ENhancing our understanding of Trade Impacts on Climate, industries, and the Environment

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D3.1 - Mapping of model improvements: what, why, how

WP3 – Extend and improve the modelling of trade and its environmental impacts

31/12/2025

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EC Summary Requirements

1. Changes with respect to the DoA

No changes with respect to the work described in the DoA.

2. Dissemination and uptake

Internal use for management and work organisation.

3. Short summary of results (<250 words)

This deliverable outlines the ambition of WP3, structured around five model-development axes designed to enhance assessment capabilities from Month 30 onwards. It defines, for each task, the objectives, scope of work, and planned activities to ensure steady progress, sustained dialogue between task leaders and modelling teams, and coherent enhancements to be used in WP4 and WP5 for scenario and policy analysis.

A preliminary survey, conducted in May 2025 with fourteen models from ten teams, provided an overview of the modelling tools involved and the expectations of the modellers. The results reveal a predominance of macroeconomic models, particularly computable general equilibrium models, many of which rely on GTAP data and operate at global scale. Several models already incorporate endogenous technological change, bilateral trade flows, environmental indicators, or land-use representation.

The work plans build on the survey findings to align modellers' priorities with the ENTICE research agenda. While most enhancement tasks are independent, some require close coordination with WP2. WP3 will therefore organise monthly meetings to review progress, alongside targeted discussions between task leaders and modelling teams, to ensure effective collaboration and timely implementation of the planned model developments.

4. Evidence of accomplishment

This report.

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Preface

In today's interconnected global economy, understanding the trade-climate nexus is more critical than ever. Trade policies significantly influence environmental outcomes, while climate change affects trade flows. However, the complex relationship between these areas remains insufficiently explored, often due to data limitations, gaps in economic modeling and the evolving nature of global supply chains. The ENTICE project aims to bridge these knowledge gaps by advancing our understanding of the trade-climate-industry (TCI) nexus. It examines how trade policies impact environmental sustainability and how climate policies shape global trade dynamics. By developing fact-based insights and innovative modeling tools, ENTICE supports informed decision-making at this crucial intersection of trade, climate, and sustainability.

E3M – E3-MODELLING AE	EL	
CMCC – FONDAZIONE CENTRO EURO-MEDITERRANEOSUI CAMBIAMENTI CLIMATICI	IT	
WI – WUPPERTAL INSTITUT FUR KLIMA, UMWELT, ENERGIE GGMBH	DE	
REFORM – FUNDACJA INSTYTUT REFORM	PL	
VUA – STICHTING VU	NL	
HOL – HOLISTIC IKE	EL	
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UNIVR – UNIVERSITA DEGLI STUDI DI VERONA	IT	
SEURECO – SEURECO SOCIETE EUROPEENNE D'ECONOMIE SARL	FR	
ICCS – EREVNITIKO PANEPISTIMIAKO INSTITOUTO SYSTIMATON EPIKOINONION KAI YPOLOGISTON	EL	
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Executive Summary

Five model-development axes (sector disaggregation; new trade theory; technological change; material flows and land use and environmental indicators) outline the ambition of WP3 of the ENTICE project and are expected to deliver enhanced model-assessment capabilities from Month 30 onwards. This deliverable therefore defines, for each task, the objectives and intended scope of work, and sets out a work plan for the coming months. Its purpose is to ensure effective progress across modelling tasks and activities, sustained dialogue between task leaders and modelling teams, and the development of coherent, relevant, and implementable modelling improvements to be used in WP4 and WP5 for scenario and policy analysis in the climate-trade nexus.

As a preliminary step—and given the diversity of modelling tools within ENTICE—we designed a comprehensive survey addressing both the characteristics of the models and the expectations for improvements of the modelling teams within ENTICE. The survey was circulated to modellers in May 2025. Fourteen models, representing ten different modelling teams, responded, providing a detailed overview of the modelling tools involved in ENTICE and of the modellers' interest in the planned enhancements. The survey results served to identify the modelling teams' priorities and formed the basis for a series of five workshops focused on specific modelling improvements that launched the model-development tasks.

Among the fourteen responding models, the majority—eight in total—are macroeconomic models, predominantly computable general equilibrium (CGE) models. Half of the models—including all CGE models—use GTAP as their main source of economic data, and most of them operate at a global scale. With regard to trade, eleven models represent trade flows, nine of them further model bilateral flows, and seven of the eight macroeconomic models rely on an Armington approach (Armington, 1969). The survey also indicates that five models already incorporate mechanisms for endogenous technological change, based, inter alia, on research investment and/or learning-by-doing. Four models include a representation of land use (two of these models are macroeconomic). Moreover, five models already incorporate some form of environmental indicators besides GHG emissions, such as biodiversity, water use, nitrogen use, etc.

The developments proposed within the ENTICE project aim to address several shortcomings in modelling capacity, particularly in relation to the trade-climate-industry framework. The survey revealed that the suite of ENTICE models is relatively diverse in both type and capability, even though macroeconomic models—especially CGE models—dominate. The report then summarises, for each of the five development/enhancements axis, the relevant context and the objectives with respect to the Trade-Climate-Industry nexus and the current state of the art in modelling. It also presents the work plan for each task, building on the survey results to align the modellers' priorities with the ENTICE research agenda.

While the proposed enhancement tasks are largely independent, some have strong interdependencies. To ensure effective, smooth, and productive collaboration between WP2 and WP3 where such links exist (notably tasks 2.2/2.3 with task 3.2, and task 2.4 with task 3.6), the leaders of the relevant tasks—as well as the work-package coordination teams—will be invited to participate in all related meetings and workshops. In addition, WP3 will organise monthly one-hour meetings to review the progress of each task, with a programme aligned with the work plan. Each meeting will follow a standard format: two tasks will present their progress and discuss critical issues for approximately 20 minutes each, with the remaining time devoted to cross-cutting topics or specific issues requiring discussion. This organisation of the work should allow each type of improvement to be ready and reported at Month 30 in the set of deliverables D3.3 to

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D3.7 and two months later, Month 32, in the deliverable D3.8, summarising the work and providing open code and data for all WP3 activities. We also have the deliverable D3.2, due in Month 17, that will enable us to take stock of the improvements underway, to correct, complete and refine the work plan, taking into account the first few months of work, and finally, it will allow us to implement solutions to mitigate any issues that may be encountered.

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1 Introduction

The ENTICE project encompasses numerous modelling tools that will be enhanced to improve their representation of the trade–climate–industry (TCI) nexus along five main axes.

The first axis concerns the expansion of sectoral coverage within the models, in particular by extending the representation of emissions-intensive industries (aluminium, iron and steel, cement, etc.) and manufacturing sectors producing clean energy technologies (e.g. electric vehicles, batteries, wind turbines, solar photovoltaics and electrolysers). This work will be carried out in coordination with, and in coherence with, the new data produced in WP2. The objective is to enable the models to capture more accurately sectoral dynamics—on both the supply and demand sides—arising from the implementation of strong climate-mitigation measures and trade-related policies, as well as to better assess the associated effects on competitiveness. Given the project's strong focus on trade, the second axis concerns improvements to the modelling of trade itself. Most macroeconomic models currently rely on the Armington (1969) framework to represent international exchanges of goods and services. However, economic theory has advanced significantly with the development of New Trade Theory and subsequent intra-industry trade approaches, which have only rarely been incorporated into large-scale macroeconomic models. The project will therefore develop a general methodology to integrate these theoretical advances into such models from simple but widely applicable to more in-depth and advanced approaches. Complementing these efforts, the third axis focuses on the representation of technological progress in large-scale models. This is critical within the TCI framework, particularly for capturing the "technique effect", one of the three core channels—alongside the "scale" and "composition" effects—commonly used to analyse the economics of trade and trade policy and the environment. WP3 will therefore propose methodological improvements to strengthen the treatment of endogenous technical change, especially in relation to climate and trade through mechanisms such as knowledge diffusion, technology diffusion and market structure. As the energy transition depends, among other factors, on substantial volumes of new critical raw materials, and given that macroeconomic models must remain consistent with physical constraints, the fourth axis will develop a proof of concept linking large-scale macroeconomic models with a physical input–output modelling tool. Finally, the fifth axis aims to improve the models' capacities to better account for agricultural and land-use greenhouse gas emissions and to assess the environmental impacts of trade, climate and industrial policies through the development of environmental indicators, besides GHG emissions and energy consumption, to implement into models.

Together, these five axes set out the ambition of WP3 and will lead to enhanced model and scenario assessment capabilities from Month 30 onwards. This deliverable therefore defines, for each task, the objectives and intended scope of work, and establishes a work plan for the coming months. Its purpose is to ensure effective progress across tasks, sustained dialogue between task leaders and modelling teams, and coherent, relevant and implementable modelling improvements to be used in WP4 and WP5 for scenario and policy analysis.

The document begins by presenting the main results of a model survey conducted to gather technical information on the models involved in ENTICE, their current and expected future capabilities, and, in particular, the interest of different modelling teams in the five development axes (section 2). It then provides a detailed description of the context, objectives, proposed approaches and work plan for each task aimed at delivering these enhancements (section 3). Finally, section 4 presents how the work in WP3 on models' improvements will be coordinated.

2 Models' survey

2.1 Objectives

ENTICE comprises a suite of modelling tools that differ in their geographical and sectoral coverage, their capacities to assess TCI policies, their theoretical foundations, and their respective ambitions regarding the developments to be undertaken in WP3. To map these differences, we designed a comprehensive survey on the models and on the expectations of the various modelling teams (see Annex 6.1 for a detailed list of the questions), which was circulated to modellers in May 2025.

The survey took the form of a multi-sheet spreadsheet. The sheets addressed: (*i*) general characteristics of the models (including basic information, geographical scope and sectoral coverage); (*ii*) the models' capabilities in assessing climate-mitigation options and policies; and (*iii*) for each development axis, both the current state-of-the-art within the model and the team's expectations regarding the proposed enhancements under ENTICE. Fourteen models, representing ten different modelling teams, participated in the survey, providing a comprehensive overview of the modelling tools involved in ENTICE and of the modellers' interest in the planned model enhancements. The survey results subsequently served to identify the priorities of the modelling teams and formed the basis for a series of five workshops that launched the model-development tasks. These workshops were held in early autumn 2025, between the 26th of September and the 9th of October (see Milestone MS10 for further details).

The following subsections summarise the survey results along two dimensions: the characteristics of the models and the expectations of the modelling teams concerning potential improvements. A description of the models is provided in Table 16 to Table 29 in section 6.2 (Annex).

2.2 Synthesis

2.2.1 Models' main features

Among the fourteen models that responded to the survey, the majority—eight in total—are macroeconomic models, predominantly Computable General Equilibrium (CGE) models. This group includes ENVISAGE[1], GEMINI-E3[2], GEM-E3[3], the ZEW model and ICES[4], alongside three neo-Keynesian general equilibrium (NKGE) models: FIDELIO[5] and the EU[6] and World[7] versions of NEMESIS (Figure 1). The remaining six models are:

[1] https://mygeohub.org/groups/gtap/envisage-docs
[2] https://www.i2am-paris.eu/detailed_model_doc/gemini_e3
[3] https://e3modelling.com/modelling-tools/gem-e3/
[4] https://www.icesmodel.org/
[5] https://joint-research-centre.ec.europa.eu/projects-and-activities/trade-and-industrial-policy-analysis/industrial-policy/fidelio-model_en
[6] https://www.erasme-team.eu/en/the-nemesis-model/
[7] https://nemesis-world.readthedocs.io

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IMAGE[8], an Integrated Assessment Model (IAM); GLOBIOM[9], a partial equilibrium model; OPEN-PROM[10], an open source energy system model and IAM; DYNERIO[11], a dynamic physical stock–flow model; SORMAC-25[12], an infinite-horizon optimal control model; and LBAM, a static trade model.

Half of the models, including all CGE models, use Global Trade Analysis Project (GTAP) as their main source of economic data. All of these rely on the most recent GTAP release, GTAP 11c[13], except IMAGE, which uses an older version. Some of these models also use alternative or complementary GTAP databases: GTAP-E (an energy-environmental version) is used by ICES, the ZEW model and ENVISAGE, the GTAP-Power (an electricity-detailed extension) and GTAP-CE (representing primary, secondary, and recycling activities for targeted economic activities) are mobilised by ICES and ENVISAGE whereas the later can also rely on GTAP Food balance sheets (nutritional accounts based on the FAO data). The NKGE models rely on alternative data sources: NEMESIS EU uses Eurostat, WIOD and the OECD; the NEMESIS World version uses EXIOBASE and the OECD; and FIDELIO is based on FIGARO from Eurostat and the OECD. GLOBIOM's economic data originate from FAOSTAT, while the LBAM model employs a diverse set of sources, including UNIDO, WITS, Eurostat, the IEA, the IPCC and the UN. Finally, DYNERIO, as a physical stock–flow model, does not use economic databases, but employs USGS data about mining and refining of materials and IEA data on energy technology capacities.

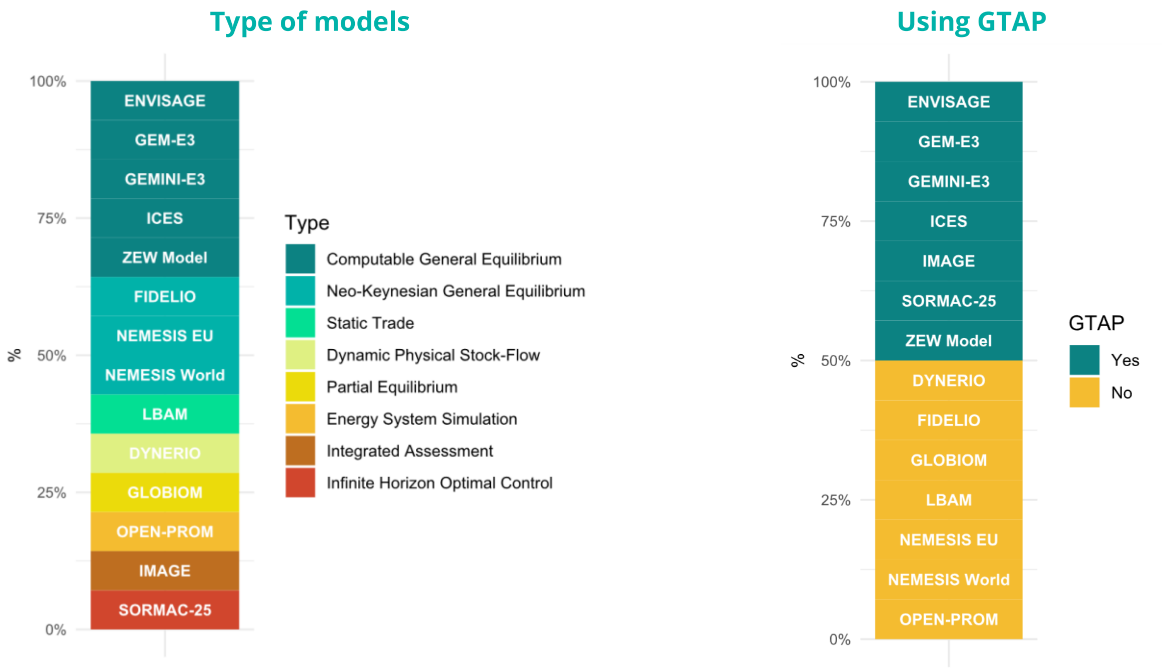

Figure 1. Models' type and GTAP users

Figure 2 illustrates the geographical coverage of the models. Most have a global scope, with the exception

8 https://models.pbl.nl/image/Welcome_to_IMAGE_3.3_Documentation
9 https://globiom.org/index.html
10 https://e3modelling.com/modelling-tools/prometheus
11 https://www.i2am-paris.eu/detailed_model_doc/dynerio
12 https://www.ordecsys.com/page/sormac
13 https://www.gtap.agecon.purdue.edu/databases/v11/index.aspx

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of the ZEW and NEMESIS EU models, which are restricted to the European Union (and some neighbourhood countries), and the DYNERIO model, which is a multi-regional (but not necessarily global) model. The LBAM model has a flexible geographical scope. Regarding geographical granularity, ENVISAGE covers more than 50 countries or regions, and can extend up to 160. FIDELIO, GEM-E3, OPEN-PROM and GLOBIOM cover between 30 and 49 regions. NEMESIS EU, NEMESIS World, IMAGE and GEMINI-E3 distinguish between 15 and 29 regions, while SORMAC-25 and DYNERIO are a bit more aggregated and represent between 0 and 15 regions. Finally, the ZEW model, LBAM and ICES offer flexible regional aggregation, which can be adapted to the needs of the study within the limits imposed by the resolution of the underlying data.

