



Can Global Food Systems become Circular?

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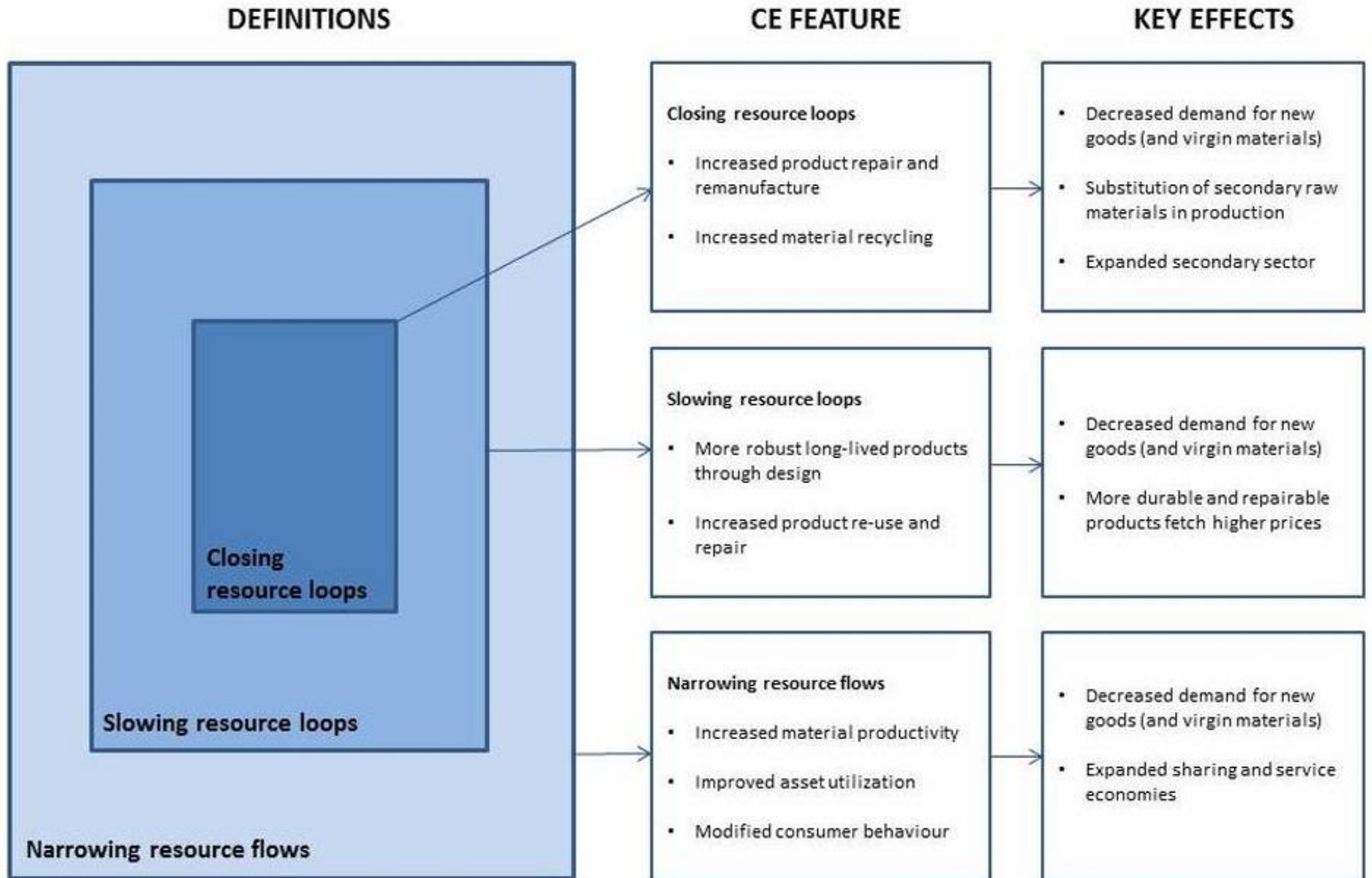
Roadmap

- Identifying approaches to Circular (Bio)-Economy
- Modeling framework
- Taxonomy of CE innovations
- Model-based scenario analysis of CE innovations and supportive policies



