Measuring the sustainability of livestock at multiple scales

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CLEANER COWS

(*C*onsequential *L*ife cycle assessment of *E*nvironment*A*l and eco*N*omic *E*ffects of dai*R*y and beef *CO*nsolidation and intensification path*W*ay*S*)

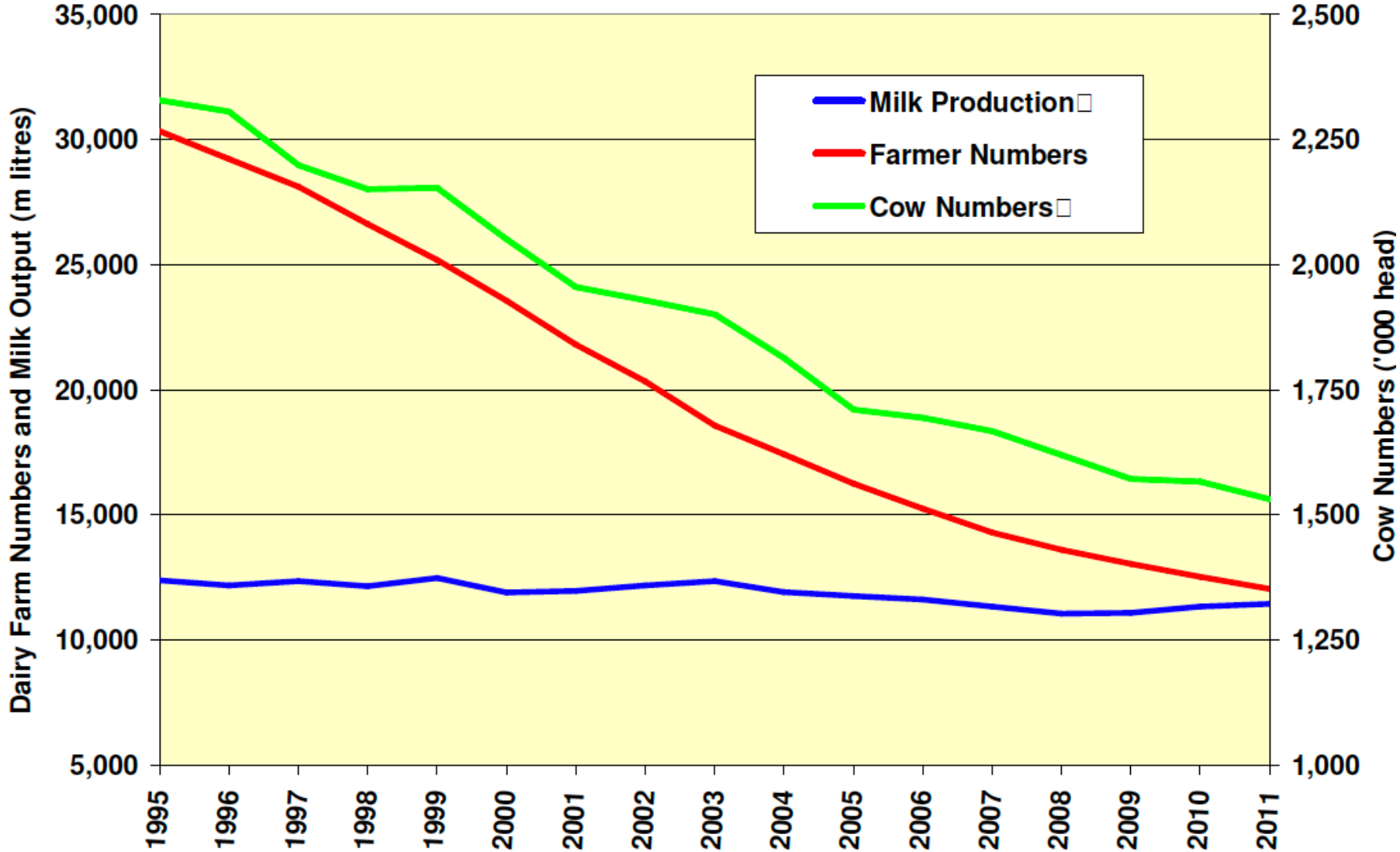
National Research Network for Low Carbon Energy and Environment (NRN-LCEE) cluster:

Bangor University (PI James Gibbons, Co-I David Styles, PDRs Alejandra González Mejía, Andreas Soteriades)

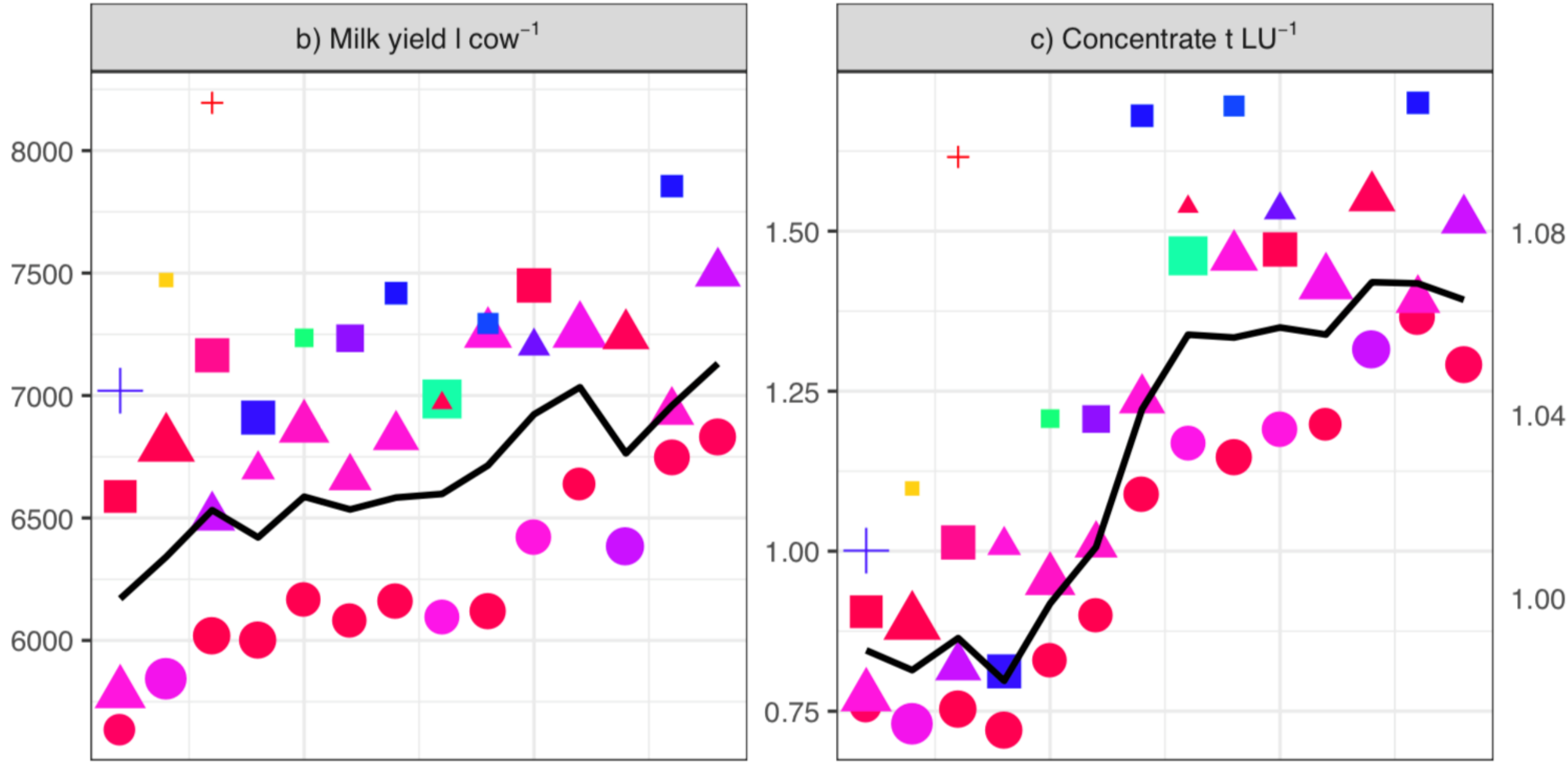
Aberystwyth University (Co-I Jon Moorby, PDR Andreas Foskolos)

Cardiff University (Co-I Max Munday, PhD Annum Rafique)

