Energy system implications of novel protein uptake in Ireland: a national scale integrated modelling analysis

44th International Energy Workshop, Cape Town

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Overview

- Why food system transition and novel proteins matter ?
- What is the challenge with novel proteins?

- Method used in this work:

→ The national integrated model, TIM-LEAF

→The scenario design

- Preliminary outputs

→Land use implications

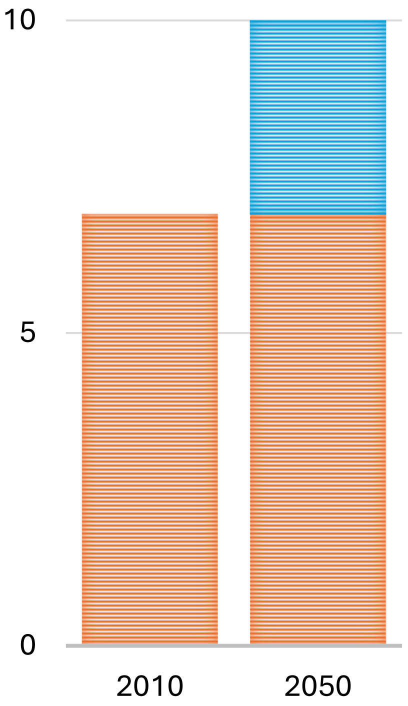
→Energy system response

→GHG emissions implications

- Concluding remarks, limitations and ongoing work

Why food systems transition matter

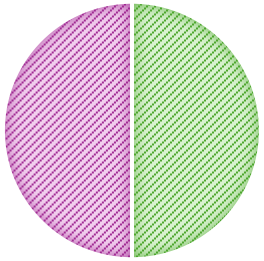
1. Meeting increasing food demand...



>50% more food to feed 10B people

Raganathan et al (2018)

2. by using less land...



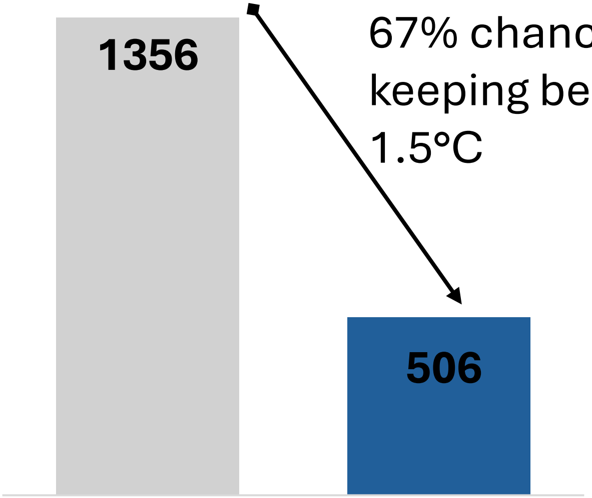
~50% of land currently used for agriculture

Prevent expansion of nearly 600 Mha, that can be restored for nature

Ritchie & Roser (2024)

3. and reducing emissions...

Cumulative emissions in $GtCO_2e$ (2020 – 2100)



67% chance of keeping below 1.5°C

Ritchie (2021)

Improved feed, resilient crop breeds, improved practices, **alternative proteins**

Alternative proteins are to food systems what renewables are to energy systems...

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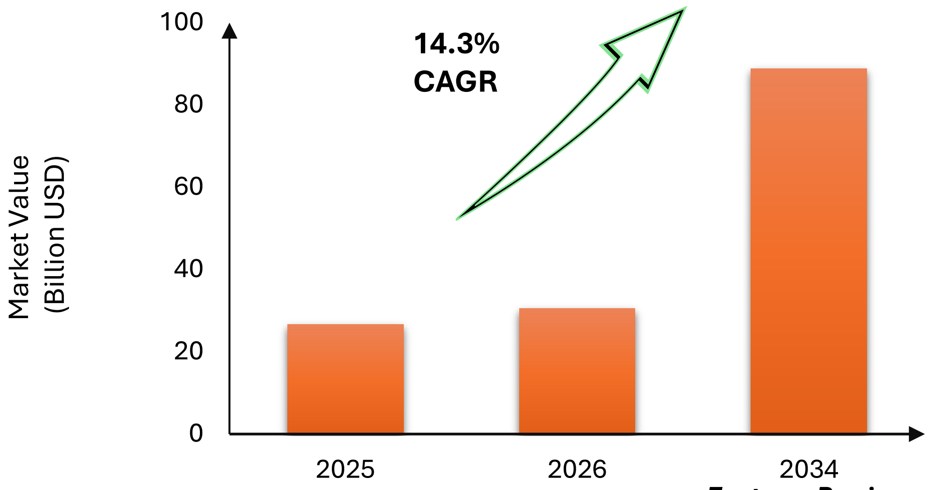
Currently available alternative proteins

- Plant based
- Microbe based (precise fermentation)
- Cell culture
- Insect based

Projected global market growth



Fortune Business Insight, 2026

***CAGR- Compound annual growth rate**

% Reduction in resource use when switching from conventional to cultivated meat

Plant based meat	Conventional meat	Land use (m^2/kg)	GHG emissions ($kgCO_2e$/kg)	Water use (L/kg)
Impossible burger 2.0	Beef burger	96%	89%	87%
Beyond burger	Beef burger	-	89%	99%
Impossible sausage	Pork	59%	29%	21%
Impossible chicken nuggets	Breaded chicken patties	49%	36%	44%

GFI and CE Delft LCA (2021)

Why novel proteins matter for energy systems?

