provision, low-carbon cognitions (values, agency, health), and GDP) on both historical and future uptake of digital technologies and circular economy behaviour.

Task 4.2: Simulating low-carbon lifestyle change (Lead: IIASA; Partners: UOX, PBL, E3M, ENPC; M1-36)

Significant lifestyle changes are essential for reducing future energy consumption and emissions to meet the goals of the Paris Climate Agreement. Expanding IAMs to endogenously represent lifestyle changes enables exploring a broader range of transformative solutions towards low-carbon futures. The LIFE (Lifestyle, Cognitions, Behaviour, and Context) model (Pettifor et al. 2023) captures the interplay between cognitions (mental processes guiding behaviour), behaviours (actions avoiding or reducing energy use), and context (material and social environments). It uses cluster analysis of large-scale social survey data from the UK, China, USA, and Australia to identify four lifestyle types which are characterized by different levels of low-carbon behaviours and cognitions. Soft-coupling the LIFE model representation of lifestyle heterogeneity and lifestyle change mechanisms with the demand modules of global IAMs enables endogenous simulation of lifestyle change as part of broader mitigation pathways analysis. A generic soft-coupling approach between the LIFE model has been developed and applied to three specific IAM demand modules - MESSAGEix-Buildings, CIRCEE and IMACLIM-R - as a proof of concept. The results of this coupling are summarized in Deliverable D4.1



and for the link between the LIFE model and MESSAGEix-Buildings the code was published in a GitHub repository under an open-source license. Several follow-up publications are in preparation.

As an additional activity, E3M works on improving the representation of low-carbon lifestyle change in its modelling tools, focusing on the transport and building sectors. A first paper on “Evaluating the impact of lifestyle changes: A scenario-based analysis for Europe’s residential buildings sector” is close to submission to a peer-reviewed scientific journal.

Task 4.3: Circular economy-based mitigation options (Lead: PBL; Partners: PSI, IIASA, E3M, PIK, CMCC; M1-36)

IIASA has utilized the “premise” package developed by PSI in “Mastrucci et al. (2024) Circular strategies for building sector decarbonization in China: A scenario analysis”. The prospective LCA package was used to determine the future embodied CO₂ emissions of buildings in China consistent with IAM scenarios modelled with MESSAGEix. More specifically, the LCA database ecoinvent 3.9.1 was partially updated with results of the MESSAGEix-GLOBIOM scenarios. This included changes in the LCA background data for electricity generation, liquid and gaseous energy carriers and the emission intensity of bulk materials. The novel methodology enabled the derivation of time series for both operational and embodied emissions that are consistent with climate mitigation scenarios from Integrated Assessment Models.

CMCC is currently working on a review paper that examines the incorporation of circular economy measures within integrated assessment models. This on-going paper aims to highlight the challenges associated with circular economy modelling and also elucidates potential future research trajectories. Moreover, CMCC is also working on the integration of the WITCH model with the PREMISE framework. E3M is working to improve the representation of circular economy-based mitigation options in the GEM-E3 model.

To better understand differences in base year data and projections of bulk material supply and demand in IAMs a model intercomparison study is currently under way. Four IAMs (IMAGE, MESSAGEix, REMIND, WITCH) will participate in the comparison study with endogenous bulk material supply and demand projections. In addition, the link between the IAMs and the “premise-PATHWAYS” tool developed under Task 4.4 will also be used to provide LCA results for the same set of commodities. The selected bulk materials include ferrous metals, non-metallic minerals, aluminum, and chemicals. In addition to the total demand for these commodities, the assessment will provide insights about demand projections in key economic sectors like construction, mobility and power generation. In addition to a business-as-usual scenario, material demands will also be compared for a mitigation scenario. The results of the prospective LCA will be compared to the original IAM pathways to analyze differences between the two methods. In preparation of the actual model intercomparison, the IAMC data template has been expanded to consistently cover material supply and demand categories.