Figure 1: Trends in the GB dairy sector: 1995 to 2011

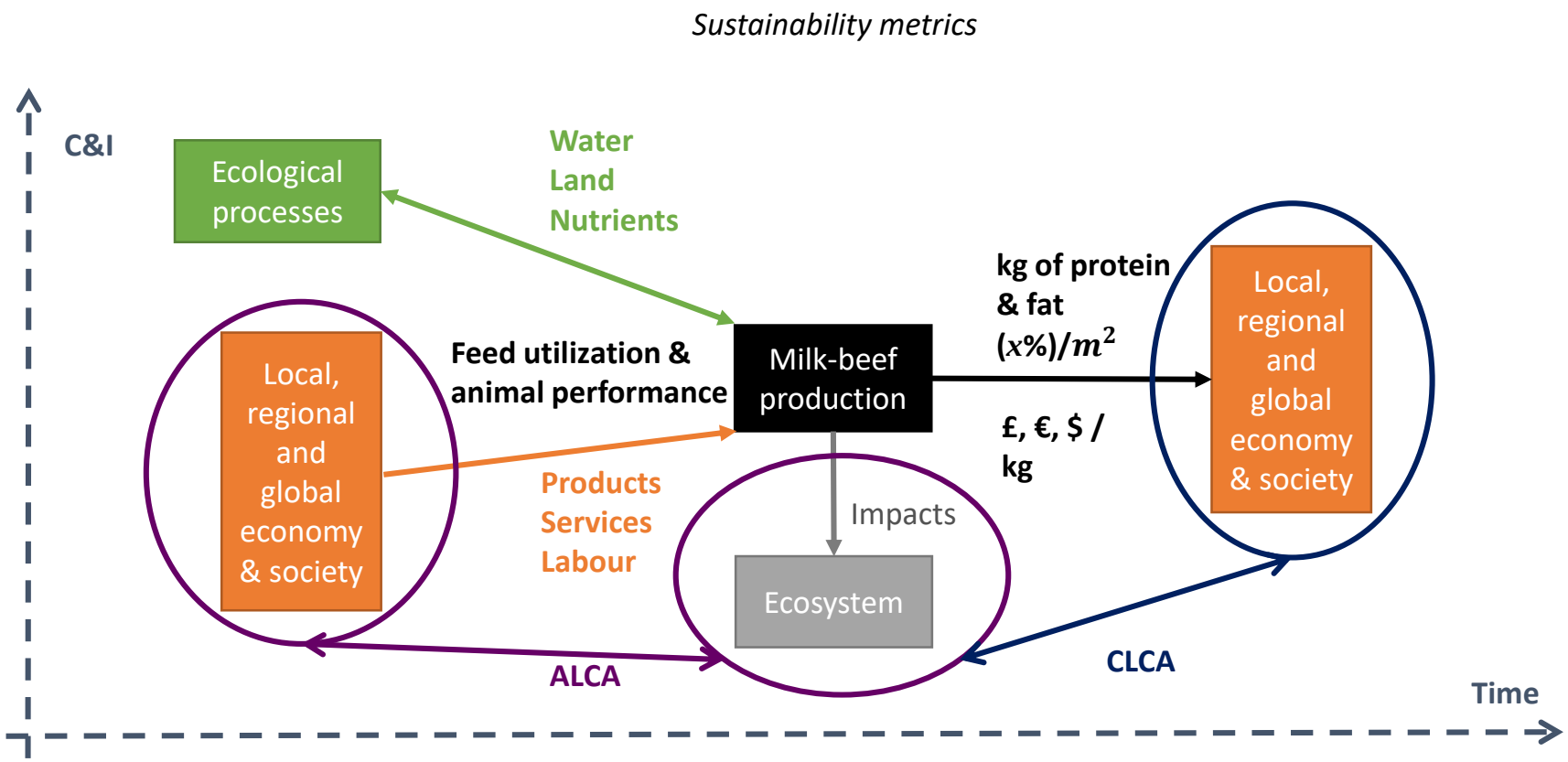


Source: DairyCo, Defra, RPA


b) Milk yield l cow^{-1}
8000
7500
7000
6500
6000
c) Concentrate t LU^{-1}
1.50
1.25
1.00
0.75
1.08
1.04
1.00

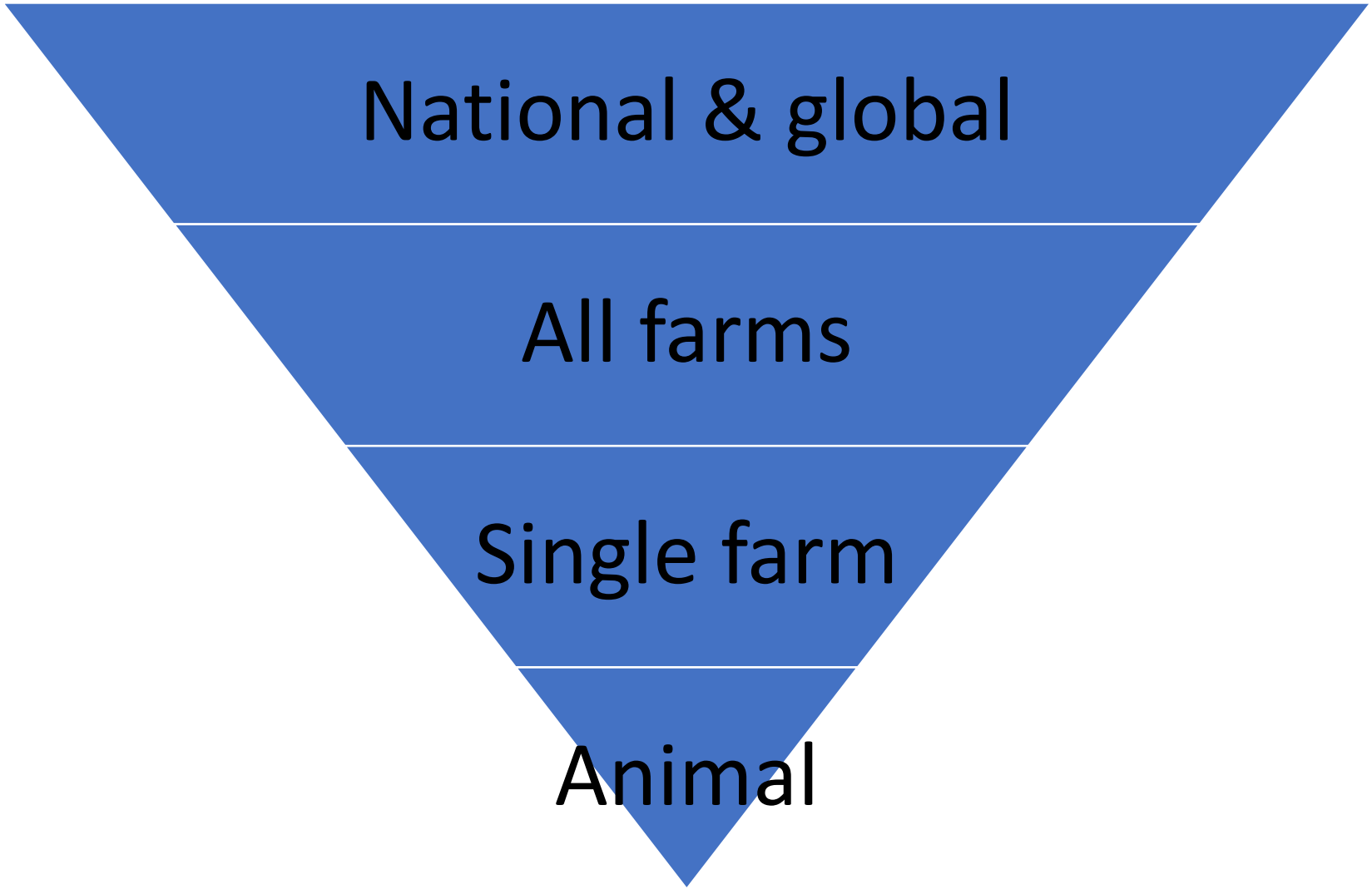
Sustainability assessment

- Dairy-beef systems as a case study for sustainable intensification



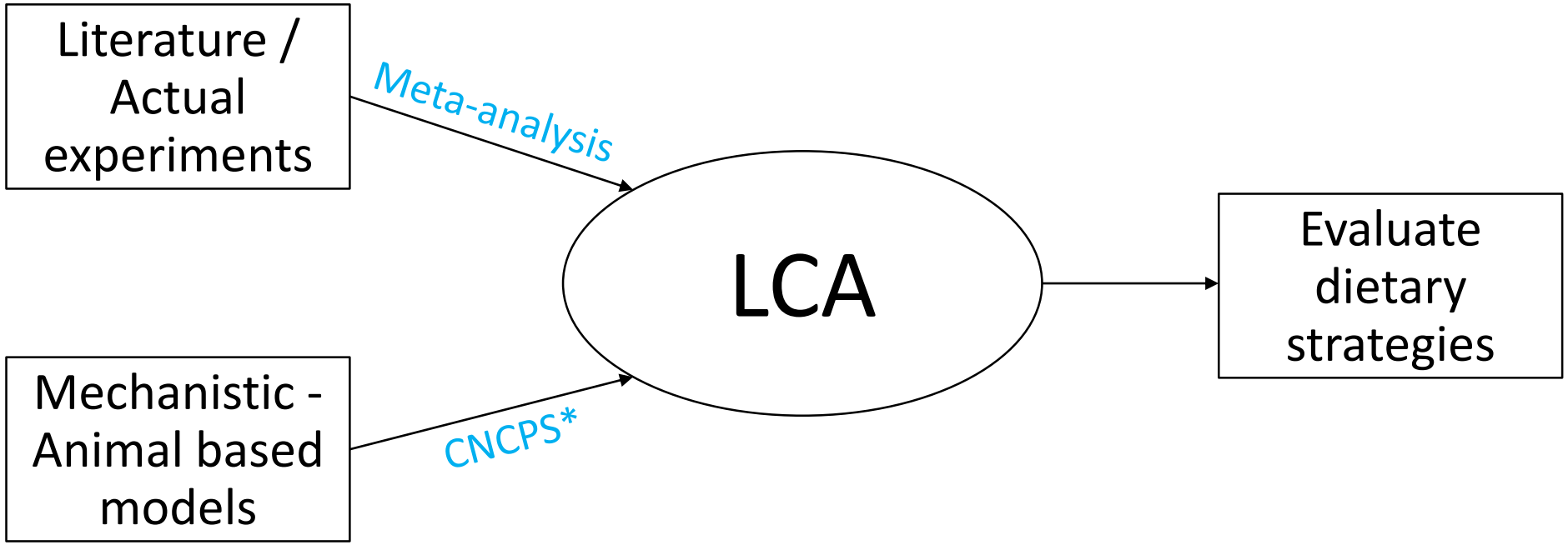
- A bottom-up approach
- Animal -> farm -> regional -> national
- Static accounting -> dynamic feedback -> macroeconomic feedback