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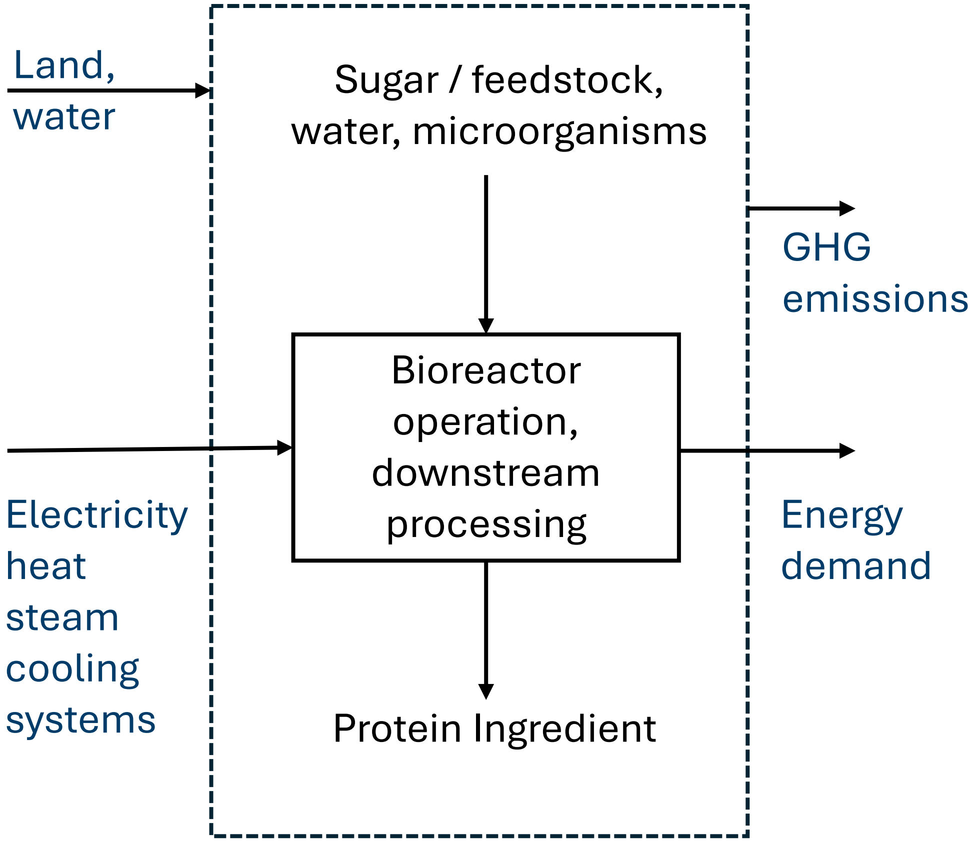
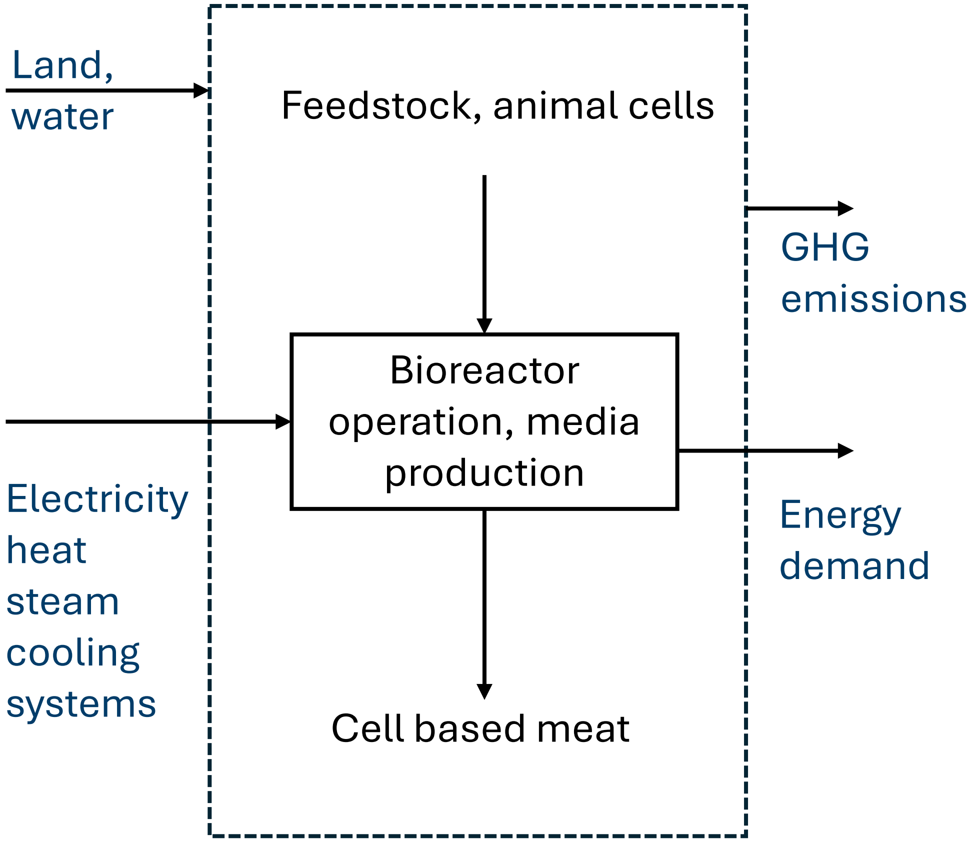
- Novel proteins are industrial food production - especially precision fermentation and cell-based protein production





.Novel proteins shift pressure from land to energy systems

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Replacing Ireland’s current meat and dairy protein output with fermentation-based and cellular protein could require on the order of 30–35 TWh of electricity annually

Year	Protein source	Type of novel protein	kg protein	Energy Intensity	Total Energy (TWh)
2020	Meat	Microbial	309037000	53	16.4
	Milk	Cell culture recombinant protein	291089000	44	13.1
	Egg		7026000		
				Total	29.5
2025	Meat	Microbial	258376000	53	13.6
	Milk	Cell culture recombinant protein	446617000	44	19.9
	Egg		6080000		
				Total	33.6

Preliminary calculations for Ireland, based on data from (El Wali et al., 2024; Järviö et al., 2021)

Novel proteins are already becoming industrial electricity consumers

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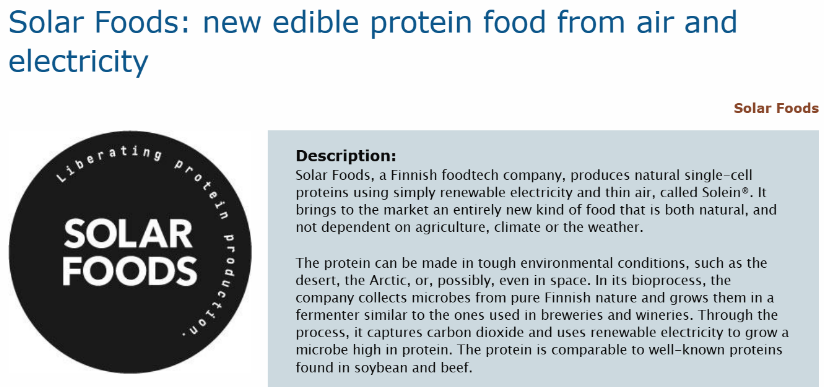
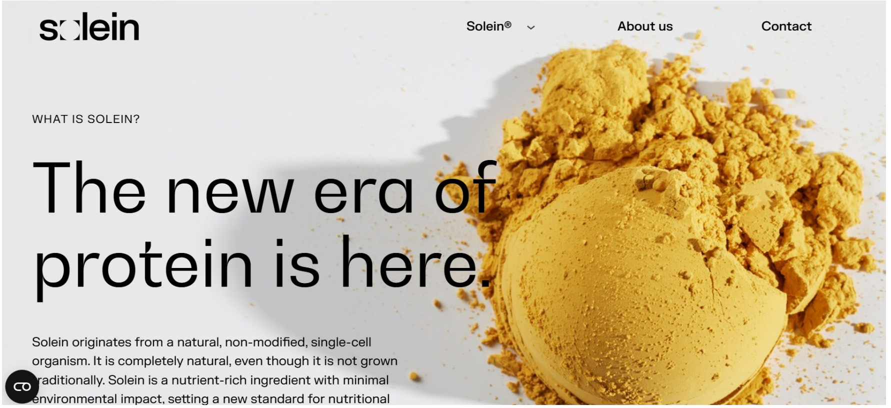
- Solar Foods provides a real-world example of this
- Commercial microbial protein production
- Produces Solein® using hydrogen fermentation
- Inputs: CO_2, water, nutrients and renewable electricity

