Using Life Cycle Invent systems modelling to determine the limits to sustainable livestock production

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The problem

- UK commitment to reduce NH3 and GHG emissions from agriculture.
  - Majority of it due to livestock
  - Ruminants = methane.
  - Non-ruminants = ammonia
- What configuration of livestock best meets the UK's commitments?
  - Hill sheep? Or lowland sheep?
  - Outdoor pigs? Or indoor?
  - Higher yielding dairy cows?
  - Extensive grass fed beef? Intensive?

LCA results

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			Burdens			Emissions			
Commodity	Unit		Primary Energy Used GJ	GWP 100 $kgCO_2$	Land use ha	NO_3-N to water, kg	NH_3-N to air kg	N_2O-N to air kg	CH_4 to air kg
Pig meat	1,000	kg dwt	22.8	4910	0.7	33	32	2.2	57
Beef	1,000	kg dwt	26.7	14704	3.4	150	71	11.6	264
Milk	10,000	litres	25.6	9875	1.0	55	35	5.8	195
Eggs	20,000	50g eggs	14.0	3799	0.6	26	28	3.6	7
Bread Wheat	1	t	2.4	549	0.1	4	1	0.8	0
Field Beans	1	t	2.4	469	0.3	8	1	0.7	0
Oilseed Rape	1	t	4.8	1083	0.3	12	3	1.6	1

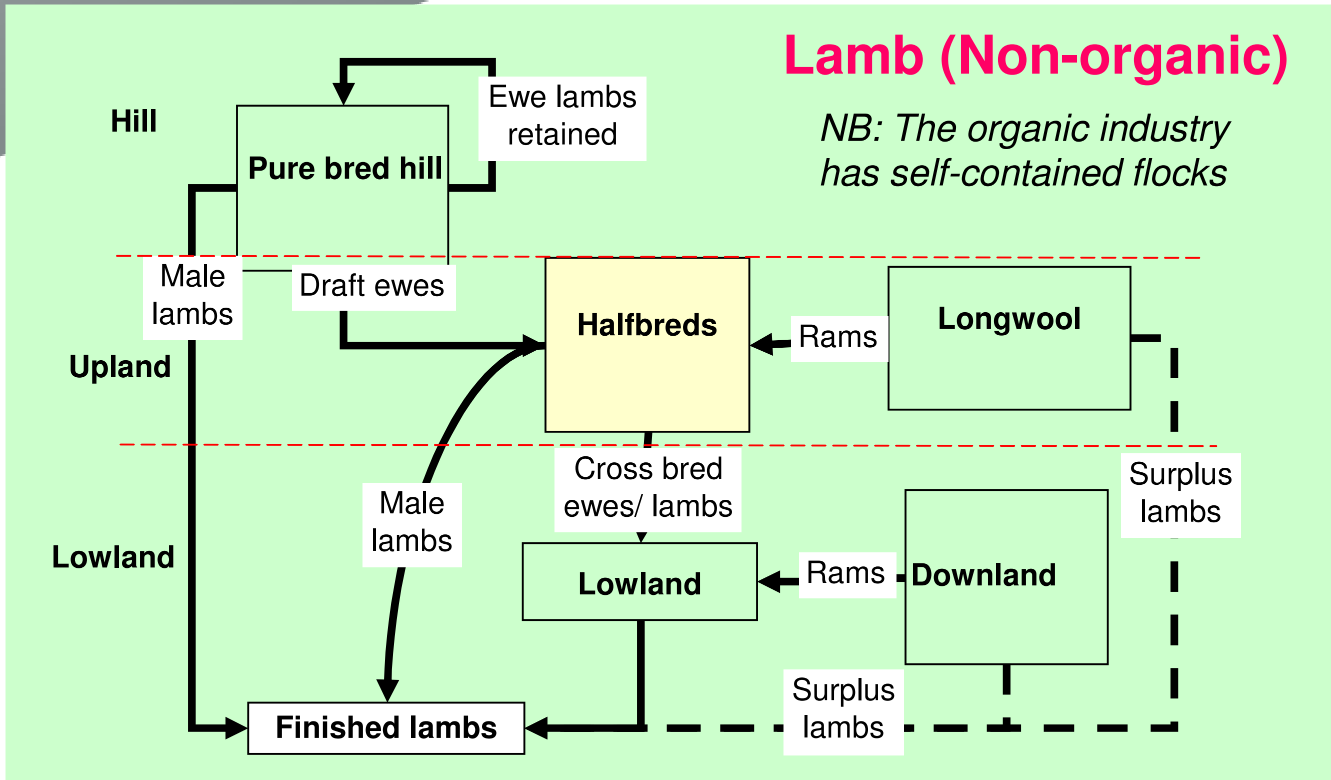
Linear regression against factors: Pig meat