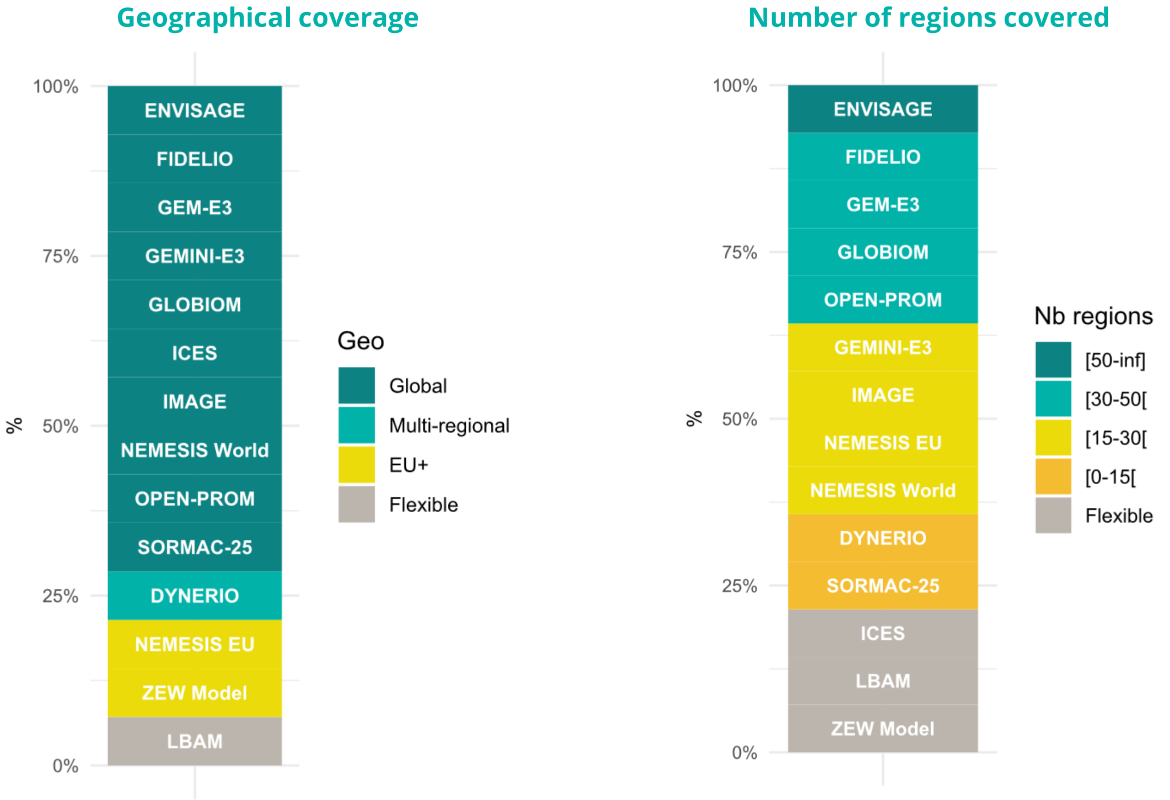

Figure 2. Geographical coverage and number of regions

Additional technical information on the models was collected and is summarised in Figure 5 to Figure 8 (in Annex 6.3). Among the main features, we observe that nine of the eleven tools that model trade represent it by using bilateral flows, with the exception of NEMESIS EU and OPEN-PROM. Seven of the eight macroeconomic models employ an Armington approach (Armington, 1969) to model trade, again with NEMESIS EU as the exception. The remaining non-macroeconomic modelling tools use alternative approaches, including IMAGE, GLOBIOM and OPEN-PROM. The survey also indicates that five models already incorporate mechanisms for endogenous technological change (Figure 7), relying, inter alia, on research investments (ENVISAGE, NEMESIS and GEM-E3) and/or learning-by-doing (GEM-E3, IMAGE and OPEN-PROM). Finally, four models—though only two macroeconomic ones—represent land use: ENVISAGE, ICES, IMAGE and GLOBIOM. Moreover, five models already include some form of environmental indicators (Figure 8).

2.2.2 Policy coverage

Table 1. Policy feasibility mapping

Feasible
Feasible with modifications
Not yet feasible but feasible after ENTICE
Not feasible

		NEMESIS EU	NEMESIS World	ICES	ZEW Model	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
GHG emissions mitigation	Tax	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible
	Emissions target / quotas	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible
	Regulations (emissions standards, etc...)	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible	Feasible with modifications	Not feasible	Feasible	Feasible with modifications	Feasible with modifications	Not feasible	Feasible with modifications
	Global Temperature / Radiative Forcing target	Not feasible	Feasible with modifications	Not feasible	Not feasible	Feasible with modifications	Not feasible	Feasible with modifications	Not yet feasible but feasible after ENTICE	Feasible	Feasible with modifications	Feasible	Feasible
	Financial supports (negative emissions, CDMs, Green Climate Fund)	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible	Feasible	Feasible	Feasible with modifications	Feasible	Feasible with modifications
Energy	Tax	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Not feasible	Feasible	Feasible	Feasible	Feasible	Feasible
	Subsidy	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Not feasible	Feasible	Feasible	Feasible	Feasible	Feasible
	Energy mix target	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible	Feasible with modifications	Feasible with modifications	Not feasible	Feasible	Feasible with modifications	Feasible with modifications	Not feasible	Feasible
	Efficiency target	Not feasible	Not feasible	Feasible	Feasible	Feasible with modifications	Not feasible	Not feasible	Feasible	Feasible with modifications	Feasible with modifications	Not feasible	Feasible with modifications
	Regulations (thermal regulation in buildings, banning of diesel cars in urban areas, etc...)	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Not feasible	Feasible	Feasible	Feasible with modifications	Not feasible	Feasible with modifications
Agriculture	Agro-ecological measures/pratices (no-till farming, agroforestry, hedgerow conservation, etc.)	Not feasible	Not feasible	Not feasible	Not feasible	Feasible with modifications	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Not feasible	Not feasible	Not feasible	Feasible with modifications
	Carbon price on agricultutural emissions	Not feasible	Not yet feasible but feasible after ENTICE	Feasible	Feasible	Feasible with modifications	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible with modifications	Feasible	Not feasible	Feasible with modifications
	Food loss and waste reduction policies	Feasible with modifications	Feasible with modifications	Not feasible	Not feasible	Feasible with modifications	Feasible with modifications	Feasible	Not yet feasible but feasible after ENTICE	Feasible	Not feasible	Not feasible	Feasible
	Regulations (fertilisers limitations, diet changes, etc.)	Not feasible	Not yet feasible but feasible after ENTICE	Feasible	Not feasible	Feasible with modifications	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible	Not feasible	Not feasible	Feasible
Land	Protected lands	Not feasible	Not yet feasible but feasible after ENTICE	Not feasible	Not feasible	Not feasible	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible	Not feasible	Not feasible	Not feasible
	Production quotas	Not feasible	Not feasible	Not feasible	Not feasible	Not feasible	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Not feasible	Not feasible	Not feasible	Not feasible
	Carbon sink pricing / Land use change emissions tax	Not feasible	Not yet feasible but feasible after ENTICE	Not feasible	Not feasible	Not feasible	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible with modifications	Not feasible	Not feasible	Not feasible
	Afforestation targets/measures	Not feasible	Not yet feasible but feasible after ENTICE	Not yet feasible but feasible after ENTICE	Not feasible	Not feasible	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible	Not feasible	Not feasible	Not feasible
Trade	Tariffs	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible
	Exports/imports quotas	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible	Feasible	Feasible with modifications	Feasible	Not yet feasible but feasible after ENTICE	Not feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible
	Exports/imports ban	Feasible with modifications	Feasible with modifications	Feasible	Feasible with modifications	Feasible	Feasible with modifications	Feasible	Not yet feasible but feasible after ENTICE	Feasible	Feasible	Not yet feasible but feasible after ENTICE	Feasible
	Carbon border tax on imports	Feasible with modifications	Feasible with modifications	Feasible	Feasible	Feasible	Feasible with modifications	Feasible with modifications	Not yet feasible but feasible after ENTICE	Feasible with modifications	Feasible	Not yet feasible but feasible after ENTICE	Feasible
	Carbon border supports on exports	Feasible with modifications	Feasible with modifications	Feasible	Feasible	Feasible	Feasible with modifications	Feasible with modifications	Not yet feasible but feasible after ENTICE	Feasible with modifications	Feasible	Not yet feasible but feasible after ENTICE	Feasible
	Regulations policies (environmental standard, certifications, Best-available technologies, standards, etc...)	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible with modifications	Feasible	Feasible with modifications	Feasible with modifications	Not yet feasible but feasible after ENTICE	Feasible with modifications	Not feasible	Not feasible	Feasible with modifications

The survey also gathered information on the capability of the modelling tools to implement and assess a set of policy options of high relevance to the project focusing in particular on the TCI nexus (Table 1). We asked the modellers whether their model could run these policy types without modification ("feasible"), with some modification ("feasible with modifications"), or, if not feasible, whether they expected to be able to implement them after ENTICE, or whether they would remain infeasible.

Without going into the detailed survey results, we observe that greenhouse gas mitigation policies are, for the most part, implementable in the models ("feasible" or "feasible with modifications"), except for policies focusing on global temperature or radiative forcing targets and, to a lesser extent, regulatory measures (e.g., emissions standards). Energy-related policies are also relatively widely implementable across the

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participating models, with the notable exception of efficiency targets, which fewer models are able to integrate. Trade policies are likewise relatively implementable across the different models, although most models require some modifications to run them. However, trade policy assessment is more limited in specialised models such as OPEN-PROM and SORMAC-25. Policies relating to agriculture and land use are largely not feasible for many of the models, with the notable exception of food loss and waste reduction policies. The GLOBIOM model can run all policy types listed in the agriculture sector, while IMAGE covers the majority of land-use and agricultural policies, and GEM-E3, ICES, and ENVISAGE are able to assess several agriculture-related policy options.

2.2.3 Modelling teams expectations on the model improvements

We now summarise the main outcomes of the survey regarding the modelling teams' expectations for potential improvements across the topics covered in WP3, as well as their expectations of the task leaders. We also present, in tables, the main directions for model development requested by the modellers. As these developments may overlap with other WPs, and depending on initial commitments, available resources, and the characteristics of existing models, some modelling teams may not be interested in certain developments. Nevertheless, all proposed improvements will be shared with the consortium to ensure that any team has the capacity to implement them if desired.

2.2.3.1 Sectoral disaggregation

Within the project, the teams express a broadly shared ambition to improve the sectoral representation, particularly for sectors linked to clean energy technologies, critical materials, and energy-intensive industries. Several partners wish to refine the modelling of value chains for strategic minerals and metals, covering their extraction, processing, and intermediate as well as final uses. Particular attention is given to energy intensive products and materials essential to the energy transition, such as steel, copper, aluminium, critical minerals, and rare earth elements. There is also strong interest in achieving a clearer distinction between primary and secondary production, especially for key metals, like steel. Clean technologies (including batteries, electric vehicles, and photovoltaic systems) constitute another major area of development, with the aim of capturing their value chains and production processes in greater detail. The responses further highlight a desire to increase the level of detail within certain supply chains, such as those related to circularity, international transport, or energy-transition technologies. Finally, some groups envisage enriching existing databases, including GTAP disaggregation, so as to incorporate new materials, technologies, or international flows.

The modelling teams primarily expect a clear overview of the existing landscape: relevant theories, established methodological approaches, available applications, and key data sources. There is frequent demand for detailed data on specific value chains —for example, in the case of photovoltaics— as well as for presentations of applied work demonstrating how to incorporate new technologies, new sectors, or complex trade dynamics.

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Table 2. Summary of sector disaggregation interest

	NEMESIS EU	NEMESIS World	ICES	ZEW Model	DYNERIO	LBAM	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
Energy-intensive industries	Low or not relevant	Low or not relevant	Low or not relevant	Strong	Low or not relevant	Low or not relevant	Strong	Low or not relevant	Low or not relevant	Strong	Low or not relevant	Low or not relevant	Low or not relevant	Low or not relevant
Clean technologies	Low or not relevant	Strong	Strong	Opportunity	Low or not relevant	Low or not relevant	Low or not relevant	Strong	Low or not relevant	Opportunity	Low or not relevant	Low or not relevant	Low or not relevant	Low or not relevant
(Critical) (raw) materials	Low or not relevant	Strong	Strong	Low or not relevant	Low or not relevant	Low or not relevant	Strong	Strong	Low or not relevant	Opportunity	Opportunity	Low or not relevant	Strong	Strong
Circular economy	Low or not relevant	Opportunity	Strong	Low or not relevant	Low or not relevant	Low or not relevant	Low or not relevant	Low or not relevant	Low or not relevant	Strong	Low or not relevant	Low or not relevant	Low or not relevant	Strong

Interest
Strong
Opportunity
Low or not relevant

2.2.3.2 International transports

The teams are expecting literature syntheses, particularly on issues related to international transport (i.e. shipping and aviation) and the endogenous switching of transport modes, including their respective strengths and limitations. A thorough description of key technologies, priority sectors, and the variables required for modelling is considered essential. Some partners emphasise the need for already-disaggregated data (FIDELIO, OPEN-PROM), or even for an updated version of the GTAP database (CGE models: GEM-E3; GEMINI-E3; ENVISAGE), accompanied by the methodological elements required to use or reconstruct it.