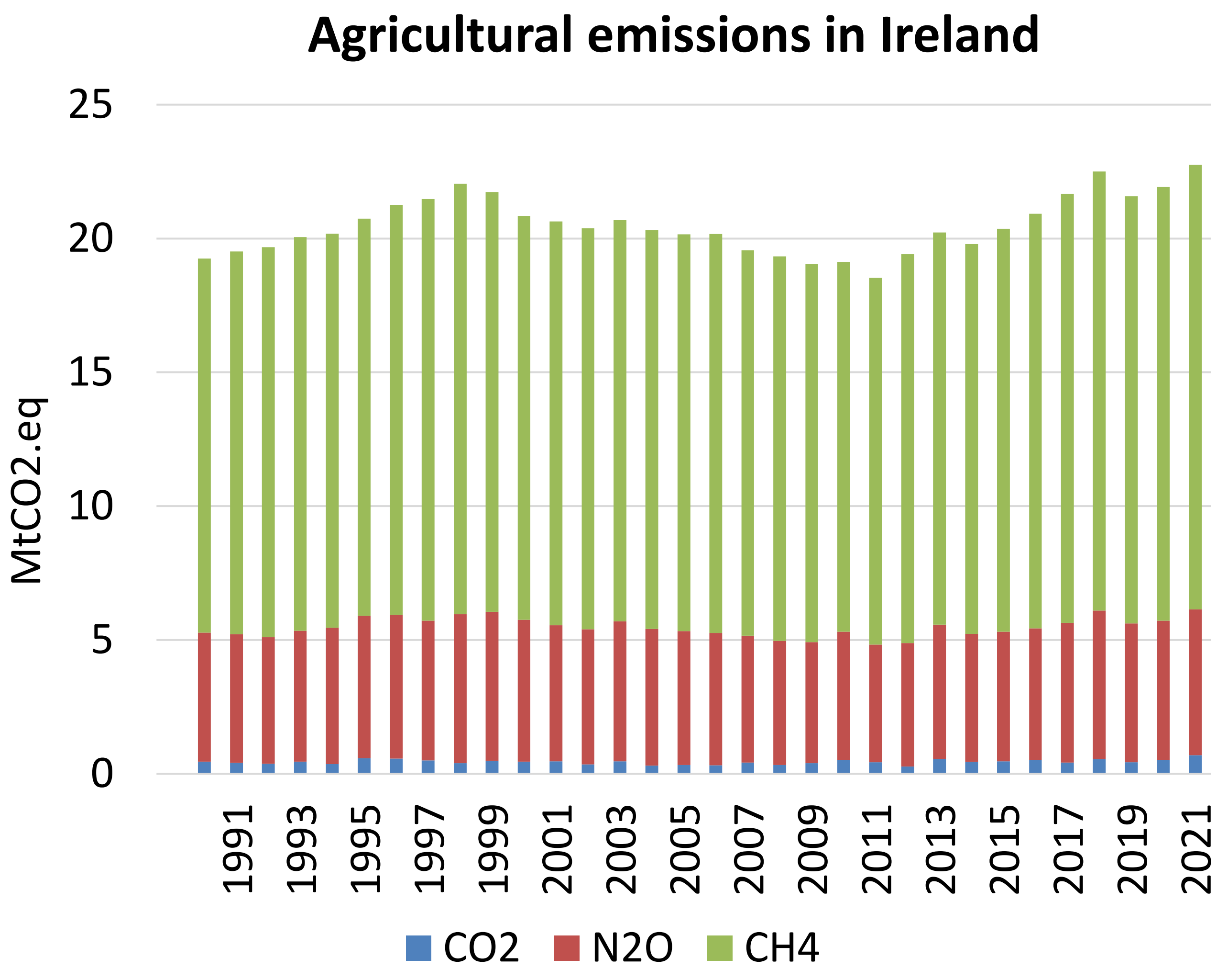


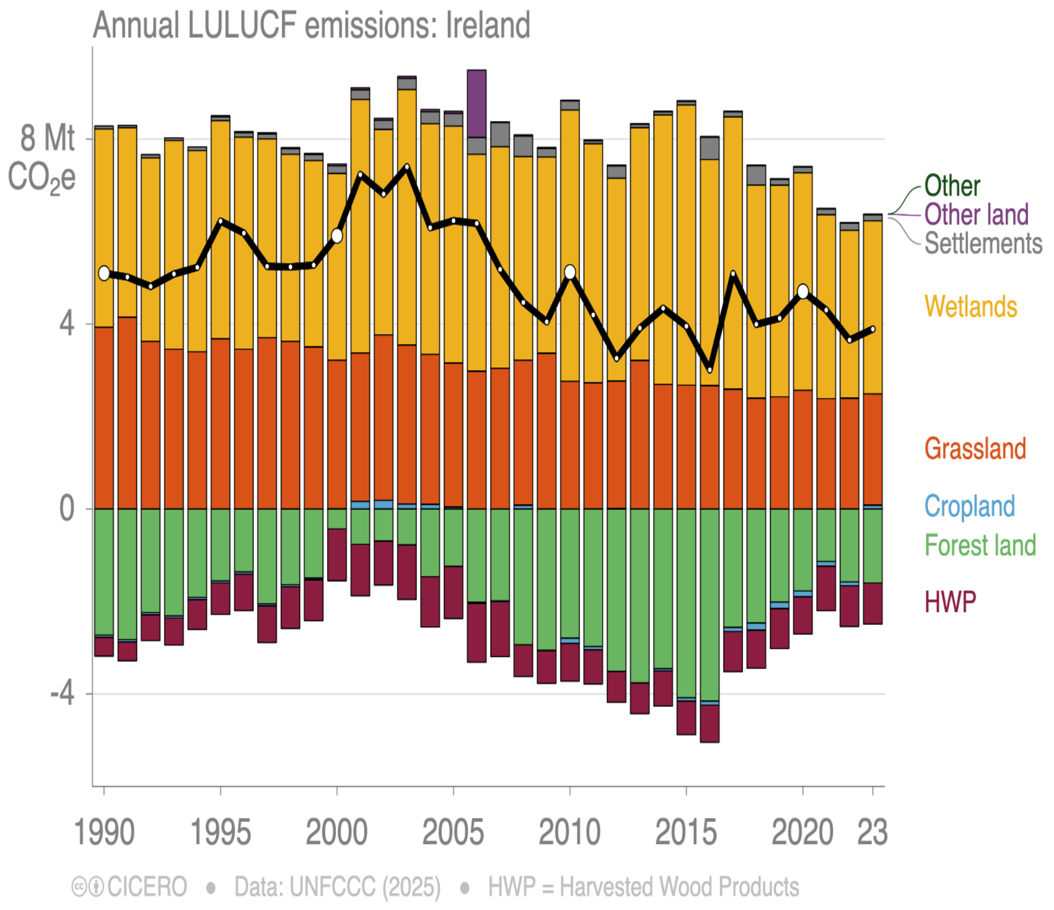
European Union Blog
https://circulareconomy.europa.eu/platform/en/good-practices/solar-foods-new-edible-protein-food-air-and-electricity



The commercially available protein rich microbial powder
https://www.solein.com/what-is-solein/

Ireland: high stakes, high opportunity





Sources: EPA National Inventory report 2024 (Duffy et al.*, 2024)*

Robbie Andrew (https://robbieandrew.github.io/) at CICERO (https://cicero.oslo.no/en))

Research objectives

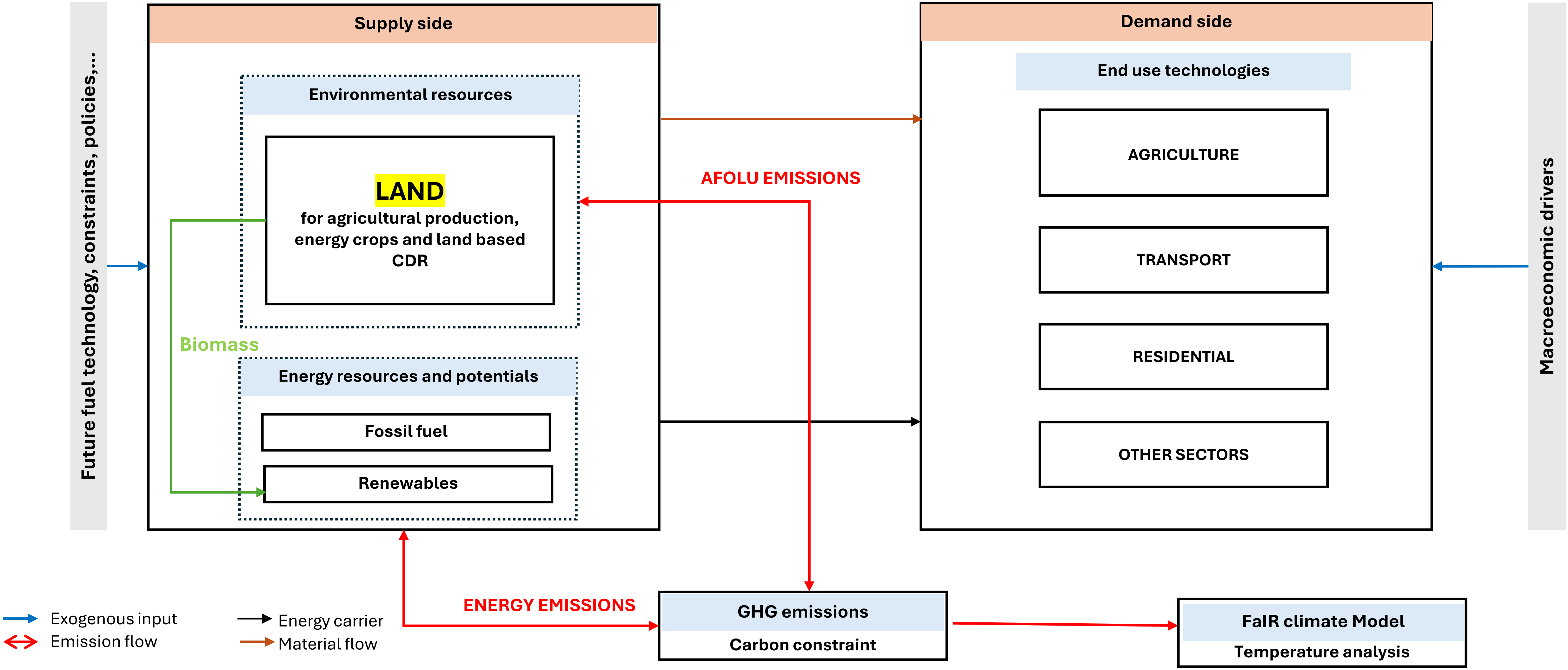
- Using the TIMES Ireland Model for Land, Energy, Agriculture and Forest (TIM-LEAF) to assess the national-scale energy implications of novel protein adoption in Ireland.