Task 4.4: Key specialty materials for mitigation (Lead: PSI; Partners: PBL, IIASA, PIK; M1-36)

PSI has collected data regarding dynamic material intensities (changing over time until 2050 to represent expected technology development) for all key components needed to transform the energy system and economy towards net zero GHG emissions, such as batteries, electrolyzers, PV panels, wind turbines, fuel cells, etc. These material intensities published in an online repository represent the achieved milestone 6. These material intensities represent a key step towards the evaluation of material criticality in net zero scenarios; further steps, for which the work is ongoing, are embedding these material intensities in the prospective LCA framework “premise”, the design of the overall scenario assessment framework “pathways” (Sacchi and Hahn 2024) linking Life Cycle Assessment and IAM or energy system models and the integration of material flow analysis into this pathways framework. First applications of these developments have resulted in submission of two journal articles, which are available as pre-prints. Both of them address the transition of the Swiss energy system towards net zero greenhouse gas emissions and the consequences regarding future demand for critical raw materials. In a subsequent step, the explicit integration of material flows will consider component-specific lifetimes and recycling rates and allow to represent stocks and flows of all scarce materials considered. In addition, the existing methods in the context of Life Cycle Impact



Assessment for material criticality have been reviewed, gaps and needs for further development identified.

IIASA has developed the post-processing module for the MESSAGEix-GLOBIOM IAM required for an operational model linkage to the prospective LCA framework “premise”. The link allows to conduct prospective life cycle assessments that are consistent with future energy system changes projected by MESSAGEix-GLOBIOM scenarios. The most relevant elements that are incorporated include IAM projections for changes in electricity mix, liquid and gaseous fuels and the deployment of carbon capture in emission intensive processes.

Task 4.5: Integrated scenarios on lifestyles, digitalization, and circularity (Lead: IIASA/PBL; Partners: all IAM teams, UOX; M13-48)

This task will integrate the updated modules and models for an integrated assessment of scenarios, which has just started in January 2024. We have contributed the definition of lifestyles of the model scenario protocol developed for Milestone 8.

Significant results:

- Pettifor & al. (2024). *Endogenous simulation of low-carbon lifestyle change in global climate mitigation pathways*. Environ. Res. Lett. 19 014016. (<https://doi.org/10.1088/1748-9326/acf6d6>)
- Müller & al. (2024). *Decarbonizing the cement industry: Findings from coupling prospective life cycle assessment of clinker with integrated assessment model scenarios*. Journal of Cleaner Production, Volume 450, 141884. (<https://doi.org/10.1016/j.jclepro.2024.141884>)
- Open-source code for coupling the LIFE and MESSAGEix-Buildings models. (Available at https://github.com/iiasa/message-ix-buildings/tree/main/message_ix_buildings/life_coupling)
- Mastrucci & al. (2024) *Circular strategies for building sector decarbonization in China: A scenario analysis*. Journal of Industrial Ecology (<https://doi.org/10.1111/jiec.13523>)
- We have completed and submitted a paper to the Journal of Cleaner Production entitled “The Impact of Digital Innovations on Carbon Emissions” (submitted July 2024).
- Sacchi R., Hahn Menacho, A. *Pathways: life cycle assessment of energy transition scenarios*. Journal of Open Source Software. 2024. 9(103), 7309, <https://doi.org/10.21105/joss.07309>
- Hahn Menacho, A.J., Sacchi, R., Bauer, C., Panos, E., McKenna, R., Burgherr, P. (submitted). *The material-energy nexus in net-zero transition scenarios: exploring environmental trade-offs and uncertainties*. Submitted to *Resources, Conservation and Recycling*. pre-print: <https://www.psi.ch/de/media/97283/download?attachment>
- Hahn Menacho, A.J., Sacchi, R., Bauer, C., Panos, E., Moretti, C., Burgherr, P. (submitted). *Switzerland's net zero objective: quantifying impacts beyond borders*. Submitted to *Communications earth & environment*. pre-print: <https://www.researchsquare.com/article/rs-4915252/v1>
- Corbier D., Pettifor H., Agnew N. and Drouet L. (2024). *CIRCEE, the CIRCular Energy Economy model: Bridging the gap between economic and industrial ecology concepts*. Journal of Industrial Ecology, Wiley. <https://doi.org/10.1111/jiec.13587>
- Šimaitis J., Butnar I., Sacchi R., Lupton R., VaggC., Allen S. (2024). *Expanding Scenario Diversity in Prospective Lca and Exploring the Life Cycle Impacts of Decarbonising Global Electricity: Coupling the Tiam-Ucl Integrated Assessment Model with Premise and Ecoinvent*. Available at SSRN: <https://ssrn.com/abstract=5006961> or <http://dx.doi.org/10.2139/ssrn.5006961>

