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Assessing the environmental synergies and trade-offs of scenario-based transformations in the Swiss food system: current modelling approaches and opportunities for prospective LCA

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DF 89 – The use of prospective LCA to support sustainability transitions, 5 February 2025

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Current modelling approach

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Sustainable and Resilient Agri-food Economy (2022 – 2025)

Objective:

Analyse the coeffects of agri-environmental policy goals on the sustainability in the Swiss food system

- Calculate synergies and trade-offs of sustainability goals
- Analyse impacts of future developments and technological changes
- Analyse impacts of food policy measures

Methods:

Simulation and optimization model of the Swiss agricultural and food system

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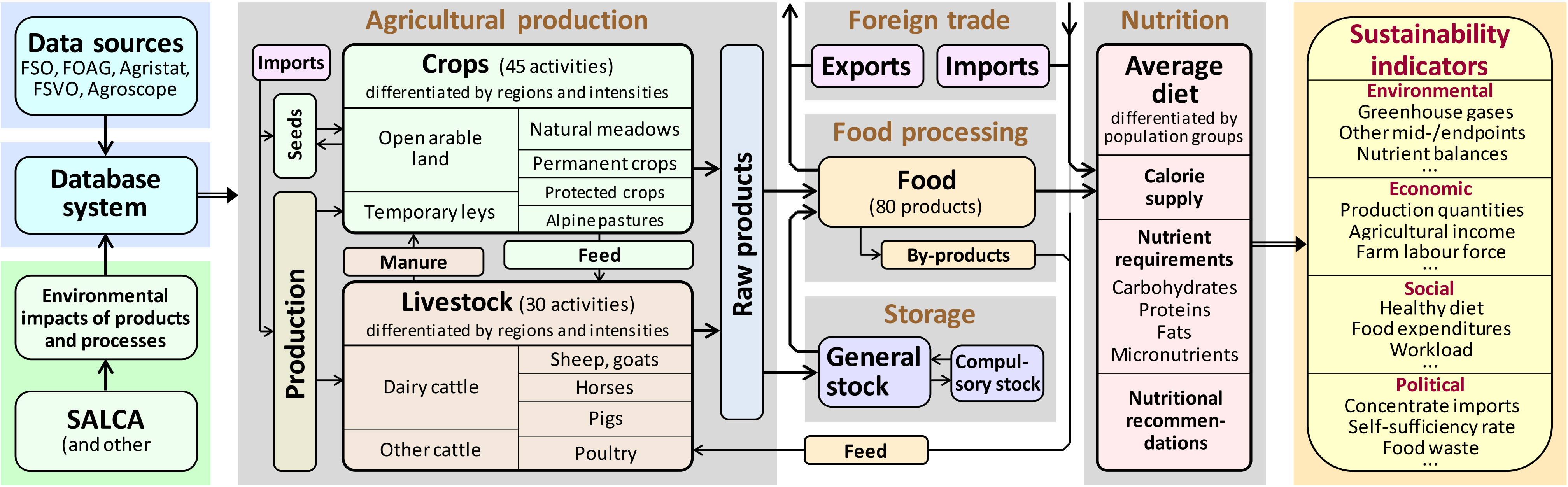
Methods: Model SWISSfoodSys

- Swiss sustainable food systems (SWISSfoodSys) model
- Linear-dynamic programming model
  Optimisation model that analyses impacts of 'what-if' scenarios on the Swiss food system
- Includes different stages of the food system
  Agricultural production | International trade | Processing and storage | Food consumption
- All the stages are interlinked



Model outputs

Economic indicators
Agricultural income
Agricultural direct payments
Agricultural employment

Environmental indicators
GHG from the entire food system
GHG from domestic agriculture
Nitrogen surplus
Biodiversity
Pesticide risks
LCA mid- and endpoint indicators

Social indicators
Health impacts
Nutrition rich index
Diet according to food pyramid
Food consumption projections
Farm employment

Political indicators
Feed production and import
Food waste from production/trade
Food waste from consumption
Food supply self-sufficiency

Future model changes: technological innovations, projected climate change, economic results of processing and retail sectors, consumer expenditures, novel foods, etc.

Model outputs: LCA indicators

Midpoints

Area of Protection	Impact indicator
Resource use	Abiotic resource use
Resource use	Renewable resource use
Resource use	Non-renewable resource use
Resource use	Water use
Resource use	Land transformation - Deforestation
Resource use	Land occupation - Total
Resource use	Land occupation - Agricultural
Resource use	Land occupation - Non-Agricultural
Resource use	Land occupation - Agricultural food
Resource use	Land occupation - Agricultural non-food
Resource use	Soil quality - LANCA
Ecosystem quality	Climate change impact GWP100
Ecosystem quality	Water scarcity
Ecosystem quality	Land use - Biodiversity Chaudhary - regional
Ecosystem quality	Land use - Biodiversity Chaudhary - global
Ecosystem quality	Terrestrial acidification
Ecosystem quality	Marine eutrophication
Ecosystem quality	Freshwater eutrophication
Ecosystem quality	Terrestrial eutrophication
Ecosystem quality	Ozone depletion
Ecosystem quality	Freshwater ecotoxicity
Ecosystem quality	Terrestrial ecotoxicity
Ecosystem quality and human health	Photochemical Ozone formation
Human health	Human toxicity - cancer
Human health	Human toxicity - non-cancer
Human health	Particulate matter

Endpoints

ReCiPe 2016 v1.1 Hierarchist Single score according to World 2010 normalization set and weighting with hierarchist's perspective

Emissions

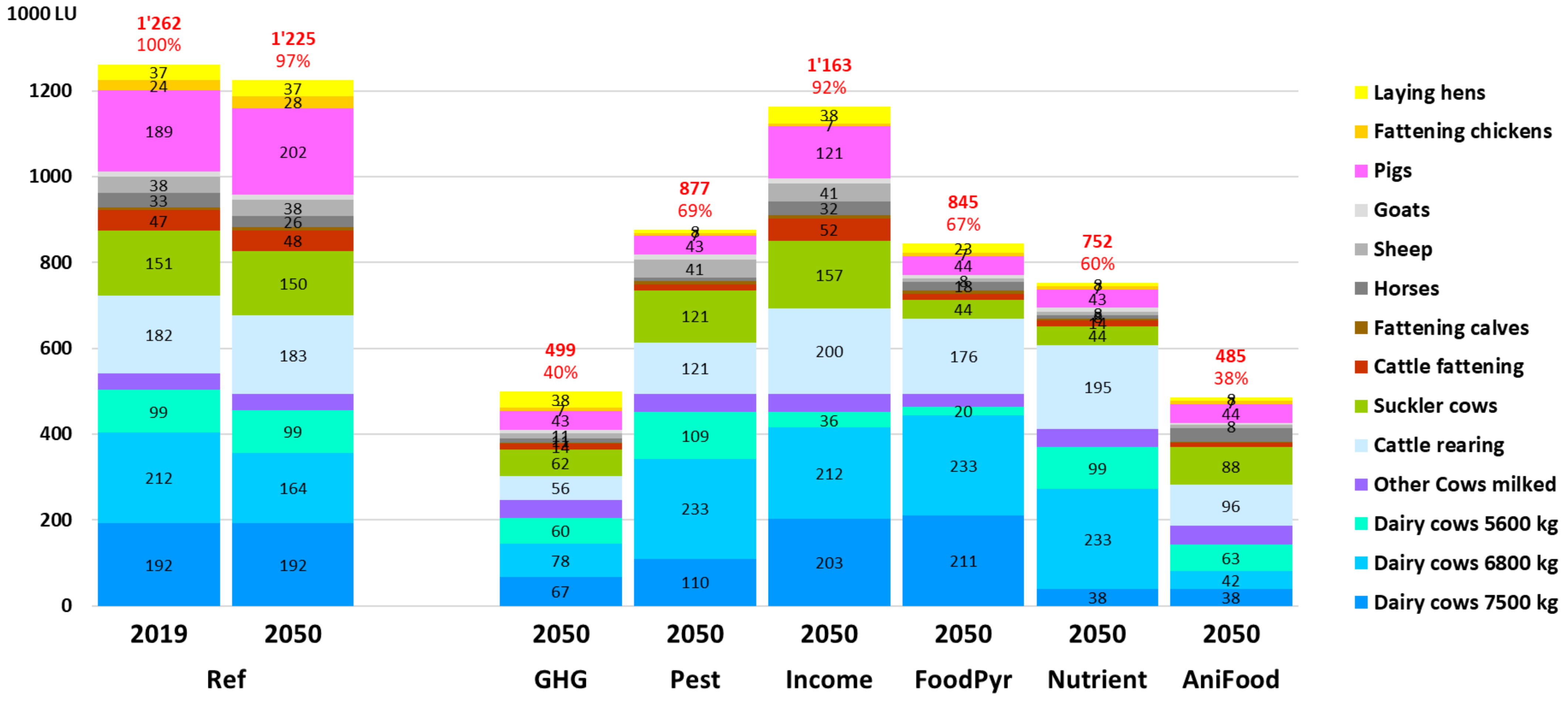
Ammonia (NH_3)
Methane (CH_4)
Carbon dioxide (CO_2)
Nitrate (NO_3)
NO_X
Phosphate (PO_4
Nitrous oxide (N_2O)
Phosphorus (P)
Phosphate (PO_4)