→ How does large-scale novel protein uptake affect Ireland's electricity demand?

→ How is this additional demand supplied within a least-cost decarbonised energy system?

→ What are the implications for long-term energy and climate planning?

The TIMES Ireland Model for Land, Energy, Agriculture and Forest (TIM-LEAF)



TIM-LEAF: Exogenous v/s Endogenous structure

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Module	Exogenous	Endogenous	Additional notes
Energy	Energy service demand CO_2 policy constraint	Technology deployment Cost optimal pathway	Core optimisation driver; determines biomass demand from AFOLU
Land	Total land availability Historical land use baseline Upper bound on land conversion limits	Allocation of residual land across uses (after meeting land for food) Land use change between categories	Land scarcity impacting energy, agriculture, forest production
Agriculture	Agricultural food demand	-	Fixes the cropland and grass land needs for food
Forest	Afforestation targets Sustainable harvest bounds	Harvest levels Biomass supply from forest Carbon stock evolution	Biomass supply and carbon sink dynamics
Bioenergy	Land priority constraints	Energy crop deployment Forest biomass extraction Bioenergy supply for energy	Main coupling variable between energy and AFOLU systems
GHG accounting	Emission intensity (National inventory based) for energy and LULUCF emissions	CO_2, CH_4, N_2O emissions and removals across sectors	System-wide emissions for climate response model (FaIR)

The TIMES Ireland Model for Land, Energy, Agriculture and Forest (TIM-LEAF)

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- Why TIM-LEAF?

Land use representation

- Limited in national energy models
- Simplified AFOLU
- Incomplete multi GHG accounting & biogenic C flows

Land competition

- Land needs for energy, agricultural, forestry and CDR

Coordinated transformative actions across sectors

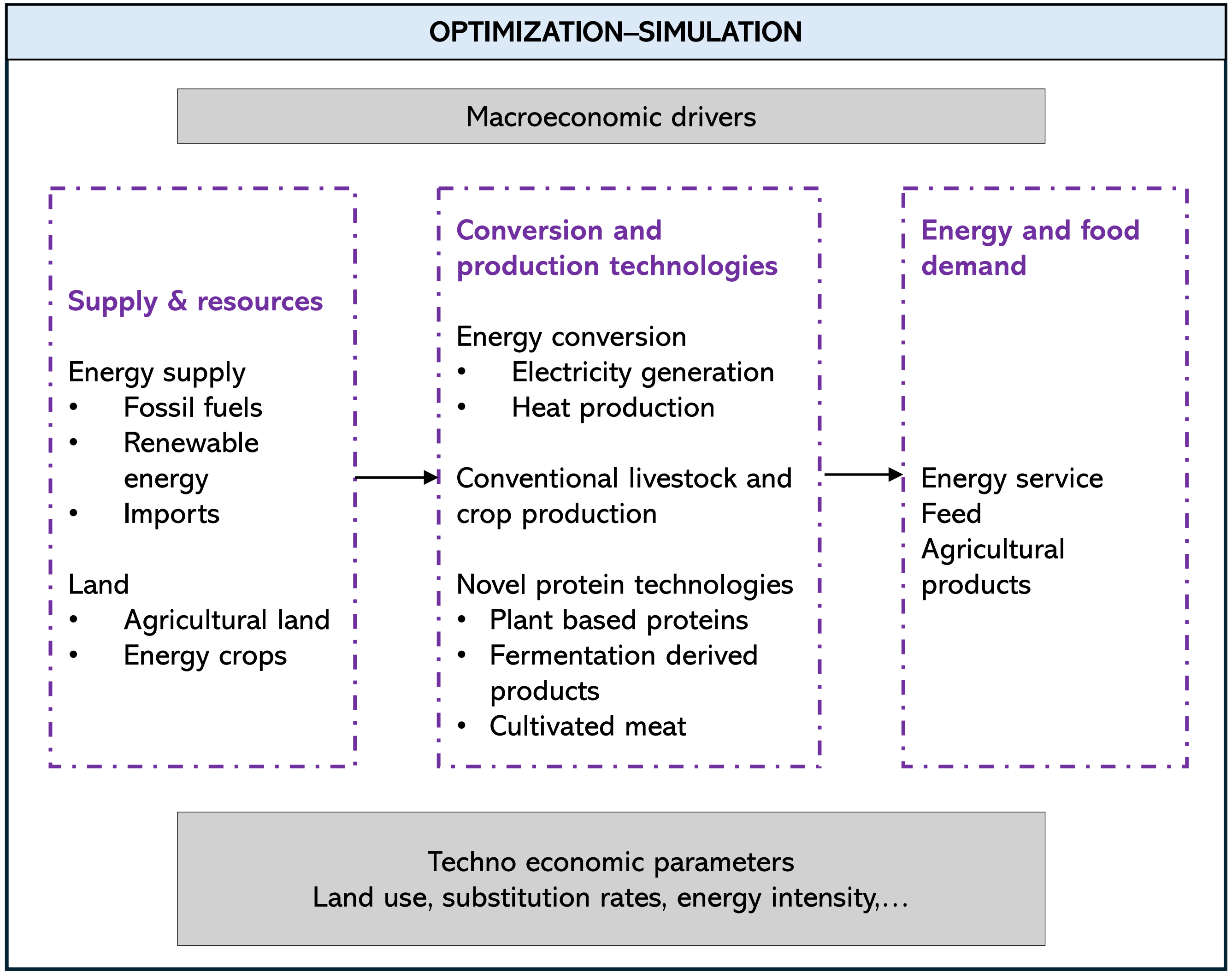
Fragmented mitigation assessment

- Energy and AFOLU mitigation pathways often separately evaluated

No link to climate outcomes

- National models typically report emissions
- Limited translation to temperature impacts and multi-gas climate responses

Novel protein representation in TIM-LEAF



Novel proteins as a new end-use electricity demand competing with other industrial loads in the energy system optimisation

Parameter	Cultivated Beef	Microbial milk Protein
Energy intensity	39.6 PJ/Mt cwe	0.00556 PJ/Mlitre
Land requirement	0.253 Mha/Mt cwe	0.0000166 Mha/Mlitre
GHG emissions	2750 $ktCO_2eq$/Mt cwe	0.428 $ktCO_2eq$/Mlitre

Values derived from literature review and converted to units compatible with TIM-LEAF demand representation.