Identifying approaches to the Circular Bioeconomy

Differing definitions of a circular economy



Approaches to Circularity in the Agrifood System

■ Circular Economy

- *From **narrowing** to **closing** resource loops*
- *Measurable concepts:*
 - Resource productivity
 - Resource efficiency
 - Relative and **absolute decoupling**

■ (Circular) Bioeconomy

- Aligns with circular economy as it focuses on reduced and sustainable use of natural resources for food security
 - Achieve sequential source reuse and recycling to create **closed-loop systems**

■ Sustainable Agrifood Systems

- Deliver food security and nutrition for all in a way that the economic, social and environmental bases for future generations are not compromised

→ **ALL: Holistic systems thinking is needed**, i.e. consider the entire life cycle of biological resources

What could circular (bio-)economy principles mean for food systems?

Circular bioeconomy outcomes	Circular bioeconomy innovations and practices
1. Regenerate natural ecosystems	- Regenerative, conservation agriculture - Reforestation
2. Eliminate (agricultural) food loss and waste and pollution	- Temperature-controlled storage, transportation and distribution - Sustainable packaging and consumer behavior to reduce food waste - Green innovations (including alternative animal feed) that raise productivity and reduce emissions
3. Upcycle and recycle agrifood products and inputs	- Use food waste for composting and biogas - Use food waste for non-food manufactures - Alternative proteins (plant-based, cultured)
4. Prioritize biomass streams for human needs	- Halt land degradation and improve biodiversity through means to outcome 1 - Reuse biomass as renewable energy and upcycled products (outcome 3)
5. Use renewable energy	- Solar-powered irrigation and cold chains (1 + 2) - Biomass for bio-energy (3 + 4)

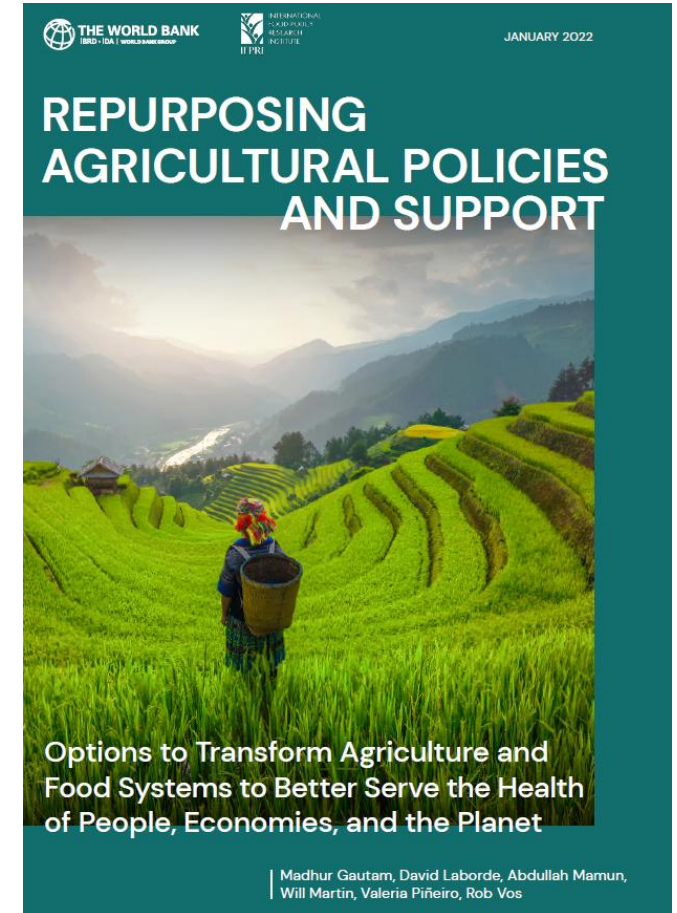


Modeling Approach

Modeling Framework: What do we need?

