ROADMAP FOR THE GREEN TRANSITION IN AGRICULTURE

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A collaborative effort with contributions from more than 300 researchers from eight Danish universities, sector organisations and industries

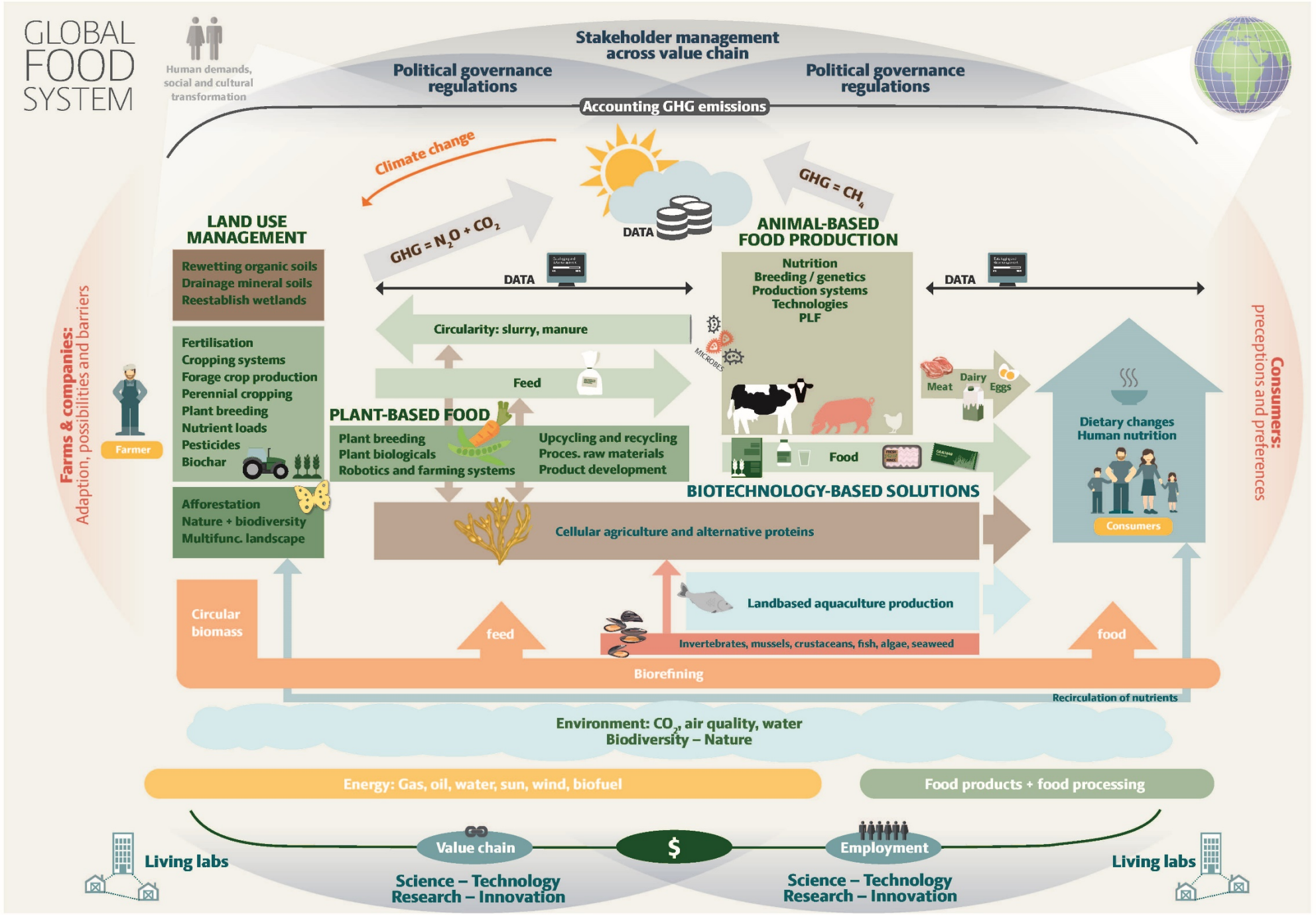
Roadmaps for agricultural research and innovation in Denmark