Novel protein scenarios

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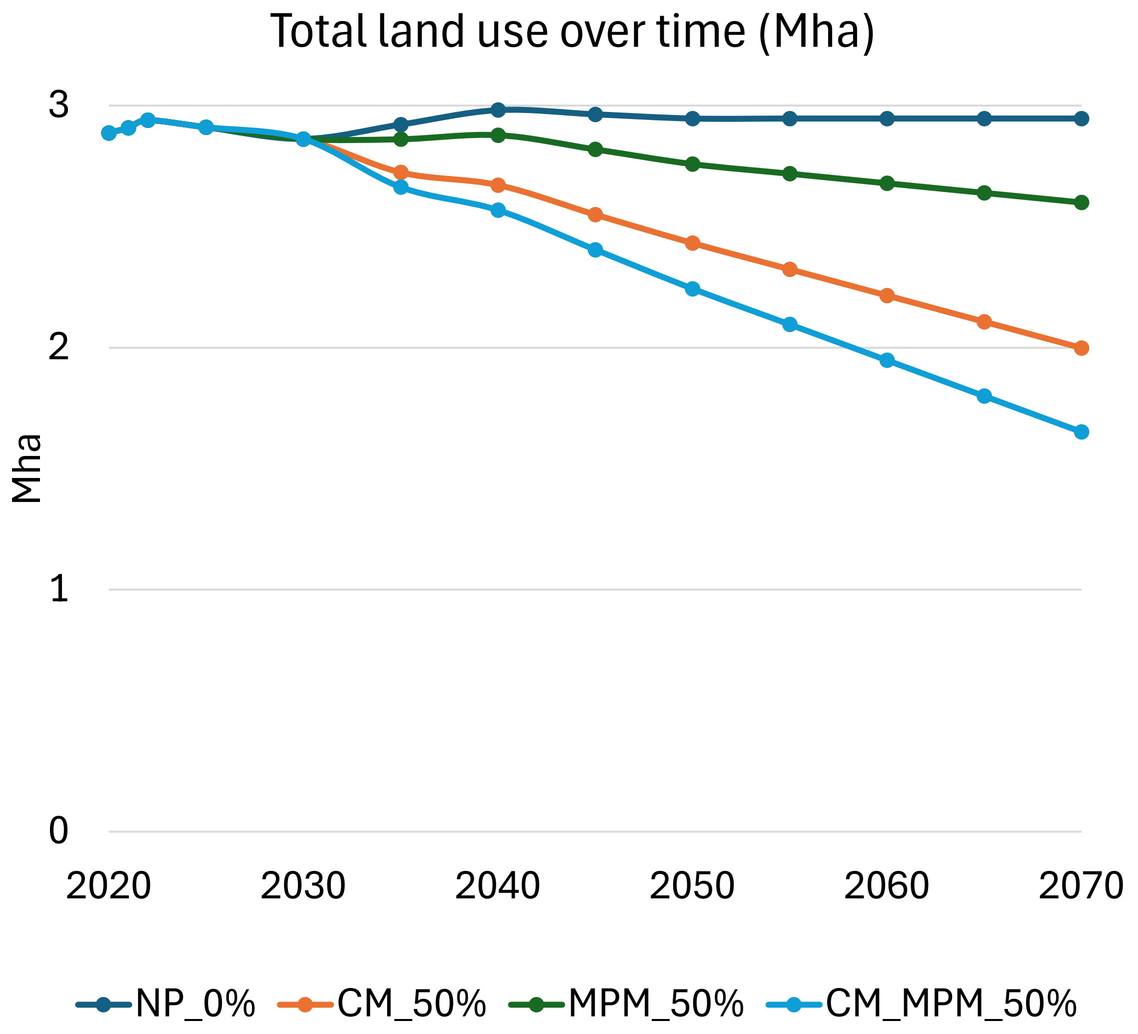
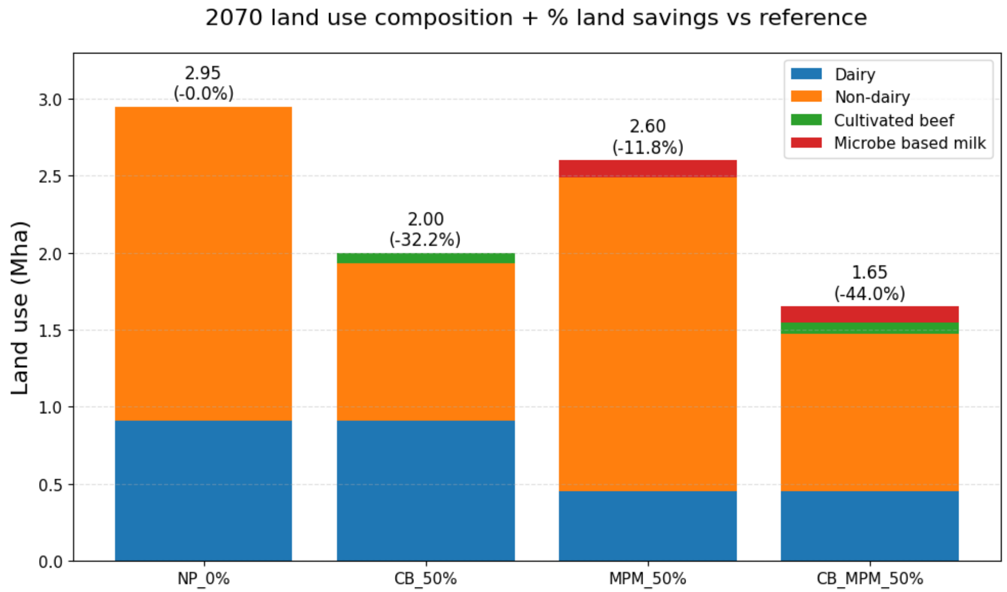
- Novel protein uptake is defined exogenously to explore "what-if" transition pathways
- Uptake is assumed to start in 2035 for both cultivated beef and microbial protein milk increases progressively to 2070
- Same protein demand is assumed in all scenarios, and demand is held constant between 2050 – 2070
- All scenarios are assessed under the same carbon budget – 450 $MtCO_2e$ applied over the period of 2021 – 2050; covering all energy and AFOLU emissions

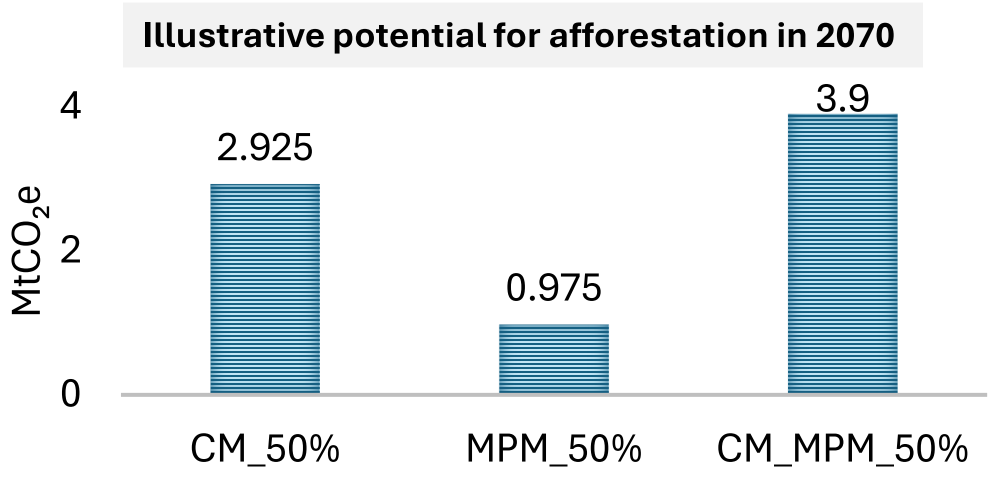
Scenario	**Description**
NP_0%	Reference case
CB_50%	50% cultivated beef uptake by 2070
MPM_50%	50% microbial milk protein uptake by 2070
CB_MPM_50%	50% uptake of both pathways by 2070