Example of model results: Synergies and trade-offs of sustainability goals

Szenarios (sustainability aspects optimized in the respective scenario)

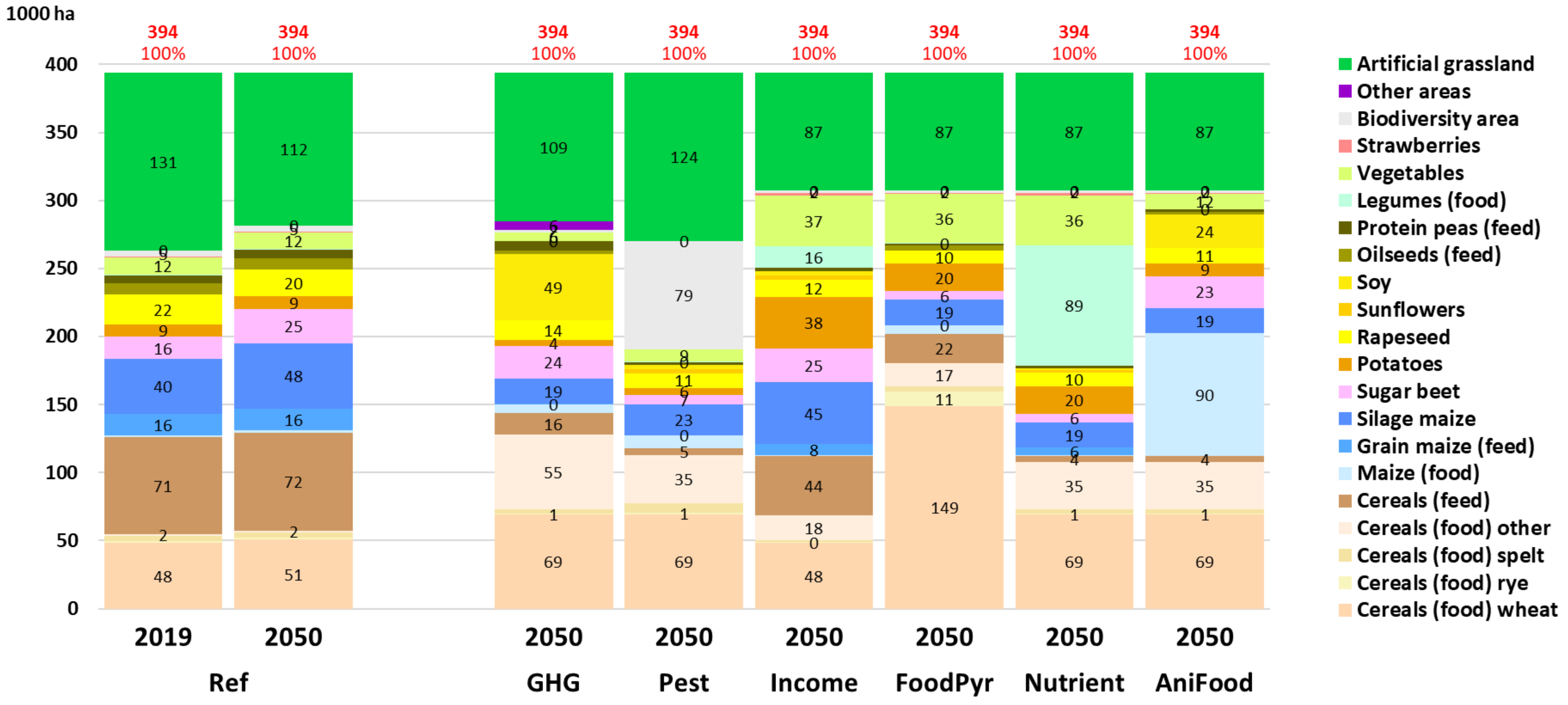
Ref	Reference scenario	Minimization of deviation to current situation
GHG	**Greenhouse gas emissions**	Minimization of greenhouse gas emissions from nutrition (LCA perspective)
Pest	**Pesticide risk**	Minimization of risk indicator for pesticide use (Risk indicators based on Korkaric et al. (2023)
Income	**Agricultural income**	Maximization of sectoral agricultural income
FoodPyr	**Food pyramid**	Minimization of deviation to Swiss food pyramid nutritional recommendations
Nutrient	**Nutrient density**	Maximization of nutrient supply in the average diet (NRF 9.3)
AniFood	**Animal food consumption**	Minimization of consumption of animal foods

Livestock



- Big differences in the development of animal populations depending on the scenario
- Decrease in pig and fattening poultry stocks in all scenarios

Arable area



- In most scenarios, grain production for human consumption increases
- Increase of other crops depending on the scenario (e.g., soy, vegetables, legumes, organic production)

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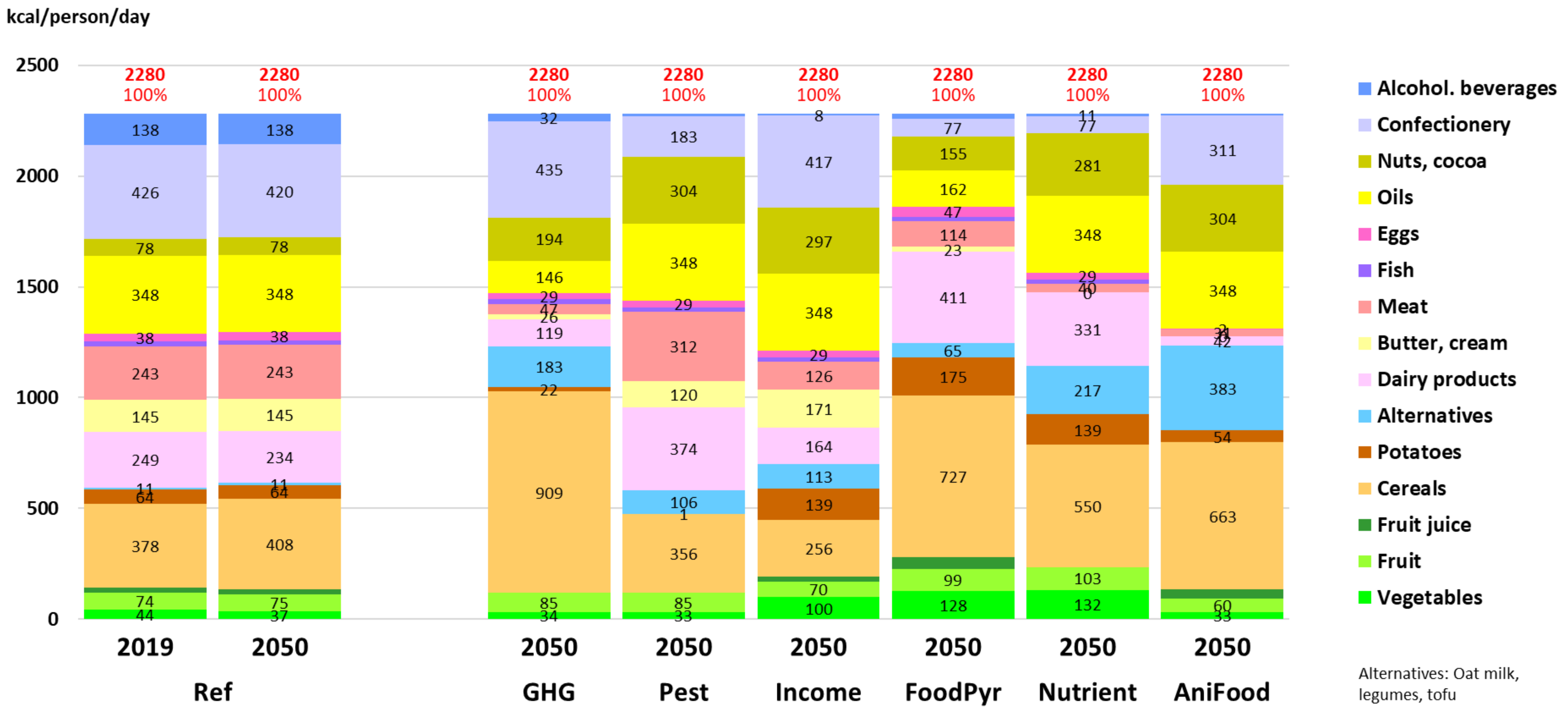
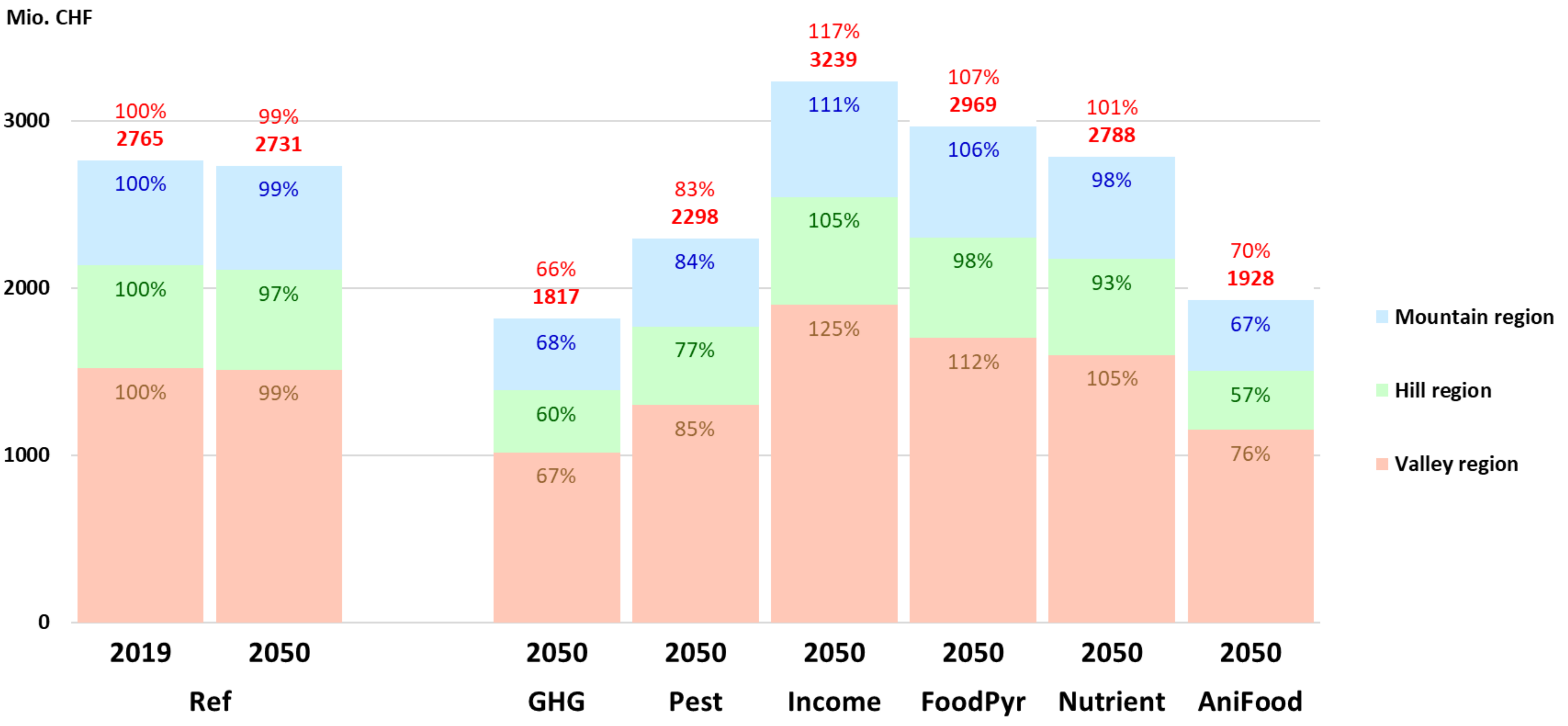
Consumption (Calorie intake per person per day)