- Ministry of Food, Agriculture and Fisheries
  - Focus on 2030, subtargets for 2025 and 2030
  - Reduced GHGs from agriculture
  - Food consumption patterns with less climate impacts
  - Climate change adaptation

- Innovation Fund Denmark, AgriFoodTure
  - Roadmap for 2030 and 2050 (carbon neutrality)
  - Achieving other sustainability targets, including environment and biodiversity
  - Four tracks to support transition with land, livestock, plant foods and biotechnology

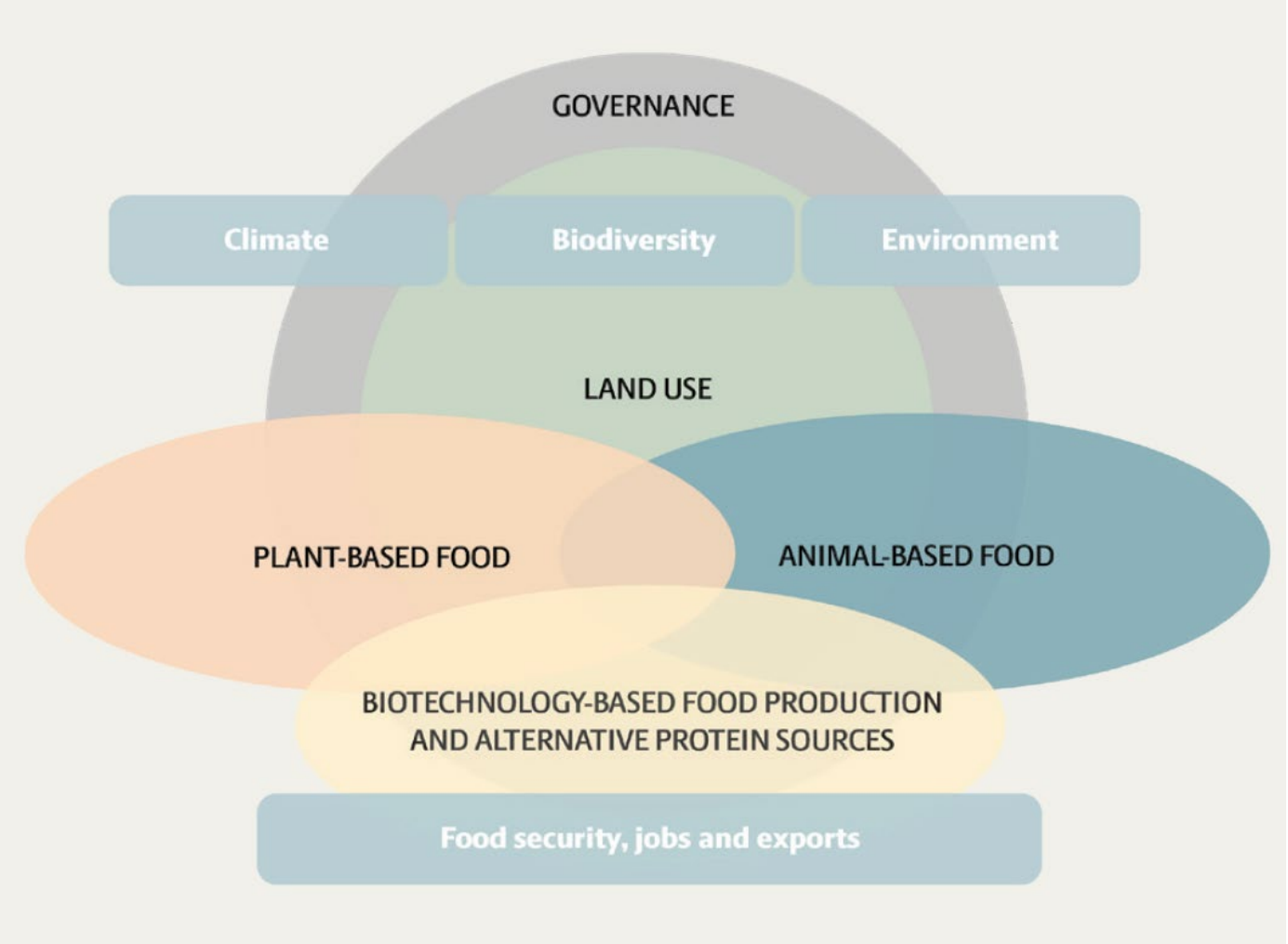
Multiple sustainability objectives

- Increase in food production (nutrition) of 45% by 2050
- 70% reduction in GHG emissions by 2030 (ref. 1990) and carbon neutrality by 2050 without leakage – and additional effects globally
- 24% reduction of ammonia emissions by 2030 (ref. 2005)
- Reduced nutrient leakages to aquatic ecosystems in compliance with Water Framework Directive
- Increase protected areas, reduce pesticide use by 50%, and reverse decline of pollinators/endangered species
- Denmark is a world leader in circular economy by 2030
- Increase jobs and wealth creation