Table 3. Summary of the interest for improving international transport modelling

	NEMESIS EU	NEMESIS World	ICES	ZEW Model	DYNERIO	LBAM	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
Energy and emissions data	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Strong	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Strong
Modes	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Opportunity	Not relevant/concerned	Strong	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned
Clean technologies	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Strong	Not relevant/concerned	Not relevant/concerned
Travel routes	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Not relevant/concerned	Strong	Not relevant/concerned	Not relevant/concerned

Interest
Strong
Opportunity
Low interest
Not relevant/concerned

2.2.3.3 New trade theory

Across the responses, modellers express a clear interest in enhancing the sophistication of trade modelling within their respective frameworks. Many emphasise the introduction of intra-sector heterogeneity, particularly in relation to productivity dynamics, endogenous productivity gains, and spillover effects linked to trade. Several partners also wish to incorporate mechanisms inspired by the New Trade Theory, such as love-of-variety effects, firm heterogeneity, and non-competitive market structures. Some respondents highlight the need to represent trade involving large firms with market power, while others focus on capturing bilateral trade flows more accurately, especially for new or disaggregated sectors such as critical minerals, energy commodities, and industrial products like steel and cement. Environmental product differentiation, for instance based on production standards (i.e. green steel), is also mentioned as a relevant dimension of future trade modelling.

The modelling teams expect the leading team to provide clear guidance on the theoretical and empirical foundations necessary for integrating advanced trade modelling features into large-scale models. This includes comprehensive reviews of the literature on how New Trade Theory, and specifically firm heterogeneity, endogenous productivity, and trade-related spillovers, has been incorporated into computable general equilibrium or other large-scale modelling frameworks. There is also a strong expectation that the leading team will propose practical avenues for introducing firm-level heterogeneity, strategic firm behaviour (such as Cournot or Bertrand competition), and mechanisms such as "learning by exporting". Some partners request methodological proposals, including equations and calibration procedures, that could be directly integrated into existing models. In several cases, respondents also seek access to relevant data sources and applied examples illustrating how these theoretical concepts have been operationalised in practice. The precise expectations may vary depending on the eventual modelling choices, but overall, the lead team is expected to support both the theoretical grounding and the technical implementation of the envisaged trade-related enhancements.

Table 4. Summary of the interest for improving the modelling of trade

	NEMESIS EU	NEMESIS World	ICES	ZEW Model	DYNERIO	LBAM	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
Trade modelling improvement	W	W	W	W	–	–	W	W	W	W	W	W	W	W
Intra-sector heterogenity	W	W	W	–	–	–	–	W	–	–	–	–	–	O
Preferences (variety, env. standards, etc.)	–	–	W	–	–	–	–	–	W	–	–	–	–	–
Trade for specific products/sectors	–	–	–	–	–	–	W	–	–	–	–	–	–	–
Non-competitive markets	–	–	W	W	–	–	–	–	–	–	–	–	–	–
Productivity	W	W	W	W	–	–	W	W	–	–	–	–	W	O

Interest: W = *Willingness to work*; O = *Opportunity*; – = *Not relevant/concerned*

2.2.3.4 Technological change modelling

Numerous partners highlight the importance of learning-by-exporting, whereby productivity improvements are driven by export capacity, as well as learning-by-research channels, including both public and private R&D. Trade-related knowledge spillovers, technological spillovers, and endogenous productivity growth formulations are also cited as key elements to integrate into the model. Overall, the aim is to capture the multiple pathways through which innovation, firm behaviour, and international trade jointly influence technological progress. Many responses emphasise the incorporation of mechanisms relevant to clean technologies, such as photovoltaic systems, wind turbines, and batteries, with a focus on knowledge spillovers and the interaction between trade and productivity gains. Modelling teams also broadly indicate a desire to enhance the representation of technological progress by linking intra-sector firm heterogeneity to productivity improvements.

Participants primarily expect the leading team to provide a comprehensive summary of the literature on the relationship between trade and technological change, covering both theoretical frameworks and empirical evidence. They also request examples of applied work and the relevant parameters that have been used in previous studies. In addition, access to data supporting the parametrisation of the associated processes, as well as clear presentations of the underlying theories, is considered essential to guide the integration of these mechanisms into the models.

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Table 5. Summary of the interest in the enhancement of the technological change modelling

	NEMESIS EU	NEMESIS World	ICES	ZEW Model	DYNERIO	LBAM	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
Firms heterogeneity	■	■						■						
Learning by reseaching		■		■			■			■			■	
Learning by exporting / market power			■	■										
Learning by doing														■
Technology specific								■						
Knowledge spillovers		■	■				■	■	■	■				■

Interest
■ *Willingness to work*
Not relevant/concerned

2.2.3.5 Materials flows and mineral resources

Modellers express a clear expectation to enhance the mapping and modelling of supply and demand for raw materials, with particular attention to those critical for the energy transition. Several respondents emphasise the need to better characterise the dependencies of specific supply chains on raw materials and to improve the representation of value chains, including the role of critical materials in the production structure of final goods. Integration with material flow analysis models from other projects, full material accounting, and the modelling of circular economy strategies are also highlighted. Some participants mention incorporating supply curves for materials, accounting for trade flows, and expanding the range of materials represented. A key objective is to assess the impacts of various scenarios on material and mineral supply and demand, providing insights into supply security. The representation of rare earths and other strategic minerals is specifically noted as an area for improvement.

Respondents expect the leading team to provide detailed guidance to provide guidance on linking material flow models to economic modelling frameworks such as MRIO tables. This includes presenting available and potential data sources, relevant parameters, and methodological approaches for integrating material flow and mineral analyses, possibly through soft linking. Literature reviews and examples of applications are requested to illustrate how supply-side constraints of raw materials can be modelled, including resource potentials, depletion dynamics, and by-product management. The task leaders are also expected to provide theoretical guidance and access to data sets that allow the parametrisation of extraction curves and other material-specific processes, supporting the accurate representation of supply and demand dynamics for critical and strategic materials.

Table 6. Summary of the interest related to materials flows and mineral resources

	NEMESIS EU	NEMESIS World	ICES	ZEW Model	DYNERIO	LBAM	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
Value chain of (critical) materials	■	■	■				■	■		■		■		
Supply curve for (crititcal) materials	■	■					■	■		■	■	■	■	■
Focus on technologies for climate transition	■	■	■				■	■		■	■	■	■	

Interest
■ *Willingness to work*
Not relevant/concerned

2.2.3.6 Land use and agriculture

Modellers aim to enhance the modelling of land use by capturing competition between different land uses, particularly agricultural land, forestry, and urbanised areas. Integrating land use, land use change and forest (LULUCF) related greenhouse gases (GHG) emissions is a key priority, alongside the introduction of marginal

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abatement cost curves. Several respondents emphasise the importance of linking land-use modelling with external models, such as MAGPIE or GLOBIOM, and consider coupling land-use changes with downstream models of LULUCF emissions to capture the full impact of policy and environmental scenarios. Some modellers do not plan to improve their models. This is the case for GLOBIOM, which is already very advanced in this area and will be linked to other models.

Respondents expect the leading team to present existing information and modelling approaches, and to propose methodological improvements for agricultural and land-use modelling to better represent GHG emissions from agriculture and LULUCF. Access to relevant data inputs is also considered essential.

Table 7: Summary of the interest in land use modelling

	NEMESIS EU	NEMESIS World	ICES	ZEW Model	DYNERIO	LBAM	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
Land uses modelling		X												
GHG emissions		X												
GHG emissions abatment curves		X	X											
Linkage										X				X

Interest
Willingness to work (X)
Not relevant/concerned (blank)

2.2.3.7 Environmental indicators

Modelling teams express a wish to enhance the models' capability to capture environmental concerns from and beyond climate change. This includes achieving a more realistic representation of agriculture-forest emissions, integrating biodiversity-related indicators and incorporating additional relevant indicators, such as those related to critical materials (mining, water use, etc.). Several respondents highlight the potential value of developing protocols to link outputs from typical CGE models to standalone biodiversity or broader environmental assessment modules, enabling more comprehensive environmental analysis. Overall, modellers seek guidance on what can be feasibly implemented and wish to explore opportunities for meaningful improvements in the models' environmental representation. Furthermore, a number of models already include some of the developments proposed here and are therefore not indicated as being of interest to them. This is particularly the case for ENVISAGE, GEMINI-E3, GLOBIOM and IMAGE that already account for GHG emissions from agriculture and land use or for GLOBIOM and IMAGE integrating biodiversity indicators.

Respondents expect the leading team to provide a comprehensive overview of existing literature, relevant environmental issues, and potential indicators, alongside the corresponding datasets. Guidance on the development of protocols for integrating biodiversity or other environmental modules is also requested. Where feasible, access to biodiversity assessment modules or frameworks, following further discussion with the task leader, would be highly valuable to support implementation within the model.

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Table 8. Summary of the interest for integrating environmental indicators

	NEMESIS EU	NEMESIS World	ICES	ZEW Model	DYNERIO	LBAM	GEM-E3	FIDELIO	GLOBIOM	OPEN-PROM	IMAGE	GEMINI-E3	SORMAC-25	ENVISAGE
Biodiversity		Willingness to work												Willingness to work
Agriculture emissions			Willingness to work											
Land use emissions			Willingness to work											
Water uses										Willingness to work				
Critical materials related											Willingness to work			

Interest
Willingness to work
Not relevant

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3 Model improvements

This section presents, for each type of model development and its corresponding task, the relevant context and the objectives of the development in relation to the TCI nexus and to the current state of the art in modelling. The results of the model survey revealed the expectations and intentions of individual modelling teams, some of which may not be of general interest, contractually relevant, or even feasible within the ENTICE framework. The following section therefore builds on the survey results to align the modellers' wishes with the ENTICE research plan. Furthermore, deliverable D3.2, "Progress in model improvements" due in Month 17, will enable the monitoring of ongoing improvements, as well as the adjustment, completion, and refinement of the work plan based on the initial months of implementation, and the identification and mitigation of any issues that may arise. By Month 30, progress achieved for each model improvement axis will be documented in five dedicated deliverables (D3.3 to D3.7), and subsequently synthesised in deliverable D3.8, "Illustration of new capacity and open code/data," which will also provide open-source data and code.

3.1 Sector disaggregation (Task 3.2)

3.1.1 Context and objectives

This task builds upon the foundational work carried out in WP2, which focused on enhancing the GTAP database. WP2 introduced a detailed sectoral disaggregation that goes beyond the standard GTAP structure, enabling a more granular representation of key industries relevant to climate and trade policy. Specifically, the database will include refined classifications for energy-intensive products such as aluminium, copper and steel (both primary and secondary (recycled) for all three metals), fertilizers, cement, and plastics (both primary and secondary). These sectors are critical because they account for a significant share of global GHG emissions and are highly exposed to carbon pricing and trade-related measures due to their high carbon and trade intensities. In addition to traditional energy-intensive sectors, WP2 incorporated data on clean technology manufacturing, which is essential for the global energy transition. This includes industries producing wind turbines, solar photovoltaic panels, electric vehicles, batteries, and electrolysers for hydrogen production. These sectors represent emerging growth areas that are central to achieving deep decarbonisation and require accurate modelling to assess policy impacts on innovation, competitiveness, and global supply chains. Furthermore, WP2 expanded coverage to critical raw materials such as cobalt and lithium, which are indispensable for manufacturing green technologies. These materials are subject to supply constraints and geopolitical risks, making their inclusion vital for analysing trade dependencies and resilience under different climate policy scenarios.

Building on the comprehensive database developed in WP2 (D2.8 – Disaggregated GTAP database), the next step is to integrate these enhanced datasets into leading macroeconomic and energy-economy models, including GEM-E3, ICES, NEMESIS, GEMINI-E3, ENVISAGE, FIDELIO, and the ZEW model. These models are widely used for climate-trade policy analysis at national, regional, and global levels, but their standard versions often rely on aggregated sectoral structures that limit their ability to capture the nuanced dynamics of the low-carbon transition. The integration aims to increase sectoral granularity, thereby improving the models' capacity to represent real-world policy challenges. By distinguishing between primary and secondary production processes, clean technology sectors, and critical materials, the models can better reflect demand-side and supply-side specificities, such as differences in energy and carbon intensity,

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technological learning curves, and trade patterns. This enhanced representation is crucial for evaluating the impacts of policies like carbon border adjustment mechanisms, green industrial strategies, and technology deployment incentives, which have heterogeneous impacts across sectors.

Ultimately, this effort will enable more robust and policy-relevant scenario simulations, supporting decision-makers in designing effective climate and trade policies that account for sector-specific characteristics and global interdependencies.

3.1.2 Approach and work plan

The proposed work plan (Table 9) follows a structured approach to integrate the disaggregated GTAP database into leading macroeconomic models, ensuring enhanced sectoral granularity for climate and trade policy analysis. The process begins with preparation and sector mapping, aligning WP2 outputs with model-specific classifications. Next, data harmonization ensures consistency in units, prices, and trade flows across datasets. In model integration, production structures and behavioural parameters are updated to reflect the new sectors. Validation and sensitivity tests will be covered in detail in WP4 and WP5 and is not the aim of this task. A step-by-step technical guidance with the implementation of the above steps and key assumptions will be provided. A bottom-up methodology will be developed for selected sectors within energy-intensive industries—such as steel (primary production, secondary production, and recycling), aluminium (primary, secondary, and recycling), and cement—as well as for key clean technology sectors, including electric vehicles, batteries, and hydrogen technologies. This approach focuses on capturing the physical and technological characteristics of production processes at a detailed level, rather than relying solely on aggregated economic data. The methodology will also incorporate substitution possibilities within and across technologies, such as the shift from primary to secondary steel or aluminium. This allows the models to reflect technological flexibility, which are critical for assessing the impact of climate policies, carbon pricing, and resource constraints. Furthermore, the bottom-up approach will integrate learning curves, cost trajectories, and material efficiency improvements, enabling a more realistic representation of how these sectors evolve under different policy and market conditions.

Table 9. Work plan for the Task 3.2

Step	Duration	Description
Sector mapping & data harmonization	January 2026 (M13) – June 2026 (M18)	Selection of sectors that will be incorporated in the macro models and data harmonization.
Bottom-up data collection & modelling	January 2026 (M13) – December 2026 (M24)	Data collection for the bottom-up representation (i.e., capacity etc.) and development of the bottom-up modules
Model integration & technical guidance	July 2026 (M19) – December 2026 (M24)	Production structures and model calibration facilitated by a detailed technical guidance.

By embedding these detailed sectoral modules into macroeconomic models, we aim to bridge the gap between process-level detail and economy-wide interactions, improving the accuracy of policy simulations related to decarbonization, trade competitiveness, and industrial transformation.

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3.2 Integrating new trade theories into large-scale macroeconomic models (Task 3.3)

3.2.1 Context and objectives

In large-scale economic models, the representation of international trade has been dominated by the Armington assumption of differentiated commodities by country of origin, within a constant returns-to-scale perfect competition framework (Armington, 1969) and, as the survey has shown, it is also largely the case with the models involved in ENTICE and, in particular, in the macro-economic models.