Global framework for these global problems – IFPRI's MIRAGRODEP model (global general equilibrium model):

- Specifies relevant policy instruments and responses
- Accounts for:
 - Greenhouse gas emissions
 - Land use and impacts on nature
 - Agricultural fertilizer & chemical input use
 - Energy use (renewable & non-renewable) throughout supply chain
 - Food loss and waste
 - Food security, diets, and livelihoods outcomes
- Allows assessing economic, social and environmental impacts at global, national & household levels, including for poverty, food security and diets



Enhancing IFPRI's MIRAGRODEP model

- **Key model extensions** required for the CE analysis
 - Split agricultural sectors by technology/practice → conservation versus conventional agriculture
 - Introduce alternative agricultural inputs → bio-fertilizer & pesticides vs chemical versions and bio-/renewable energy vs fossil fuel-based energy
 - Single-out high-potential CE food products → alternative (plant-based) proteins
 - Specify recycled products and recycling industries
- **Demanding new parameterization and data**
 - What are yields/productivity, resource- and emission-intensities of circular-economy innovations?
 - What are existing adoption rates of CE innovations, how much do they cost, and what are affordability thresholds for adoption at scale?



Taxonomy of CE innovations

Template for taxonomy of CE innovations

Innovation 1: Template					Adoption	Output	Material input use			Natural Resource use					GHG emission reduction	
	LGP	Region <i>(If data available, select region(s) from the table located at AC3)</i>	# of Years <i>(Select number of years, if lagged or different yearly effects)</i>	Applicable to which crops or other agrifood production	Current adoption rates (% of production)	Change in output <i>(excluding effects already captured by input changes)</i>	Energy	Chemicals (fertilizer, pesticides, plastics)	Other	Water	Natural land	Pastures	Crop Land	Forests	From production	From land use change
	uniform	Global	1													
	LGP1	Global	1													
	LGP2	Global	1													
	LGP3	Global	1													
	LGP4	Global	1													
	LGP5	Global	1													

1. Taxonomy must quantify (potential) impacts on input use, productivity, emissions, etc. for model parameterization into MIRAGRODEP and should also identify the cost and time lags of adoption and scaling
2. Taxonomy was used to prioritize across potential CE innovations

CIRCULAR ECONOMY INNOVATIONS

		Feasibility	Adoption Requirements & Costs			CE Contribution — Absolute Decoupling				Livelihood Potential				Circularity
#	Innovation	Feasibility Level	Tech Adaptation	Cost Short-term	Cost Long-term	Material Input Use	Natural Resource Use	Energy Use	GHG Emissions Reduction	Farm Incomes	Food Security	Poverty Reduction	Healthy Diets	Loop Quality (1–4 scale)
1	Minimum Tillage	High	Medium to High	↔	↔	Medium	Medium	Medium	Medium to High	Low to Medium	Medium	High	Low	2–3 Material recycling to Reuse/redistribute
2	Cover Cropping	High	Low	↔	↑	High	Medium	Medium	Low	Medium	Low to Medium	Low	Low	4 Prevent / avoid
3	Crop Rotation	High	Medium to High	↑	↔	High	High	High	Low	High	High	Medium	Medium	2 Material recycling
4	Improved Biogas Production	Medium	High	↓	↔	High	High	Medium	High	High	Low	Low	Low	3–4 Reuse/redistribute to Prevent/avoid
5	Insect-Based Alternative Feeds	Medium	Low	↔	↔	High	High	High	Medium	High	Medium	Medium	Medium	3–4 Reuse/redistribute to Prevent/avoid
6	Algae-Based Alternative Feeds	Medium	Low	↓	↓	Medium	High	High	Low	Medium	Medium	Low	Low	3 Reuse / redistribute
7	Composting for Bio-Based Fertilizers	High	Medium	↔	↔	Medium to High	Medium	Low	Low	Medium	Low	Low	Low	3 Reuse / redistribute
8	Improved Breeding & Genetic Innovations	High	High	↑	↔	High	Medium to High	Medium	Low to Medium	Medium	Medium	High	Medium	3–4 Reuse/redistribute to Prevent/avoid
9	Biopesticides & Biological Control	High	Medium to High	↔	↔	High	High	Low	Low to Medium	High	Medium	High	Low	3–4 Reuse/redistribute to Prevent/avoid
10	Perishable Food Cold Chain Logistics	Medium	Medium to High	↓	↔	Medium to High	High	High	Medium	High	Medium	High	Medium	4 Prevent / avoid
11	Dry Chain Development	Medium	High	↔	↑	Medium	Medium to High	Medium to High	Low to Medium	Medium	High	High	Medium	2 Material recycling
12	Alternative Proteins for Human Consumption	Medium	High	↔	↔	High	Medium	High	Medium	High	Medium	Medium	Medium	4 Prevent / avoid
13	Waste-Based Biofuels	High	High	↓	↔	Medium	High	Medium	Medium	High	Medium	Low	Medium	2 Material recycling
14	Food Scrap Collecting & Composting	Low	High	↓	↔	Medium	Medium	Medium	Medium	High	Medium	Medium	Low	3 Reuse / redistribute
15	Education & Awareness on CE Consumerism	High	High	↑	↔	Medium	Medium	Low	Low	Medium	Low	Low	Low	2–3 Material recycling to Reuse/redistribute
16	Digital Food Sharing & Redistribution	Low	High	↔	↔	Medium	Medium	Low	Low	Medium	Low	Low	Low	3 Reuse / redistribute
17	Promotion of Upcycled Foods	Low	High	↔	↑	Medium	Medium	Low	Low	Low	Medium	Low	Low	4 Prevent / avoid