Alternatives: Oat milk, legumes, tofu

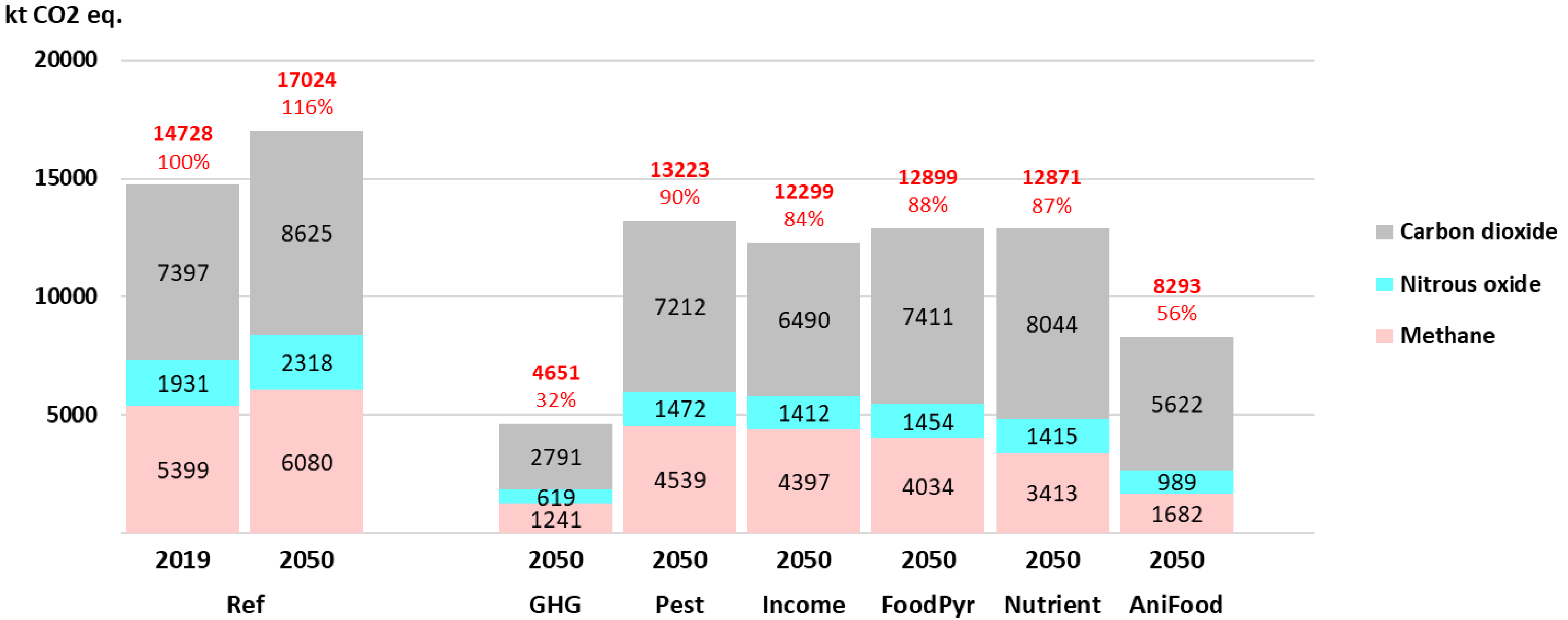
- Big differences in the consumption of animal foods depending on the scenario

Agricultural income



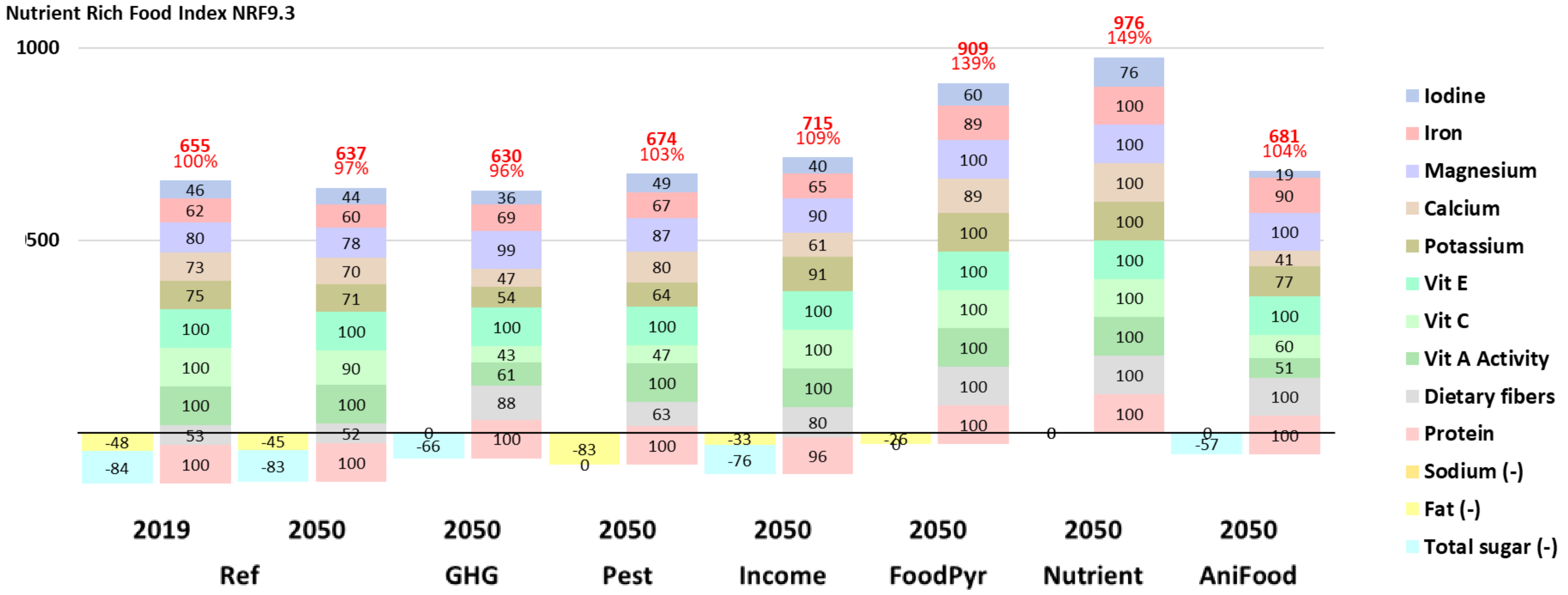
- Decreasing incomes due to falling animal population. Partly compensated by crops with high added value
- Stronger decline in hill region than in valley and mountain regions

Greenhouse gas emissions



- Falling animal populations and imports lead to lower greenhouse gas emissions in all scenarios