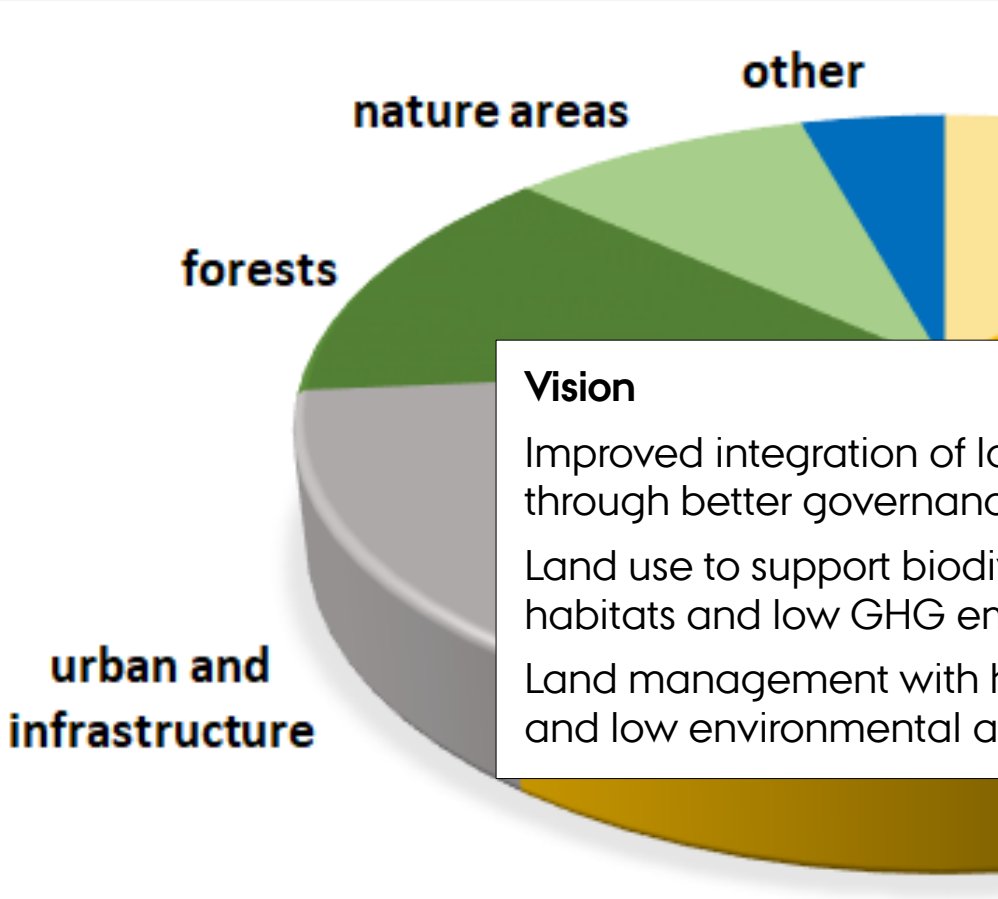

GLOBAL FOOD SYSTEM
Human demands, social and cultural transformation
Stakeholder management across value chain
Political governance regulations
Political governance regulations
Accounting GHG emissions
Climate change
GHG = N_2O + CO_2
GHG = CH_4
DATA
LAND USE MANAGEMENT
Rewetting organic soils
Drainage mineral soils
Reestablish wetlands
Fertilisation
Cropping systems
Forage crop production
Perennial cropping
Plant breeding
Nutrient loads
Pesticides
Biochar
Afforestation
Nature + biodiversity
Multifunc. landscape
Farmer
Farms & companies:
Adaption, possibilities and barriers
DATA
ANIMAL-BASED FOOD PRODUCTION
Nutrition
Breeding / genetics
Production systems
Technologies
PLF
DATA
Circularity: slurry, manure
Feed
MICROBES
PLANT-BASED FOOD
Plant breeding
Plant biologicals
Robotics and farming systems
Upcycling and recycling
Proces. raw materials
Product development
Meat
Dairy
Eggs
Food
BIOTECHNOLOGY-BASED SOLUTIONS
Cellular agriculture and alternative proteins
Dietary changes
Human nutrition
Consumers
Consumers:
preceptions and preferences
Circular biomass
feed
Landbased aquaculture production
Invertebrates, mussels, crustaceans, fish, algae, seaweed
food
Biorefining
Recirculation of nutrients
Environment: CO_2, air quality, water
Biodiversity – Nature
Energy: Gas, oil, water, sun, wind, biofuel
Food products + food processing
Living labs
Value chain
$
Employment
Living labs
Science – Technology
Research – Innovation
Science – Technology
Research – Innovation

Four tracks

- Land use and management
- Animal-based food
- Plant-based food
- Biotechnology-based food production



The Danish land is largely agriculture

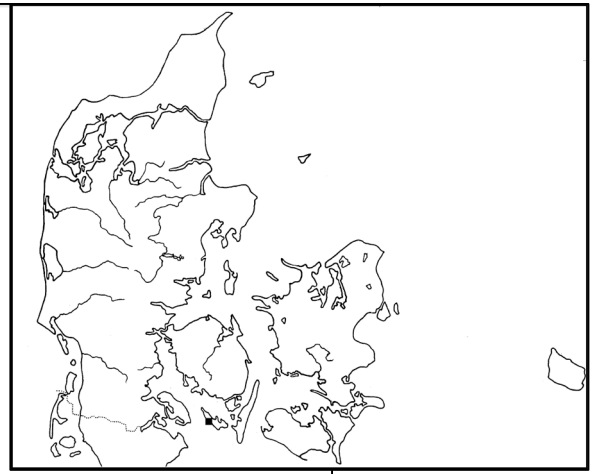


Vision

Improved integration of landscape functions through better governance

Land use to support biodiversity, high quality habitats and low GHG emissions

Land management with high productivity and low environmental and climate impacts



Land use and management is key to mission goals

Changes in landscape structure

Changes in functions and management

Governance to facilitate change

Reduced net GHG emissions

Greater primary production

Reduced nutrient loads

Reduced pesticide use

Greater bio-diversity