NP: Novel proteins, CB: Cultivated beef, MPM: Microbial protein milk

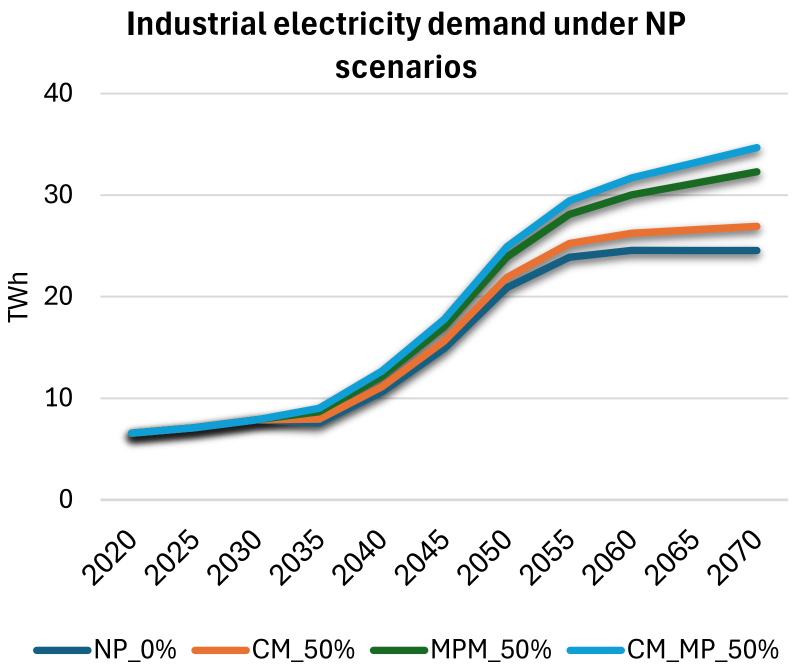
Results – Land use implications



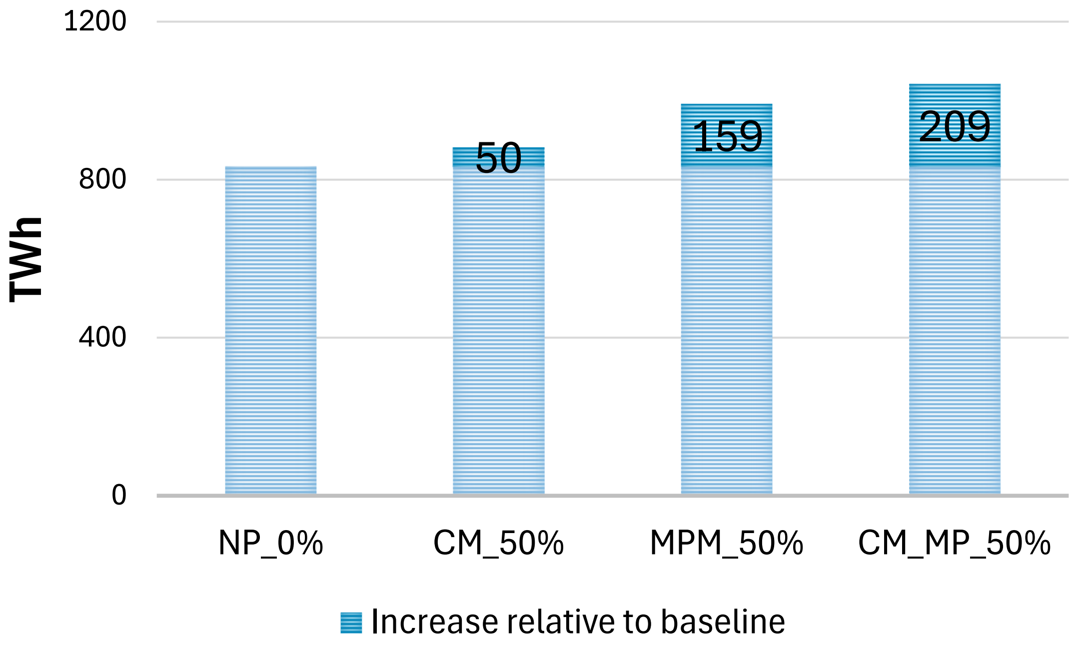




Results – Industrial electricity demand implications



by 2070, cumulating to a total demand of



- Industrial electricity demand increases by ~6–21%
- Additional ~50–210 TWh by 2070 relative to baseline
- Electricity system impacts are moderate under 50% transition scenarios, reflective of the partial substitution of livestock system

Results – Energy system response

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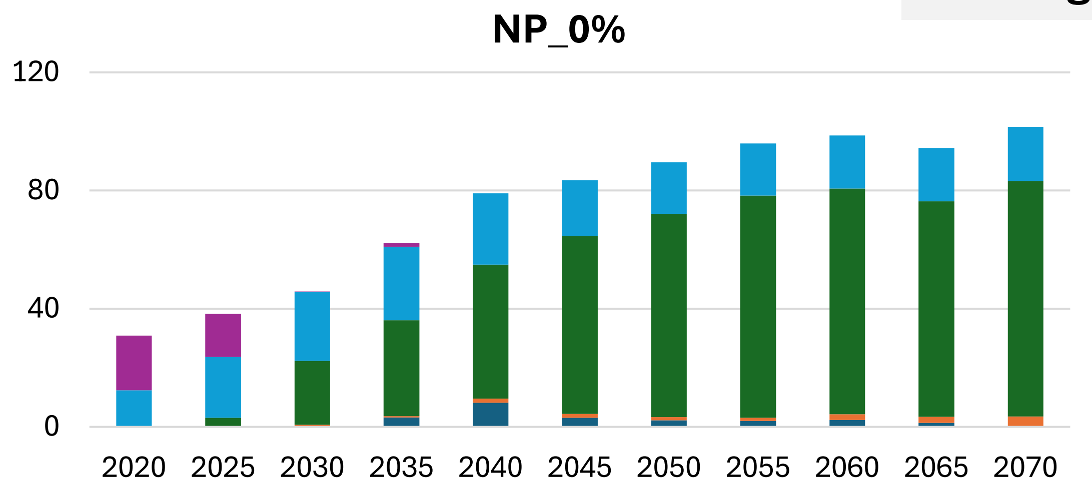
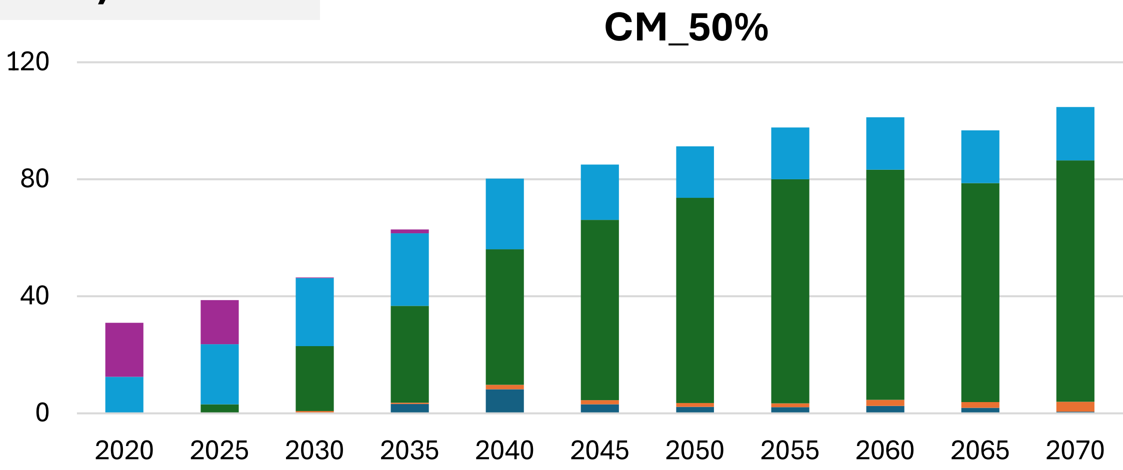
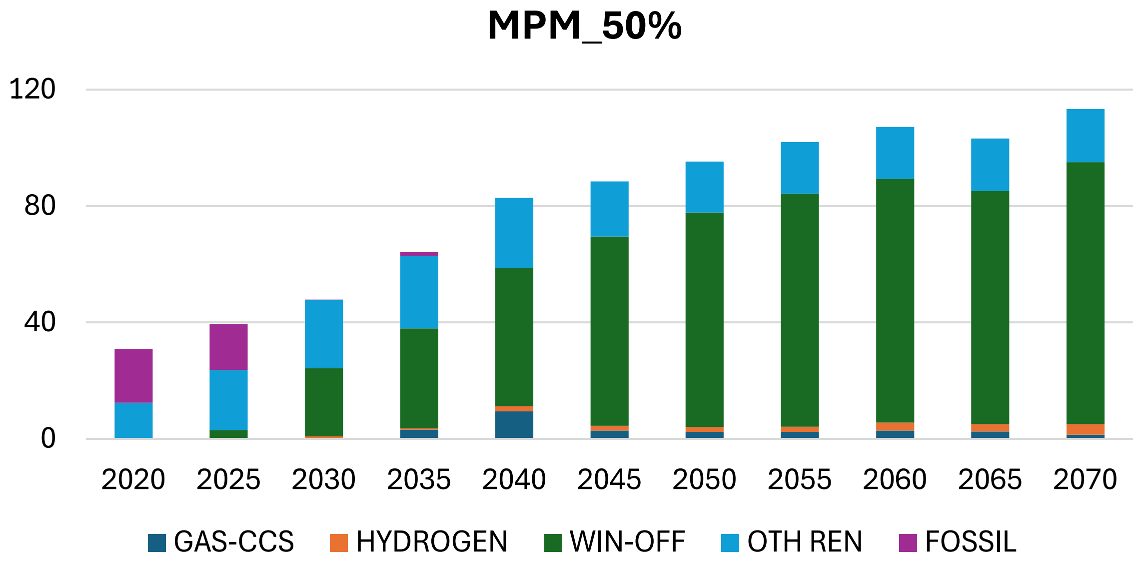
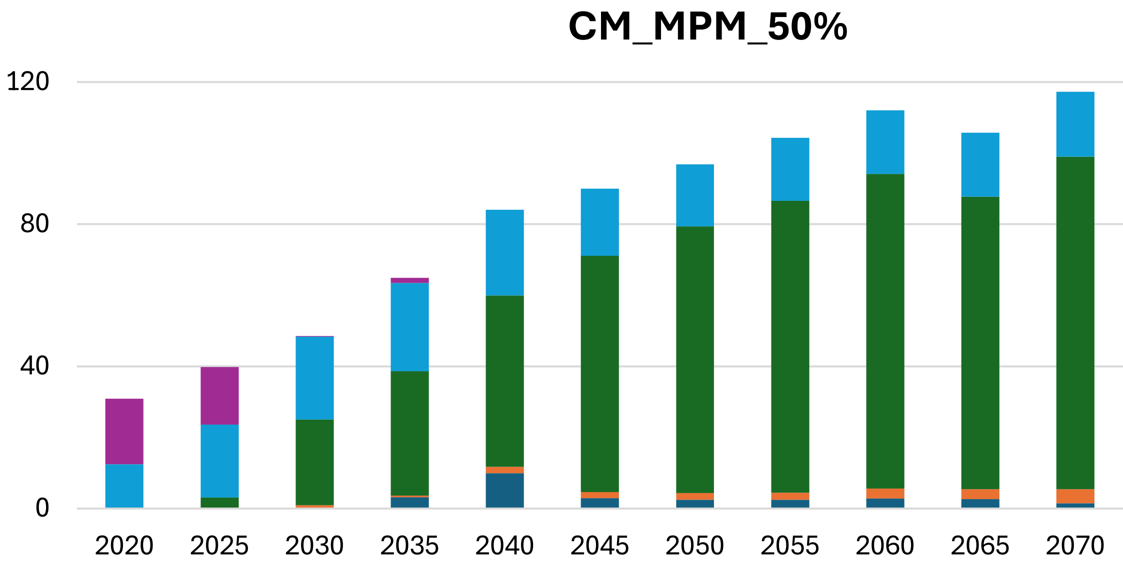
Power generation mix (TWh)