1.1.5.WP5: SDGs synergies and trade-offs, and biophysical climate impacts [Months: 1-48]

Lead partners: PBL; IIASA

WP5 is aimed at improving the representation of biodiversity (task 5.1), biophysical climate impacts, adaptation and maladaptation effects (task 5.2), economic climate impacts and risks (5.3) and other sustainable development goals (task 5.4). Teams in task 5.1 (biodiversity) are mainly working



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individually. However, there will be possibilities to integrate the work at a later stage. The teams are generally close to a first working version of their model improvement. Task 5.2 has an emphasis on climate change adaptation and maladaptation effects and is based on broadly four research streams that are currently underway (focusing on desalination, wastewater treatment, water scarcity, cooling options in buildings and an assessment of the representation of adaptation in models). In task 5.3, the analyses of labour productivity impacts will start in the coming months. Teams have started working on a first assessment of damage curve literature and data, which will be the basis for a model comparison. In the first half of 2025, task 5.4 will organize a model comparison exercise to improve and assess various SDG dimensions in IAMs. There is a flexible scenario setup where teams can focus on sub-topics of interest.

Deliverables:

None

Milestones:

- *MS9 “Model-based insights from integrated SDG scenarios as input for synthesis scenarios” - achieved*

Task 5.1: Improving the representation of biodiversity in IAMs (Lead: PIK; Partners: IIASA, PBL, CMCC, PSI; M1-36)

The work involves increasing the spatial resolution of biodiversity indicators in MAgPIE (PIK), developing a simplified GLOBIO Mean Species Abundance (MSA) emulator (PBL), quantifying land impacts on ecosystems, extend indicators (PSI), expand welfare functions RICE (CMCC).

The work has advanced very well. PIK has finalized the work and is currently preparing an article submission (von Jeetze et al., in prep). PBL has made a functioning tool that represents the MSA of plants well. PSI and CMCC have finalized initial analyses and model developments, including a scoping analysis regarding regionalized Life Cycle Impact Assessment in the context of metal and mineral mining, land use and biodiversity. Potential data sources have been collected and evaluated, regarding both location-specific inventory data as well as regionalized impact assessment methodology. CMCC has finalized and published work that incorporates the economic costs of climate-change-induced shifts in terrestrial vegetation cover in a regional IAM (Bastien-Olvera et al. 2023). CMCC is also working on a review paper about current inclusion of biodiversity in Integrated Assessment Models (IAMs) and proposed methods for endogenization. Similarly there is ongoing work on including natural capital in the WITCH model.

Task 5.2: Biophysical impacts, adaptation and maladaptation (Lead: PBL/IIASA; Partners: PBL, IIASA; M1-36)

There are several ongoing activities in task 5.2 that mainly have a strong focus on maladaptation effects (i.e. negative side-effects of adaptation efforts). IIASA is providing an econometric analysis and projections of desalination, wastewater treatment and drinking water treatment with a focus on energy consumption. Both teams will collaborate with ISIMIP (Inter-Sectoral Impact Model Intercomparison Project) to identify any water-related research synergies. PBL is performing a literature analysis of cooling options (AC + passive cooling), and is working towards a scenario analysis of cooling and heating demand and associated energy requirements. PBL will perform an assessment of the representation of adaptation in IAMs. This will involve a PRISMA-internal model expert elicitation as well as an assessment of the ISIMIP climate impact modeling work. The latter assessment can be combined with activities in task 6.1.