There have been ever-growing discussions among the economic modelling community on shifting from the traditional Armington assumption to more modern theories that are more consistent with micro-level observations. In this direction, the Krugman (1980) and Melitz (2003) models established modern trade theory frameworks by incorporating monopolistic competition, endogenous firm entry, and firm heterogeneity. However, their integration into large-scale quantitative systems models representing a large number of commodities and countries still entails considerable computational and empirical data challenges. Despite computational barriers, the Krugman and Melitz models have remained at the centre of debate, especially among those attempting to go beyond the Armington assumption in computational economics, and particularly in CGE modelling. The Krugman trade theory assumes that product varieties are distinguished by firm, where each firm produces a unique variety under increasing returns-to-scale. It is a monopolistic competition model with symmetric firms. Producers are monopolistically competitive and consumer preferences are characterised by love-of-variety between varieties produced by different firms (Dixon et al., 2016). Intra-industry trade effects emerge naturally due to the so-called love of varieties i.e., the desire of consumers to buy as many different varieties as possible. However, the Krugman approach has also been criticised over its assumption that all firms are identical in terms of productivity (Bekkers et al., 2023). The Melitz trade model, in turn, preserves Krugman's features but, additionally, allows for heterogeneous productivity at firm level. While markets in both models are imperfectly competitive, Krugman's framework assumes homogeneous firm productivity, whereas Melitz's model incorporates heterogeneous productivity and a fixed cost of export market entry. These additions provide more realism in economic representation, as the Melitz model predicts that not all firms export and that average productivities in the domestic and export markets change endogenously in response to trade policies. Also, firm heterogeneity provides an additional mechanism for welfare effects from trade, with re-allocation of within-sector market shares between less and more productive firms (Balistreri et al., 2025; Dixon et al., 2018).

To summarise the core features of the transition in computational economics and CGE modelling, from Armington to Krugman, and, subsequently, to Melitz:

- In Armington, firms in a country behave competitively; in Krugman and Melitz, they are monopolistically competitive.
- In Armington and Krugman, producers in a country have the same productivity (homogenous firm productivity), while Melitz allows for productivity variation across a country's producers (heterogenous firm productivity).
- In Armington and Krugman, producers in a country sell on all trade links; in Melitz, only high productivity producers "survive"—they may sell in some markets, but not in all.

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Beyond Armington, Krugman, and Melitz, there also exist other trade mechanisms that have gained traction recently, such as the Eaton-Kortum (Eaton & Kortum, 2002) and Bilateral Representative Firm (BRF) models (Balistreri et al., 2025):

- The Eaton-Kortum international trade mechanism is based on countries' differences in comparative advantage, while it additionally assumes a continuum of varieties based on stochastic specification for productivity. An important feature of this model is that, contrary to Armington, the landed bilateral import price does not vary by source country.
- The BRF model, introduced quite recently in the CGE modelling domain, proposes a trade structure that includes monopolistic competition among bilateral representative firms, capturing the import-variety gains while retaining the Melitz model's bilateral selection with relatively low computational effort.

However, the implementation of such enhancement of the trade modelling in large scale-models faces numerous and diverse challenges. While the Melitz specification is theoretically appealing, its existing implementations in CGE models seem to struggle with numerical stability, implying limitations in sectoral and regional detail. Indeed, the endogenisation of free entry and exit in a multi-sector, multi-region Melitz model that includes intermediate inputs may give rise to computational difficulties related to multiple and/or corner equilibria. Nonetheless, faced with the inherent computational challenges, modellers have invented various solutions to overcome associated barriers and adopt—at least partially, not globally across their models—a Melitz-based mechanism. For instance, Bekkers & Francois (2018) use a set of endogenous supply and demand shifters, such that an Armington model "mimics" a Melitz one. Their computational approach has similarities with the decomposition algorithm of Balistreri & Rutherford (2013), where the Armington demand system is iteratively re-calibrated; in the latter case, the model involves nine sectors in total, with only two being of Melitz type. Furthermore, due to the assumption that import prices are identical for each source country, incorporating the Eaton-Kortum framework in a GTAP model is quite complicated and the code must be restructured regarding the price basis of the model. And finally, firm heterogeneity requires additional information that is not readily available in the standard database, like GTAP, such as on key firm heterogeneity parameters, fixed set-up costs, and fixed trading costs.

3.2.2 Approach and work plan

The overall objective of this task is therefore to provide modelling teams with the concepts, tools and practical guidance needed to enrich a selected subset of sectors—primarily manufacturing—with modern trade structures incorporating firm entry and exit decisions as well as heterogeneity. The enhancements will be implemented in ways that preserve numerical tractability and minimize calibration burdens, recognizing the high dimensionality of large-scale multi-country, multi-sector CGE models.

Our methodological approach is intentionally incremental. We begin with a streamlined, transparent representation of the transition from Armington to Krugman and then to Melitz, so that modelling teams can clearly identify which elements can be added with relatively minor structural changes and which require deeper model re-engineering. This approach ensures early alignment across modelling groups and reduces the risk of divergence in implementation choices.

To support a wide range of modelling capacities and ambitions across partners, we envisage delivering two outputs:

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1. **A core toolkit,** this will include the steps listed below and will allow all modelling teams to assess feasibility and identify the simplest viable integration path for their own model structure.
    - A minimal analytical model, following (Balistreri & Rutherford, 2013), clearly documenting the structural differences between Armington, Krugman and Melitz frameworks.
    - A mapping table showing precisely which additional variables, equations, and parameters are required when moving beyond Armington.
    - A discussion of calibration strategies for fixed costs and productivity distributions, diversifying between models that are solved using "hat algebra" and models that are solved in levels.
2. **Advanced extension (proof of concept),** that aims to help modelling teams to adopt a richer representation of firm heterogeneity consistent with the final shared reference model and it will form the basis for the one-to-one support provided during the final phase of the task. Thus, with the information gathered in the first step we will develop:
    - A more detailed version of the simplified model agreed with partners during the first step, extended only to the level of complexity that most modellers consider feasible/relevant for implementation in multi-country, multi-sector CGE environments.
    - A proof-of-concept implementation of this enriched model to illustrate how the Melitz elements can be embedded without creating excessive dimensionality or numerical instability.

To achieve this work for Month 30, i.e. June 2027 and the related report D3.4 – "Integrating new trade theories", we propose the following work plan and schedule, as summarised in Table 10.

Table 10. Work plan for task 3.3

Steps	Indicate time frame
Development of the minimal model and comparative structure • Construct a simple but fully documented baseline model illustrating the transition: Armington → Krugman → Melitz. • Identify the minimal set of changes in variables, equations and calibration requirements. • Conduct collective consultation with modelling teams to compare the simplified model to each partner's structure.	November 2025 (M11) – February 2026 (M14)
Agreement on common enriched model and creation of a proof-of-concept • Using the results of Step 1, design a "shared enriched model" relevant for the majority of project models. Implement Melitz in this model. • Develop the corresponding numerical implementation and calibration protocol. • Produce a proof-of-concept simulation to demonstrate feasibility and to serve as a technical template for partners.	February (M14) – September 2026 (M21)
Model-specific support and implementation guidance • Provide one-to-one guidance to each modelling team as they incorporate Melitz features into their own frameworks. • Assist with model-specific adaptations of the theoretical structure.	October 2026 (M22) – June 2027 (M30)

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3.3 Technological change modelling (Task 3.4)

3.3.1 Context and objectives

The literature review performed in WP1 (D1.3 - State of the art of TCI economic theory, political science, economic modelling) has shown that there is "*an evidence across decades and methodological approaches [...] that the technique effect –the ability of economies to innovate, regulate, and adopt cleaner production methods– plays a far greater role than the relocation of pollution-intensive industries*". Thus, it is essential that macro-economic models and other forward-looking and impact assessment modelling tools be able to account for this technique effect, that takes place through knowledge and technology diffusion and innovation. From the early macroeconomic models reliance on exogenous technological change (Duan et al., 2017), the rise of endogenous growth theory has moved the models toward the endogenisation of technological change. The recent work of Witajewski-Baltvilks (2025) identifies two dominant trends in endogenising technical change in large-scale economic models:

- Learning-based mechanisms that relate efficiency parameters or production costs to cumulative sectoral production output. In particular, the family of learning-based mechanisms is mostly represented through the so-called *learning-by-doing* (LBD) curves. From a CGE perspective, learning curves are typically implemented by linking efficiency parameters (or cost reduction) to sectoral output or installed capital.
- R&D-based mechanisms entailing the incorporation of knowledge stock that is built up through R&D investments; in this approach, knowledge is treated in a form similar to physical capital. Potential invested resources in R&D activities result in productivity improvements through enhanced innovation dynamics. In the macroeconomic setting, these insights are typically implemented through a knowledge accumulation equation, where the knowledge stock grows with R&D expenditure and depreciates over time and that enters as a total factor productivity shifter in the production function both across regions and sectors (Wang et al., 2009).

Beyond the learning and knowledge stock mechanisms, (Wing, 2006) identifies two additional modes to introduce technological change endogenously (or semi-endogenously): the price-induced input augmentation and the consideration of backstop technologies. Both approaches are less popular, while, especially, backstop technologies fit better to bottom–up engineering models (Löschel, 2002), since they are closely related to the concept of "technology snapshot". In particular:

- Price-induced input augmentation mechanisms link factor-augmenting parameters directly to relative input prices;
- Backstop technologies mechanisms are considered as a semi-endogenous approach; the "adoption" of a technology is considered endogenous due to a price-induced response, with the technology/production parameters themselves remaining exogenous.

Two additional modes are also present in the literature: directed technological change, and spillover mechanisms, which may be considered as alternative forms of the priced-induced and the knowledge stock mechanisms, respectively, to those described above (or mechanisms with additional features):

- Spillover mechanisms: With productivity improvements *de facto* closely connected to various forms of spillovers and technology diffusion, the knowledge created in one sector or region may benefit other sectors or regions through channels of trade, knowledge sharing, foreign direct investment

(FDI), etc. (Löschel, 2002).

- Directed technological change mechanisms: innovation can be targeted toward specific factors and corresponds to endogenous responses against applied policies and/or changes to relative prices (Acemoglu et al., 2012; Van Den Bijgaart, 2017). Macroeconomic models may operationalise this rationale, e.g., by allowing factor-augmenting productivity parameters to depend on policy-driven R&D allocation (Otto et al., 2008).

Despite the relatively abundant and diverse literature on the implementation of endogenous technological mechanisms into large-scale macroeconomic models, numerous challenges remain; CGE models, by construction, rely on a well-structured behaviour of agents (e.g., nested CES structure for producers). Innovation processes, which might be characterised by increasing returns, heterogeneity in agents, stochasticity, etc., are difficult to be "aligned" with the structure and granularity level of established models. Furthermore, sector-specific R&D expenditures are poorly documented for various countries and key parameters for knowledge stocks such as initial stocks or depreciation rates are not widely documented while they are crucial in the model response. Endogenous technological change mechanisms increase models' "non-linearity" in various ways, which might lead to solving issue for large-scale models.

3.3.2 Approach and work plan

To address these challenges and to ensure that the ENTICE model suite can capture endogenous technological mechanisms and provide a robust assessment of the technique effect in policy analysis within the TCI nexus (WP4 and WP5), we propose three main pillars of development. The first concerns the collection, completion and analysis of the data required to quantify R&D investments, R&D and knowledge stocks, and spillover effects. The other two pillars relate to complementary modelling approaches for representing technological change in large-scale models, reflecting the diversity of possible endogenisation mechanisms: one based on R&D-driven processes augmented by knowledge spillovers, and the other grounded in the directed technological change framework.

To implement R&D- and spillover-based approaches effectively, it is essential to begin by investigating and addressing data availability issues. We therefore propose to build on the methodological approach developed by Le Mouël et al. (2025), which employs a two-step procedure to complete publicly available data on R&D investment (e.g. OECD, 2025; Eurostat, 2025; JRC, 2025) by economic activity and, using patent accounting, enables the allocation of R&D expenditures across technologies, technological fields or clusters. On this basis, we will explore alternative methods for constructing knowledge stocks that combine R&D investment with knowledge exchange and will undertake a comparative assessment of these methods.

In parallel with the data work and drawing on a review of the literature on modelling research capacity and needs (D1.4 – Modelling research needs), we will examine the various practical approaches used to endogenise technological change in macroeconomic models. This will be complemented by the existing experience within the ENTICE model suite, as five of the models already incorporate mechanisms for endogenous technological change (Figure 7). We will review functional forms and parameter estimates available in the literature and will develop a modelling toolkit—including data, functional forms and parameter values—to assist modellers in implementing these approaches.

In addition, building on the GTAP-based recursive-dynamic ZEW CGE model, which currently features a standard directed technical change framework in the spirit of Acemoglu et al. (2012) and monopolistic competition with fixed mark-ups, we will extend the market structure to allow for Cournot competition with

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entry and exit of energy-technology firms. In this extended setting, upstream and downstream producers make strategic decisions on prices and R&D efforts, and these decisions jointly determine technology adoption, innovation direction, and the relative competitiveness of clean versus fossil energy services. A subsequent stage will extend to a multi-county setup where international trade in goods (including energy), driven by preferences and comparative advantages, affect firms' profits. Climate and trade policies shape competition and markups and thus firm profits, which in turn affects the incentives to invest into R&D in the respective sectors, adding an additional margin that governs technological change. This extension will enable the assessment of unilateral policy instruments—such as carbon pricing and border adjustment measures—with particular emphasis on their dynamic innovation and competitiveness impacts.

Table 11. Work plan for task 3.4

Steps	Indicate time frame
Review existing modelling approaches	December 2025 (M12) – June 2026 (M18)
Data collection and processing for R&D investment, stocks and knowledge spillovers	February 2026 (M14) – September 2026 (M21))
Propose and design a generalized approach to endogenise technological change via R&D investment and knowledge spillovers	May 2026 (M17) – April 2027 (M28)
Propose and design a directed technological change approach with implementation in macro-economic models	February 2026 (M14) – October 2027 (M22)

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3.4 Linking macroeconomic models with material flows and mineral resources (Task 3.5)

3.4.1 Context and objectives

In a highly globalized world, complex international value chains make it difficult to account for the energy and material use, as well as the associated environmental impacts of economic activities (Wiedmann & Lenzen, 2018). To craft effective and sustainable policies, decision-makers need to understand the full life-cycle impacts of technological choices, including their dependencies on critical raw materials. Many technologies essential for the green energy transition (such as solar panels, wind turbines, and electric vehicle batteries) rely on a consistent supply of critical materials. The projected growth in these technologies is expected to put significant pressure on the supply chains of raw materials like lithium, cobalt, and nickel, which are often concentrated in a few geographic regions and face geopolitical instability and trade tensions (IEA, 2025). Monitoring the flows of these strategic materials is therefore crucial, yet this effort is frequently hindered by a lack of detailed data in mainstream economic databases and models.

A substantial body of work in ecological economics and industrial ecology shows that purely economic analyses are often inadequate for assessing the use of physical resources and their geographic distribution (Martin et al., 2022; Rinaldi et al., 2023). Traditional economic models rely on monetary indicators and do not explicitly represent material flows, making it difficult to capture biophysical constraints, critical resource dependencies, and vulnerabilities linked to the spatial concentration of production processes. Research on material flow analysis and physical input–output models demonstrate that integrating physical data is essential to fully understand how economic dynamics affect material demand, environmental pressures, and the structure of global supply chains. Without such integration, assessments risk underestimating key issues such as resource depletion pressures, embodied emissions in traded goods, and geopolitical risks associated with the territorial concentration of critical materials.