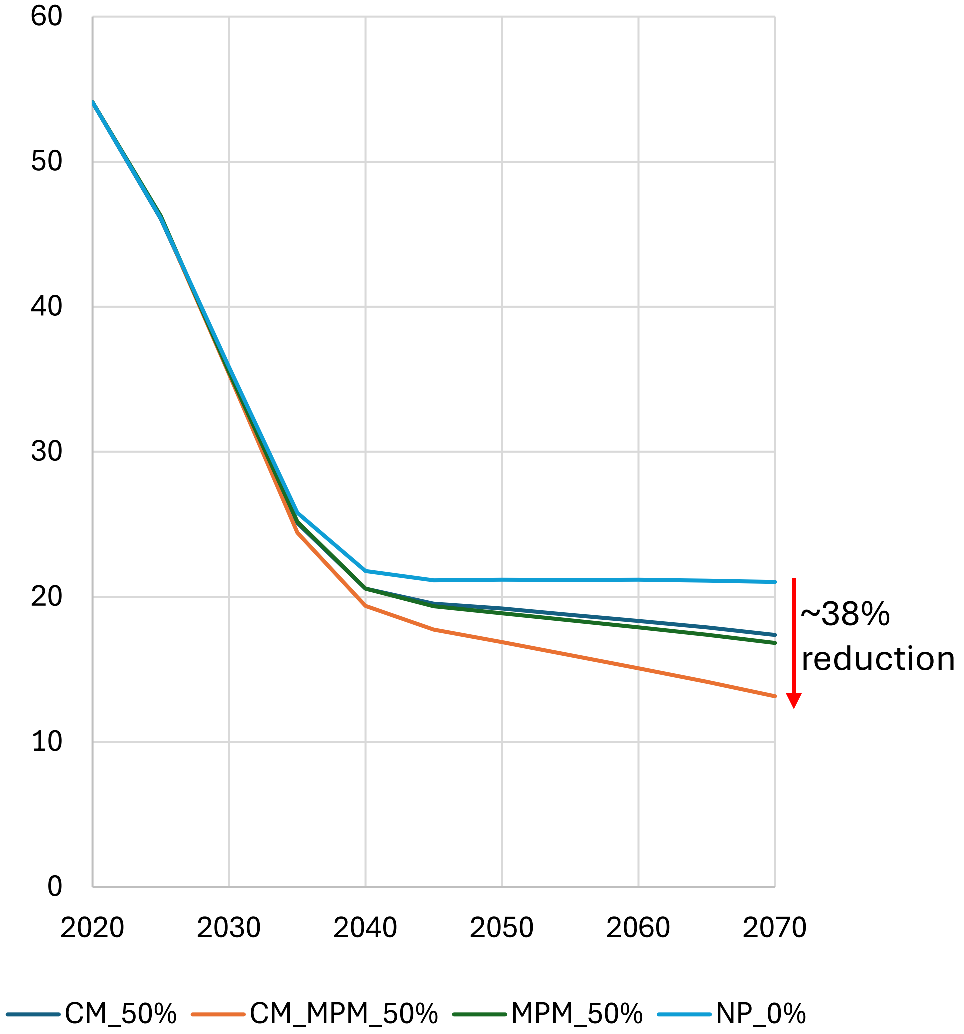




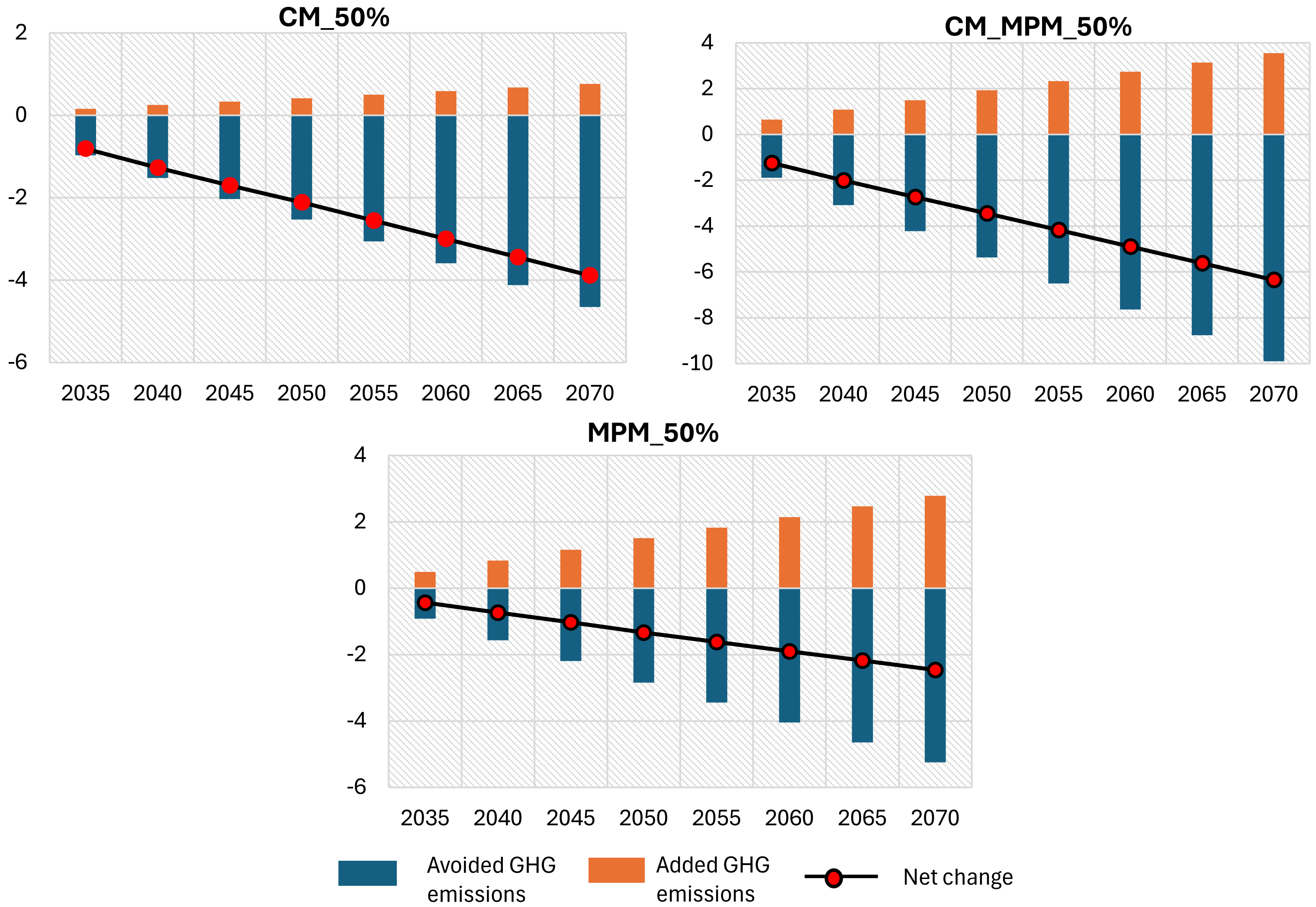


Results – GHG emissions implications

GHG emissions (($MtCO_2e$)



Conventional AGR emissions v/s NP production emissions ($MtCO_2e$)



Takeaways

- Novel proteins introduce a new industrial electricity demand equivalent to a 6–21% increase in industrial electricity consumption under the analysed scenarios.
- Additional demand is supplied primarily through offshore wind, supported by hydrogen and Gas-CCS.
- Agricultural methane reductions are the primary driver of climate benefits
- The magnitude of emissions reductions is also influenced by the carbon intensity of electricity supplied to NP production.
- Integrated systems model at a national level are required to capture these emerging interactions.

Limitations and ongoing work

- Results are based on partial livestock substitution (50% transition of selected dairy and non-dairy livestock products); not interpreted as representing a full Irish livestock replacement

- Energy requirements for alternative protein production remain highly uncertain across the literature. Assumptions regarding electricity demand and process efficiency can significantly influence results