Changes in landscape structure

- Restoring 200,000 ha of former wetlands (reduction of nutrient loadings, increased carbon sequestration and biodiversity hot spots).
- Rewetting 100,000 ha of low-lying agricultural soils and rewetting all organic soils for substantial reductions in GHG emissions and nutrient loadings.
- Establishing 10,000 constructed wetlands/filters and saturated/intelligent buffer zones to reduce N and P loads with low costs and with enhancement of biodiversity.
- Development, formulation, and testing of new compact filter structures and principles for N and P retention that allows for nutrient recycling.
- Formulation and testing of new measures to reduce N_2O emissions from poorly drained mineral soils

Cropping systems for organic and conventional

FUNCTION AND MANAGEMENT


Foto - Colourbox


Foto - Colourbox


Foto - Colourbox


AU Foto – Lars Kruse

Arable cropping

- More biodiverse cropping systems, including legumes and mixtures
- Earlier harvesting of annual crops - improved establishment of cover crops to be harvested for biorefining (double cropping)

Forage cropping

- Grassland-based forage production based on multispecies mixtures

Perennial cropping systems

- Novel productive perennial crop production systems (incl. agroforestry)
- Integration with energy production (including photovoltaic)

Management

- Novel fertilizers and fertilization (including recycled nutrients)
- Precision farming technologies (sensors and robotics)
- Plant breeding - focus on environmental/climate aspects and efficiency in production chain
- Biorefining technologies - upcycle biomass from across the landscape
- Enhance soil carbon through biochar (integration with energy systems)

Animal-based food production

- Develop production of the most climate efficient animal-based food products in the world to accommodate and meet a growing worldwide demand for animal-based proteins and foods.
- Documentation and datasharing e.g., use of big data and technologies through an established common data platform collecting data from sensors and other sources to enable intensive monitoring, control and decision support for precision management thereby increasing resource efficiency and waste utilisation as well as reducing emissions.