Upscaling from animal to global

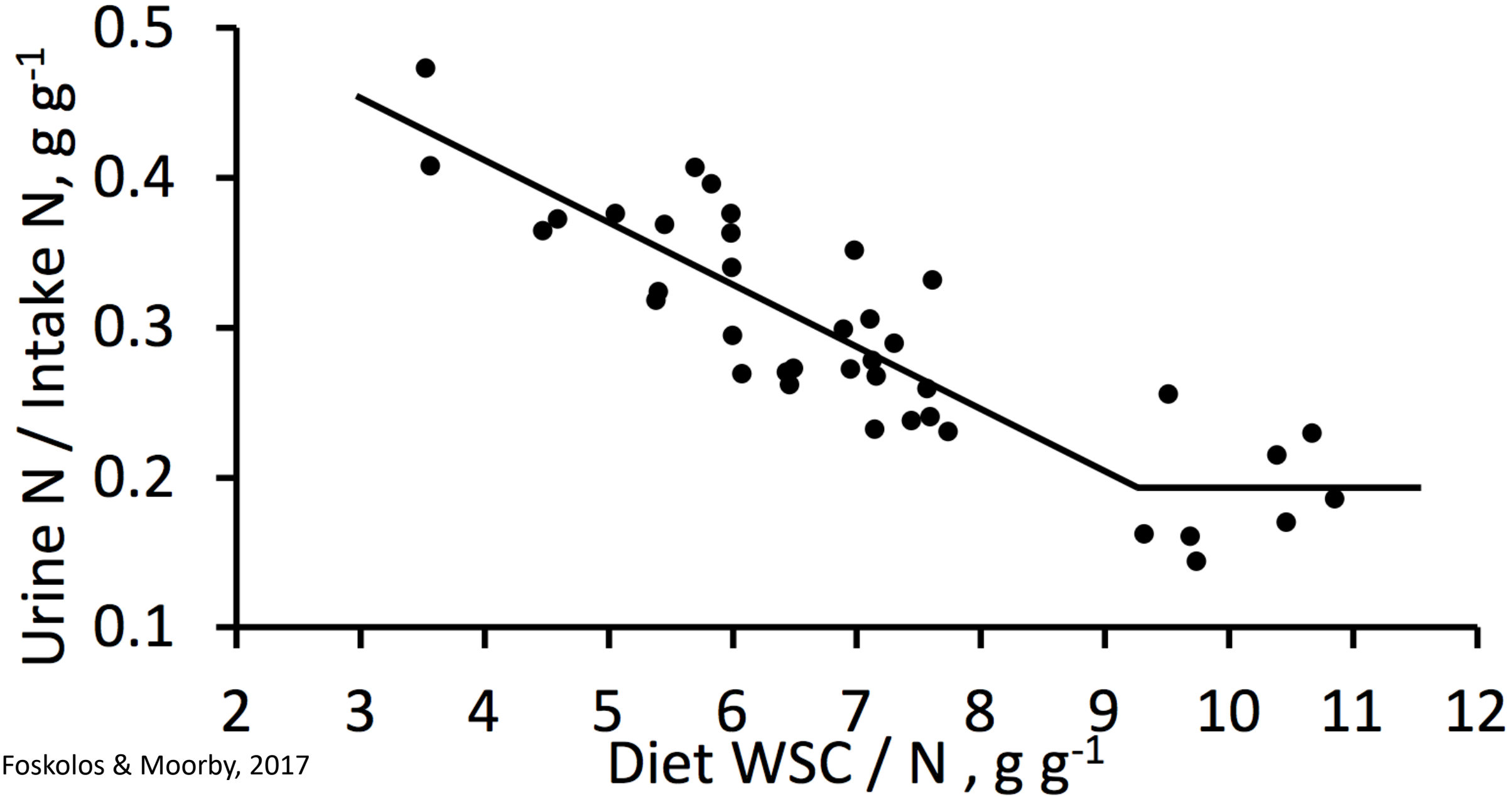


Animal scale

Modelling cow diets

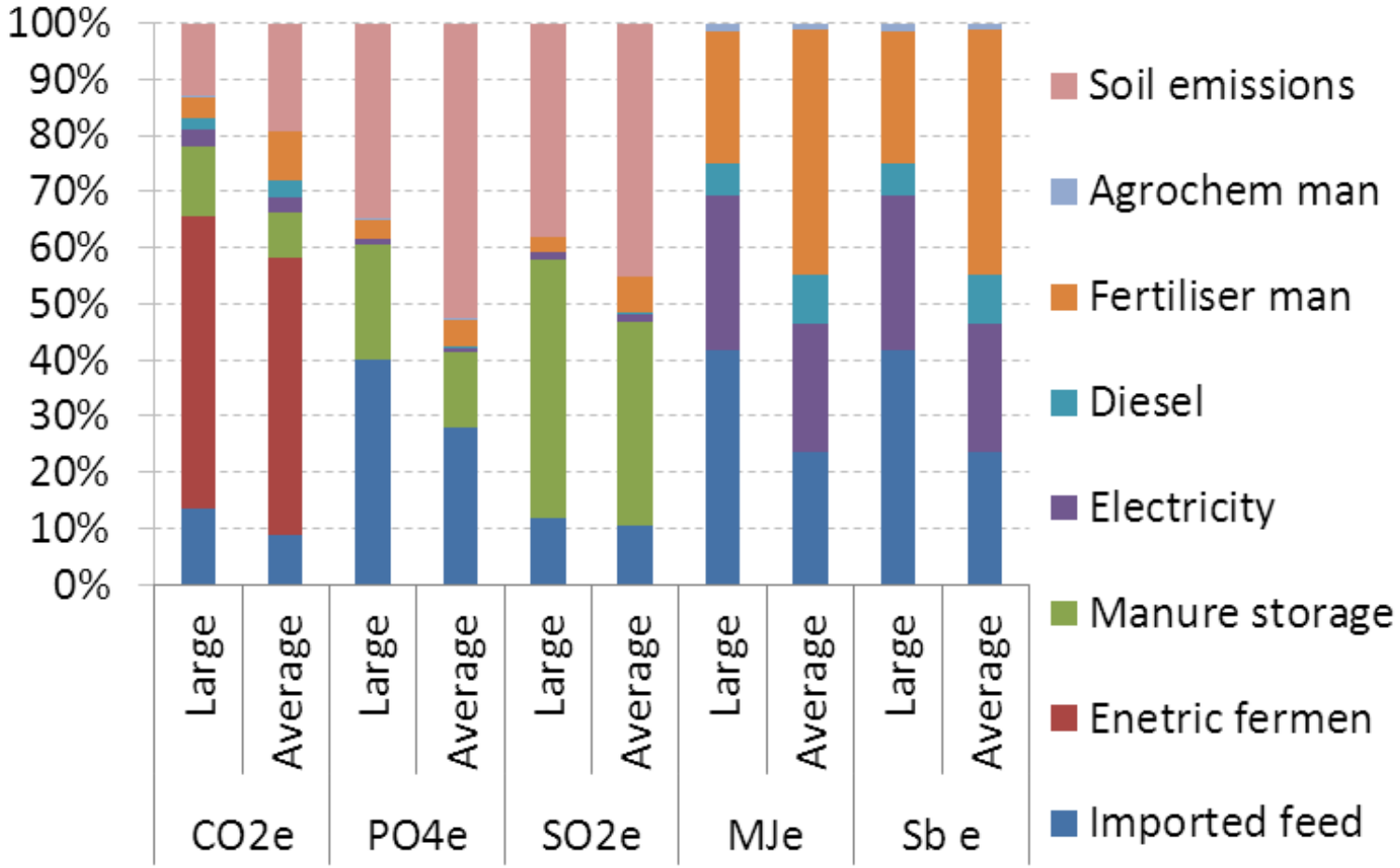


*Cornell Net Carbohydrate and Protein System



Foskolos & Moorby, 2017

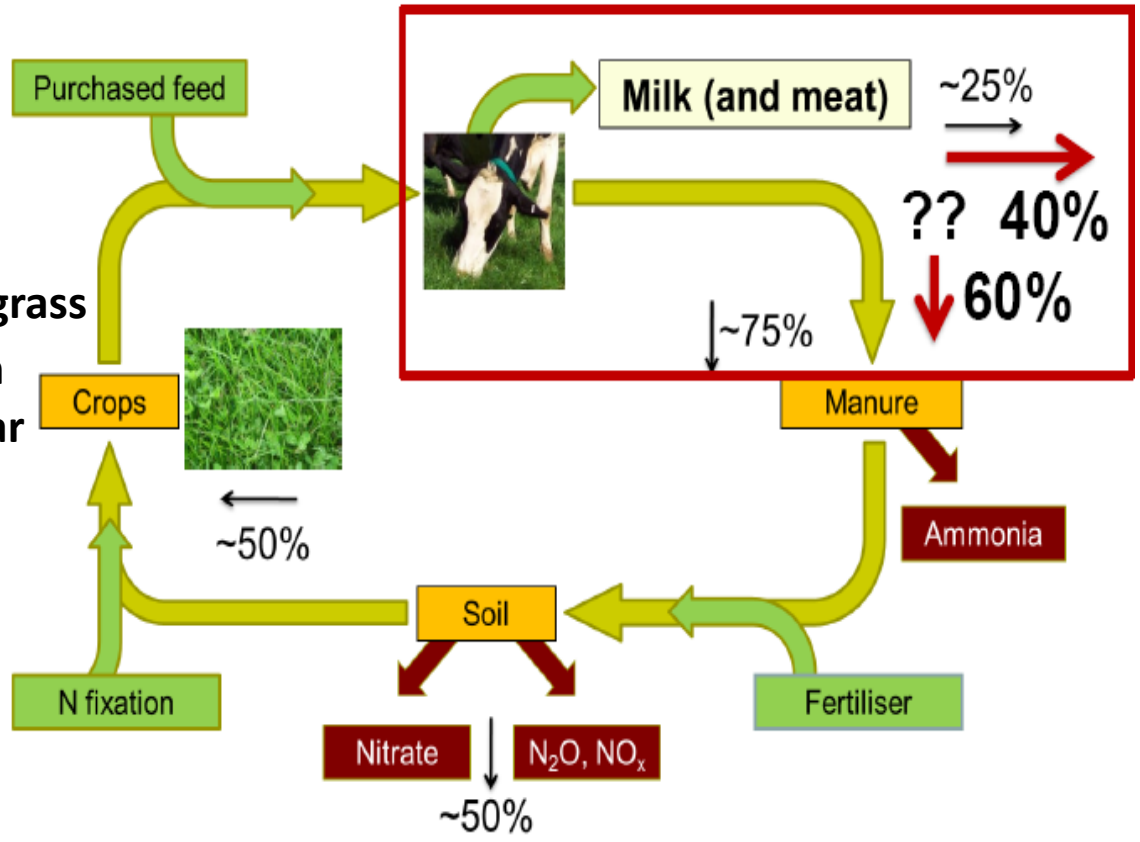
	CO_2e	PO_4e	SO_2e	MJ e
	kg per L milk			
Large	0.90	0.0037	0.0076	1.55
Average	1.02	0.0039	0.0066	1.98
Source: **Bangor University farm LCA tool**				