Emissions per tonne pig meat

Proportion of	Land use	NH3	N2O	CO2	CH4	GWP100
Intercept	0.691	34.0	2.8	2575.0	44.6	4994
Outdoor Breeding	-0.002	-4.5	0.1	-163.5	-4.6	-209
FYM Breeding	0.002	3.4	0.1	13.7	3.4	152
Outdoor Weaning	0.001	-2.3	0.1	-90.7	-4.3	-154
FYM Weaning	0.001	1.7	0.1	6.4	-3.7	-56
Finish Light	-0.018	0.2	0.0	18.9	1.1	25
Finish Medium	-0.016	0.3	0.0	-10.5	0.6	-15
FYM Finishing	0.006	9.0	0.6	44.4	-9.5	98
Organic	0.539	-16.8	1.0	-279.6	-12.4	-115

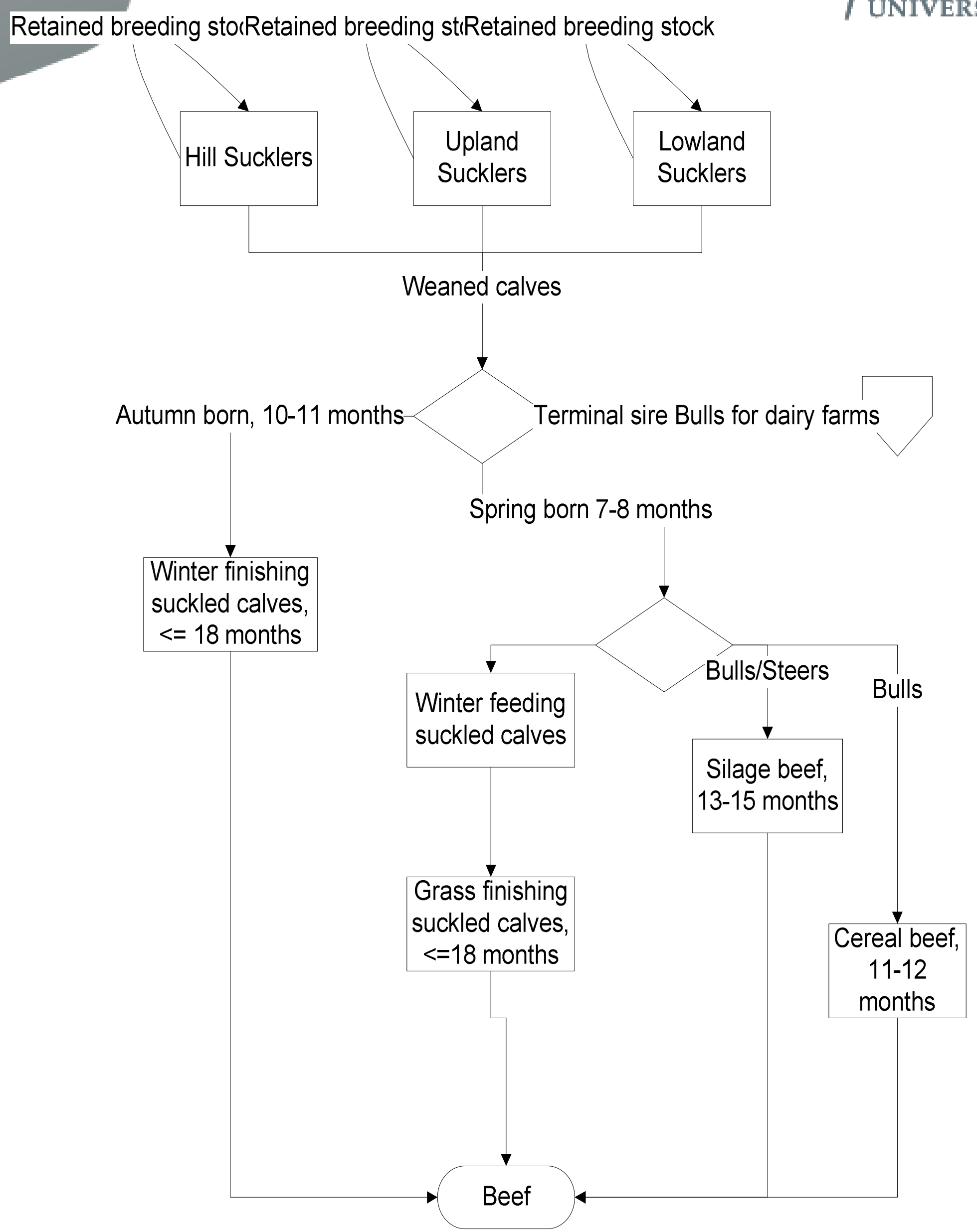
If the proportion of outdoor breeding is 0.5, then the ammonia is reduced by 0.5*4.5=2.25.

Industry Structure Model (simplified)



The most complicated structure is sheep, but all systems have the same concept of producing breeding stock which produce the final animals.