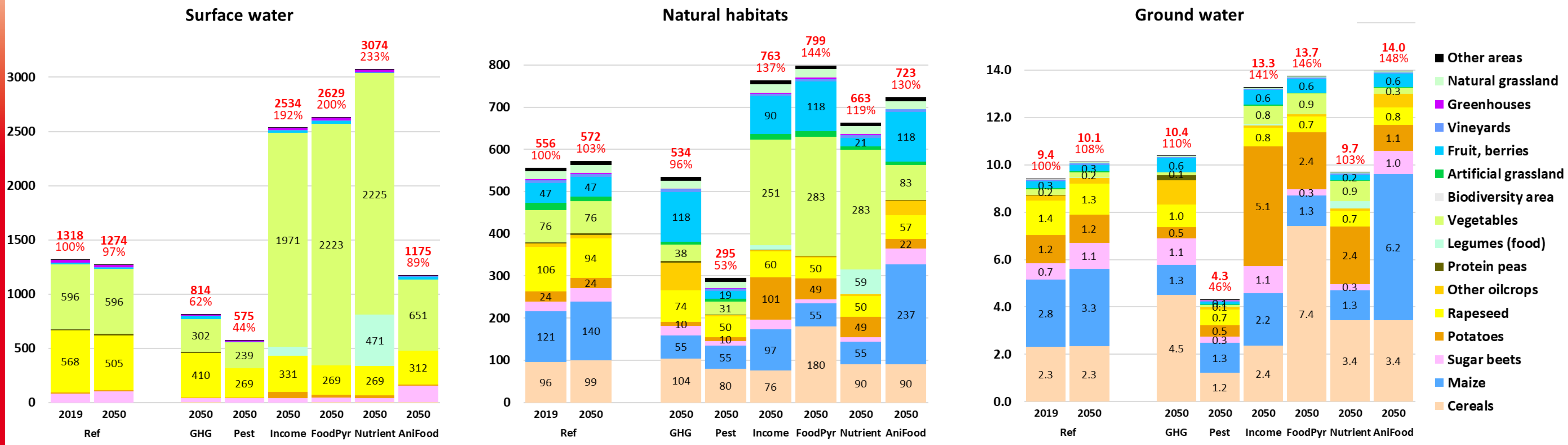
Nutrient density (nutrient supply in the diet)



- NRF increases in scenarios with high consumption of vegetables, fruits or dairy products

Pesticide risk

(Risk indicator based on Korkaric et al. (2023), in Mio. units)



- Higher pesticide risk with increasing cultivation of specific plant-based foods (e.g., vegetables)

Synergies and trade-offs

Indicator	Unit	Ref 2050	Best value	+/- (=100%)	2050 GHG	2050 Pest	2050 In-come	2050 Food Pyr	2050 Nutr-ient	2050 Ani Food
Greenhouse gas emissions	kt CO2 eq	17024	4651	**-12373**	100%	31%	38%	33%	34%	71%
Pesticide risk	Indica-tor	1.02	0.47	**-0.55**	24%	100%	-99%	-111%	-90%	-37%
Agricultural income	Mio. CHF	2731	3239	**508**	-180%	-85%	100%	47%	11%	-158%
Food pyramid	Portions	13.3	1.1	**-12.2**	9%	8%	8%	100%	45%	7%
Nutrient density	NRF9.3 Index	637	976	**+339**	-2%	11%	23%	80%	100%	13%
Animal food consumption	kcal /P./day	768	78	**-691**	76%	-24%	26%	22%	50%	100%

100% = Maximum achieved target improvement per indicator
(Difference between value *Ref 2050* and best value of all scenarios)

- Many synergies (e.g., GHG emissions - Animal foods; Consumption-related targets)
- Some trade-offs (income; pesticide risk)

Conclusions for the case study

A more sustainable food system goes in the following direction:

- **Use of arable land for direct human nutrition**
- **Milk/meat production is based on grassland and by-products**
- **Consumption goes towards the food pyramid**
- **Reduction of food waste** (result of additional scenario calculations)

This leads to improvements in the areas of environmental impacts, healthy nutrition, biodiversity and self-sufficiency rate.

Conflicting objectives exist in the areas of income and pesticide risks. Specific measures can compensate for these effects:

- Cultivation of plant-based foods with high added value
- Technical measures to reduce emissions.

Opportunities for integrating prospective LCA with food system modelling

- current SWISSfoodSys modelling approach operates within a static framework
- scenarios simulations are based on present-day conditions and show how the system would adjust under specific targets
- but without accounting for potential future developments
  - LCIs based on current emissions factors, energy mix, agricultural practices, etc.

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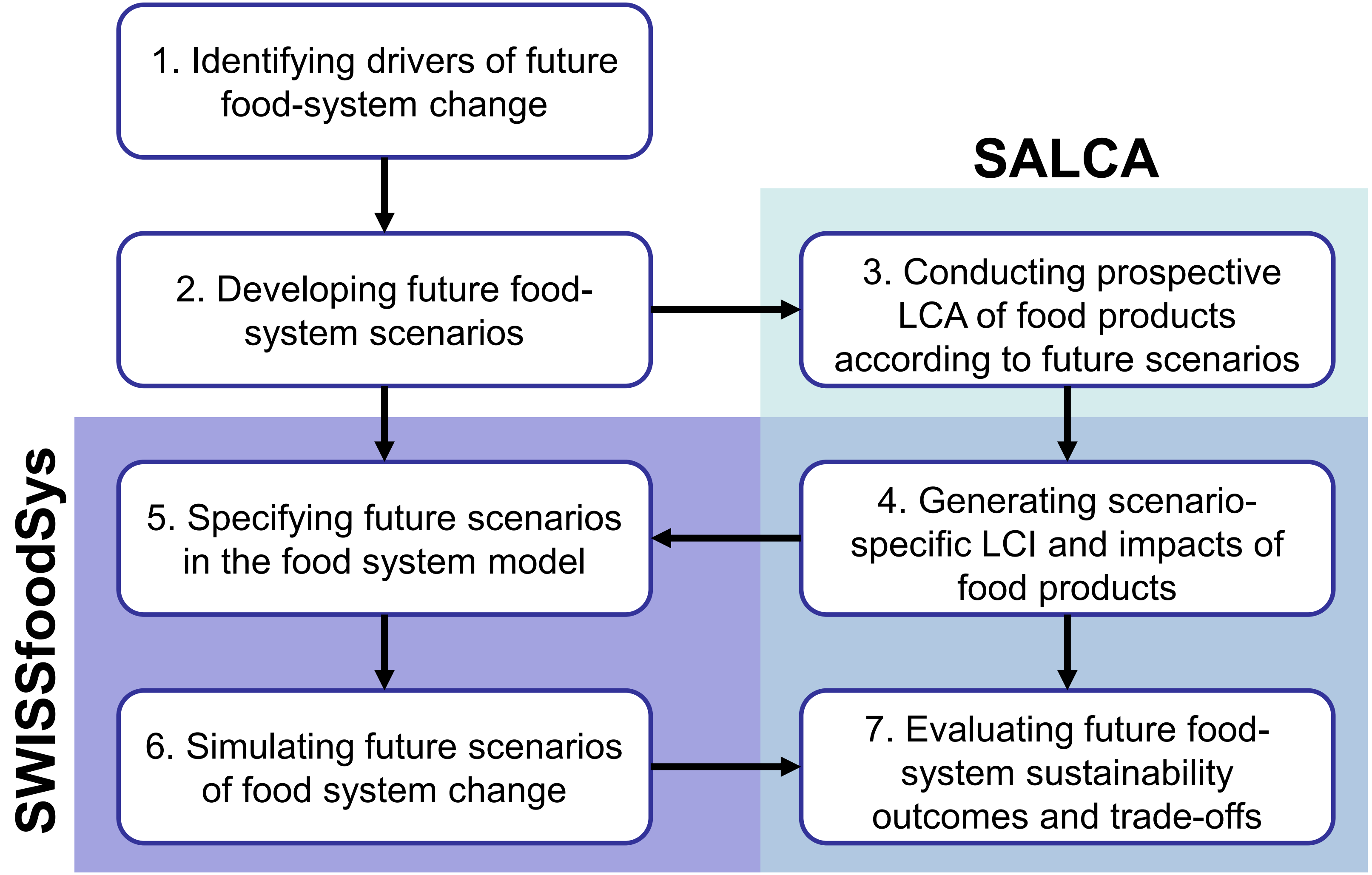
Opportunities for integrating prospective LCA with food system modelling