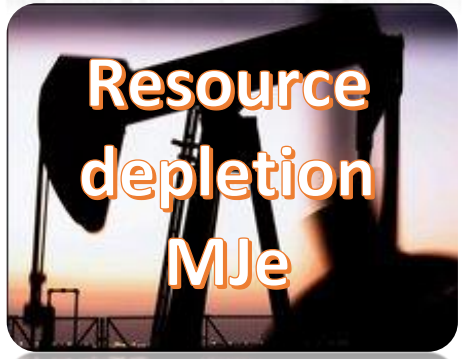


Single farm scale

Integration of farm modelling and LCA

a) Ryegrass
b) High Sugar





Conventional ryegrass (**Sc-CTR**) and High Sugar Grass (**Sc-HS**) Scenarios

- Mixed pasture-indoor dairy system with a 6 months grazing period
- Cows & heifers were supplemented with concentrate CON_{Lact} & CON_{Heifer}
- Daily DMI and GHG per animal were estimated by the Cornell Net Carbohydrate and Protein System (CNCPS) (Van Amburgh et al., 2015)

ANNUAL FARM CHARACTERISTICS	HS	CTR
Annual milk yield (l/cow)	6,874	6,437
Number dairy cows (lactating and dry)	132*	
Heifers	118	
Grazing area (ha)	65	
Cut-grass area (ha)	40	
Slurry storage system	Tank crust	
Slurry spreading method	Trailing shoe	

* In preparation for submission, Gonzalez-Mejia et al. (2017)

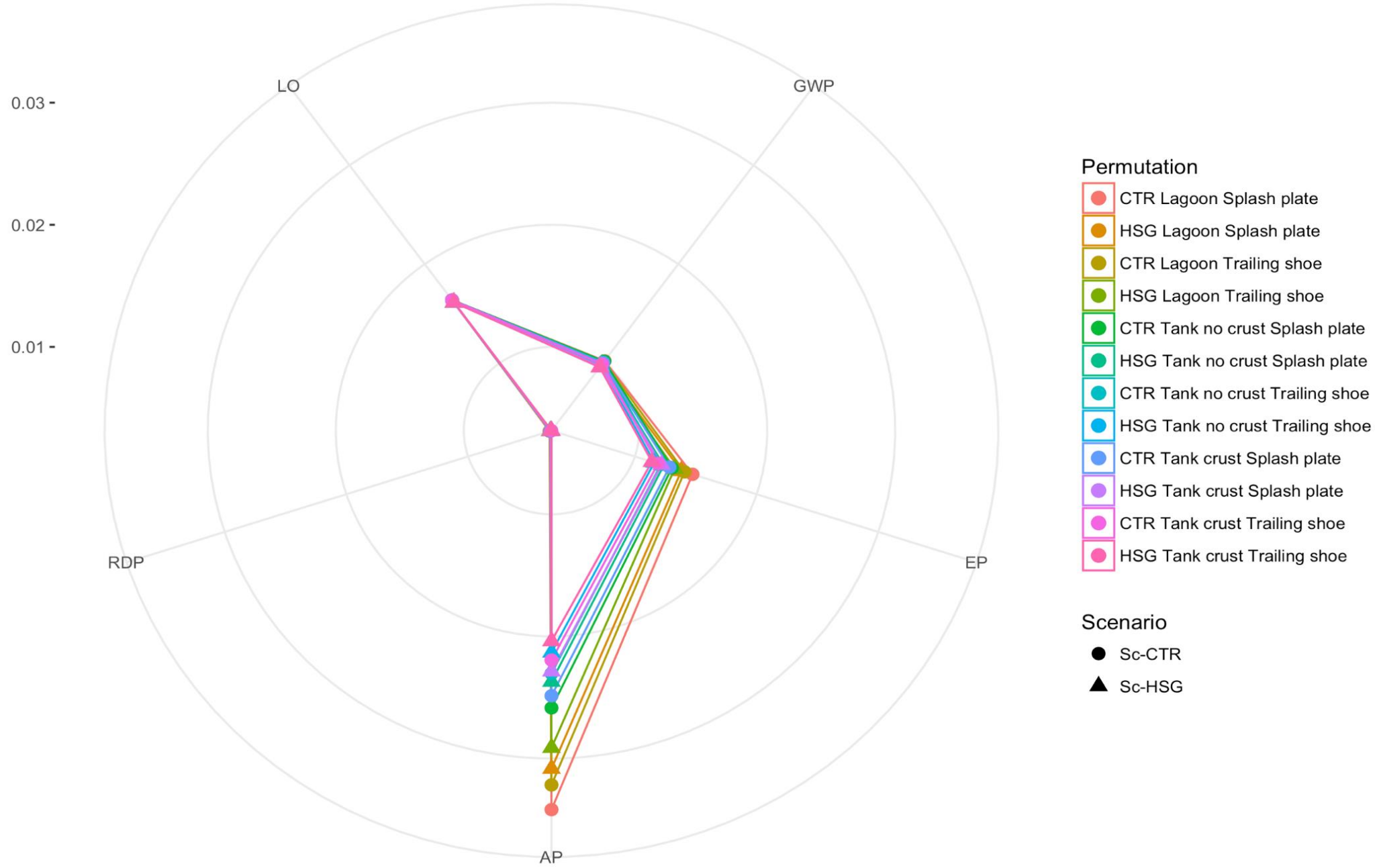
Chemical composition of conventional ryegrass (CTR) and water soluble elevated ryegrass (HS) used in model simulations

	Forage[1]		Silage[2]	
	CTR	HS	CTR	HS
DM, %	18.9	20.6	23.7	24.4
CP, % DM	14.3	13.2	24.6	22.1
WSC, % DM	16.9	21.3	8.6	21.3
Fat, % DM	2.8	2.8	NR[3]	NR
ADF, % DM	27.3	25.5	30.0	26.5
NDF, % DM	51.0	47.5	48.2	42.0
Ash, % DM	7.6	7.7	4.5	3.6

[1] Adopted by Foskolos and Moorby (2017)
[2] Adopted by Merry et al. (2006)
[3] NR: not reported

Ingredient and chemical composition of concentrates used in model simulations

Item	CON_{Lact}	CON_{Heifer}
Ingredient, % DM basis		
Wheat grain, ground	45.1	7.7
Barley grain, ground	-	11.3
Sunflower meal, 40 CP	10.7	5.5
Soybean meal, 44 %CP	5.1	16.1
Canola meal, solvent	2.6	15.2
Palm Kernel, expeller	5.1	11.2
Soybean Hills, ground	20.4	-
Beet Pulp, dry	2	11.8
Corn gluten feed	2	-
Molasses, dried	1.5	7.1
Wheat Midds	-	3.7
Corn Distiller, solubles	-	5.2
Limestone	-	2.4
Begafat	-	1.2
Fat Safflower	5.1	-
Mineral & Vitamin mix	0.4	1.6
Chemical composition		
DM, %	90.0	83.4
CP, % DM	18.5	24.3
WSC, % DM	4.7	11.6
Fat, % DM	7.7	5.1
NDF, % DM	29.0	26.0
Ash, % DM	4.2	11.0



Soteriades et al (forthcoming), *Journal of Cleaner Production*

Representing farm diversity

Questions

- What measures of intensification can we derive from farm survey data?
- Can we statistically identify distinct groups of similar dairy farms?

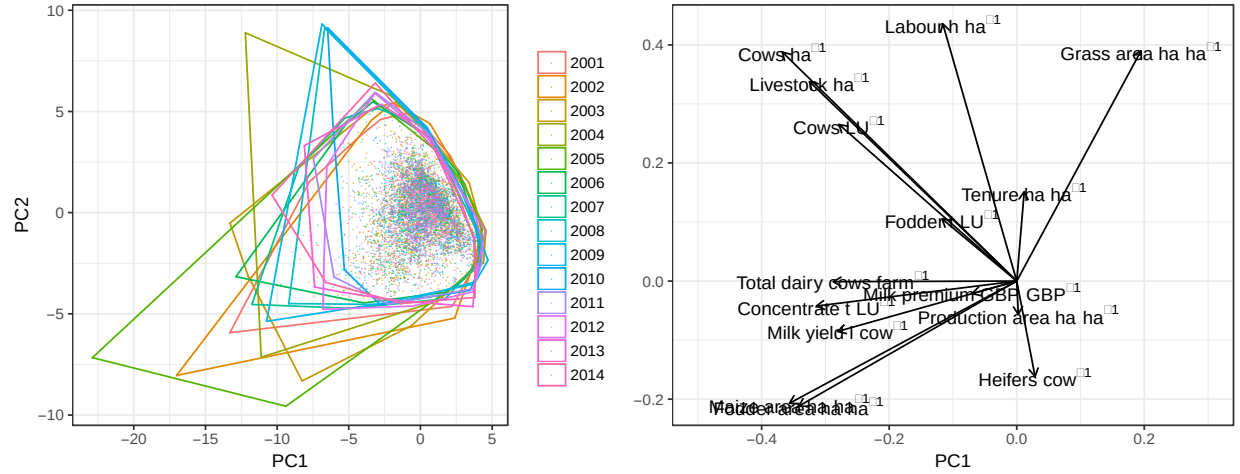
The UK Farm Business Survey (FBS)