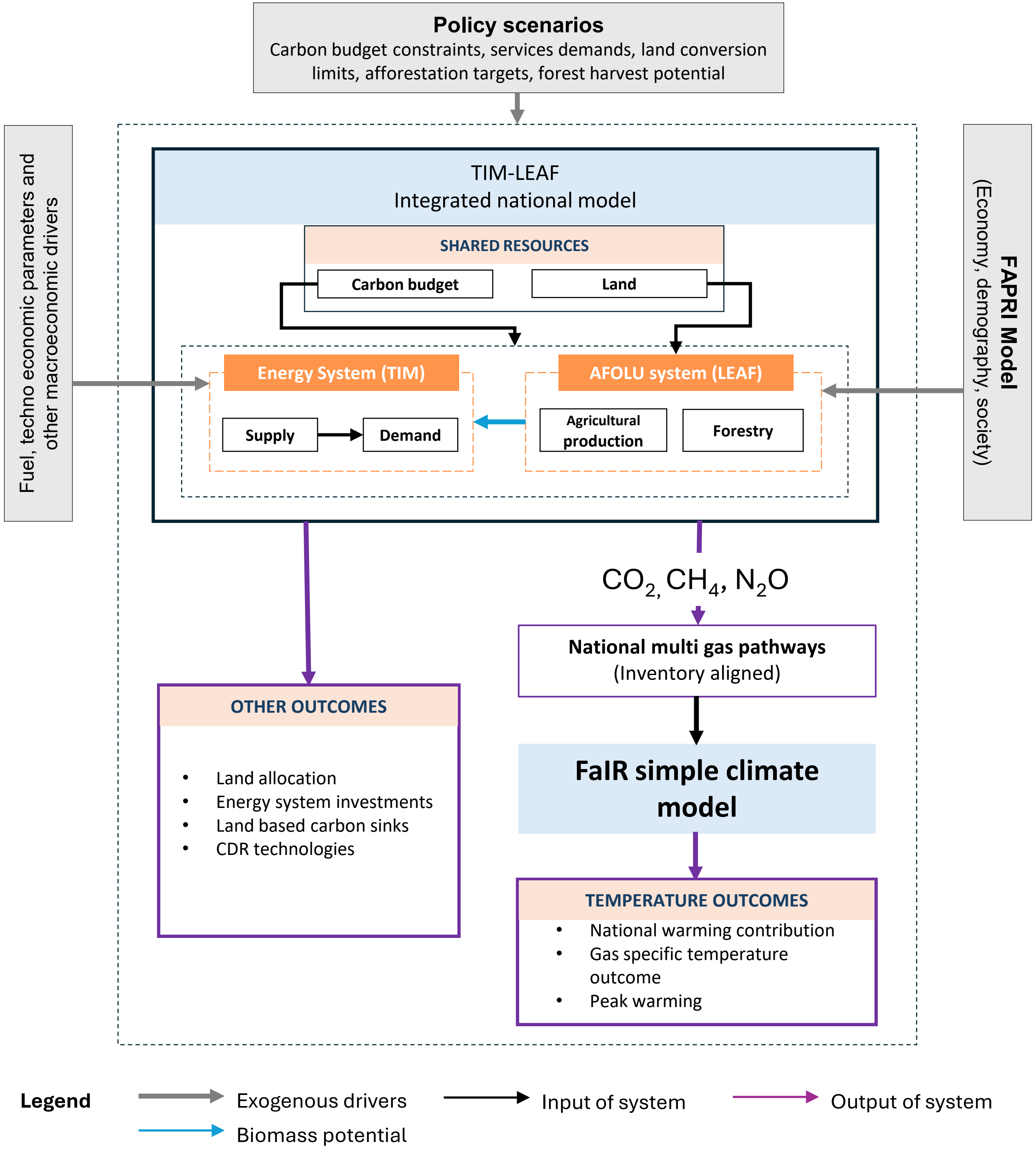
- Ongoing work

→Sensitivity analysis of alternative protein energy intensity assumptions

→Assessing higher substitution rates and alternative deployment pathways.

→Full livestock-system substitution scenarios

- Thank you ☺


Policy scenarios
Carbon budget constraints, services demands, land conversion limits, afforestation targets, forest harvest potential
Fuel, techno economic parameters and other macroeconomic drivers
TIM-LEAF
Integrated national model
SHARED RESOURCES
Carbon budget
Land
Energy System (TIM)
Supply
Demand
AFOLU system (LEAF)
Agricultural production
Forestry
FAPRI Model
(Economy, demography, society)
CO_2, CH_4, N_2O
National multi gas pathways
(Inventory aligned)
FaIR simple climate model
OTHER OUTCOMES
Land allocation
Energy system investments
Land based carbon sinks
CDR technologies
TEMPERATURE OUTCOMES
National warming contribution
Gas specific temperature outcome
Peak warming
Legend
Exogenous drivers
Input of system
Output of system
Biomass potential