Task 5.3: Economic impacts of climate change (Lead: ENPC & CNRS; Partners: PBL, CMCC, PIK,



E3M; M1-36)

Task 5.3 involves two main activities: 1) An evaluation of the impacts of climate change on labour productivity (ENPC/CNRS and PBL), and 2) Implementation of damage functions into IAMs (all teams). The first activity will commence shortly after summer. For the second activity, teams are collecting relevant literature and data and assessing how this can be implemented in the models. The climate impact data represents impacts on different levels: on GDP; on production factors; and across sectors. The work is coordinated with the [ACCREF](#) and [SPARCCE](#) projects. The damage curve work will likely be assessed in a model comparison exercise (with an option to focus on overshoot scenarios). Alternatively, this work could also be done under task 6.1. In addition to the main activities, E3M is also developing a model-endogenous damage function, with explicit impact-specific damages linking specific impact channels with economic costs and productivity variables.

Task 5.4: Integrated SDG scenario assessment (Lead: PBL; Partners: IIASA, PIK, CMCC, E3M; M13-48)

Task 5.4 will explore the sustainable development consequences of climate strategies and options of achieving multiple SDGs, including SDG13 (Climate Action). At the core of the task, various SDGs will be assessed with IAMs (GEM-E3, IMAGE, MESSAGEix, REMIND-MagPIE). The SDG representation and implementation in the model benefits from earlier work in other research projects (e.g. [SHAPE/PICASSO/NAVIGATE](#)). The SDGs will be assessed in a model comparison exercise that allows for differences in scenario setup for the different models, due to differences in model focus. The results will be shared via a set of dedicated SDG indicators, including climate action (all teams), energy access (PBL, IIASA), air quality and related health impacts (CMCC, PBL), poverty and inequality (PIK, CMCC, E3M), sustainable production and consumption (based on input from WP4) (IIASA, PBL) and life on land SDGs, energy and food security (PBL, E3M). The scenario protocol will be finished by end-2024. The scenario runs are aimed to be finished mid 2025. Milestone M9 was delivered in December 2024. This provides a basis for the scenario exercise.

Significant results:

- Bastien-Olvera, B.A., Conte, M.N., Dong, X., Briceno, T., Batker, D., Emmerling, J., Tavoni, M., Granella, F., Moore, F.C., (2023). *Unequal climate impacts on global values of natural capital*. Nature 1-6. (<https://doi.org/10.1038/s41586-023-06769-z>).

I.1.6. WP6: Robust and resilient climate mitigation and adaptation pathways **[Months: 1-48]**

Lead partners: CMCC; ENPC

This WP aims at capitalizing on the methodological developments carried out in WP2-5 to provide a revised assessment and understanding of climate strategies. Although most of the task core work is foreseen for the second part of the project, task work has already begun and in some cases provided measurable contributions. Task 6,1 has only recently started and is leveraging the impact work from WP5 and adding adaptation and resilience layers on top. Group meetings have already begun. Task 6.2 is advancing fast, with already one publication and individual research work. Task meetings have taken place regularly with scheduled community activities. In Task 6,3 the shared socio-economic pathways (SSPs) have been revised and initial implementation in the models have begun. Task 6.4 has just begun. The main outcome has been the drafting and vetting of the scenario protocol which is summarized in Milestone 8.

Deliverables:

None

Milestones:



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*8 Scenario protocol for new pathways and Net zero implementation for policy analysis [CMCC, M18] - **achieved***

Task 6.1: Integration of impacts and adaptation (Lead: CMCC; Partners: PBL, IIASA, E3M, WISE, ENPC; M13-42)

This task draws on results on climate change damages and adaptation from WP5, integrating new developments into integrated assessment models. The improvements will be used for enhanced scenario analysis. Work on this task has recently started and a first stocktake workshop will take place in September. It will gather current and planned developments on how partners are integrating adaptation and new damage functions into different IAMs, mindful of the complementarities and synergies across models.

Task 6.2: Uncertainty exploration and robust decision making (Lead: ENPC; Partners: UNIGE, CMCC, UCAM; M1-36)

The aim of this task is to explore and quantify the uncertainties characterising model scenarios and to identify emission reduction (and adaptation) strategies which are robust to deep uncertainties. The partners involved in the task started working with computational (e.g., scenario discovery) and machine learning (e.g. clustering) techniques to quantify the key uncertainties in existing scenario ensembles, most notably the IPCC AR6 scenario database. A first article was published, exploring the uncertainties characterizing fossil fuel reduction pathways in mitigation strategies: Achakulwisut et al. (2023). First analyses have also started to use social choice models - including models beyond standard economic ones (e.g., capturing inequality, risk and ambiguity aversion) - to study policy relevant outcomes under the uncertainty of scenarios as characterized. Finally, the project envisages to organize one of the summer schools within PRISMA, in 2025 or 2026, on the topic of methods for uncertainty analysis.