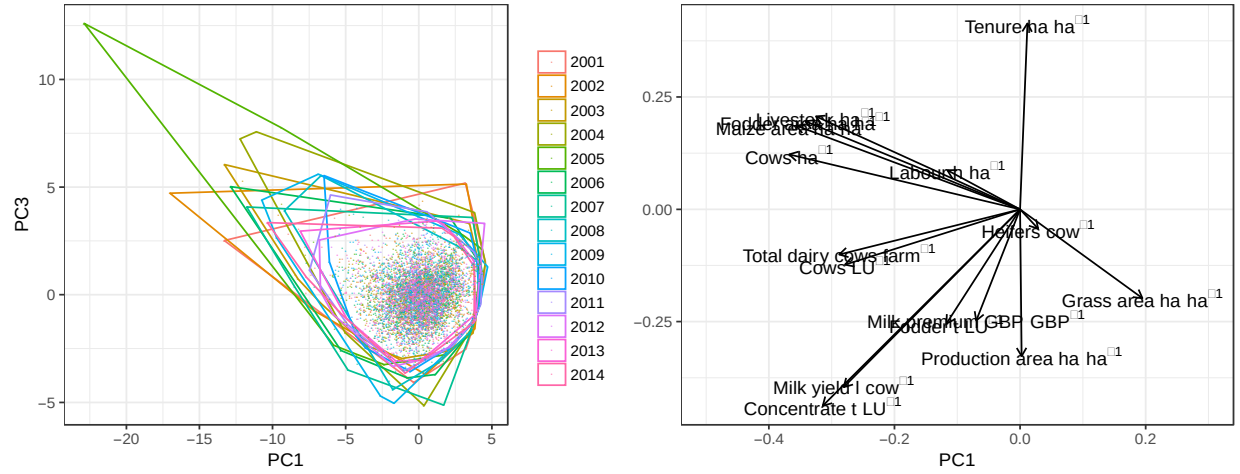
- *The Farm Business Survey is an annual survey commissioned by the government under which a range of management accounting information on all aspects of farmer's and grower's businesses is collected. The survey uses a sample of farms that is representative of the national population of farms in terms of farm type, farm size and regional location.*
- The survey includes >2,300 farms.
  - ~450 dairy
- Years 2001-2014

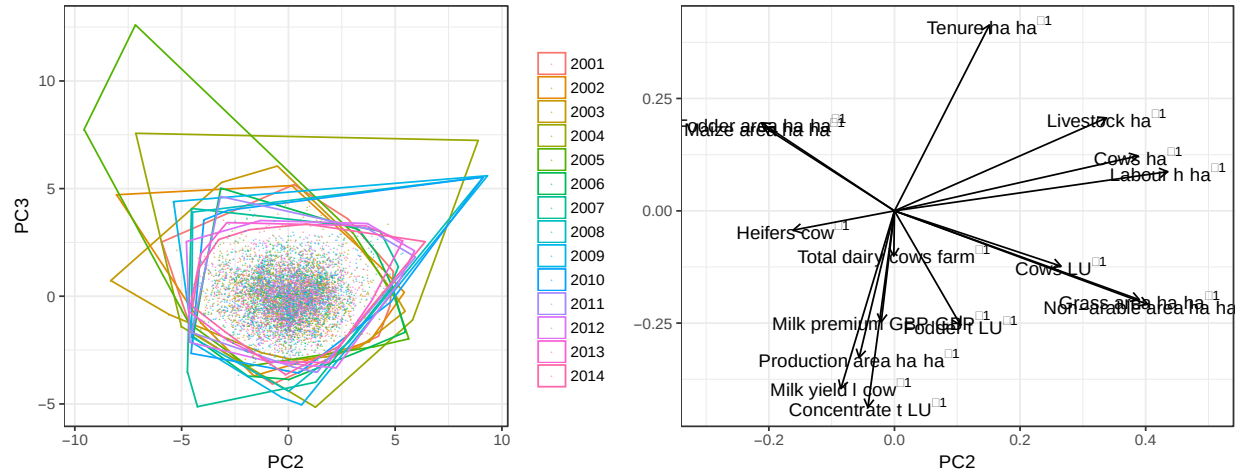
Milk Production	Dairy Cows	qty	Number of dairy cows	Herd size comparison
	Milk Yield	l/ qty	Milk production / Dairy Cows	Measure of production efficiency. Higher yield generally means less inputs per production unit
	Milk Price Premium	£/l / £/l	Milk Product Revenue / (Milk Products Sold *Average Milk Price)	Milk price received by farm compared to other farms. Premium >1 is desirable and <1 non-desirable
	Grazing Animals Concentrate	tonne/ LU	Concentrate Feed Cost / (Concentrate Price * Grazing animals in Livestock Units (LU))	Feed bought into the farm that embodies upstream land and environmental impact (e.g., resource depletion, GHG emissions) per livestock unit
	Grazing Animals Coarse Fodder	tonne/ LU	Coarse Fodder Cost / (Fodder Price * Grazing animals in Livestock Units (LU))	Measure of feed bought into the farm that embodies upstream land and environmental impacts (e.g. resource depletion, GHG emissions) per livestock unit

Intensity of Livestock Production	Dairy Fraction	qty/ LU	Dairy Cows / All animals in Livestock Units (LU)	Indicates the degree of the specialization and heterogeneity of the livestock enterprise.
	Livestock Density	LU/ ha	Cattle in Livestock Units (LU) / Non-Arable Area	Measure of overall farm land use intensity. Useful for characterising farms and comparing management practices
	Stocking Density	qty/ ha	Dairy Cows / Non-Arable Area	Measure land use intensity for dairy cows
	Labour Intensity	hours/ ha	Annual worked hours / Farm Area	Indirect measure of technology. Useful for comparing farm productivity, and for socio-economic characterisation

Grass, Fodder and Maize mix	Fodder Grass Ratio	ha/ ha	Fodder Area /Grass Area	Measure of the reliance on fodder in feeding strategy. Could be used for inferring indoor/outdoor systems and land use footprints.
	Maize Grass Ratio	ha/ ha	Maize Area/Grass Area	Measure of maize dependence in feeding strategy. Could be used to infer land use footprints.
Farm Structure for Grazing Animals	Fraction of Non-Arable Area in Agricultural Area	ha/ ha	Non-Arable Area / Agricultural Area	Measure of farm livestock specialisation
	Fraction of Grass in Agricultural Area	ha/ ha	Grass Area / Agricultural Area	Measure of grass dependence in feeding strategy. Could be used for inferring indoor/outdoor systems. Useful for comparing farm land use footprints
Production Area	Farm Agricultural Fraction	ha/ ha	Agricultural Area / Farm Area	Measures proportion of farm used for agricultural production.
Tenure	Owner Tenure Fraction	ha/ ha	Owner Occupied Area / Agricultural Area	Measure of ownership structure and socio-economic characterisation.
Replacement Rate	Replacement Rate	qty/ qty	Heifers / Dairy Cows	Measure of non-productive herd