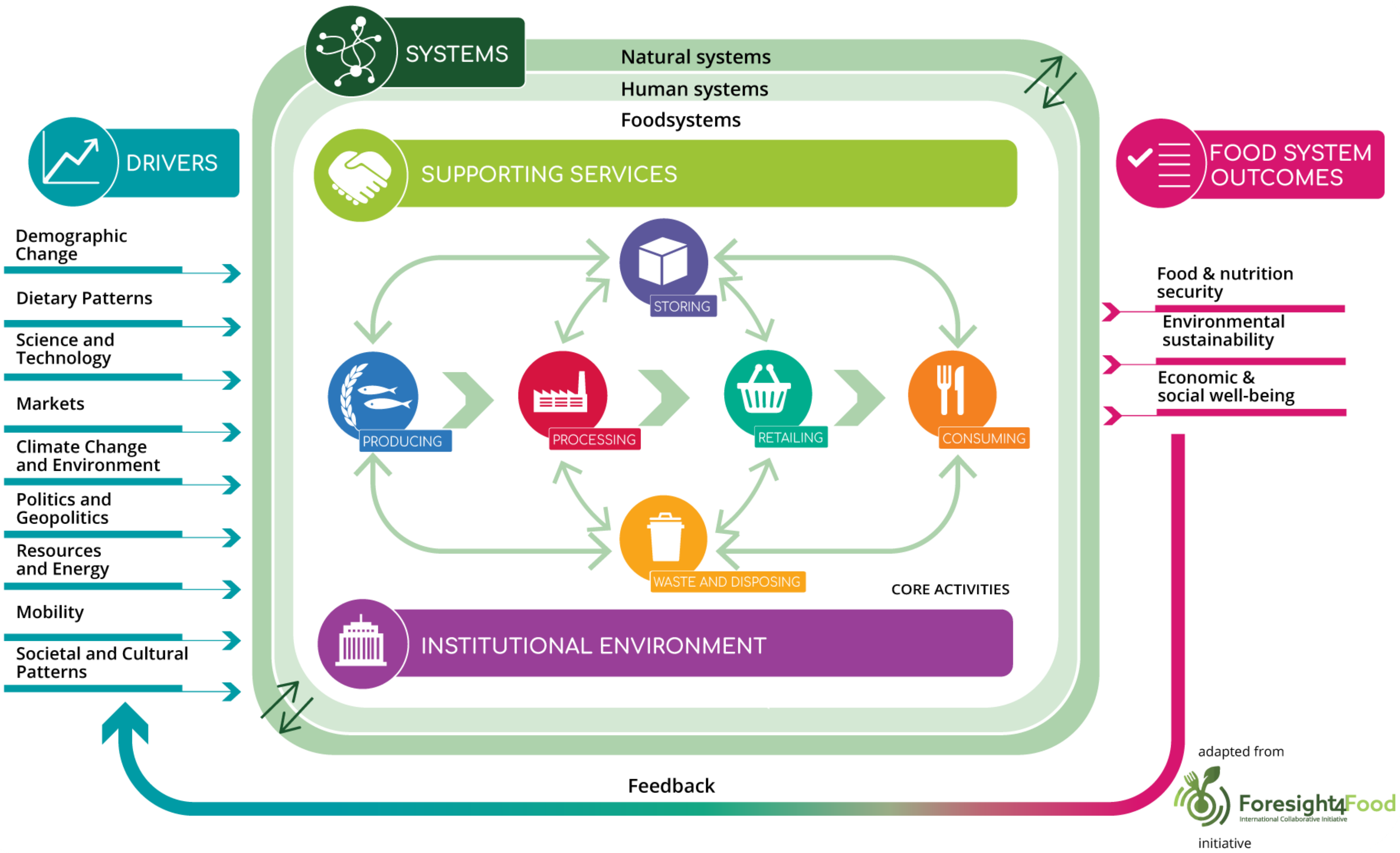
- Exploring the option space for a sustainability transition in the Swiss food system requires:
  - Assessing and identifying the sustainability synergies and trade-offs resulting from different interventions and changes pathways
  - accounting for dynamic system changes and multiple interacting climate and socioeconomic developments
  - according to alternative scenarios

Challenge: How to adapt and integrate prospective LCA into food system modelling, considering dynamic future conditions?

A roadmap to integrate prospective LCA into food system modelling for exploring future Swiss food-system scenarios