Task 6.3: Scenario pathways: an expanded exploration of futures (Lead: CMCC; Partners: all partners; M1-48)

This task aims to develop new scenarios pathways expanding on the workhorse of the shared socio-economic pathways (SSPs). In the project meeting in early 2024, we had extensive discussions about revising the SSPs main assumptions. Meanwhile, the scenario community has developed revised projections for demographic and economic variables for all the 5 SSPs. The models participating in PRISMA have begun incorporating the new socio-economic assumptions and developing revised SSP versions. The revised SSPs appear to be closely correlated with the existing ones, but a formal assessment is still undergoing. Variants on socio-economic assumptions will be needed to expand the set towards alternative future pathways.

Task 6.4: Policy synthesis - impact assessment of updated national, EU, and international climate policies (Lead: CMCC; Partners: all partners; M13-48)

The task focuses on assessing the impact of updated national, EU, and international climate change policies, including the latest European 2040 targets and developments toward the UNFCCC Global Stocktake. Although the policy assessments are forthcoming, we have laid out the key building blocks of a scenario protocol addressing the impact assessment of climate policies. This protocol is designed to be flexible to accommodate the fast-changing evolution of climate policies. The protocol adheres to five principles: it is innovative and complementary to previous and ongoing model comparisons, leverages the PRISMA model's capacity and methodological innovations, is relevant for decision-making including negotiations and the private sector, engages the larger modeling community, and remains flexible to accommodate new policies as they arise.

In addition to the principles, we identified five organizational criteria for the scenario protocol. These



criteria ensure the protocol addresses realistic policies while maintaining long-term climate ambition and encouraging diversity in socio-economic development patterns. The criteria include a focus on realism by avoiding idealized scenarios and vetting short-term behavior, ensuring ambition compatible with the Paris Agreement, encouraging diversity in Shared Socioeconomic Pathways (SSPs) and assumptions, adopting an open Model Intercomparison Project (MIP) approach, and pre-registering study and research design for transparency.

We have developed an initial structure for the scenario protocol with the overarching theme of addressing climate overshoot in the context of the Paris Agreement goals. WP6 will develop realistic policies that diverge from the traditional focus on uniform carbon pricing across regions. Instead, these policies will differentiate carbon prices across time and space and include additional measures such as subsidies and industrial policies. The developed policies are expected to result in overshoot pathways, demonstrating how the overshoot can be contained. Different Work Packages (WPs 2, 3, and 4) will run complementary scenarios to evaluate enabling conditions that can limit climate overshoot. Meanwhile, WP5 and WP6 will examine the economic and physical hazards of the overshoot scenarios.

Significant results:

- Achakulwisut, P., Erickson, P., Guivarch, C., Schaeffer, R., Brutschin, & Pye, S. (2023). *Global fossil fuel reduction pathways under different climate mitigation strategies and ambitions*. Nature Communications, 14 (5425). (<https://doi.org/10.1038/s41467-023-41105-z>)

1.1.7.WP7: Management and Dissemination [Months: 1-48]

Lead partner: CMCC

The overall objective of this Work Package is to ensure the smooth and efficient coordination of the various research activities under the PRISMA project, alongside ensuring robust administrative management. WP7 is led by the project coordinator CMCC, assisted by all partners. During the first half of the project CMCC consistently engaged in sound project management. The implementation of the work plan, its supervision and the coordination of research activities were ensured through the regular virtual meetings of the Project Steering Committee (PSC), the central decision-making body of the PRISMA project, composed of one representative from each project partner. Furthermore, WP leaders supported the PSC, informing about the WP activities and problems, to eventually take the appropriate and timely corrective actions. CMCC set up and managed the internal communication of the consortium, e.g. through a Google Drive folder for data sharing and the organization of Consortium meetings.