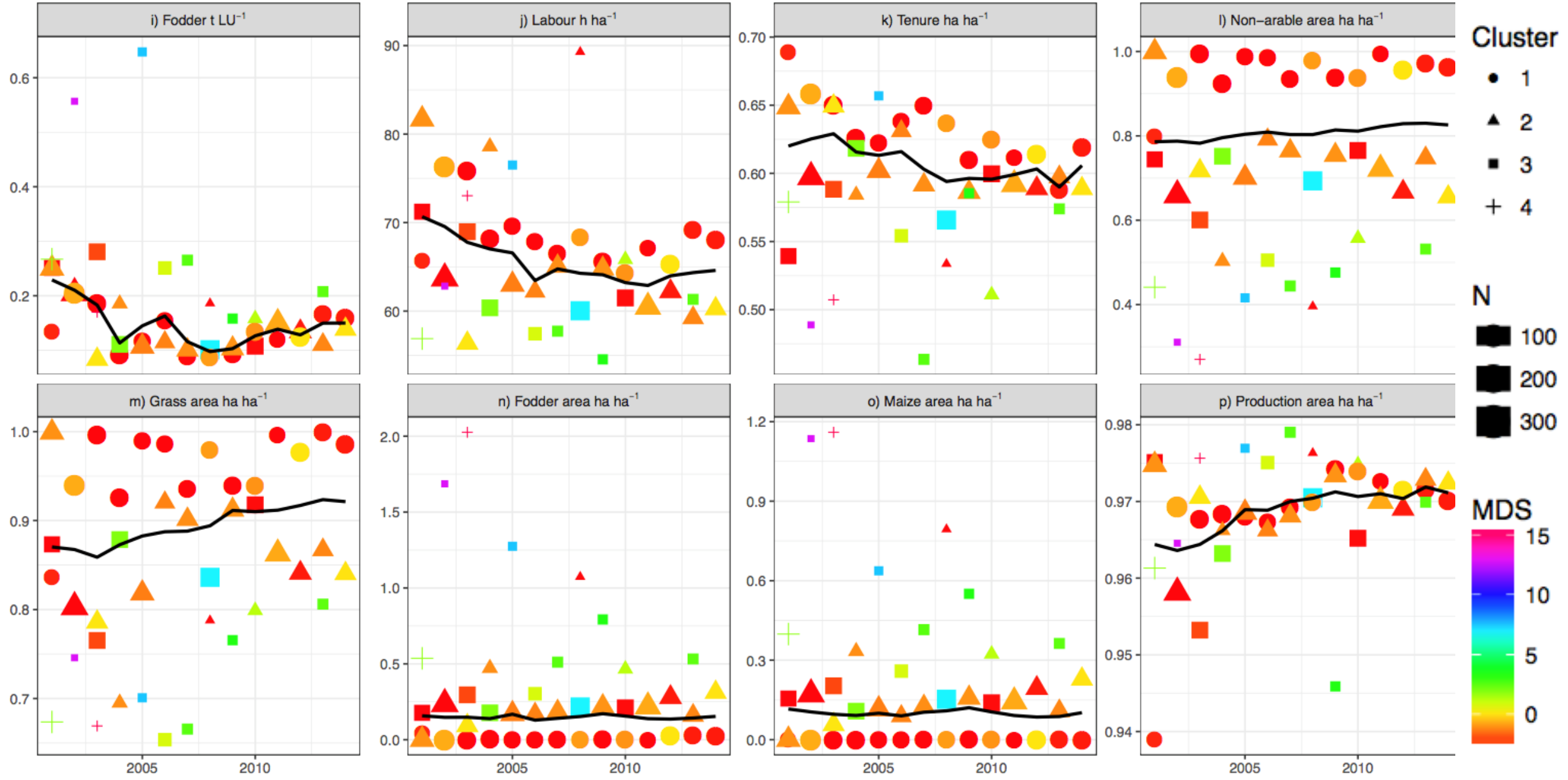


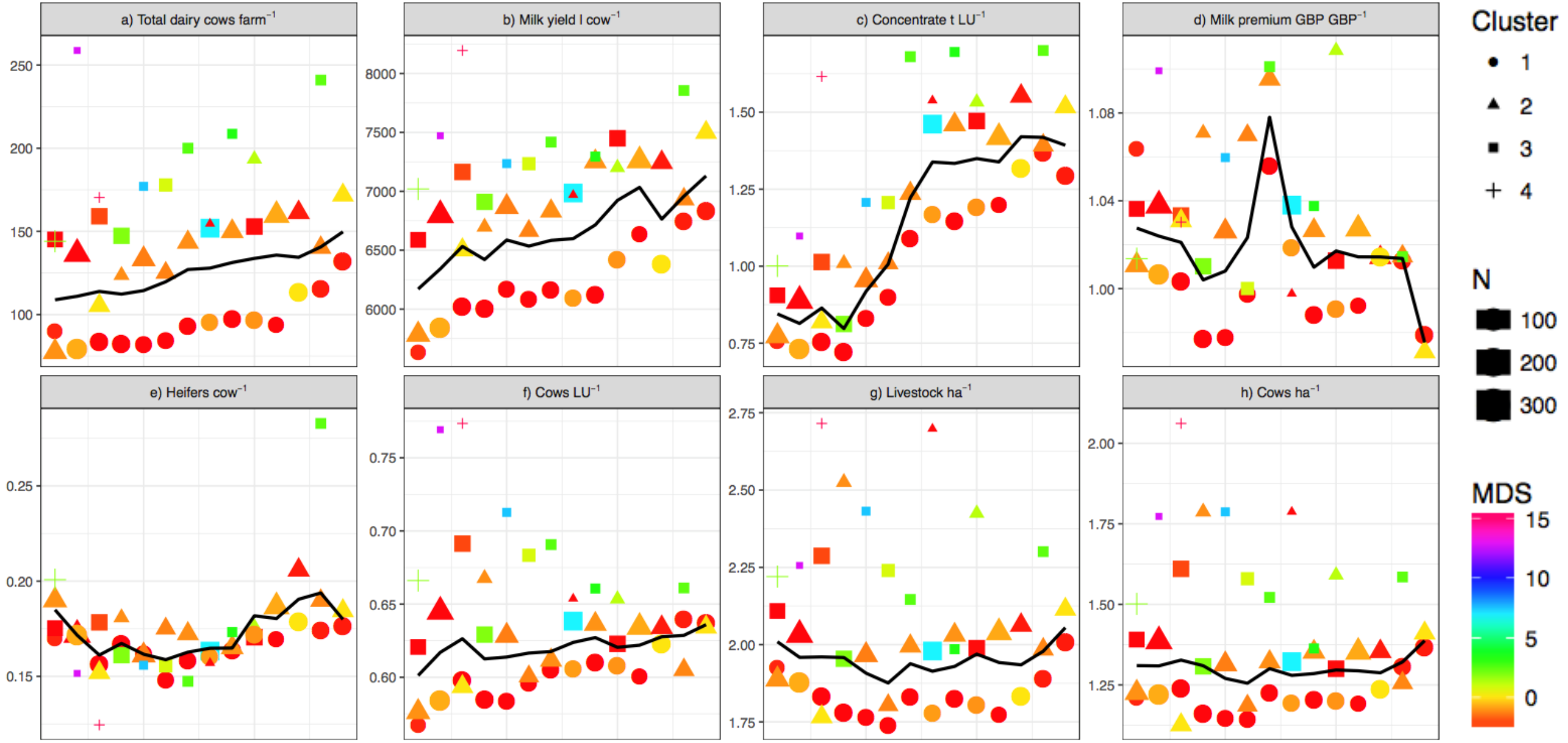




González-Mejía et al. (2018). *PLOS One*

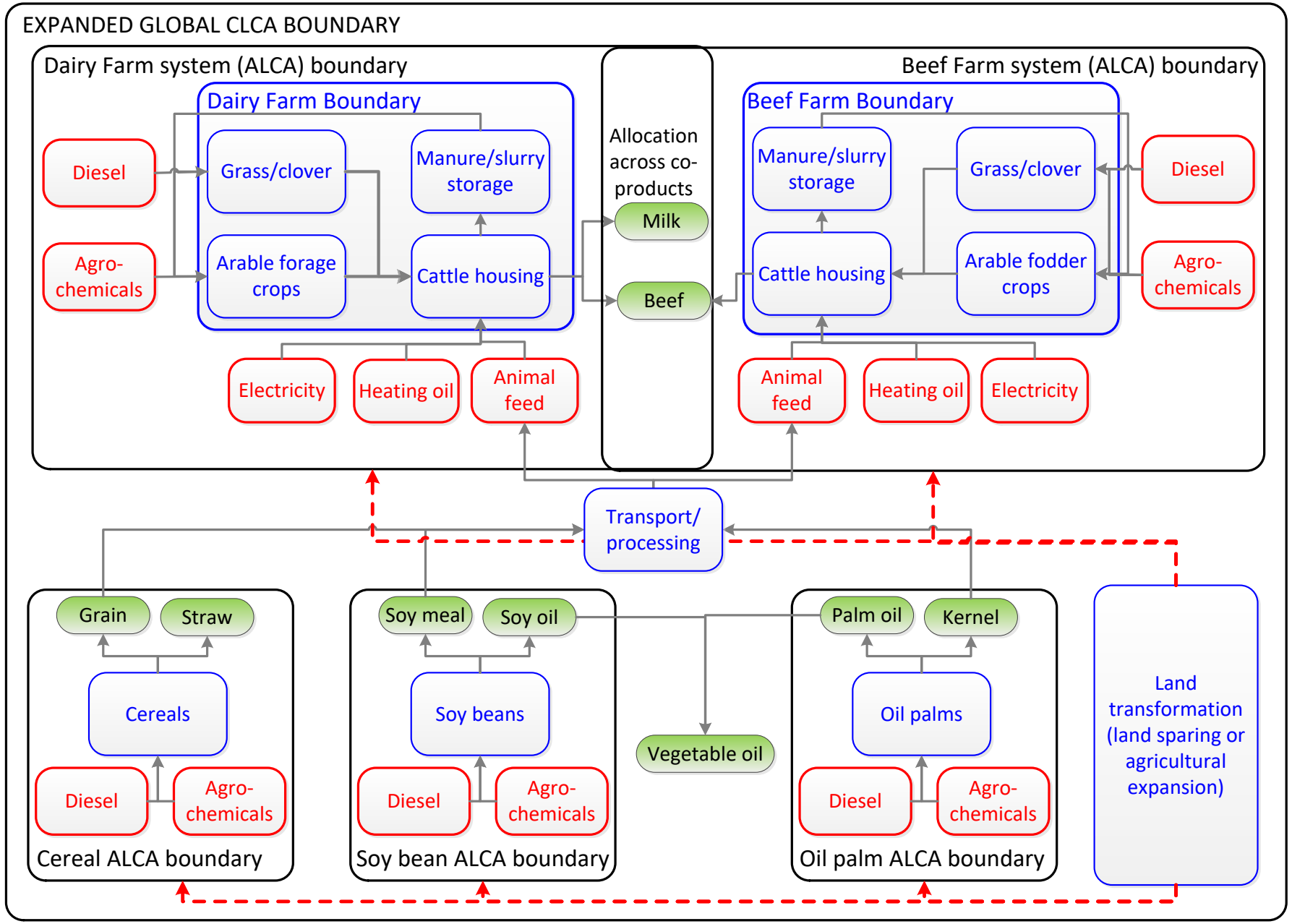
Year	Cluster configuration	Number of clusters	log likelihood	n	df	Mixing probabilities			
						1	2	3	4
2001	VVV	4	-1611	724	611	0.22	0.23	0.35	0.20
2002	VVV	3	-431	678	458	0.50	0.48	0.02	
2003	VVV	4	-862	643	611	0.38	0.30	0.30	0.02
2004	VVV	3	-182	512	428	0.48	0.37	0.16	
2005	VVV	3	-32	477	458	0.42	0.52	0.06	
2006	VVV	3	-393	464	458	0.42	0.35	0.23	
2007	VEV	3	-67	469	428	0.46	0.42	0.12	
2008	VVV	3	-337	493	458	0.55	0.42	0.03	
2009	VEV	3	-366	488	428	0.47	0.44	0.09	
2010	VEV	3	-623	479	428	0.40	0.15	0.45	
2011	VVV	2	-390	479	305	0.37	0.63		
2012	VVV	2	-454	467	305	0.44	0.56		
2013	VVV	3	-1122	455	458	0.48	0.39	0.12	
2014	VVV	2	-505	432	305	0.56	0.44		

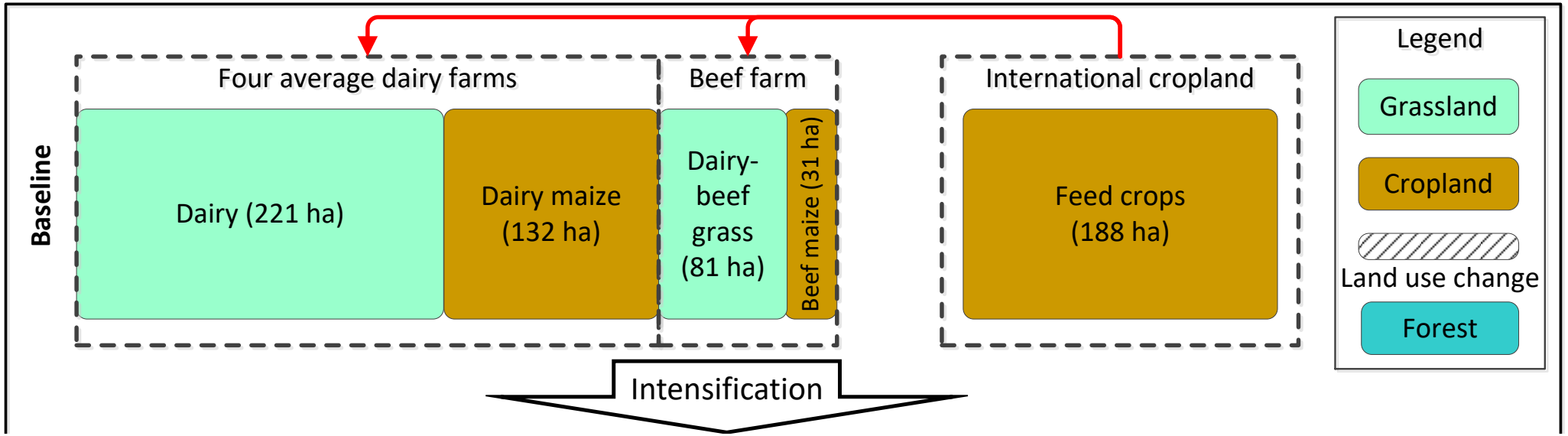

i) Fodder t LU^{-1}
j) Labour h ha^{-1}
k) Tenure ha ha^{-1}
l) Non−arable area ha ha^{-1}
m) Grass area ha ha^{-1}
n) Fodder area ha ha^{-1}
o) Maize area ha ha^{-1}
p) Production area ha ha^{-1}
2005
2010
Cluster
1
2
3
4
N
100
200
300
MDS
15
10
5
0


a) Total dairy cows farm^{-1}
b) Milk yield l cow^{-1}
c) Concentrate t LU^{-1}
d) Milk premium GBP GBP^{-1}
e) Heifers cow^{-1}
f) Cows LU^{-1}
g) Livestock ha^{-1}
h) Cows ha^{-1}
Cluster
1
2
3
4
N
100
200
300
MDS
15
10
5
0