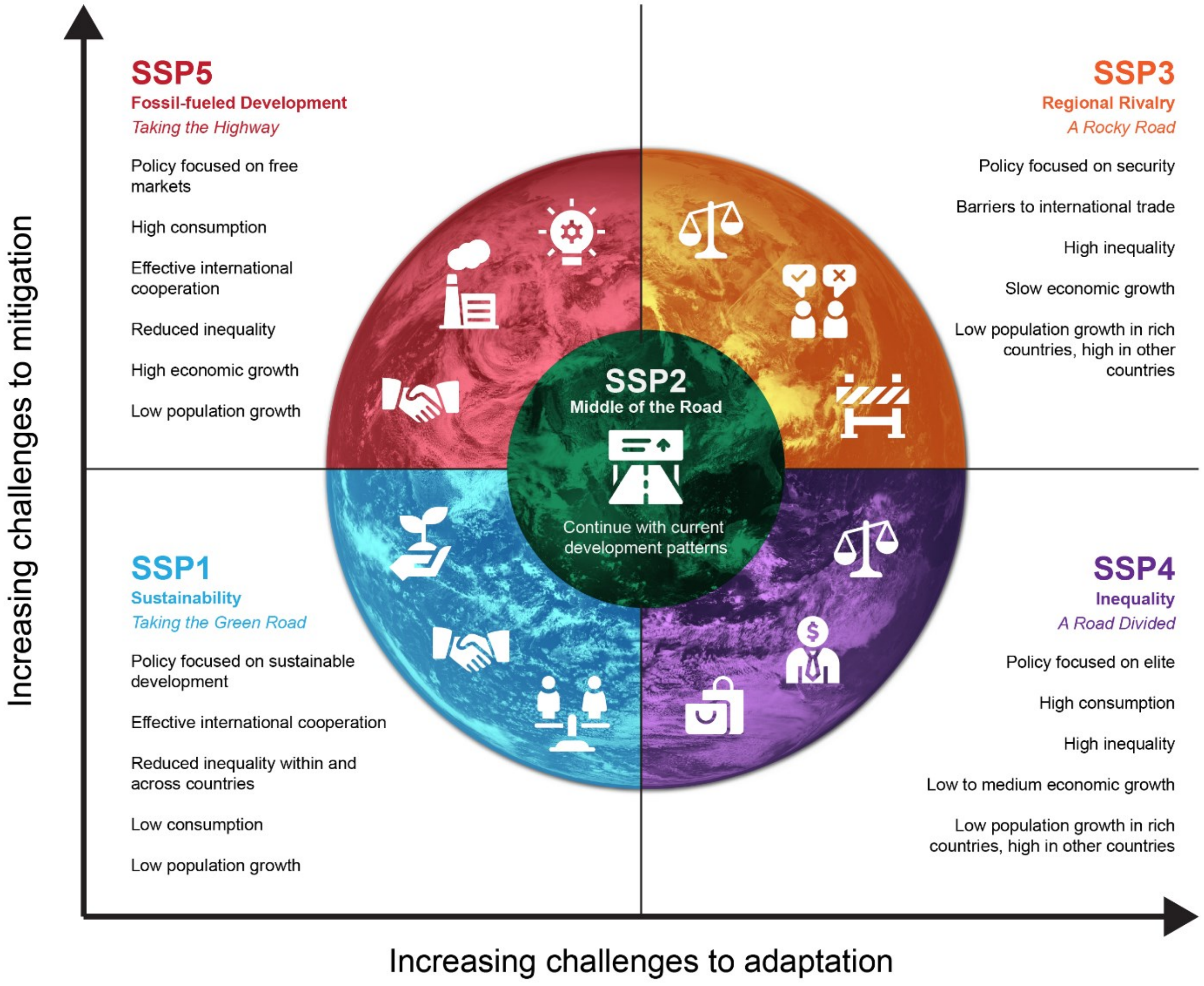


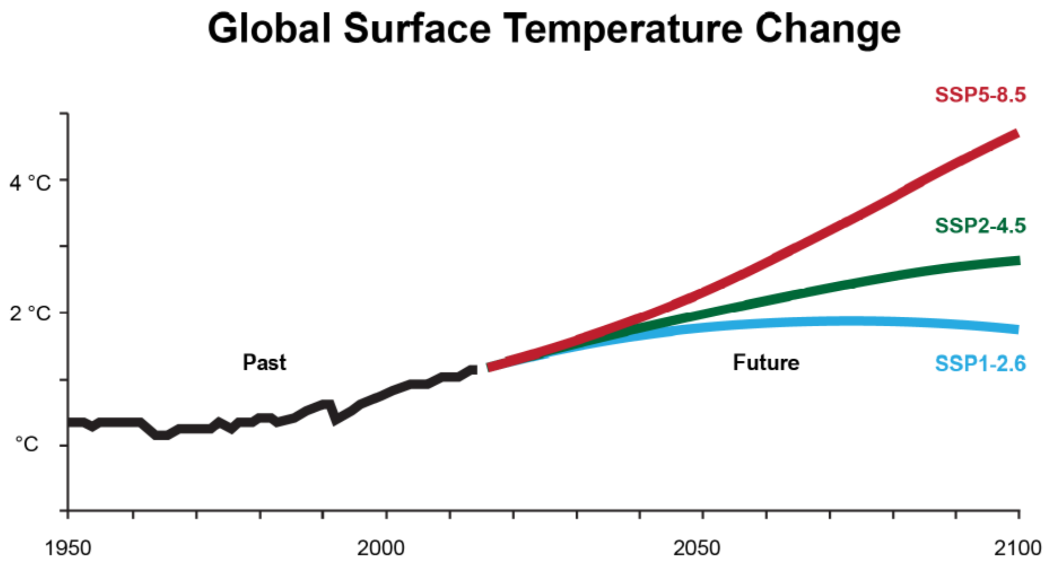
Drivers of food system change



Scenarios of global climatic and socioeconomic change…

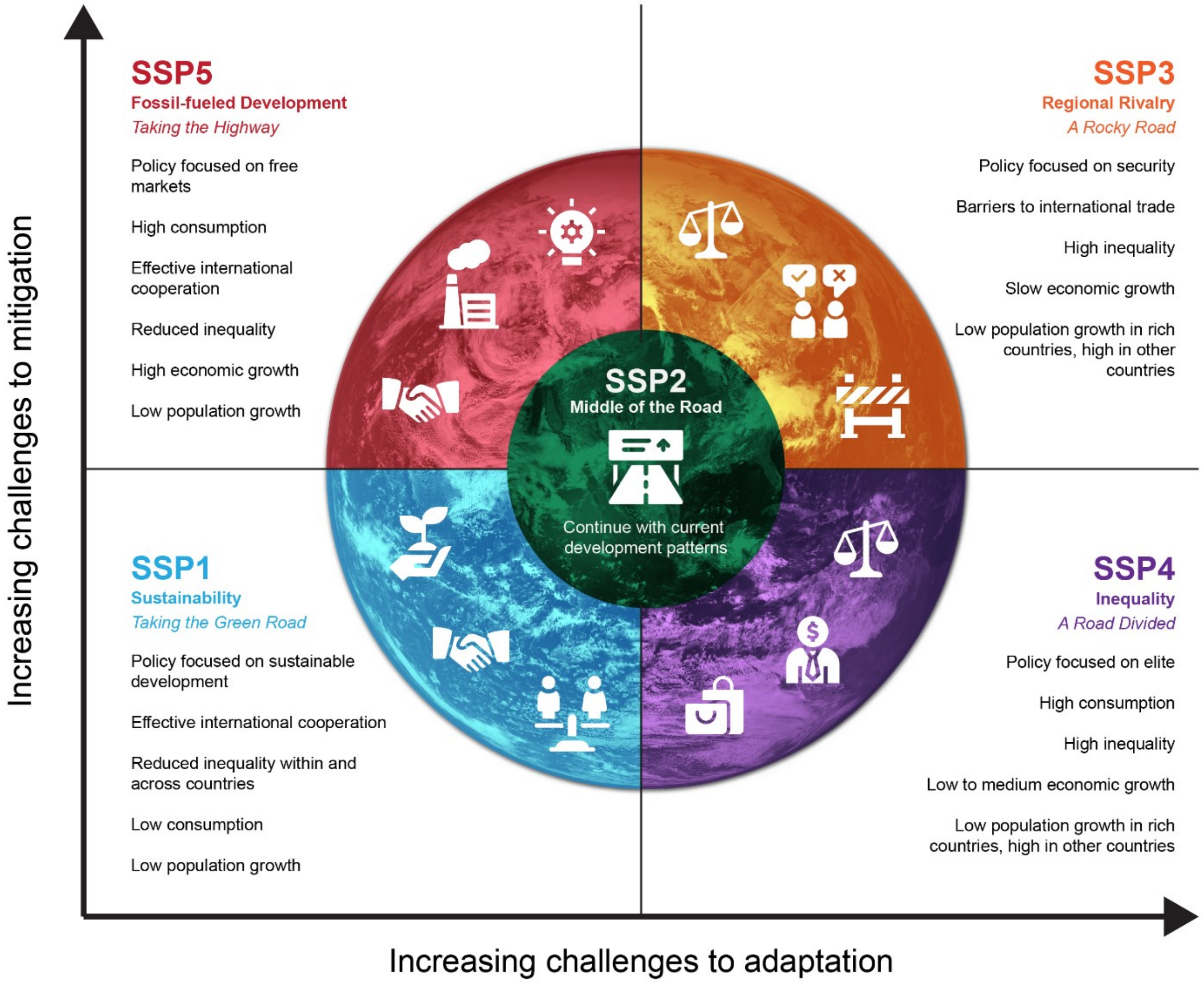
Shared Socioeconomic Pathways (SSPs)

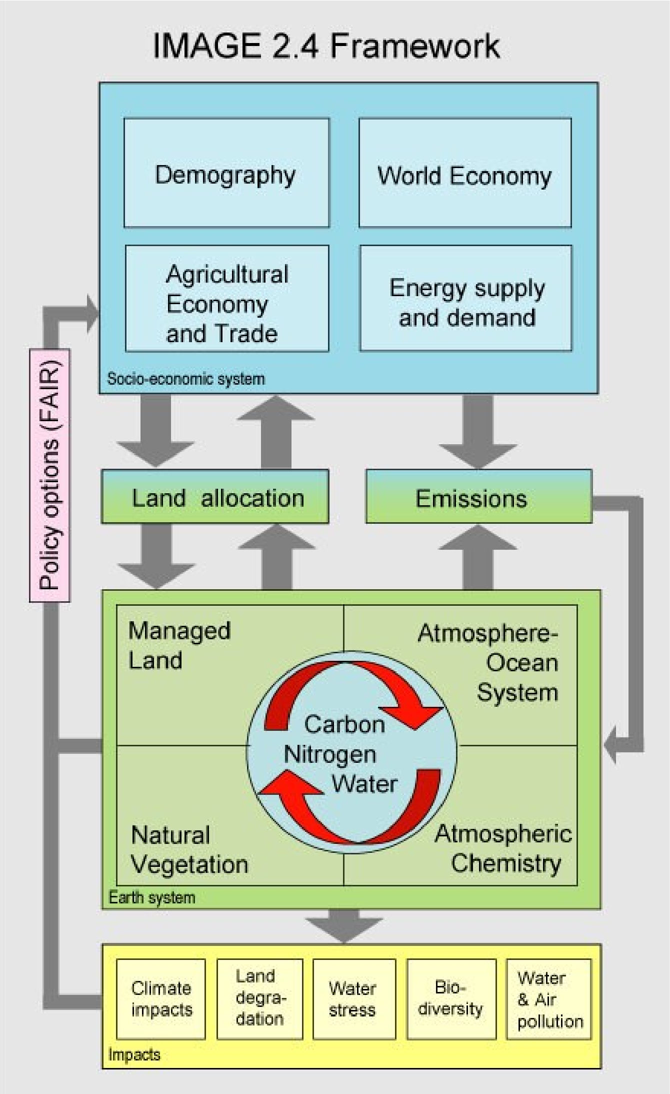




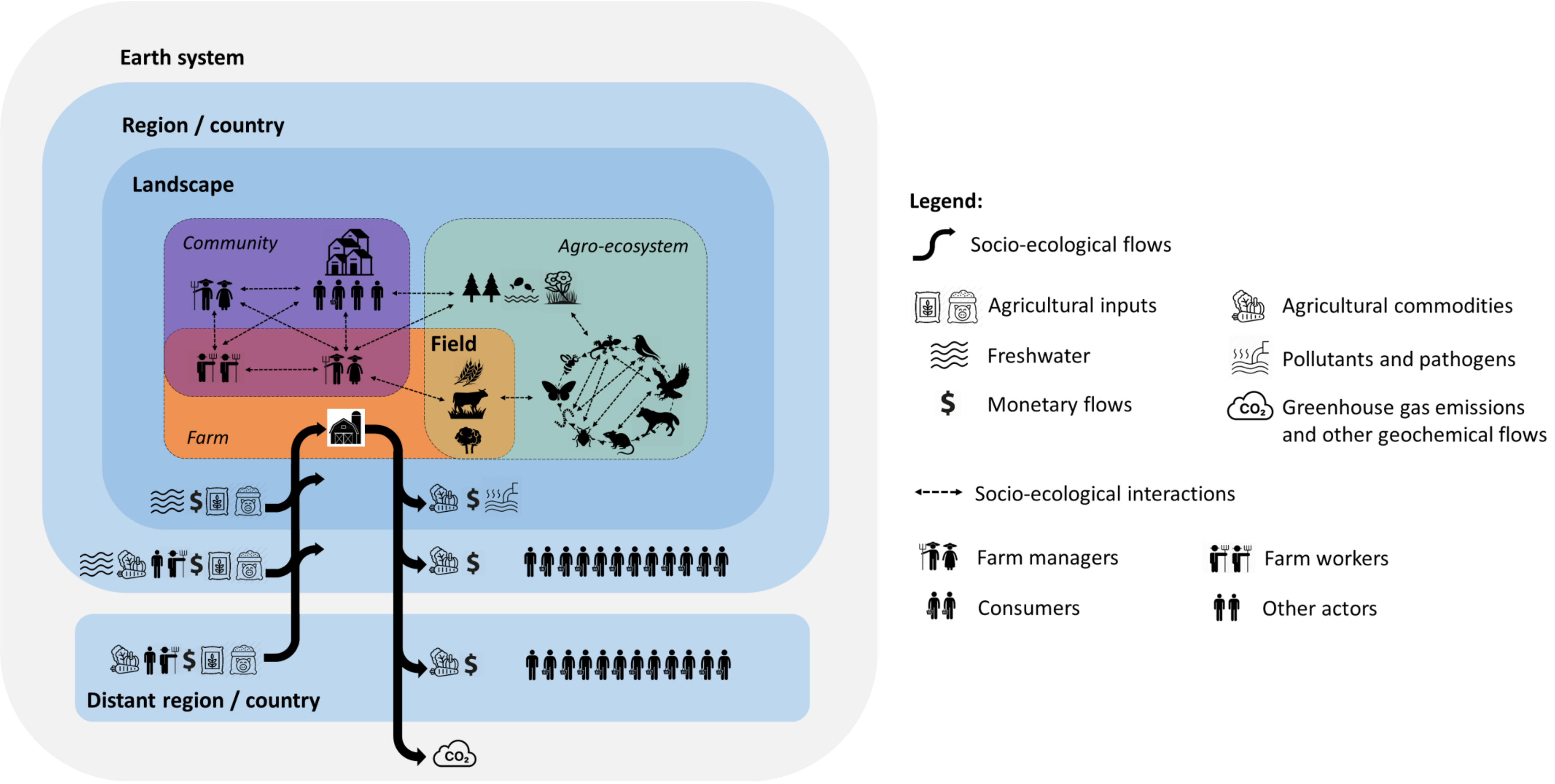
… can be simulated with integrated assessment models (IAMs)