Key activities and work streams

Cli	Env	Inn	Nat	Barr	
				BHR	Farmers' and consumers' perceptions as possibilities and barriers for reaching the climate goals for livestock farming
				CFG	Methane and ammonia reduction (Livestock)
				CFG	Capturing methane and ammonia (Buildings and systems)
				CFG	Circular perspectives
				FGR	Management and precision livestock farming
				CFR	Food product processes
				BFR	Alternative animal production systems

Effects on Climate (**Cli**), Environment (**Env**), Growth and Innovation (**Inn**), and Nature (**Nat**) from key activities within the track. Relative contribution is assessed by the colour intensity: darker is higher contribution than lighter, white is no contribution. In addition, barriers (**Barr**) are identified and include **B** Behaviour (Consumer); **C** Cost; **F** Financing; **G** Governance and Legislation; **H** Health; **R** Resistance to change in the sector.

Plant-based food production

- Contribute to the reduction of global GHG emissions by supporting the global transition towards healthier and more sustainable plant-based diets.
- Develop plant-based protein-rich crops for the manufacturing of gently processed, nutritious and tasty plant-based food products of high quality for both domestic use and export, they could replace the consumption of between 325,000 and 515,000 t meat (40% beef, 40% pork and 20% chicken).

Key activities and work streams

Cli	Env	Inn	Nat	Barr	
				BFLR	Collaboration and value chains
				BG	New and improved traditional breeding and propagation technologies
				FG	Plant biologicals
				CF	AI, robotics, remote sensing
				BR	New food crops and farming systems
				BFGL	Upcycling and recycling
				CFHL	Sustainable value-added processing of raw materials
				BGHL	High quality plant-based food products
				BCGH	Consumers and dietary change
				CFGR	Drivers and measures

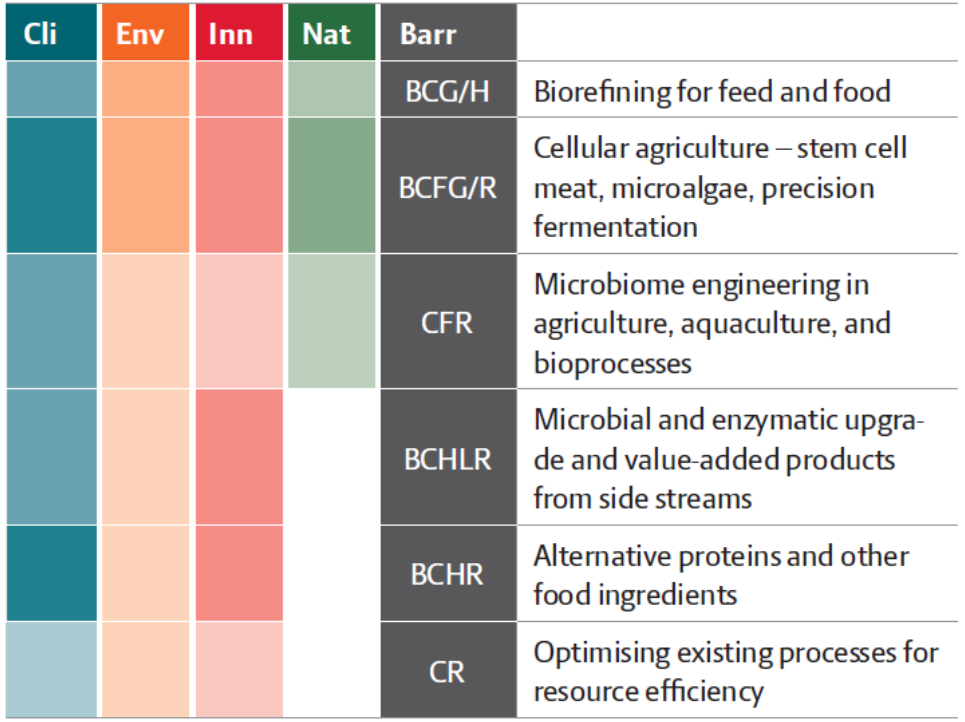
Effects on Climate (**Cli**), Environment (**Env**), Growth and Innovation (**Inn**), and Nature (**Nat**) from key activities within the track. Relative contribution is assessed by the colour intensity: darker is higher contribution than lighter, white is no contribution. In addition, barriers (**Barr**) are identified and include **B** Behaviour (Consumer); **C** Cost; **F** Financing; **G** Governance and Legislation; **H** Health; **L** Logistics; **R** Resistance to change in the sector.