Deliverables:

D7.1 Critical risks analysis [CMCC] - Submitted

D7.2 Dissemination, Communication & Exploitation Plan [CMCC] - Submitted

D7.3 Data Management Plan [CMCC] - Submitted

D7.4 Ethics Management Plan [CMCC] - Submitted

D7.5 Mid-term project report [CMCC] - Submitted

Milestones:

MS1 Kick-off project meeting [CMCC] - achieved

MS3 Website with link to PRISMA explorer set-up [CMCC] - achieved



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Task 7.1: Administrative coordination (Lead: CMCC; Partners: all partners; M1-48)

This task is related to the overall responsibility for the project. During the first half of the project, as coordinator, CMCC acted as an interface between the Consortium and the European Commission. PRISMA Consortium Agreement was drafted and signed by all the partners and its maintenance was ensured. Moreover, legal, administrative and financial management of the project, in compliance with contractual obligations and the Commission's rules, was ensured. Together with the participation of all WPs' Leaders, CMCC supervised the implementation of the project's work plan, the coordination between different WPs and the timeliness and quality of the deliverables.

Furthermore, the main activities of this task were implemented during this period. They include the management of the internal communication with the EC and within the Consortium; the monitoring of project progress against milestones and deliverables; the identification and management of critical risks, related to the project implementation and the supervision of ethical and gender aspects.

Task 7.2: Scientific coordination (Lead: CMCC; Partners: all partners; M1-48)

Throughout the first half of the project, CMCC oversaw the implementation of the project's work plan and coordinated research activities with representatives from each institution, ensuring the high scientific quality standards of the project. Monthly virtual Steering Committee meetings were held to facilitate communication between work packages and plan next steps. CMCC monitored project milestones and deliverables, reminded beneficiaries of deadlines, and organized internal communication through a shared Google Drive folder. This folder contains a project dashboard, meeting minutes, communication activities, publications, datasets, official documents, and materials for meetings and events, as well as individual folders for each work package.

Task 7.3: Monitoring and quality assurance (Lead: CMCC; Partners: all partners; M1-48)

This task focuses on the identification of monitoring and quality assurance mechanisms to ensure the quality controls for the scientific activities and deliverables of the project and to identify delays or problems with specific tasks sufficiently early so that correcting measures can be implemented.

Two project meetings were organized, respectively by CMCC (13-15/02/2023, PRISMA kick-Off Meeting, Milan (Italy) and PBL (30-31/01/2024, PRISMA Consortium Meeting, The Hague (The Netherlands)). Moreover, WP leaders organized online meetings for their respective work-packages, as needed. The PRISMA Data management Plan (D7.3) was developed and submitted to the EC. Moreover, the integration of data quality assurance mechanisms was integrated to allow a continuous process of monitoring and updating throughout the lifetime of the project. In particular, all deliverables have been reviewed by at least one internal reviewer prior to submission, thanks to a rotation system.

An Advisory Board (AB) has also been appointed, during the first months of the project. The AB is the core group of experts and stakeholders, aiming to provide vital input from policymakers and experts in science-based policymaking during the project's lifetime. It is composed by four members:

- Laura Cozzi (Director of Sustainability, Technology and Outlooks at the International Energy Agency),
- Leon Clarke (Director of Decarbonization Pathways at the Bezos Earth Fund and a Senior Fellow at the University of Maryland's (UMD's) Center for Global Sustainability (CGS)), and
- Asami Miketa (Head Energy Transition Planning and Power Sector Transformation at International Renewable Energy Agency (IRENA)).
- Vicky Pollard (Head of the unit in the European Commission's Directorate General for Climate Action).

The Advisory Board has been invited to attend the Consortium Meeting in The Hague to give their feedback on the research activities of the project. They have also been invited to the next project meeting, which will take place in Athens, in 2025.



Task 7.4: Scientific dissemination, networking and collaboration (Lead: CMCC; Partners: all partners; M1-48)

All the activities related to Communication and Dissemination within PRISMA have been detailed in the Deliverable 7.2 Dissemination, Communication & Exploitation Plan.

This Plan describes the specific activities and presents the detailed timeline of outreach and the dissemination of the results and knowledge generated in the project tailored for the different interested target groups.