The main goal of this task is to connect macroeconomic modelling with the physical analysis of material flows through a soft-link approach. This connection will allow for a more robust and realistic evaluation of how TCI policies influence resource use, environmental impacts, and economic dynamics. While the link will be defined analytically, it can also enhance the applications developed in WP4, broadening the analytical scope and ultimately offering policymakers a transparent, comprehensive, and scientifically sound tool to support the transition toward a sustainable low-carbon economy. These enhancements directly address the TCI framework's core objective: to systematically analyse their complex, intertwined dynamics. Task 3.5 will contribute improving the granularity of data regarding material use (deliverable D1.2 section A2|3), and as a consequence it will be possible to effectively identify the material flows that expose specific commodities to supply chain risks (deliverable D1.2 section A1|5). Moreover, this allows for a better specification of the environmental impact connected to the use of raw materials across their value chains (deliverable D1.2 section A1|5). It is worth noting the data-related improvements primarily concern the integration of WP2 outputs, specifically the enhanced disaggregation of the GTAP database, into the modelling framework, ensuring that the newly added sectors can be systematically represented and utilised across the various models.

The implementation of this task relies on a diverse suite of advanced modelling tools provided by the consortium partners. The macroeconomic perspective is captured by a set of established models, specifically GEM-E3, GEMINI-E3, ICES, NEMESIS, ENVISAGE, and FIDELIO, which are being enhanced to support greater sectoral disaggregation. These economic models will be coupled with the DYNERIO model, which serves as the dedicated physical counterpart in this framework. DYNERIO acts as the physical dynamic stock-flow model, responsible for simulating the concrete material flows, capital aging, and mass-energy balances that will constrain and inform the macroeconomic projections.

3.4.2 Approach and work plan

Preliminary steps: data collection and implementation

The execution of the work plan follows a sequential logic that builds directly upon the outputs of concurrent project activities. The initial phase is grounded in the data enhancements established in WP2. We will leverage the extended GTAP database produced in tasks 2.2 and 2.3, which provides the necessary disaggregation of critical supply chains and new technological sectors. This step is crucial to ensuring that the economic data entering the linkage algorithm possesses the required granularity to be meaningful for physical analysis.

Simultaneously, the work plan proceeds in close coordination with task 3.2, which focuses on the individual enhancement of the models prior to linkage. While task 3.2 prepares the specific nodes of the network, by improving the sectoral disaggregation of macroeconomic models (such as GEM-E3, ICES, and NEMESIS) and refining the stock-flow dynamics of the DYNERIO model, task 3.5 focuses on building the analytical bridge between them. Once the macroeconomic models are updated to utilize the new GTAP version and DYNERIO is optimized for capital aging and mass balances, the task will move to defining the specific technical specifications for the soft and hard connections.

Task 3.5: Approach and work plan

The primary methodological objective of task 3.5 is to establish a pivotal connection between macroeconomic modelling and the physical analysis of material flows through a soft-link approach. Rather than relying on isolated economic assessments, this task aims to construct a feedback loop where economic scenarios are constrained and informed by physical realities. The approach is designed to create a bi-directional linkage: macroeconomic models drive the demand for technologies and resources, while the physical model (DYNERIO) assesses the feasibility of these demands based on material availability, recycling rates, and mass-energy balances. This structure ensures that the resulting policy evaluations regarding trade, climate, and industry are not only economically sound but also physically viable, providing a transparent and comprehensive tool for decision-makers.

The core operational phase involves the development of a Proof–of-Concept (PoC) model. We intend to test the proposed connection on simplified versions of the models to validate the data exchange protocol before full-scale implementation. In this workflow, the macroeconomic models will generate prospective economic growth scenarios, activity by sector, and international trade flows. These outputs, properly cleaned via an harmonization/mapping protocol, serve as inputs for the improved DYNERIO model, which processes the physical supply chain data and material requirements.

Subsequently, DYNERIO feeds back critical physical constraints and structural changes, such as shifts in power or transport mixes and recycling potentials, into the macroeconomic models. This iterative process allows for the endogenous adjustment of economic parameters based on physical limitations.

It is worth noting that a key challenge here is the calibration of economic and physical representations of the same quantities: for an historical year, for instance, the macroeconomic model may express cobalt

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demand in monetary terms while DYNERIO expresses it in tonnes, requiring a consistency check through reference prices or comparisons with external models, analyses, or literature to ensure both systems refer to compatible baselines.

The activities for task 3.5 are scheduled to span a twenty-month period, commencing in Month 10 (October 2025) and concluding in Month 30 (June 2027). This duration is structured to allow sufficient time to absorb the data updates from WP2, conduct the iterative testing of the PoC, and refine the linkage mechanisms. The culmination of this work will be the production of deliverable D3.6, a report detailing the model links with mineral resources and material flows. Ultimately, this integrated framework will serve as the analytical foundation for the applications and scenario analyses to be conducted in WP4.

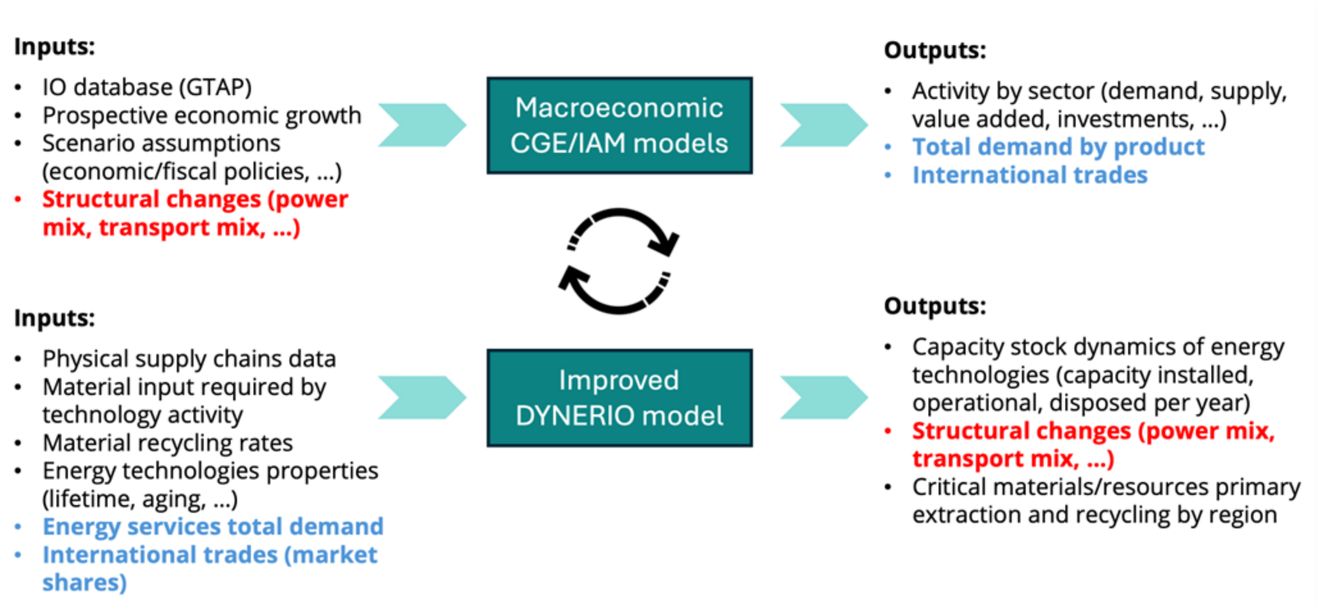

Figure 3. Soft-linking schematic workflow

Note: Red variables are outputs of DYNERIO and inputs for macroeconomic models. Blue variables are outputs of macroeconomic models and inputs for DYNERIO

Table 12. Work plan for task 3.5

Steps	Indicate time frame
Harmonization of models' sets and definition of variables to be exchanged for the soft and hard connections	June 2026 (M18) – November 2026 (M23)
Development of a Proof –of Concept model, of which: • Test the proposed connection on simplified versions of the models • Full-scale implementation	 September 2026 (M21) – November 2026 (M23) November 2026 (M21) – March 2027 (M27)

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3.5 Land-use changes and environmental indicators (Task 3.6)

3.5.1 Context and objectives

In an increasingly globalized economy, agricultural and land-based production systems have become highly specialized, with particular crops concentrated in specific regions and traded around the world. For example, oil palm cultivation is centred largely in tropical regions—especially Indonesia—while soybean production is dominated by Latin and North America. Major grain outputs are concentrated in China, India, Russia, and the European Union. The expansion of agricultural land, driven by population growth, GDP growth and dietary changes, has been one of the main drivers of environmental degradation. The conversion of forests, permanent grasslands, and other natural ecosystems into cropland and intensive grassland has led to significant environmental impacts, including increased pressure on water resources, disruptions to global nitrogen cycles (Chang et al., 2021), and accelerating biodiversity loss (Leclère et al., 2020).

The environmental impacts of trade are not yet fully understood. The volume of trade (scale effect), its sectoral composition (composition effect), and changes in technology and production processes (technique effect) may each lead trade to either increase or decrease the environmental footprint of production. For example, the scale effect has amplified global demand for products previously not consumed widely, thereby increasing the pasture and cropland required to supply them. The composition effect has shifted production to countries where certain goods can be produced more cheaply due to natural endowments, climate, labour costs, or land availability—for instance, soybean production in Latin America or horticulture in Europe. The technique effect has promoted technology transfer and encouraged producers to adopt cleaner and more efficient methods. However, it can also contribute to offshoring production to regions with less stringent environmental regulations. Taken together, these mechanisms imply that trade likely exerts a substantial influence on environmental outcomes, yet the direction and magnitude of this influence remain insufficiently explored and quantified.

Most macroeconomic modelling tools, particularly CGE models based on the GTAP framework, are well suited to address the impacts of trade on production. However, these models generally include only a limited representation of land use and environmental pressures. Agricultural production is typically modelled in aggregate crop and livestock groups, based on a total of 20 agri-food sectors —the granularity in GTAP. Land for agricultural production is often embedded in nested CES production functions without much spatial detail when it is not simply aggregated into capital stock. There are two noteworthy exceptions. First, explicit land heterogeneity has been introduced through the GTAP-AEZ extension. Through GTAP-AEZ, models can incorporate agro-ecological zones (AEZs) to distinguish productivity classes; however, they do not track where land conversion actually occurs or how environmental impacts vary across landscapes. As a result, their capacity to capture the physical consequences of trade, for instance, on deforestation, soil erosion, or biodiversity, remains limited. Second, more recently, the Simplified International Model of agricultural Prices, Land use and the Environment: Gridded version (SIMPLE-G) was developed. The SIMPLE-G model is a gridded model that connects policy drivers to ground-level impacts and their broader systemic feedback. SIMPLE-G is a partial equilibrium (PE) model that operates at a fine gridded resolution, typically 5 arcminutes, and it is specially designed for detailed spatial analysis (Hertel et al., 2023). However, this type of modelling is generally more suited for regional-level analysis, not for the global scale analysis on which ENTICE focuses. Further, it is very demanding regarding data and computation and does not allow for a more flexible set-up of adoption on which ENTICE focuses.

Some GTAP-based CGE models explicitly represent land as a distinct production factor, with varying degrees

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of spatial and agro-ecological detail, including models with and without AEZ-based extensions such as MAGNET, AIM, MIRAGE, GTAP-BIO, and CGE-Box. Similarly, the CGE frameworks employed in recent EAT-Lancet simulation exercises incorporate, to different extents, explicit representations of land-use patterns and land allocation dynamics. Most recently, an ensemble of global economic models, amongst which GTAP-based CGE models, assessed the impacts of food system transformation measures on food security, human health and environmental sustainability (Sundiang et al., 2025).

However, the survey results have revealed that most of the CGE models within ENTICE do not have this level of spatial detail and do not distinguish land as a separate production factor. In fact, in ENTICE, only three CGE models, ENVISAGE (van der Mensbrugghe, 2024), ICES[14], and GEMINI-E3 represent land as a differentiated production factor in their CES production framework. Further, only two ENTICE CGE models explicitly include land use, respectively ENVISAGE at the level of countries and ICES at the level of macro-regions. This is in contrast to partial-equilibrium (PE) models, and some integrated assessment models such as IMAGE, which can offer the spatial and biophysical resolution needed to assess the environmental consequences of trade and agricultural policies. Spatially explicit models can track where production expands, contracts, or intensifies; they can trace deforestation, habitat conversion, biodiversity impacts, water stress, and other location-specific outcomes that aggregate economic models cannot capture. GLOBIOM (IBF-IIAS, 2023), CAPRI (Britz & Witzke, 2014), and MAGPie (Dietrich et al., 2019) are amongst the global partial-equilibrium frameworks that assess impacts on supply, land use and the environment at a fine spatial scale. For example, in GLOBIOM, available in ENTICE, simulation units are defined by soil, slope, and altitude, allowing for the consideration of detailed biophysical properties in land use change across agriculture, forestry, and bioenergy over time. Further, natural and productive land covers are differentiated by explicitly considering different types of natural lands (e.g. permanent grasslands, shrubs) and forestry (logged forests, pristine forests), and different agricultural uses (intensive grasslands, croplands). This differentiation is necessary to be able to capture well the environmental impacts of trade, as carbon stocks and biodiversity richness highly differs per land cover. Through this gridded structure in both land covers and biophysical potential of production, it is possible to link demand and trade shifts to concrete land-use changes and therefore the impacts on the environment.

Because of the limited coverage of land and land use within macroeconomic models in ENTICE, we aim for a more flexible set-up, that will allow these models to assess the environmental impacts of trade without necessarily having to structurally revise their models or use model coupling techniques to get to an estimation. This involves four main steps (see section 3.5.2):

1. The disaggregation of agricultural sectors important for the estimation of environmental impacts.
2. The estimation of past and future land cover changes caused by main economic drivers.
3. The design of an approach for LULUCF and environmental indicators (Biodiversity Intactness Index—BII—, LULUCF emissions) within and outside of macro-economic models.
4. Enhancing the environmental indicators to assess trade-induced environmental impacts.

These four steps provide a practical and flexible pathway for improving the representation of land-use dynamics and environmental impacts in macroeconomic models, thereby directly supporting the core

[14] https://www.icesmodel.org/

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objectives of task 3.6. By disaggregating key agricultural sectors, models gain the level of detail needed to attribute emissions and resource use more accurately across production systems. Estimating past and future land-cover changes driven by trade and economic drivers enables a consistent linkage between trade-induced shifts in demand and their spatially explicit environmental consequences. Developing an approach for calculating LULUCF emissions and biodiversity indicators—both for models with and without explicit land as a production factor—ensures that environmental pressures can be assessed even in frameworks with simplified land representations. Finally, translating these land-use changes into quantified environmental indicators, such as BII, nitrogen pressures, and LULUCF emissions, equips macro-models with the capacity to evaluate trade- and climate-related policies in a scientifically sound manner. Together, these steps offer a harmonized and scalable methodology that strengthens the agriculture, forestry and other land use (AFOLU) components across macro-level models and fulfils the ambition of Task 3.6: to more accurately capture the environmental consequences of trade-induced land-use change within the ENTICE modelling ensemble.