Biotechnology-based food production

- Reduce the harmful impacts of food production on climate, environment, and biodiversity and lower the land use required for feeding the growing global human population through
  - biorefining for feed and food
  - cellular agriculture
  - alternative proteins and side-stream upgrade
  - new functional feed additives and biologicals
  - food processing technology to reach circularity

Key activities and work streams

Each work stream contributes to different Innomission targets and are characterised by several key barriers.



Cli	Env	Inn	Nat	Barr	
				BCG/H	Biorefining for feed and food
				BCFG/R	Cellular agriculture – stem cell meat, microalgae, precision fermentation
				CFR	Microbiome engineering in agriculture, aquaculture, and bioprocesses
				BCHLR	Microbial and enzymatic upgrade and value-added products from side streams
				BCHR	Alternative proteins and other food ingredients
				CR	Optimising existing processes for resource efficiency

Effects on Climate (**Cli**), Environment (**Env**), Growth and Innovation (**Inn**), and Nature (**Nat**) from key activities with the track. Relative contribution is assessed by the colour intensity: darker is higher contribution than lighter, white is no contribution. In addition, barriers (**Barr**) are identified and include **B** Behaviour (Consumer); **C** Cost; **F** Financing; **G** Governance and Legislation; **H** Health; **L** Logistics; **R** Resistance to change in the sector.

Stipulated GHG reduction (carbon neutrality)

Source	Baseline (Mt CO_2eq) 2018	Reduction (%) 2030	Reduction (%) 2050	Reduction (Mt CO_2eq) 2030	Reduction (Mt CO_2eq) 2050
Enteric fermentation (CH_4)	3.77	40	70	1.51	2.64
Manure management (CH_4, N_2O)	2.81	50	90	1,41	2.53
Fertilization (N_2O)	2.83	40	70	0.91	1.60
Crop residues (N_2O)	0.61	10	40	0.06	0.24
Ammonia volatilization (N_2O)	0.34	20	40	0.07	0.13
Nitrate leaching (N_2O)	0.33	10	30	0.03	0.10
Liming (CO_2)	0.24	10	20	0.02	0.05
Energy use (CO_2)	1.25	50	100	0.62	1.25
Organic soils (CO_2, N_2O)	5.75	30	80	1.73	4.60
Soil carbon (CO_2)	-	-	-	1.80	4.30
Total	17.37	48	100	8.16	17.44

Targets are extremely ambitious, but feasible with extraordinary large and coordinated efforts