The communication plan defines various actions and communication channels, outlines the strategy for communication and dissemination, and provides communication material, considering the needs of and differences between the diverse target groups. Following this plan and the definition of a graphical identity for the project, several dissemination activities have been implemented during the first half of the project.

Since then, the website of the project has been regularly updated with news from the consortium and with blog posts, resulting in numerous entries till Dec 2024, approximately one per month. Also, the PRISMA hashtag (#net0prisma) has been regularly used on social media platforms. PRISMA has recently left Twitter and moved to LinkedIn.

Significant results:

- The graphical identity materials supporting the dissemination and communication of the project's results were defined early in the project and are fully deployed and adopted by all partners.

1.2.Impact

The PRISMA project is expected to have significant impacts across multiple domains, aligning with the goals of the EU Strategic Plan and contributing to broader climate action and policy objectives. In the following list, we show the progress thus far in 9 key impact categories.

1. Advancing Integrated Assessment Models (IAMs):

PRISMA has already led to further development of leading IAMs, with significant developments having been made in biodiversity, circular economy, and structural change. Moreover, the coupling of IAMs and financial sector modelling has been pursued and innovation dynamics have been expanded.

2. Supporting Climate Policy Processes:

The project has contributed to the 2040 climate target discussion in the EU, having contributed to the impact assessment report. Moreover, two policy briefs on this topic have been produced and one already presented at a high-level event in Brussels. The scenario protocol of PRISMA is designed to further support the next rounds of international climate negotiations towards the next global stocktake.

3. Contributing to International Scientific Assessments:

PRISMA's outputs have already revised attention and citations in the relevant literature. The scenario protocol for the model comparison has been set up with an explicit focus on informing the 7th assessment of the IPCC and the global stock take of 2028, given the stated goal of aligning IPCC and international negotiations. Moreover, several consortium members have



submitted their candidature to the scoping meeting of the 7th assessment report of the IPCC. The meeting will be held in December 2024 and will define the outlet and content of the report. Several consortium members have directly contacted and discussed issues with the IPCC leadership, including the Chair and the WGIII co-chairs.

4. Increasing Model Transparency and Usability:

The IAMC wiki has been further developed within the project to ensure transparency about climate economic models and IAMs.

5. Enhancing Coherence Between Climate Action and Other Objectives:

PRISMA improves the representation of interactions between climate action and other environmental/sustainability objectives, such as biodiversity, climate justice, fair finance and innovation. This allows for more realistic assessments of co-benefits and trade-offs in climate policy.

6. Promoting Citizen Involvement:

The “low-carbon lifestyle change simulator” has been finalized and will be made available publicly, and the discussion of different lifestyles has been started. In the second half, citizen surveys will further contribute to the people dimension to foster better understanding of how small-scale actions contribute to large-scale climate policy objectives.

7. Scientific and Policy Relevance:

PRISMA is expected to generate at least 5 publications in top-ranked journals; so far, it has already produced 19 publications, out of which several in leading international outlets including Nature and PNAS. The first series of stakeholder workshops has been successfully completed and several webinars have been held. A Zenodo community has been created at <https://zenodo.org/communities/net0prisma> where all publications will be made available. More than 30 presentations of PRISMA research have been done in international conferences.

8. Capacity Building:

Through capacity building initiatives, including summer schools, webinars, and hands-on sessions at dedicated conferences (IAMC, ECEMP), PRISMA aims to make models more accessible to scientific target groups, notably early career researchers and modellers, national modelling teams in Europe and elsewhere. This commitment will help to build and improve national modelling capacities, increase the user base of the existing large scale IAMs and the networking and collaboration on the scientific and policy side.

So far, the following activities have been organized:

- Event on “EU’s Climate targets 2040: Bridging modelling and policy”, on September 13, 2023



- Stakeholder Workshop on Climate Finance at IAMC 2023 on “Relevance of climate scenarios for finance and private sector”, on November 16, 2023
- ECEMP 2023 online conference, as co-organizing project
- Stakeholder Workshop on Biodiversity and Biophysical Impacts, on November 22, 2023
- Stakeholder Workshop on Impacts of climate (in)action, on January 22, 2024
- PRISMA Lifestyle Webinar, on January 25, 2024
- Stakeholder Workshop on Sector-specific Green Transformations, on March 5, 2024
- Stakeholder Workshop on Citizens and Behavioural Change, on March 14, 2024

A Finance Workshop, organized by E3Modelling, has been planned for January 2025. The main objective is to bring together leading climate transition researchers and scientists with practitioners from the finance field to discuss about the financial requirements of the low-carbon transition and how emerging climate risks impact the operation of financial institutions.