National and global scales

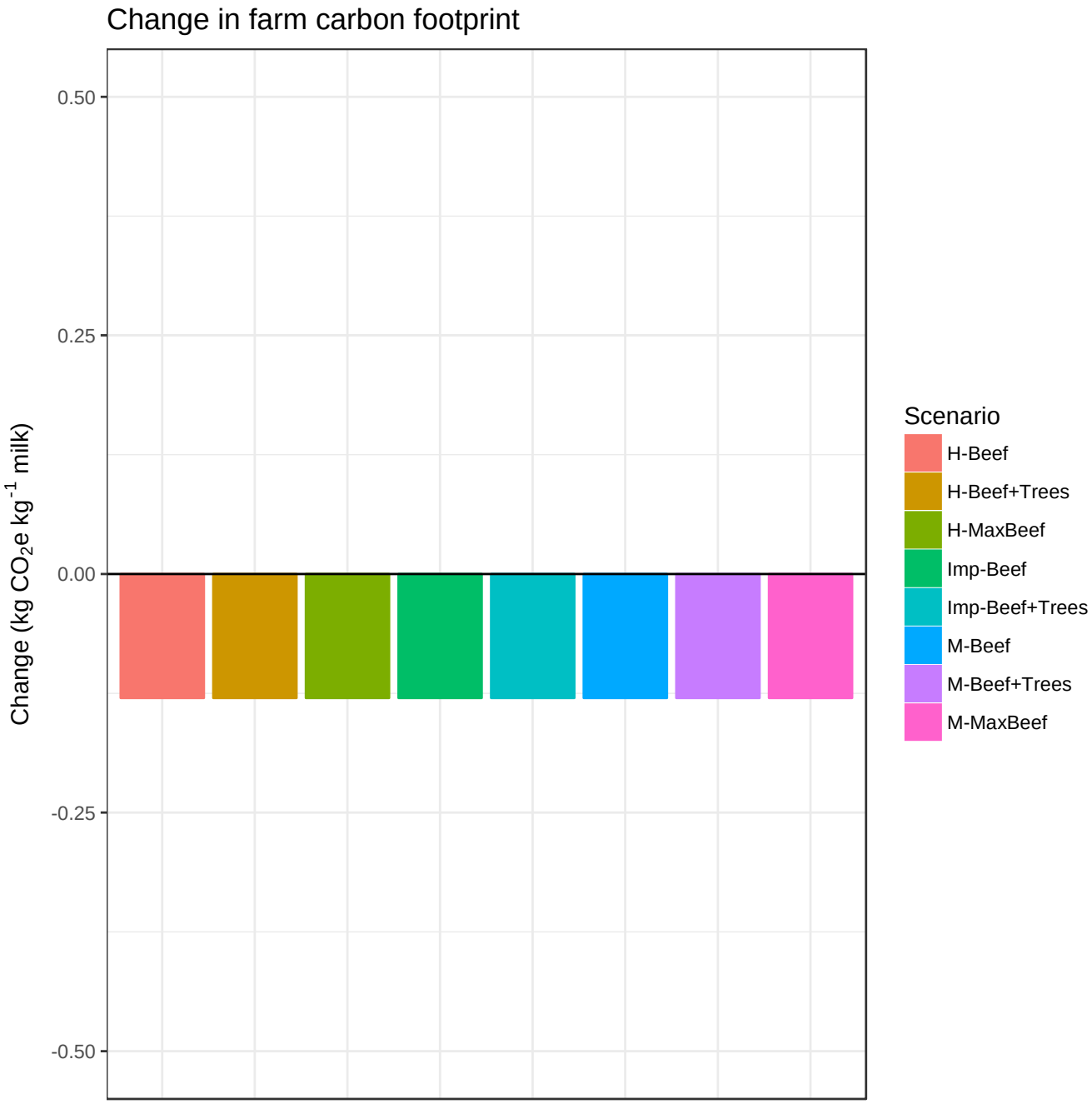
Global, inter-linked dairy & beef systems