SUMMARY OF INNOVATIONS FOR SCENARIO ANALYSIS			Adoption	Output	Material input use			Natural Resource use				
	LGP	Applicable to which crops or other agrifood production	Current adoption rates (% of production)	Change in output (excluding effects already captured by input changes)	Energy	Chemicals (fertilizer, pesticides, plastics)	Other	Water	Natural land	Pastures	Crop Land	Forests
1-3 Conservation Agriculture	uniform	Primarily maize, wheat, rice & barley with pulses as rotation crops	12.5%	20% to 30%	-20%	0%		-10% to -40%				
	LGP1											
	LGP2											
	LGP3	India, Bangladesh - rice	1.25%	10%	-10% to - 60%	0%		-10% to -20%				
	LGP4	Sub-Saharan Africa	1.25%	20%		0%		-10% to -20%				
	LGP5											
	LGP6											
4 Biopesticides and IPM	uniform	All crops		0% to 40%		-5%						
	LGP1											
	LGP2	India cotton		4%		-7%						
		India - rice		3%		-4%						
	LGP3	India maize		12% to 25%		-5%						
	LGP4	Sub-Saharan Africa - multiple crops		20%		0%						
	LGP5	Brazil - soybeans		3%		-5%						
	LGP6											
7 Algae-based feedstock	uniform	Livestock and aquaculture	low	20%			-10% to-50%					
	uniform	Porphyridium sp. , WhiteLeghorn chickens					-10%					
	uniform	Nile Tilapia, Nannochloropsis oculata, Schizochytrium sp.					-30%					
	mixed	Poultry, Ruminant, Swine, Aquaculture, Pet-Animals										
	mixed	Microalgae produced from manure nutrients for animal feed		600-1200%								
	mixed	Lithuanian Black-and-White cows (Milk), Spirulina platensis		21%								

SUMMARY OF INNOVATIONS FOR SCENARIO ANALYSIS

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	LGP	Region (If data available, select region(s) from the table located at AC3)	# of Years (Select number of years, if lagged or different yearly effects)	Applicable to which crops or other agrifood production	Current adoption rates (% of production)	Change in output (excluding effects already captured by input changes)	Energy	Chemicals (fertilizer, pesticides, plastics)	Other
8, 13, 14 Bio-fertilizers	uniform	Global	1	All crops	15%	10%		TBD	
	uniform	Global	1	Shanghai Cabbage					
	uniform	Global	1	Eggplant					
	LGP1		1						
	LGP2		1						
	LGP3	RoEFTA	1	Winter Wheat		0%			
	LGP4	Global	3	Tall Fescue					
	LGP5	EU28	3	Maize (Zea mays L.) (Pioneer “Costanza” FAO 600), wheat (Triticum aestivum L.) (cv. Blasco), and sunflower (Helianthus annus L.) (PR64H41 variety)					
	LGP6	RoLAC	1	Sugarcane					
	LGP6	RoLAC	1	Banana	18%				
	LGP6	RoLAC	1	Vegetable and Tuber Crops	18%				
9 Improved seeds and breeding Bio-fertilizers	uniform	Global	1	All crops & livestock	0% to 100%	3% to 30%	-10%	-25% to -40%	
	LGP1		1	Detailed parameters available for adoption rates, productivity and input use effects by crop, region and AEZ					
	LGP2		1						
	LGP3		1						
	LGP4		1						
	LGP5		1						
	LGP6		1						