9. Long-term Impact:

The methodological developments and innovations produced by PRISMA have resulted in new or updated model code repositories including the RICE50+, PREMISE, and LIFE models so far. The collected data on technology costs and probabilistic forecasts is also being made available for future applications, also by other models.

The following table summarizes the progress towards the impacts in terms of **key performance indicators (KPIs)**, identified in the Grant Agreement:

Tools	Number	Key Performance Indicators (KPI)	Objective	Dec 2024, actual value
Website and blog	1 blog post per month	Matomo analytics	1000+ visits by the end	< 100 visits per month
Social Media	Monthly	LinkedIn, RG Analytics	20 interactions monthly	Average of 400 impressions and 3 likes monthly on Twitter and LinkedIn
Scientific Publications	18+	Number and citations	5+ citations on average	26 publications
Conference presentations	5 per year	Number of presentations	500+ attending academic events by the end	33 conference presentations
Stakeholder workshops	2 for each of the 5 work streams	Number and type of participants	Minimum 10 participants	1) Stakeholder Launch Event on EU's 2040 Climate Target, on September 13, 2023 (62 people on-site and approx. 300 online, from DG ENER, DG CLIMA, Energy and Climate NGOs, EU Industry Associations) 2) Stakeholder Workshop on Climate



				<i>Finance on November 16, 2023 (plenary session at IAMC 2023, with participants from IMF, World Bank, OECD, Ministries of Finance and Academics)</i> <i>3) Stakeholder Workshop on Biodiversity and Biophysical Impacts on November 22, 2023 (online, approx. 100 participants from DG ENV, DG CLIMA, ECF, EEB)</i> <i>4) Stakeholder Workshop on Impacts of climate (in)action on January 22, 2024 (online, 48 participants from DG ENV, DG CLIMA, JRC Environmental NGOs, Academics)</i> <i>5) Stakeholder Workshop on Sector-specific Green Transformations on March 5, 2024 (close-door meeting, approx. 20 people from DG ENER, DG CLIMA)</i> <i>6) Stakeholder Workshop on Citizens and Behavioural Change on March 14, 2024 (online, 30 participants from Industry and consumer representatives)</i>
Stakeholder Database		> 1,000 stakeholders	Operational stakeholder database	<i>Operational, managed by Bruegel</i>
Data visualization Tools	3 (Explorer, Visualization, DPET)	Web analytics, backlinks	1000+ visits per month by the end	<i>1 so far</i>
Webinars	Around 3-4 per year	Number of participants	100+ per webinar	<i>5 (approx. 100 participants per webinar)</i>
Online dissemination events and final conference	3+1	Number of participants	100+ participants per event	<i>2 (IAMC 2023 plenary session on climate finance and ECEMP 2023 as co-organizing project);</i> <i>> 100 participants per event</i>
Policy briefs	5	Number and citation in policy documents	At least 5 references	<i>2</i>
Press releases	Approx. 12	Press review	50+ journalists reached	<i>2</i>

Table 4: Progress over KPIs



2. DEVIATIONS FROM ANNEX 1 AND ANNEX 2 (IF APPLICABLE)

2.1. Tasks/objectives

The MS 4 (First round of the five research stream workshops [Bruegel, M12]) was delayed by 5 months, as organizing the 5 workshops turned out more challenging given not many results had been produced to provide relevant material to stakeholders. As the extension was granted, eventually all five workshops were successfully completed by M17.

In WP3, the integration of a more detailed financial system into the large-scale IAMs turned out to be more challenging than anticipated, due to conceptual challenges to add a banking sector, and numerical challenges to run models jointly. The concept of model coupling has been used more successfully, notably with a pioneering modelling coupling between WITCH and DSK. E3M on the other hand managed to further integrate the financial sector in its CGE model, while in other large-scale IAMs the integration has only been partially feasible until now.