Shared Socioeconomic Pathways (SSPs)





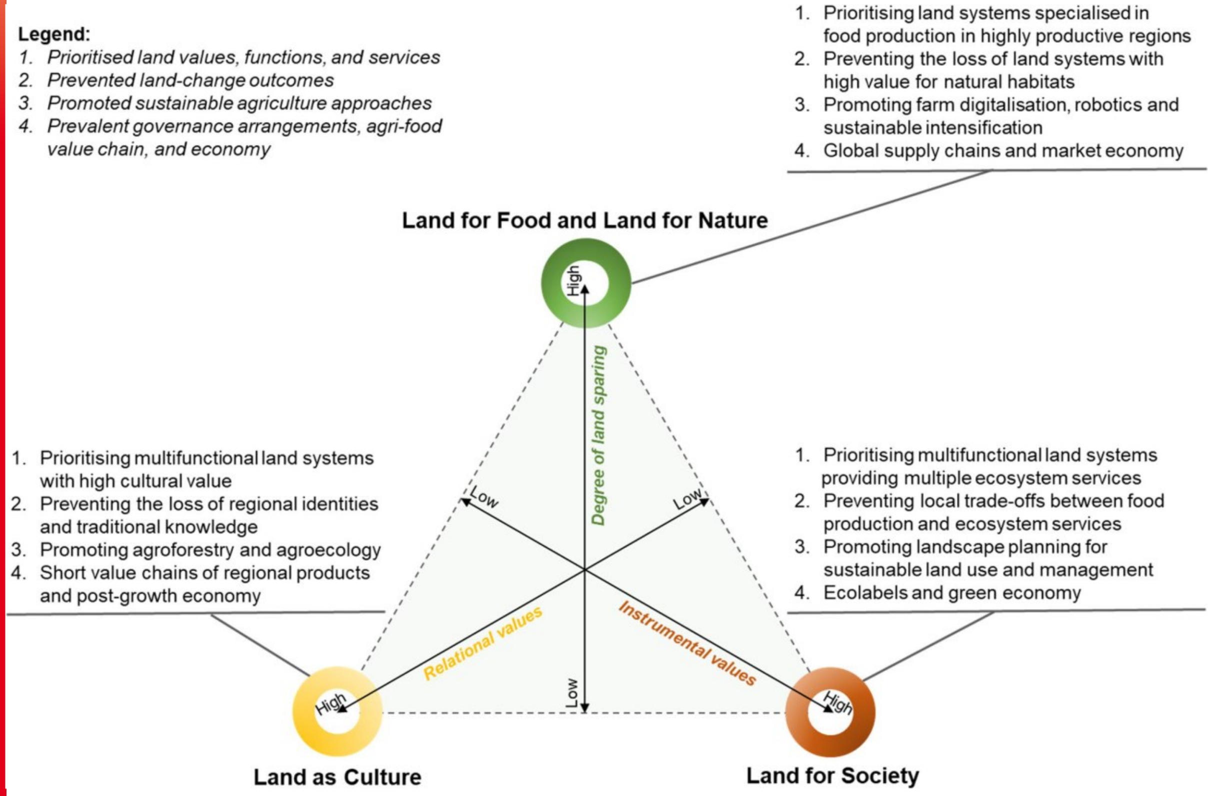
However, the global developments also involve cross-scale interactions



Diogo et al., 2022

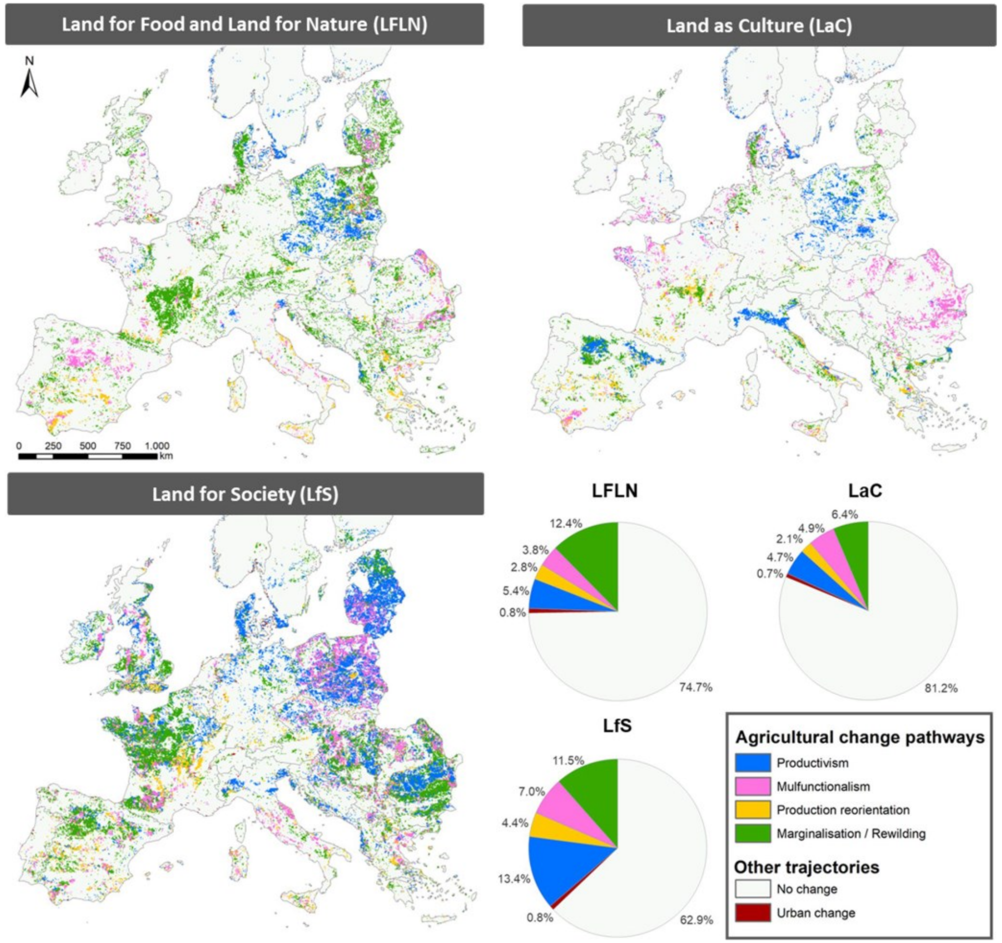
The same global scenario may be realised differently at the regional/local scale

Agricultural Futures framework



Diogo et al., 2025

Alternative realisations of SSP1: Same land demands, different land-use change pathways



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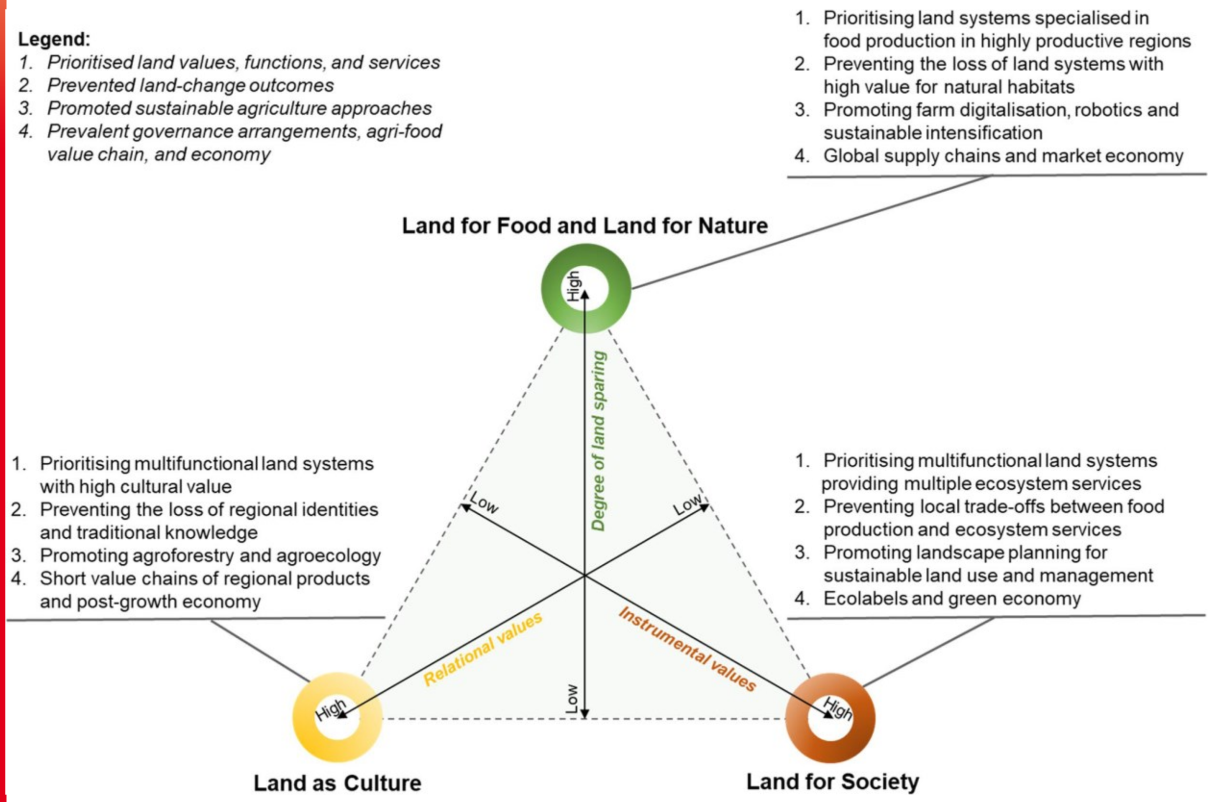