3.5.2 Approach and work plan

The primary methodological objective of this task is to enhance the capacity of macroeconomic models to represent trade- and climate-induced land-use changes and their environmental consequences by improving the AFOLU components along three key dimensions:

1. Disaggregating agricultural sectors—especially livestock systems—to better attribute GHG emissions to specific products and production intensities.
2. Developing a more detailed, land-cover–specific representation of land-use change and associated emissions, using GTAP and emissions factor data.
3. Integrating refined AFOLU emissions and introducing biodiversity indicators (e.g., BII) into macro-models

Through these three key dimensions, task 3.6 aims to build a more accurate, spatially informed, and multidimensional representation of land-use and environmental impacts of trade, enabling not only the assessment of emissions but also biodiversity and other environmental effects of trade and climate policies. We can subdivide the workplan to get to this main aim into four steps.

Step 1. The disaggregation of agricultural sectors, important for the estimation of environmental impacts

This step will create a detailed livestock representation suitable for assessing trade-induced land-use and environmental impacts in macro-models. Building on Task 2.1, the GTAP agricultural sectors are expanded to distinguish large ruminants (cattle, buffalo), small ruminants (sheep, goats), pork, and poultry. Each livestock category will be further split into production systems—three for ruminants (grazing, mixed, intensive) and two for monogastrics (low- and high-intensity)—to capture differences in feed demand, land requirements, and emission intensities. These refinements will be linked to the GTAP nutritional accounts, food loss and waste data, and updated emission and air-pollution coefficients to ensure consistency across environmental indicators. The resulting highly disaggregated livestock dataset will be harmonised with GLOBIOM, enabling improved feed balancing, spatially explicit land-use allocation, and more accurate estimation of livestock-related environmental pressures.

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Step 2. The estimation of past and future land cover changes caused by main economic drivers

The second step focuses on constructing a robust land-use and land-use-change (LULUC) matrix that links economic drivers to land cover changes on the ground. Using Copernicus Land Cover products, we will assess current land-cover distributions and, where possible, reconstruct historical land-cover trajectories over recent decades, relying on Google Earth Engine to process, harmonize, and spatially aggregate the high-resolution datasets into larger grid cells and broader land-cover classes suitable for modelling. Natural land, forest land, arable cropland, and grassland will be distinguished as the minimum set of core categories, with additional refinement applied where relevant and data allows. These harmonized land-cover datasets will then be integrated into GLOBIOM, which will simulate how trade dynamics and major economic drivers—aligned with those identified in task 4.1—translate into spatially explicit land-cover changes, including deforestation, cropland expansion, grassland conversion, and loss of natural ecosystems. The combined empirical land-cover reconstruction and GLOBIOM-based projections will be consolidated into a lookup table that quantifies how marginal changes in production across regions and sectors induce corresponding land-use transitions, resulting in the trade-induced LULUC matrix required in deliverable D2.5.

Step 3. The design of an approach for LULUCF and environmental indicators (BII, LULUCF emissions) within and outside of macro-economic models.

In step 3, we will follow a two-tiered approach. The survey results have shown that on the one hand, modelling teams see value in creating protocols that link CGE model outputs to standalone products on environmental impacts. On the other hand, teams seek guidance on what environmental enhancements are feasible and how to meaningfully improve model representations. We will therefore on the one hand aim to conceptually develop an approach to include environmental impact assessment in CGE models. On the other hand, we will use the lookup table developed in Step 2 to estimate LULUCF emissions, as well as biodiversity impacts, under different economic drivers. LULUCF emissions will be calculated by combining land-cover transitions identified in the lookup table with standard emission factors from agriculture and forestry production, capturing key components of CO_2-equivalent emissions: carbon losses from deforestation and conversion of natural vegetation; changes in soil organic carbon resulting from cropland and grassland expansion or intensification; and non-CO_2 gases (CH_4 and N_2O) linked to agricultural practices. In parallel, we will estimate changes in the BII following the approach of Leclère et al. (2020), which quantifies how different land-use types reduce the abundance of originally present species relative to undisturbed ecosystems. By applying land-cover transitions from the lookup table to BII response functions for each land-cover class, we will compute how trade- and economy-driven land-use change affects biodiversity through habitat loss, fragmentation, and intensification. Together, these components will produce a consistent set of LULUCF emissions and biodiversity indicators that can be combined with macro-economic model output to reflect environmental consequences of trade and economic activity.

Step 4. Enhancing the environmental indicators to assess trade-induced environmental impacts.

In step 4, a broader suite of environmental indicators beyond carbon and BII will be developed, allowing for a multidimensional assessment of environmental impacts. In addition to the LULUCF emissions and biodiversity impacts developed in step 3, we will explore the feasibility of incorporating supplementary indicators that capture other dimensions of planetary boundaries. These may include soil degradation risk—drawing on global datasets that classify land by erosion vulnerability, nutrient depletion, or loss of organic matter—as well as water stress indicators that track the allocation of irrigation water across basins with differing scarcity levels. Biodiversity indicators could be expanded beyond BII to include Mean Species

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Abundance, extinction-risk proxies based on Species–Area Relationships, or vulnerability-weighted species richness, each offering different perspectives on how habitat loss and intensification affect species persistence. Further, the impacts of climate change on agricultural trade and the environment can be assessed. Slow-onset climate change alters the relative profitability of agricultural production, overall leading to a decrease in agricultural production, depending on the degree of warming. Further, extreme climate events cause agricultural production losses. Together, this leads to a reconfiguration of trade and agricultural land use, in turn impacting the environment. The exact list of expanded environmental indicators will be decided upon based on a literature review and further discussions with ENTICE consortium members.

The two-tiered approach of environmental impact assessment with macro-economic models will be tested with interested models.

Table 13. Work plan for task 3.5

Steps	Indicate time frame
Data collection process (livestock sector, land cover and land cover change −WP2 / T2.4)	December 2025 (M12) – October 2026 (M22)
Design approach for LULUCF and environmental indicators (BII, LULUCF emissions, nitrogen) calculation with and without including land as production factor in models	February 2026 (M14) – September 2026 (M21)
Environmental indicator (e.g. biodiversity, water, forest/natural land reduction, yields) impacts based on climate and land cover responses from land use models	May 2026 (M17) – December 2026 (M24)
Experimentation on inclusion with interested models	December 2026 (M24) – May 2027 (M29)

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4 Coordination of the model improvements

As the previous section has shown, the model developments proposed within the ENTICE project aim to address a range of shortcomings in modelling capacity, particularly with regard to the TCI framework. The survey of ENTICE models revealed that the suite of models is relatively diverse in terms of type and capability, although macroeconomic models, especially general equilibrium models, dominate.

The work plan for the different model-enhancement tasks is largely independent. However, there are some notable dependencies. In particular, task 3.2, "Enhancing the sectoral disaggregation of models", is linked to task 3.5, "Linking macroeconomic models with material flows and mineral resources". There are also significant connections between task 3.2 and WP2, "Improved data and empirics on trade and climate", especially with task 2.2, "Rearranging the GTAP sectoral structure for both green and emissions-intensive industries", and task 2.3, "Representation of future/promising technologies and products", as well as between task 3.6 and task 2.4, "Enhanced data and understanding of the land-use effects of trade". To ensure effective, smooth, and productive collaboration between WP2 and WP3 on these tasks, the leaders of the relevant tasks, as well as the work package coordinating teams, will be invited to participate in all related meetings and workshops. Some teams are already involved in both work packages and tasks, which will further facilitate coordination.

In addition, WP3 will organise monthly one-hour meetings to present the progress of each task. We propose the following programme (see Table 14—this program is indicative and will be adjusted following needs), aligned with the work plan summarised in Figure 4. The meetings will follow the general framework outlined below: two tasks will present their progress and discuss critical points for approximately 20 minutes each, with the remaining time devoted to cross-cutting issues or specific topics requiring discussion. These meetings will be complemented by coordination and discussion sessions between task leaders and modelling teams, organised as needed, to ensure that work progresses according to plan.

Table 14. Indicative programme for the WP3 monthly meeting from January 2026 to May 2027

<table>
<tr><th rowspan="2">Month</th><th colspan="5">Tasks</th><th rowspan="2">Month</th><th colspan="5">Tasks</th></tr>
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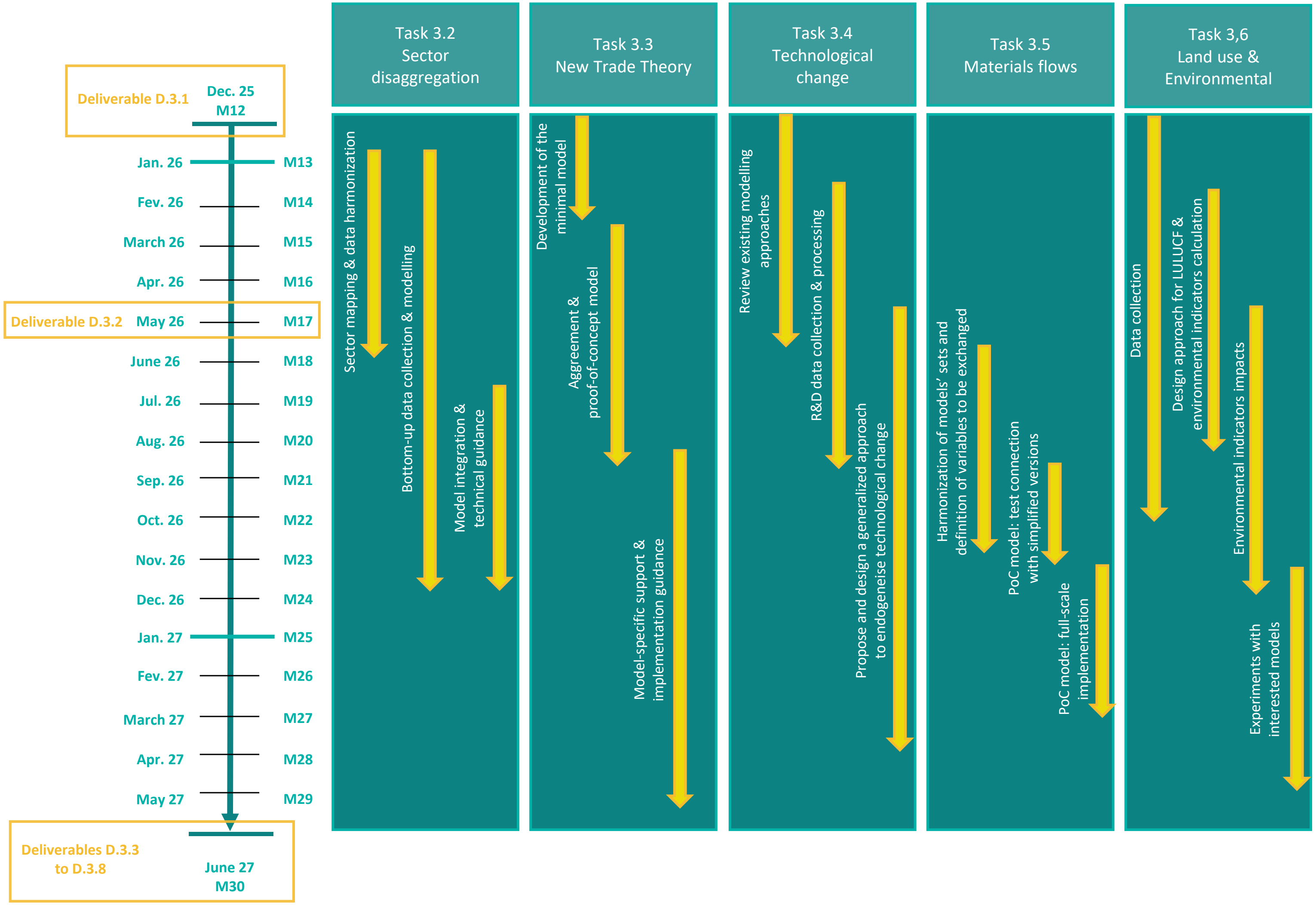

Figure 4. Summary of WP3 models' enhancements work plan

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ANNEX

A.1 Models' survey questionnaire

Table 15 lists the questions of the survey. The first column corresponds to the sheet names used in the Excel file, with one to two sheets per theme, and the second column shows the question.

Table 15. Models' survey's list of questions

Sheets	Questions
General	Technical information about the model, regarding Full name; Version; Short description; Lead institute; Type of model; Final base/calibration year; Time-step; Horizon simulation; Software; Web info
Geo	List of countries covered by the model, with corresponding native country/region code of the model
GTAP	Questions: • Do you use GTAP database for your model? • If yes, please indicate which version; if no, please indicate the main sources of economic data for your model. • Please indicate whether you use other GTAP satellite data such as the GTAP-E database, the GTAP circular economy database, etc. • If yes, please specify" • Please fill-in the indicated sheet, either "Sector_GTAP" or "Sector_NACE". • In case, you used older version than GTAP 10 please fill-in sheet ""Sector_NACE" instead of ""Sector_GTAP"
Sector_GTAP	Questions: • Please fill-in the column "current version" with the corresponding sectors of your model if you are using GTAP database otherwise fill-in the sheet "Sector_NACE". • Please indicate in column "ENTICE extension" the sectors you would like to detail in ENTICE and add relevant information in the "comments" column.
Sector_NACE	Questions: • Please fill-in the column "current version" with the corresponding sectors of your model if you do not use GTAP data otherwise fill-in the sheet "Sector_GTAP". • Please indicate in column "ENTICE extension" the sectors you would like to detail in ENTICE and add relevant information in the "comments" column.
Sector_desc	Questions: • Comments • Please indicate which data you would need to carry out the developments expected in ENTICE. • Please indicate what you expect from the team(s) leading these developments (e.g. presentation of theory, existing applied works, available data, etc.).
Int' Transport	Questions:

	• Does your model distinguish between international and national transport services? If so, please indicate which sectors are covered (e.g. road, rail, air, sea transport). • Does your model include a direct link between trade and the demand for international transport? • Does your model account for GHG emissions from international transport (e.g. bunkers)? If yes, please specify. • Do you expect to development or/and improve the modelling of international transport in your model? • If yes, please specify • Please indicate which data you would need to carry out the developments expected in ENTICE. • Please indicate what you expect from the team(s) leading these developments (e.g. presentation of theory, existing applied works, available data, etc.).
Trade_modelling	Questions: • Please specify the type of trade modelling in the model (e.g. Armington) • Are trade flows bilateral in your model? • Does your model distinguish between imported/exported goods/services by type of demand (i.e. intermediate consumption, households final consumption, government final consumption, gross fixed capital formation, others). • If yes, please specify." • Does your model include measures of intra-sector heterogeneity? • If yes, please specify." • Could you specify what kind of developments in trade modelling you would like to implement in your model with the ENTICE project? • Please indicate which data you would need to carry out the developments expected in ENTICE. • Please indicate what you expect from the team(s) leading these developments (e.g. presentation of theory, existing applied works, available data, etc.).
Technological_process	Questions: • Does your model include some endogenous mechanisms related to technological progress? • If yes, could you give some brief explanation of these mechanisms?" • If your model includes endogenous mechanisms, is technological progress biased or neutral (i.e. does it save a particular input or all inputs homogeneously)? • Does trade have an impact on technological change in your model? • If so, please specify how? • Do you expect to add/improve the representation of technological progress in your model for the ENTICE project? • If you would like to improve the modelling of technological progress, do you have any particular mechanisms you would like to implement? • If yes please specify. • Please indicate which data you would need to carry out the developments expected in ENTICE.