SUMMARY OF INNOVATIONS FOR SCENARIO ANALYSIS					Adoption	Output	Material input use		
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10-11 Improved cold & drychain logistics	uniform	Global	1	Food LOSS : All crops & livestock		5% to 30%	10% to 15%		
		Global	1	Food WASTE: HH level. Food services and retail		5% to 30%	10% to 15%		
	LGP1		1	Adapt by country/region proportional to observed levels of food loss and food waste					
	LGP2		1						
	LGP3		1						
	LGP4		1						
	LGP5		1						
	LGP6		1						
12 Alternative proteins	uniform	Global	1	New plant-based, high-protein foods	Impacts on production, productivity, material input use, etc. to be estimated by creating new product/sector which competes with meat & dairy sector				
				Protein-conserving plant-based alternatives to all meat in the mean American diet (dominated by tofu, soybeans, peanuts, lentils)					
	mixed	USA		(Replacing) Animal Products					
	mixed	Global		(Replacing) Beef Cattle					
	mixed	Global		(Replacement) = Tofu					
	mixed	Global		(Replacement) = Groundnuts, other pulses, peas, nuts					
		Global	1						

From taxonomy to model simulations

A. Need to make broad assumptions

- Parameterization difficult because of lack of comparable evidence regarding impacts on key model variables
- Incomplete evidence on likely impacts of innovations when brought to scale and scattered evidence regarding impacts across AEZs and countries/regions
- Insufficient systematic evidence on investment cost and affordability thresholds for adoption → *experimentation required to identify needs for **policy support** and **awareness raising***

B. Model-specification changes needed to simulate several innovations (see above)

C. Innovations and policy support will need to be **bundled** for system change and impact



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Preliminary model-based scenario analysis

Two scenario approaches

A. Broad-brush CE policies and innovations

- Policy reforms with current technologies
- Innovations that expand our technological possibilities

B. Scenarios of promising CE innovations and policies

- Promising CE innovations with and without policy support
- Bundles of CE innovations with and without policy support

A. Broad-brush CE scenarios

- Analyzing broad implications of policy & innovations

- Policies that would shorten supply chains
- Improvements in agricultural productivity and resource efficiency
- Policies to reduce consumer food waste

- Policy measures and 'innovation shocks'

- 20% tariff increase to shorten supply chains
- 10% agricultural productivity growth induced by R&D in improved varieties and VC efficiency
- 10 percentage point cut in food wasted at consumer level (assumed to be achieved through awareness, sustainable packaging, etc.)

A. Broad-brush CE scenarios

- **20% tariff increase to shorten supply chains**
 - *Does not help move towards CE:* slight declines in incomes, increased domestic production and input use in developing countries, cost of food increases, though lower income and higher food prices reduce emissions)
- **(a) Uniform 10% agricultural productivity growth and (b) Improved seeds and breeding (Innov. 9)** for higher yields and greater resource efficiency (less input and land use)
 - *Helps move partially towards CE:* improves in global welfare, increased efficiency in food production, lower food prices and less land use and lower food prices.
 - *However,* lower food prices stimulate consumption, thereby production, *increasing energy use and agricultural emissions* (Jevons effect)
- **10% point cut in food waste at consumer level**
 - *Helps towards CE: improves in global welfare, increased efficiency in food consumption, lower food prices, less energy use, and less land use and lower food prices.*

Long-term (comparative static) impact for WORLD (in % deviation from baseline)