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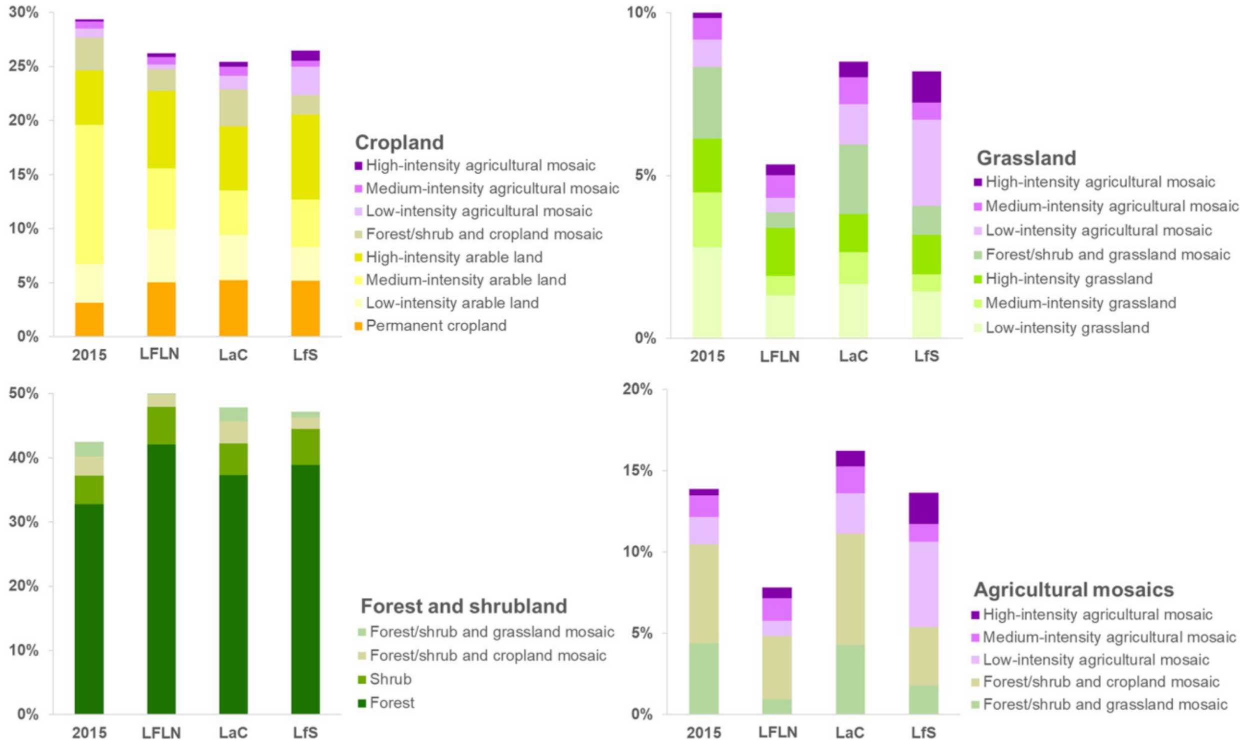


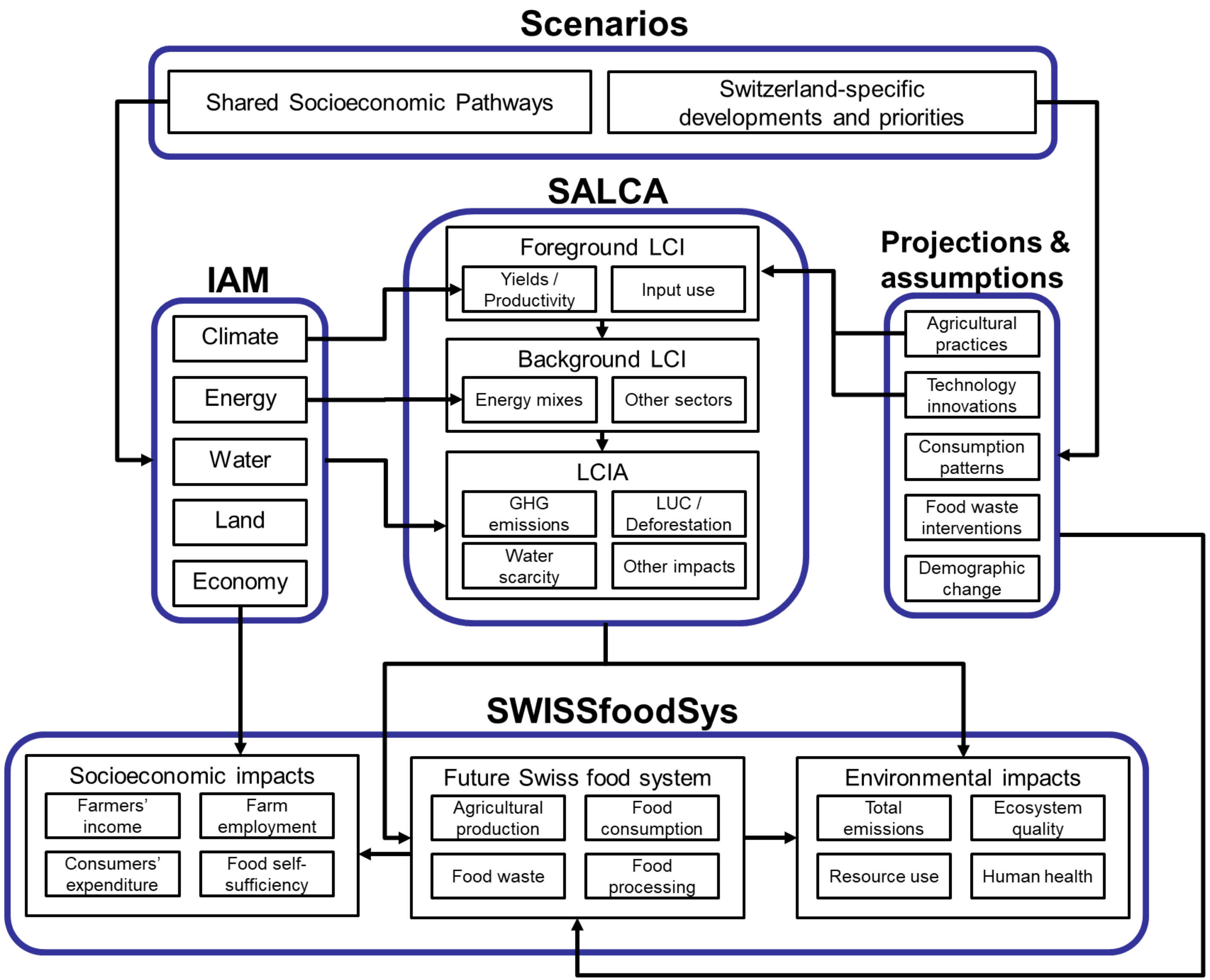
Diogo et al., 2025

Future food-system scenarios need to capture developments both at the global and local scales

- Agricultural practices
- Techonological innovations
- Food waste interventions
- Dietary changes
- Policy targets

Global scenarios	Switzerland-specific scenario variants		
	Variant 1	Variant 2	Variant 3
SSP1: Sustainability	• High-tech farming for improved input efficiency • Adoption of technological innovations in food processing and waste reduction • Dietary shift through increased consumption of novel foods • Minimise GHG emissions	• Agroecological practices for improved nutrient circularity • Short supply chains • Dietary shifts through increased consumption of regional and seasonal products • Minimise overall env. impacts	….
SSP2: Middle of the Road	…	…	…
SSP3: Regional rivalry	…	…	…
…..	…	…	…

Integrating prospective LCA with food system modelling



Challenges and opportunities

The integration of prospective LCA with SWISSfoodSys presents significant challenges:

- Key methodological and technical innovations are needed
  - systematic updating of LCI parameters, for both domestic production and imports, to reflect scenario-specific conditions, and also allow for sensitivity analysis -> Parametric approach?
  - LCIA methods: how to account for multiple potential future conditions and impact pathways?
  - Uncertainty propagation -> incorporate Monte Carlo methods in the simulation?

Challenges and opportunities

But also opportunities:

- understand the range of possible developments and outcomes, and how uncertainties may affect them
- Identify which (combination of) interventions could enhance the future sustainability of the Swiss food system

-> identify pathways that maximise synergies among health and sustainability outcomes and navigate trade-offs in the Swiss food system by 2050

-> understand how the magnitude of the impacts resulting from domestic changes compares to the impacts resulting from global developments under different scenarios

-> highlight the most critical factors and trends for decision-making











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