	• Please indicate what you expect from the team(s) leading these developments (e.g. presentation of theory, existing applied works, available data, etc.).
Materials	Questions: • Does your model include individualised materials in monetary units (e.g. crops, wood, metals, energy, etc.). Please specify. • Does your model include individualised materials in physical units (e.g. crops, wood, metals, energy, etc.). Please specify. • Does your model take into account critical raw materials (in physical units)? If yes, please specify. • Does your model take resource potential into account? • If so, please specify the materials involved." • How is the supply of raw materials modelled in your models (e.g. CES production function, Hotelling rule, specific supply curves, etc.)? • What are your expectations in terms of improving material modelling for your model in ENTICE? • Please indicate which data you would need to carry out the developments expected in ENTICE. • Please indicate what you expect from the team(s) leading these developments (e.g. presentation of theory, existing applied works, available data, etc.).
Materials_detailed	Please fill in the tables for your model. First table corresponds to materials (used for Materials Flow Accounting). Second table corresponds to strategic and critical raw materials (as identified by European Commission in the Fifth list 2023 of critical raw materials for the EU). For the columns 'After ENTICE model developments', please indicate how you expect your model's coverage to evolve following the developments planned in ENTICE
LandUse	Questions: • What is the level of model granularity for land use? Region (aggregation of countries), countries, grid • Does your model consider biomes (geographical region with specific climate, vegetation, and animal life) ? If yes, based on which classification (e.g. GAEZ) • Could you explain the sectoral coverage of the agriculture and land use sector(s) in your model? E.g. agriculture (arable farming, livestock farming), forestry, bioenergy, fisheries • Specify the modelling approach of the land use sector (e.g. CES production functions) • Does your model include land as a production factor ? • If yes, which land cover classes do you distinguish (cropland, grassland, forest, natural land, urban land)? • Does the modelling of the land use sector include usage useful for environmental accounting? Specifically, do you consider water use (blue, green, grey) and fertilizer use (nitrogen, phosphorus)? • Does your model account for GHG emissions from land use and land use change? • If yes, please specify which gases and sectors are concerned." • Please detail your expectations regarding the modelling of the agriculture and forestry sector(s) for your model in ENTICE?

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	• Please detail your expectations regarding the modelling of the land use for your model in ENTICE? • Please indicate which data you would need to carry out the developments expected in ENTICE. • Please indicate what you expect from the team(s) leading these developments (e.g. presentation of theory, existing applied works, available data, etc.).
EnvIssues	Questions: • Does your model include GHG emissions not related to land use and land use change? If so, related to which sector? • Does your model include tailored-environmental indicators (e.g. (non-)cancer human toxicity, fresh water toxicity, biodiversity, generation of waste, energy consumption, carbon footprint, air quality)? If yes, please specify. • More precisely, does your model include some biodiversity related indicators? E.g. biodiversity intactness index. If yes, please specify." • Are there any environmental indicators that you would like to focus on in ENTICE? (e.g. water use (blue, green, grey), nitrogen and phosphorus, land-based CO_2 and non-CO_2 emissions, biodiversity indicator, environmental footprint) • What are your expectation, for the ENTICE project, in terms of improving your model's ability to assess environmental concerns (with the exception of climate change)? • Please indicate which data you would need to carry out the developments expected in ENTICE. • Please indicate what you expect from the team(s) leading these developments (e.g. presentation of theory, existing applied works, available data, etc.).
Climate_technologies	Fill in the table for the model that lists climate mitigation technologies (Upstream technologies; Electricity and heat generation technologies; Transport; Buildings; Industry; Agriculture; Non-energy use; Direct Air Capture) withy the following options: • Yes, • Yes, but partially • Not yet but expected during ENTICE • No • Not applicable
Policy	Fill in the tables for the model, that list policy option on GHG emissions mitigation, Energy, Agriculture, Land and Trade and wirth the following options for the responses: • Feasible • Feasible with modifications • Not yet feasible but feasible after ENTICE • Not feasible • Other (please specify in the comment tabs)

A.2 Models' description

Table 16. DYNERIO description

<table>
<tr><th colspan="2">DYNERIO</th><th colspan="2">https://www.i2am-paris.eu/detailed_model_doc/dynerio</th></tr>
<tr><td>Lead Institute</td><td>Type of model</td><td>Reference/calibration year</td><td>Time-step</td></tr>
<tr><td>POLIMI</td><td>Dynamic Physical Stock-Flow Model</td><td>2019</td><td>To define</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">The DYNERIO module is a dynamic physical stock-flow model that estimates the quantities of critical raw materials (CRMs) required for the deployment and decommissioning of energy technologies, as well as their recycling potential. Based on capacity deployment trajectories (possibly provided by other models), DYNERIO computes quantities of a selected number of primary materials to be extracted, processed and recycled in order to support the deployment, operation and disposal of energy technologies and infrastructures. This model enables a time- and region-specific material demand quantification, including domestic and trade flows, enabling assessment of resource supply security and related sustainability considerations. The model is based on a input-output structure and has a flexible regional and technological scope: this allows for a consistent link with a variety of macroeconomic and energy models. Here we also clarify the reason why we left some of the requested information blank:
• Climate technologies: DYNERIO accounts for materials embedded within technologies, so can potentially work with all the listed technologies
• Policy: results from DYNERIO can be complementary to other models in giving policy insights</td></tr>
</table>

Table 17. ENVISAGE description

<table>
<tr><th colspan="2">ENVISAGE</th><th colspan="2">https://mygeohub.org/groups/gtap/envisage-docs</th></tr>
<tr><td>Lead Institute</td><td>Type of model</td><td>Reference/calibration year</td><td>Time-step</td></tr>
<tr><td>Purdue</td><td>Computable General Equilibrium Model</td><td>2017</td><td>1-year (flexible)</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model is a global recursive dynamic CGE model designed to assess the interactions between economies and the global environment. A set of non-linear behavioural equations is at the core of the ENVISAGE model, representing the production and consumption choices of all key economic agents. The model relies on the Global Trade Analysis Project (GTAP) Data Base, with the latest publicly available version (v11c) covering 160 regions, of which 141 are individual countries. Global production is divided into up to 99 sectors (GTAP-CE Data Base) with extensive details for agriculture, food and energy (coal mining, crude oil production, natural gas production and distribution, refined oil and various electricity generation technologies). Due to numerical and algorithmic constraints, a typical model is limited to some 30-40 sectors and 20-25 regions. The ENVISAGE model has been used in various applications focusing on a variety of global economic issues, including but not limited to trade policies, climate impacts and mitigation, dietary transition, circular economy, stranded assets, carbon border adjustments, distributional analysis, food security, etc.</td></tr>
</table>

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Table 18. FIDELIO description

FIDELIO			
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
CMCC	Neo-Keynesian General Equilibrium Model	2015	1-year
Description			
FIDELIO is a multi-country, multi-sector general equilibrium model designed to assess the socioeconomic and environmental impacts of policies related to trade, climate, investment, and innovation. It covers all EU Member States, 18 additional countries, and a residual "rest of the world" region. The default database provides a detailed breakdown into 64 economic sectors. Each country is structured around a multi-regional input-output (IO) core based on a Leontief framework, which links sectors and countries through trade and production chains. The IO-based general equilibrium structure enables the model to capture both direct policy impacts on targeted sectors or agents and indirect effects across the economy—through production linkages, income generation, redistribution, consumption choices, and sectoral or international spillovers and rebound effects. Key outcome variables include employment, economic growth, trade balance, resource use, and emissions. Trade is modelled using a two-step Armington specification, allowing for substitution between domestic and imported goods and allocation across trading partners. On the supply side, production is governed by a three-level nested CES function: firms first choose between material and non-material inputs (the KLE bundle), then between capital–labour and energy services, and finally between capital, labour, electricity, and non-electric energy. Production prices are set under Cournot competition with a markup over marginal cost, while investment and capital accumulation drive long-term dynamics. Households allocate disposable income—earned from labour, capital, and transfers—between consumption and savings. Consumption patterns are modelled using an AIDS demand system. The government collects revenue through taxes and allocates spending across consumption, investment, transfers, and debt service, with the fiscal balance determining the path of public debt. In addition to production prices, other behaviourally determined prices include wages and interest rates. Wages follow a generalized Phillips/Wage-Setting curve, while interest rates are set via a Taylor rule. A key feature of FIDELIO is dynamic adjustment: economic agents gradually adjust prices and quantities toward notional (optimal) levels, reflecting frictions and adjustment costs. These mechanisms enable realistic short-run dynamics and ensure convergence to a neoclassical steady state in the long run.			

Table 19. GEM-E3 description

GEM-E3		https://e3modelling.com/modelling-tools/gem-e3/	
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
E3M	Computable General Equilibrium Model	2017	5-years
Description			
The GEM-E3 model is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model which provides details on the macro-economy and its interaction with the environment and the energy system. It is an empirical, large scale model, written entirely in structural form. GEM-E3 allows for a consistent comparative analysis of policy scenarios since it ensures that in all scenarios, the economic system remains in general equilibrium. In addition, it incorporates micro-economic mechanisms and institutional features within a consistent macro-economic framework and avoids the representation of behaviour in reduced form. Particularly valuable are the insights the model provides regarding the distributional aspects of long-term structural adjustments. The GEM-E3 model is extensively used as a tool of policy analysis and impact assessment.			

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Table 20. GEMINI-E3 description

GEMINI-E3		https://www.i2am-paris.eu/detailed_model_doc/gemini_e3	
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
ORDECSYS	Integrated Assessment Model	2017	1-year
Description			
GEMINI-E3 is a multi-country, multi-sector, recursive computable general equilibrium (CGE) model. It simulates all relevant markets, domestic and international, considered as perfectly competitive, which implies that the corresponding prices are flexible in markets for commodities (through relative prices), for labour (through wages), and for domestic and international savings (through rates of interest and exchange rates). Time periods are linked in the model through endogenous real rates of interest determined through the balancing of savings and investment. National and regional models are linked by endogenous real exchange rates resulting from constraints on foreign trade deficits or surpluses. There is one notable—and usual—exception to this general assumption of perfect competition, which concerns foreign trade. Goods of the same sector produced by the different countries are not supposed to be perfectly competitive; they are considered as economically different goods, more or less substitute according to an elasticity of substitution known as the Armington assumption. The main outputs of the GEMINI-E3 model are on a country and annual basis: carbon taxes, marginal abatement costs and prices of tradable permits (when relevant), effective abatement of CO2 emissions, net sales of tradable permits (when relevant), total net welfare loss and components (net loss from terms of trade, pure deadweight loss of taxation, and net purchases of tradable permits when relevant), macro-economic aggregates (e.g. production, imports and final demand), real exchange rates and real interest rates, and data at the industrial level (e.g. change in production and in factors of production, and prices of goods).			

Table 21. GLOBIOM description

GLOBIOM			https://globiom.org/index.html
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
VUA	Partial Equilibrium Model	2000	10-years
Description			
GLOBIOM is a partial equilibrium model that covers the global agricultural and forestry sectors, including the bioenergy sector. Commodity markets and international trade are represented at the level of 58 economic regions (including EU28 individual member states). Prices are endogenously determined at the regional level to establish market equilibrium to reconcile demand, domestic supply and international trade. For crops, livestock, and forest products, spatially explicit Leontief production functions covering alternative production systems are parameterized using biophysical models like Environmental Policy Integrated Model, Global Forest Model or the RUMINANT model. For the EU, the model represents eight different livestock production systems, three tillage systems as well as alternative crop rotations for the EU. For the present study, the supply side spatial resolution was aggregated to 2◦ (about 200 × 200 km at the equator). Land and other resources are allocated to the different production and processing activities to maximize a social welfare function which consists of the sum of producer and consumer surplus. The model includes six land cover types: cropland, grassland, short rotation plantations, managed forests, unmanaged forests, and other natural vegetation land. Depending on the relative profitability of primary, by-, and final products, the model allocates production activities and can switch from one land cover type to another. Spatially explicit land conversion over the simulation period is endogenously determined within the available land resources and conversion costs that is considered in the producer optimization behaviour. Land conversion possibilities are further restricted through biophysical land suitability and production potentials, and through a matrix of potential land cover transitions. GLOBIOM covers major GHG emissions (CO_2, N_2O, and CH_4) from agricultural production, forestry, and other land use and different mitigation options for the land use sector.			

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Table 22. ICES description

ICES			https://www.icesmodel.org/
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
CMCC	Computable General Equilibrium Model	2017	5-years
Description			
ICES is a recursive dynamic multiregional Computable General Equilibrium (CGE) model to assess impacts of climate change on the economic system and to study mitigation and adaptation policies. ICES is a multipurpose tool to assess impacts of climate change on the economic system, evaluate costs of mitigation and adaptation policies, describe the key role of public sector for mitigation and adaptation polices, and draw future sustainability scenarios. The model's general equilibrium structure allows for the analysis of market flows within a single economy and international flows with the rest of the world. This implies going beyond the "simple" quantification of direct costs, to offer an economic evaluation of second and higher-order effects within specific scenarios either of climate change, climate policies or different trade and public-policy reforms in the vein of conventional CGE theory.			

Table 23. IMAGE description

IMAGE	https://models.pbl.nl/image/Welcome_to_IMAGE_3.3_Documentation		
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
PBL	Integrated Assessment Model	2022	1-year
Description			
IMAGE is an IAM of intermediate complexity that represents human and natural systems in a process-oriented way and simulates their interaction through land use and emissions. Model drivers are demographic, economic and technological developments and resource availability, lifestyle choices and different policies. Using socio-economic pathways, it projects implications for energy, land, water, emissions, climate, and resource depletion, thereby addressing environmental issues such as climate change, land-use change, biodiversity loss, nutrient cycle modifications, and water scarcity. IMAGE has a modular structure, with some components integrated directly and others running independently but soft-linked via data exchange. The core model covers key aspects of the human and Earth systems, including the energy system (TIMER), land use (IMAGE-management), and the carbon, water, and vegetation model LPJmL. Soft-linked models include the agro-economic model MAGNET, the climate model MAGICC and impact models, such as FAIR (climate policy), GLOBIO (biodiversity), GLOFRIS (flood risks), GISMO (human development), and IMAGE-MATERIALS for capital stocks, material demand and circularity. The socio-economic processes and most human system parameters are represented across 26 global regions, while the earth system is simulated on a 5x5 minute grid for land use and land-use change, and a 30x30 minute grid for plant growth as well as carbon and water cycles. IMAGE runs in annual time steps, making it well-suited for long-term climate mitigation analyses extending to 2100.			