Biodiversity and pesticides require additional effort

Pesticide use

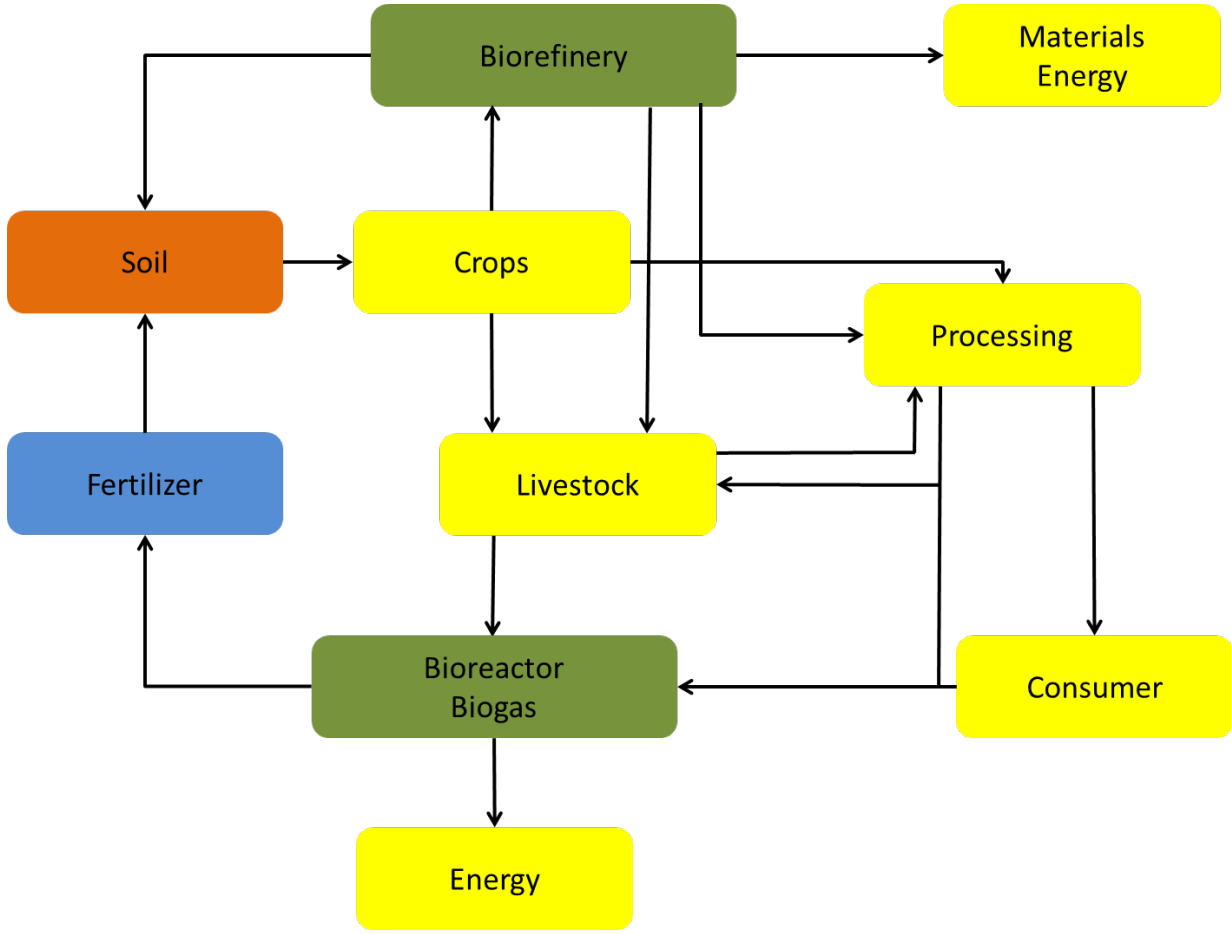
Measure	Reduction (%) 2030	2050
Perennial cropping systems	10	15
Diversity of arable cropping	5	20
Plant biologicals	5	10
Plant resistance breeding	10	15
Precision technologies	15	30
Total	45	90

Enhancing biodiversity

Category	Source	Area (1000 ha) 2030	2050
Land sparing	Rewetted areas	100	250
	Set-a-side	50	100
	Afforestation	50	100
Land sharing	Agroforestry	50	100
	Biodiverse perennial cropping	300	500
	Biodiverse arable cropping	500	1000
Total		1100	2050

Circularity is part of all topic areas

- Recycling of biomass and nutrients with use of side streams and bioenergy production enable
  - Lower external inputs
  - Higher production efficiency
  - Lower emissions through less waste
  - Energy production (e.g. biogas)
- New biorefining technologies enable
  - Cultivation of highly productive crops with low environmental and GHG as biomass for biorefining
  - Replacement of traditional feed crops, ingredients for food industry and biomaterials