	Tariffs	Production Efficiency (10% TFP)	Prod. & Resource Efficiency (Innov. 9)	Cons Waste Reduction
Real Income	-0.03	0.8	2.5	1.4
World food prices	-0.06	-12.2	-32.1	-4.6
Cost Healthy Diets	0.09	-10.3	-26.7	-2.5
Agric Land	0.00	-0.6	-2.7	-0.3
Energy in agriculture (MToE)	0.03	4.2	14.1	-2.8
Ag Emissions (production)	-0.01	5.4	7.4	-1.5
Ag. emissions (total) (thousands of MT CO2eq)	-2.7	231.5	69.4	-202.1

Identifying rebound effects on material input use throughout the food system and the economy

Climate resilient breeding varieties (innovation 9):

- (Chemical) input, land, and water use down
- Energy input intensity down, but actual fossil fuel use up
- Use of agricultural output for intermediate demand increase and reuse shares are up – both positive and negative for CE outcomes
- Need for bundling of innovations

Long-term (comparative static) impact for WORLD (in % deviation from baseline)

	Prod. & Resource efficiency (Innov. 9)
Chemical input use - Agriculture	-69.97
Chemical input use - Crops	-72.03
Energy input use - Agriculture (coal-oil-gas)	1.15
Chemical input intensity - Agriculture (per unit output)	-74.54
Chemical input intensity - Crops (per unit output)	-76.99
Chemical input per hectare - Agriculture	-69.13
Energy input intensity - Agriculture (per unit output)	-14.25
Land intensity - Agriculture (ha per unit output)	-17.53
Land intensity - Crops (ha per unit output)	-18.52
Ag output to intermediate use - all sectors	22.03
Ag output to intermediate use - within agriculture (feed-seed)	19.53
Ag output to intermediate use - non-ag sectors	24.11
Ag output to intermediate use - food processing	23.14
Ag output to intermediate use - chemicals sector	21.03
Ag output to intermediate use - energy sector	26.65
Reuse share - non-ag intermediates (% of ag output)	30.79
Feed-seed share - within agriculture (% of ag output)	24.69
Reuse share - non-ag intermediates (pp change)	1.53
Reuse share - food processing (pp change)	0.66
Reuse share - chemicals sector (pp change)	0.02
Reuse share - energy sector (pp change)	0.00
Feed-seed share - within agriculture (pp change)	0.32
Water use - stylized (% change)	-39.22
Water use - model response only, no shock (% change)	21.57
Water intensity - stylized, per unit output (% change)	-50.00

B.Scenarios of promising CE innovations and policies (*in preparation*)

- Explore bundles of innovations and policy reforms to achieve CE objectives and identify trade offs and economic, social and environmental feasibility
- **Bundles:**
 - Bundle A = Conservation agriculture (*CE Innovations 1-3*)
 - Bundle B = *Bundle A* + Biopesticides & IPM (*CE Innovation 4*)
 - Bundle C = *Bundle B* + Bio-fertilizers (*CE Innovations 8, 13 & 14*)
 - Bundle D = *Bundle C* + Improved inputs (seeds and altern. animal feed) (*CE innovations 9 & 7*)
 - Bundle E = *Bundle D* + Improved value chain efficiency for FLW reduction (*CE Innovations 10-11*)
 - Bundle F = *Bundle E* + Promotion of plant-based protein consumption (*CE Innovation 12*)
 - Bundle G = *Bundle F* + Demand-side policy support and CE awareness raising (*CE innov. 15 & 16*)

Conclusions and further research agenda

- Taxonomy documents a broad range of high potential and scalable CE innovations exist
- Parameterization of the potential and estimating cost of adoption of those innovations is challenging given scattered evidence and lack of practice in many contexts
- CGE modeling framework requires important revisions (new products, sectors, recycling activities etc.) to properly assess CE scenarios for food systems
- Initial simulations suggest that many resource-efficient innovations may not be fully CE compliant (“absolute decoupling”), because of rebound effects.
- Points at need for food systemwide (holistic) approach, including changes in consumer behavior
- Link analysis of required policy support to ongoing discussions on “repurposing of agricultural support” to ensure full realignment of economic incentives within food systems