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Table 24. LBAM description

LBAM			
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
UNIVR & UoS	Static Trade Model	2018	To define

Table 25. NEMESIS EU description

NEMESIS EU		https://www.erasme-team.eu/en/the-nemesis-model/	
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
SEURECO	Neo-Keynesian General Equilibrium Model	2017	1-year
Description			
The NEMESIS - EU model is a multi-sector multi-region macroeconomic model. It is a system of economic models for each EU Member State + UK, NO & IS, devoted to study issues that link economic development, competitiveness, employment and notably structural policies involving long term effects, such as climate policy. The essential purpose of the model is the assessment of the socioeconomic impact of EU policies in a scenario comparative analysis framework. The main mechanisms of the model is based on the behaviour of representative agents: firms, households and governments. From the supply side, the model distinguishes 30 different economic activities that produce goods and services through production functions and, to do so, use production factors: capital, energy, low and high-qualified labour and other intermediate consumption. All these economic activities are interrelated by inter-sectoral exchanges (conversion matrices) and external trades. NEMESIS includes a detailed energy-environment module that allows the model to deal with climate mitigation policies. This module enhances the representation of the energy-system of each region by detailing the energy used by each economic activity but also by households. It will also details the power generation sector by allocating electricity production between different technologies through diffusion curves.			

Table 26. NEMESIS World description

NEMESIS World		https://nemesis-world.readthedocs.io	
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
SEURECO	Neo-Keynesian General Equilibrium Model	2019	1-year
Description			
NEMESIS-World is a multi-country, multi-sector, recursive dynamic macroeconomic model, inspired by the EU version of the NEMESIS model. It is a system of interconnected economic models covering 22 world regions, dedicated to studying issues related to economic development, competitiveness, employment, and, in particular, long-term structural policies such as climate policy. The primary purpose of the model is to assess the socioeconomic impacts of various policies through scenario-based comparative analysis. The model's core mechanisms rely on the behaviour of representative agents: firms, households, and governments. On the supply side, the model distinguishes 59 different economic activities that produce goods and services using production functions. These activities employ various production factors: capital, energy, low-, medium-, and high-skilled labour, and other intermediate inputs. All sectors are interlinked through inter-sectoral exchanges (conversion matrices) and international trade. NEMESIS-World also features a detailed energy-environment module, enabling the model to address climate mitigation policies. This module improves the representation of each region's energy system by detailing energy use across economic activities and households. In addition, it refines the modelling of the power generation sector by allocating electricity production across different technologies.			

Table 27. OPEN-PROM description

OPEN-PROM		https://e3modelling.com/modelling-tools/prometheus/	
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
E3M	Energy System Simulation Model	2021	1-year
Description			
PROMETHEUS is a global energy system model covering in detail the complex interactions between energy demand, supply and energy prices at the regional and global level. Its main objectives are: 1) Assess climate change mitigation pathways and low-emission development strategies for the medium and long-term 2) Analyse the energy system, economic and emission implications of a wide spectrum of energy and climate policy measures, differentiated by region and sector) 3) Explore the economics of fossil fuel production and quantify the impacts of climate policies on the evolution of global energy prices. The PROMETHEUS model provides detailed projections of energy demand, supply, power generation mix, energy-related carbon emissions, energy prices and investment to the future covering the global energy system. PROMETHEUS is a fully fledged energy demand and supply simulation model aiming at addressing energy system analysis, energy price projections, power generation planning and climate change mitigation policies. OPEN-PROM is a new open version of the model, now being finalised, including several spatial, technological, temporal and policy-related improvements.			

Table 28. SORMAC description

SORMAC-25		https://www.ordecsys.com/page/sormac	
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
ORDECSYS	Infinite Horizon Optimal Control Model	2022	5-years
Description			
SORMAC-25 is a five-region optimal economic growth model representing the global energy transition to net-zero emissions when carbon dioxide removal (CDR) technologies are available. The main features of the model are (i) the representation of the economy and energy use with nested CES production functions; (ii) the representation of climate policy through the use of a safety cumulative emissions budget concept; and (iii) the introduction of an international emissions trading scheme for the implementation of climate policy. Using an infinite horizon optimal control paradigm, several contrasting scenarios are analyzed both in an asymptotic steady state or "turnpike" point, and in an optimal transition to sustainability. This very compact model produces dynamic path simulations that are consistent with the main recommendations from IPCC for long term climate policies.			

Table 29. ZEW model description

ZEW model			
Lead Institute	**Type of model**	**Reference/calibration year**	**Time-step**
ZEW	Computable General Equilibrium Model	2017	5-years
Description			
The recursive dynamic general equilibrium model features a multi-sector, multi-regional structure with a directed technical change mechanism. It captures fossil and renewable energy use across sectors with varying carbon intensity, and models endogenous innovation in fossil- and electricity-based energy services. Granular household behaviour is represented through 240,000 heterogeneous EU households, based on matched microdata from EU-SILC and HBS. Heterogeneity spans income, consumption, and skill-specific labour supply. Regional and skill-specific unemployment is modelled via a wage-curve approach.			

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A.3 Synthesis of the survey' results (additional figures)

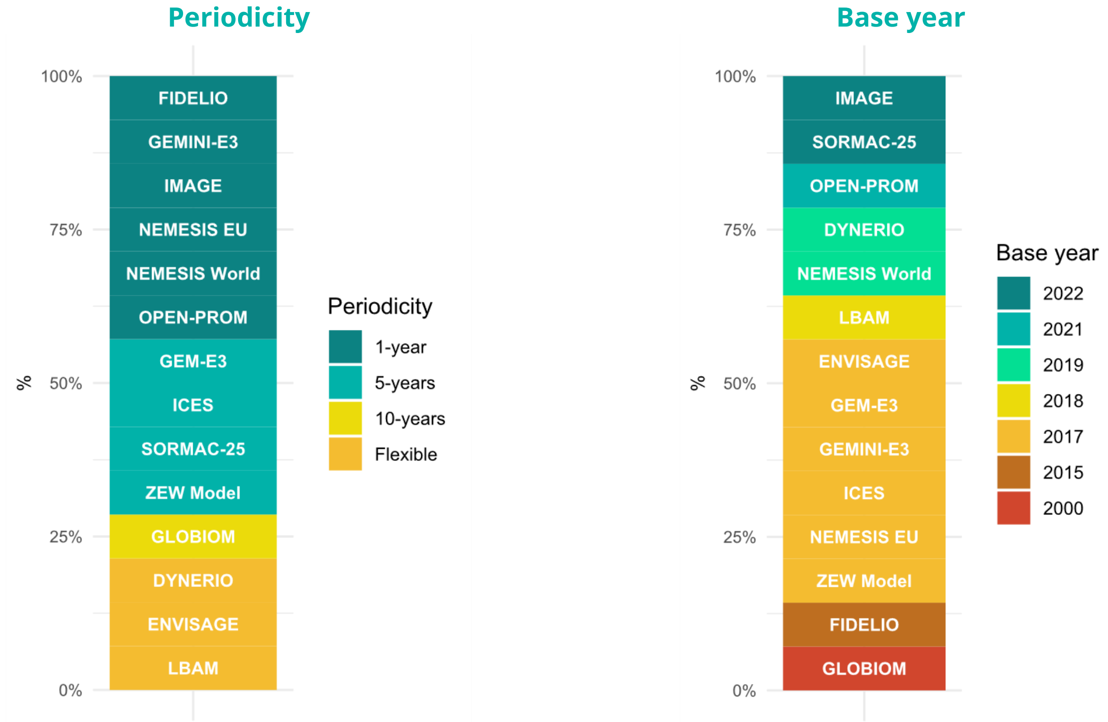

Figure 5. Models' periodicity and base year

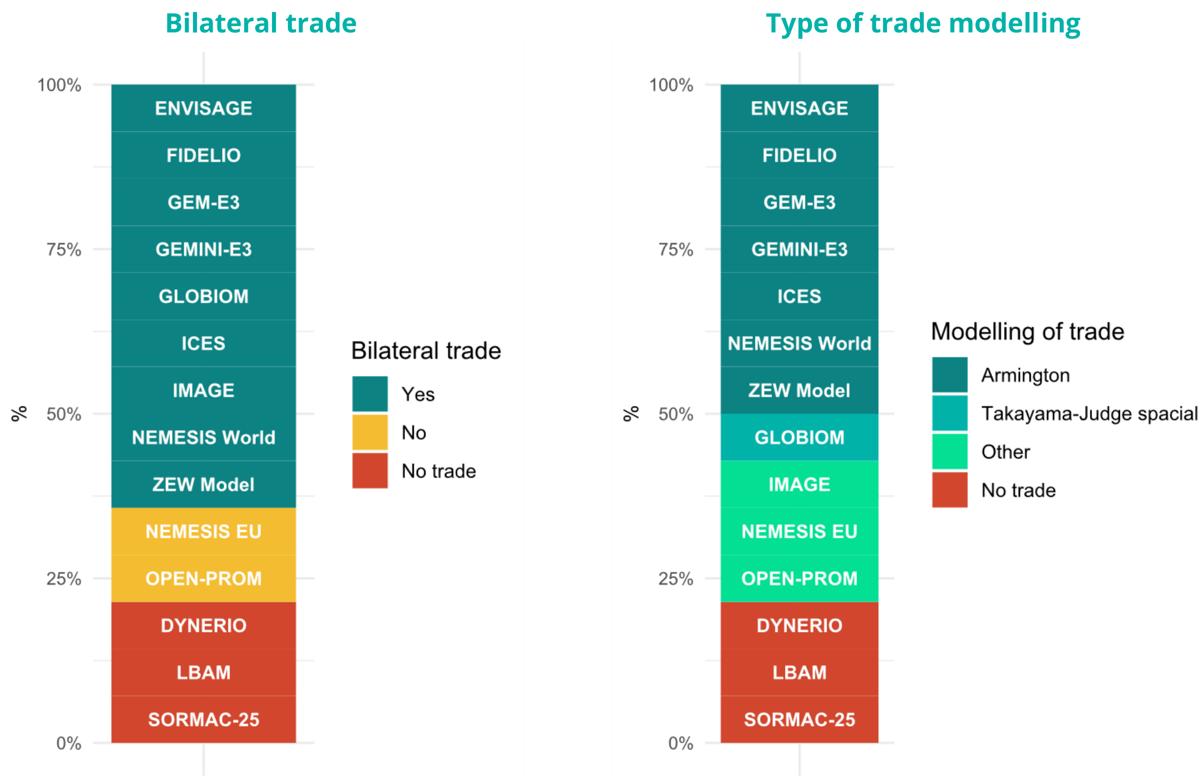

Figure 6. Representation of trade in the models

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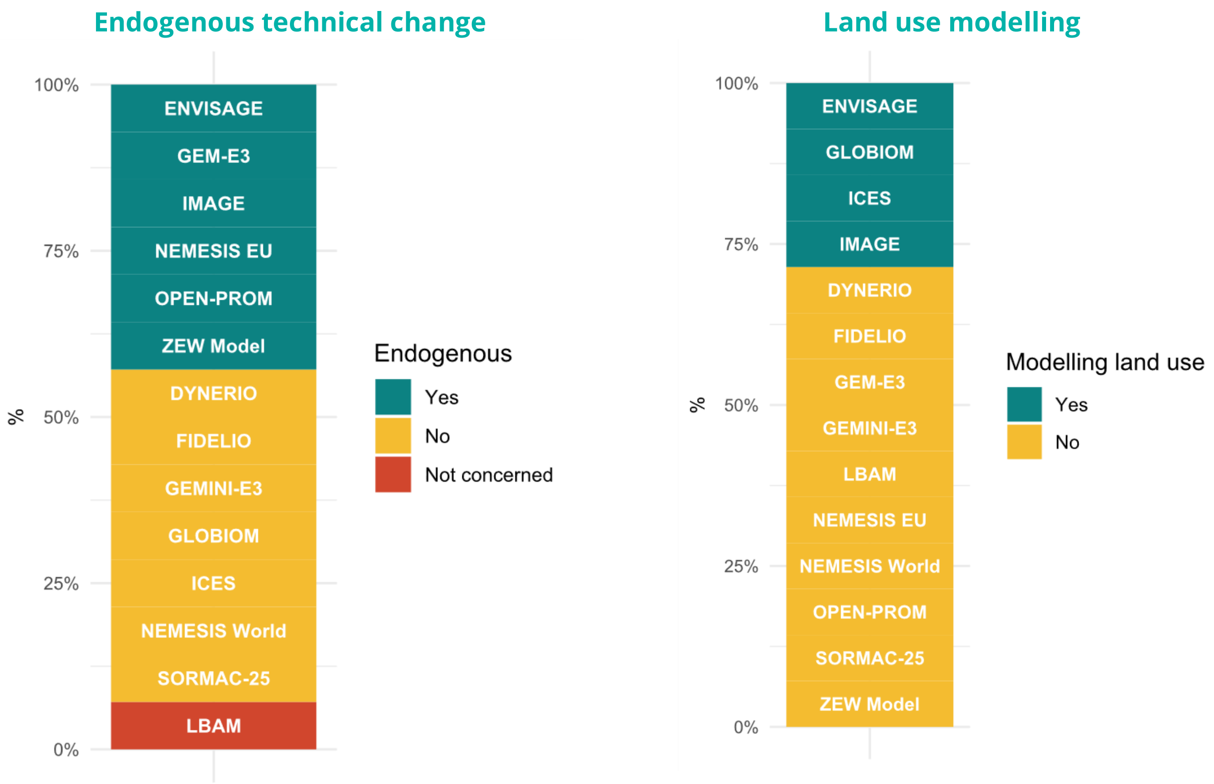

Figure 7. The modelling of technological change and of land use

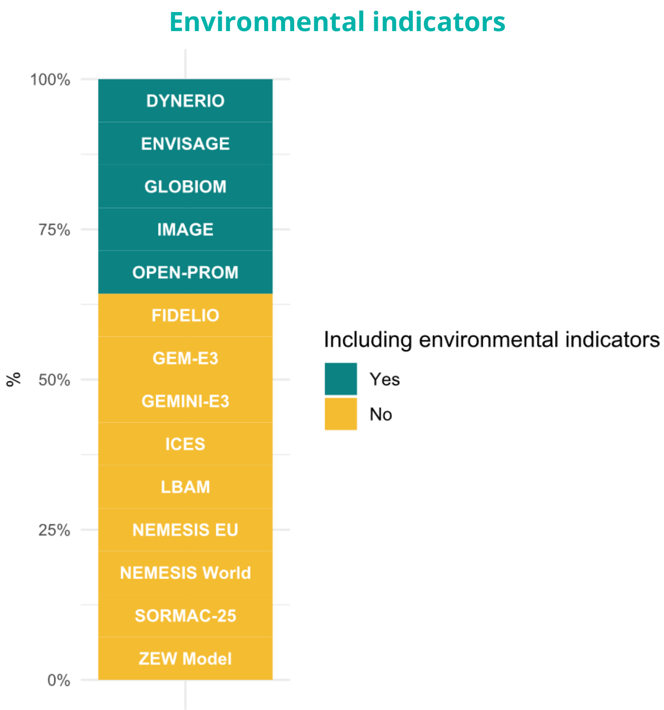

Figure 8. Environmental indicators

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