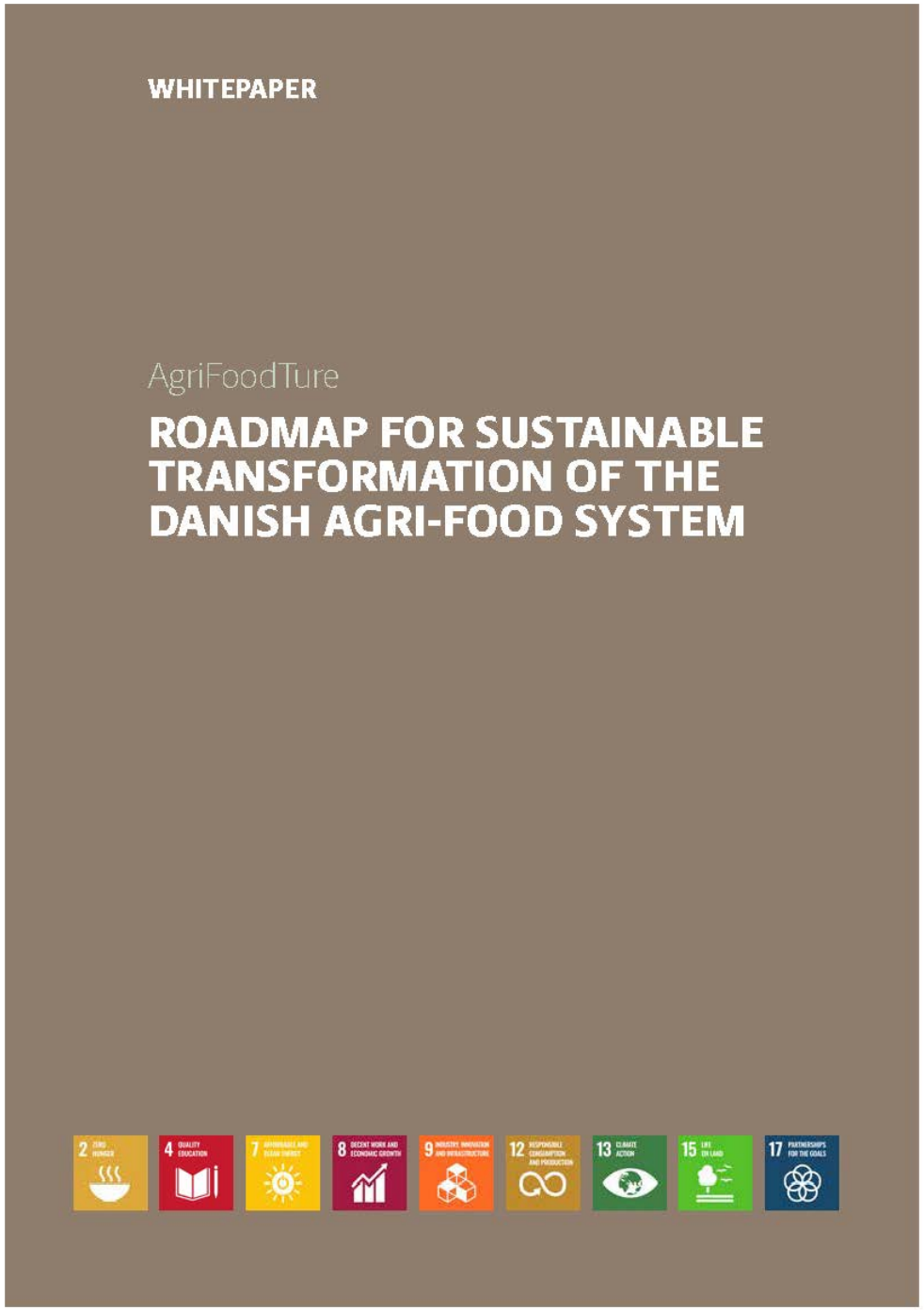
Cross-cutting issues and investments

Issues

- Improved GHG accounting
- Data-driven agri-food system
- Regulation and incentives from farm to consumer

Vast investments need for the transition

- Research and innovation capacity
- Establish R&I partnerships
- Funding the transition
  - Research and technology development
  - Demonstration and implementation
  - Commercialization and entrepreneurship
  - Required about 10 billion DKK annually



WHITE PAPER PUBLICATION

- Whitepaper: extended version of submitted Roadmap
- Where: https://www.seges.dk/innovation-og-udvikling/landbrug_og_klima/white_paper