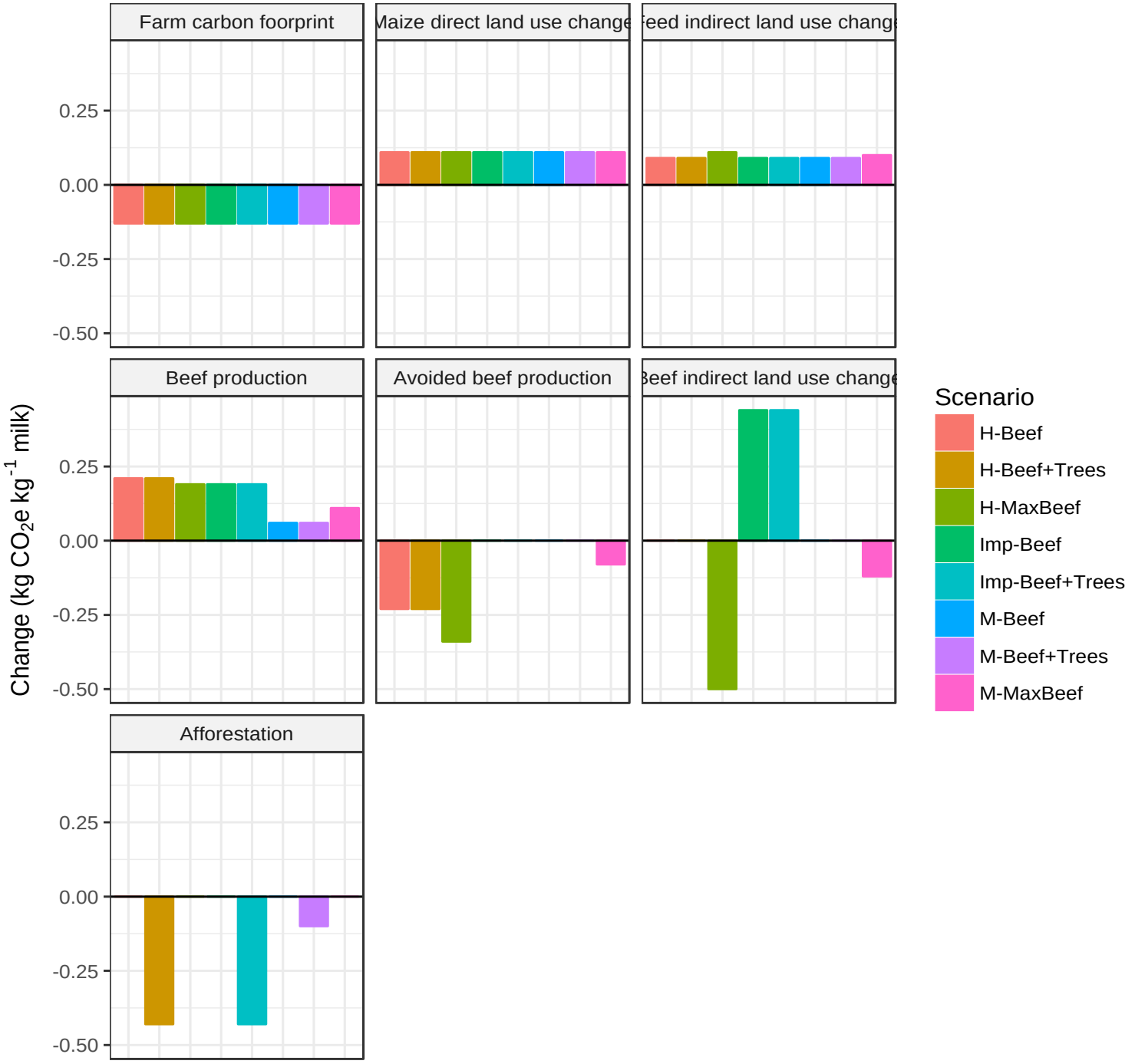


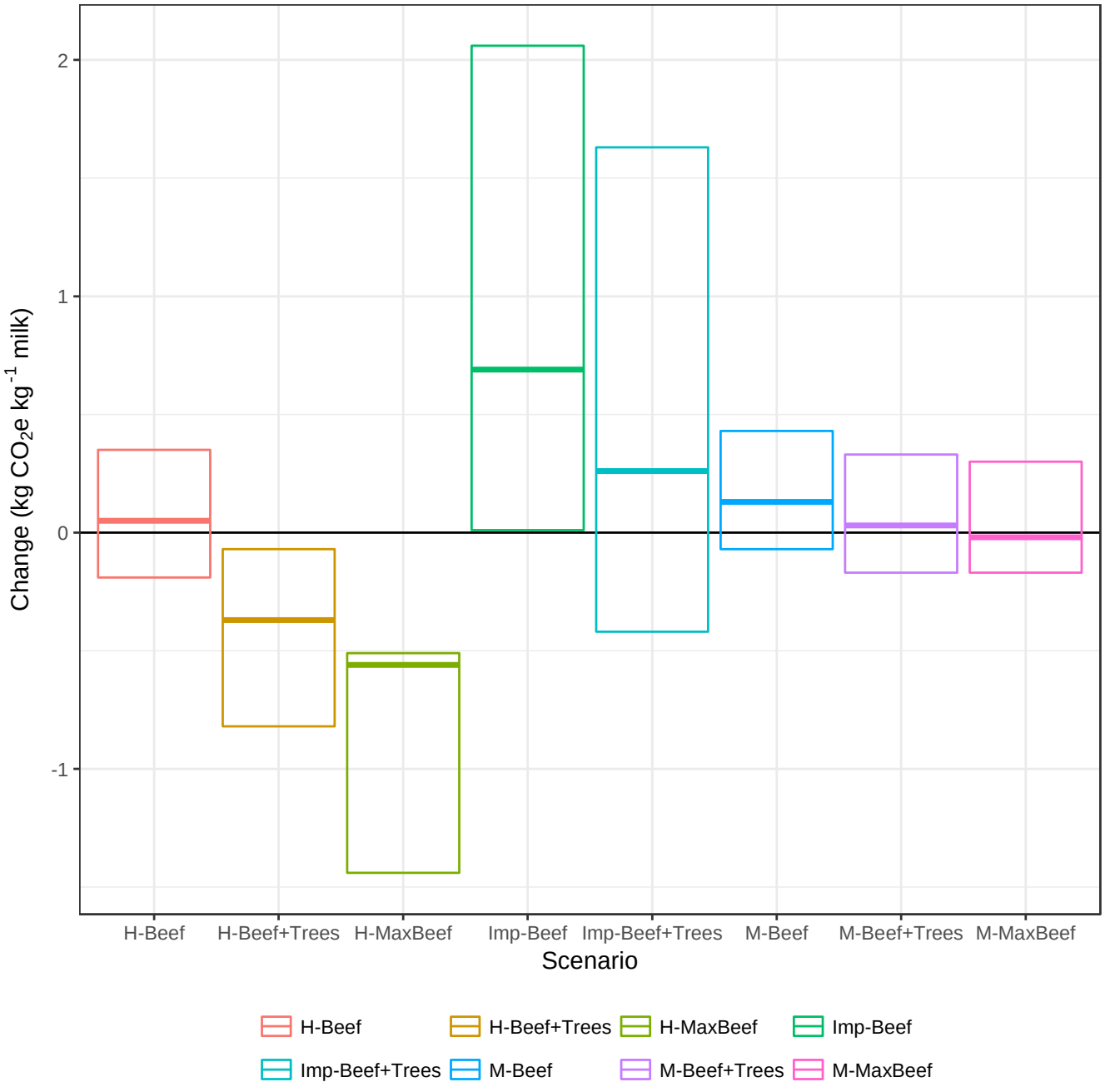


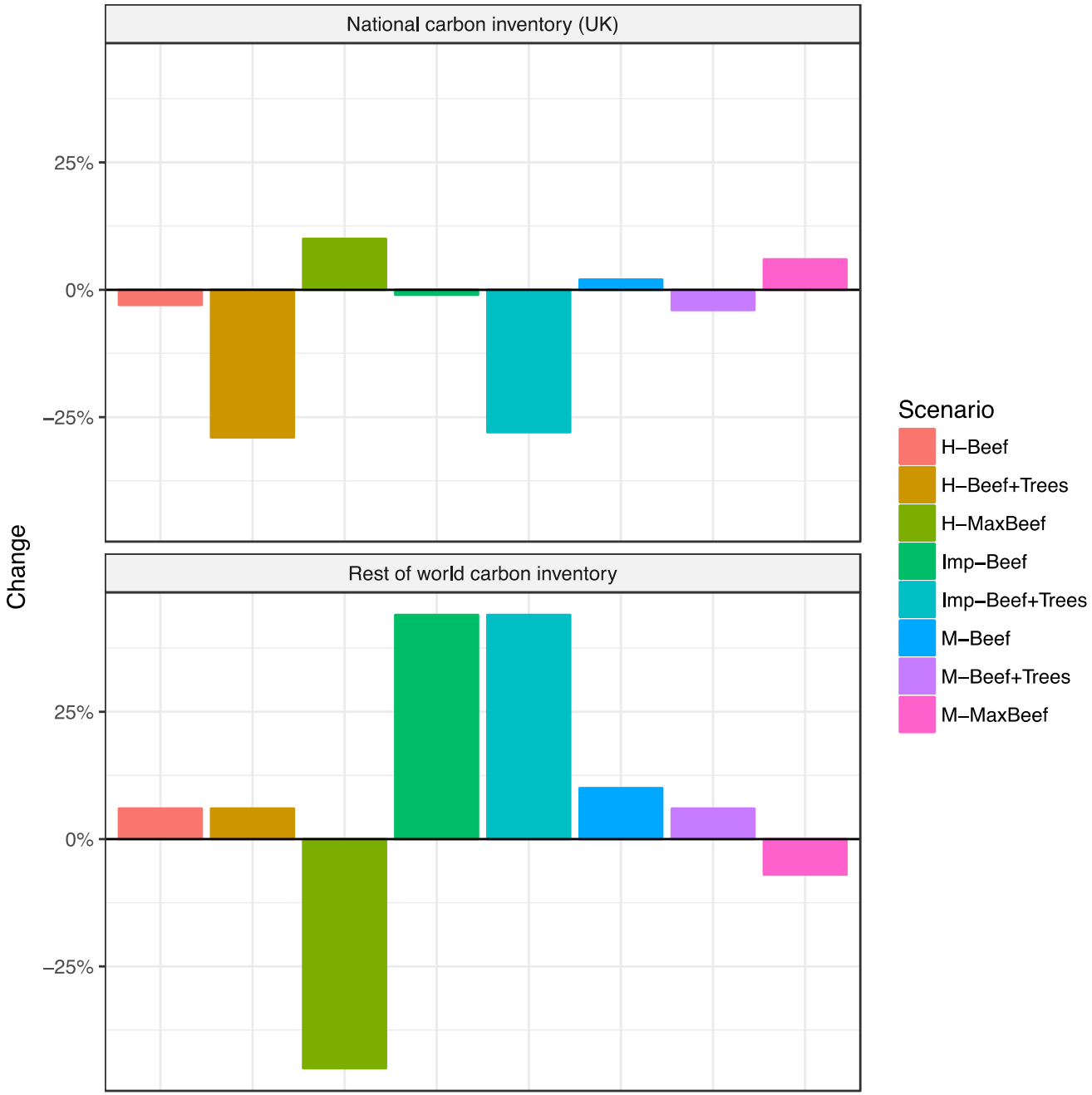
Styles et al. (2018) *Global Change Biology*

	Primary consequences	
Scenario	Dairy feed	Use of net spared ex-dairy grassland
M-Beef (medium-intensity replacement beef)	Additional maize production (grassland conversion, UK) & concentrate feed demand	Medium-intensity rearing of replacement suckler beef, with remaining area left as fallow (UK).
M-Beef+Trees (medium-intensity replacement beef plus afforestation)	Additional maize (grassland conversion, UK) & concentrate feed demand	Medium-intensity rearing of replacement suckler beef, with remaining area afforested (UK).
H-Beef (high-intensity replacement plus additional beef)	Additional maize (grassland conversion, UK) & concentrate feed demand	High-intensity rearing of as much suckler beef as possible (UK).
H-Beef+Trees (high-intensity replacement beef plus afforestation)	Additional maize (grassland conversion, UK) & concentrate feed demand	High-intensity rearing of as much suckler beef as possible (UK).
Imp-Beef (replacement beef imported)	Additional maize (grassland conversion, UK) & concentrate feed demand	Fallow (UK).
Imp-Beef+Trees (replacement beef imported, plus afforestation)**	Additional maize (grassland conversion, UK) & concentrate feed demand	Afforestation of entire spared grassland area (UK).
M-MaxBeef (Medium-intensity rearing of replacement plus additional suckler beef)	Additional maize (grassland conversion, UK) & concentrate feed demand	Medium-intensity rearing of as much suckler beef as possible over entire area (UK).
H-MaxBeef (High-intensity rearing of replacement plus additional suckler beef)	Additional maize (grassland conversion, UK) & concentrate feed demand	High-intensity rearing of as much suckler beef as possible over entire area (UK).


Change in farm carbon footprint
0.50
0.25
0.00
-0.25
-0.50
Change (kg CO2e kg-1 milk)
Scenario
H-Beef
H-Beef+Trees
H-MaxBeef
Imp-Beef
Imp-Beef+Trees
M-Beef
M-Beef+Trees
M-MaxBeef


Farm carbon foorprint
Maize direct land use change
Feed indirect land use change
Beef production
Avoided beef production
Beef indirect land use change
Afforestation
0.25
0.00
-0.25
-0.50
Change (kg CO2e kg-1 milk)
Scenario
H-Beef
H-Beef+Trees
H-MaxBeef
Imp-Beef
Imp-Beef+Trees
M-Beef
M-Beef+Trees
M-MaxBeef


2
1
0
-1
Change (kg CO_2e kg^{-1} milk)
H-Beef
H-Beef+Trees
H-MaxBeef
Imp-Beef
Imp-Beef+Trees
M-Beef
M-Beef+Trees
M-MaxBeef
Scenario
H-Beef
H-Beef+Trees
H-MaxBeef
Imp-Beef
Imp-Beef+Trees
M-Beef
M-Beef+Trees
M-MaxBeef


National carbon inventory (UK)
Rest of world carbon inventory
Change
25%
0%
−25%
Scenario
H−Beef
H−Beef+Trees
H−MaxBeef
Imp−Beef
Imp−Beef+Trees
M−Beef
M−Beef+Trees
M−MaxBeef

Conclusions

- Need to consider
  - Modelling scale/system boundaries
  - Farm diversity
  - Measures of sustainability
- Simple substitution can be modelled with single farm
- Management changes that substantially alter production or diet can only be accurately modelled with wide system boundaries.
- Many different measures of sustainability
- Ideally all integrated together but this is hard
- Good quality animal science required!