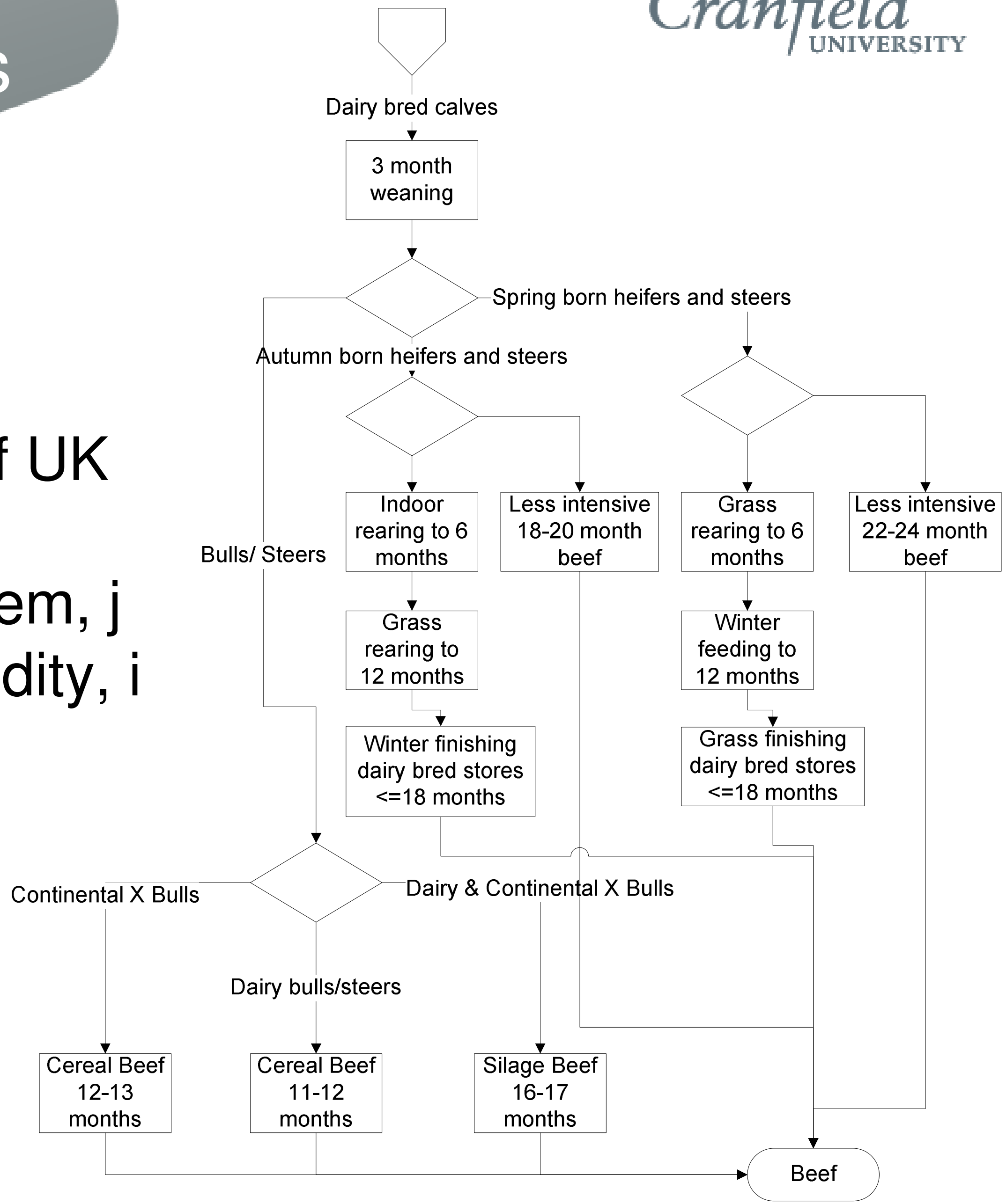
Beef suckler cows



Dairy bred beef calves

Our model-based LCA of UK agriculture analyses the impact of every sub-system, j of each livestock commodity, i

Thus we know
GHG emissions – g_{ij}
NH3 emissions - a_{ij}



Mathematically

The problem is thus: Find the amount x_{ij} of livestock i, sub-system j, such that:

Maximise value of production:

$$z = \sum v_{ij} x_{ij}$$

such that

GHG limit: $\sum g_{ij} x_{ij} \leq G$

NH3 limit: $\sum a_{ij} x_{ij} \leq A$

Plus any other constraints

$$\sum B_{ij} x_{ij} \leq \geq Y$$

Which is a standard linear programme

Other constraints

- Food
  - Limit on the amount of chicken people can eat!
- Land
  - Only so much “Hill” land available
- Structure
  - Beef calves from the dairy herd
- System
  - Need to replace breeding females
- Production
  - Need to produce food all year round

Improvement analysis

- The model-based LCI also calculates the impacts after improvements
    - Food Conversion Ratio
    - Higher yielding dairy cows
    - Greater dairy cow longevity
    - Higher fecundity (more piglets per sow)
    - More clover based grassland
    - Covering slurry stores
    - Reducing methane from ruminants
- (changes the coefficients g_{ij}, a_{ij} of the LP)

Seasonality of lamb

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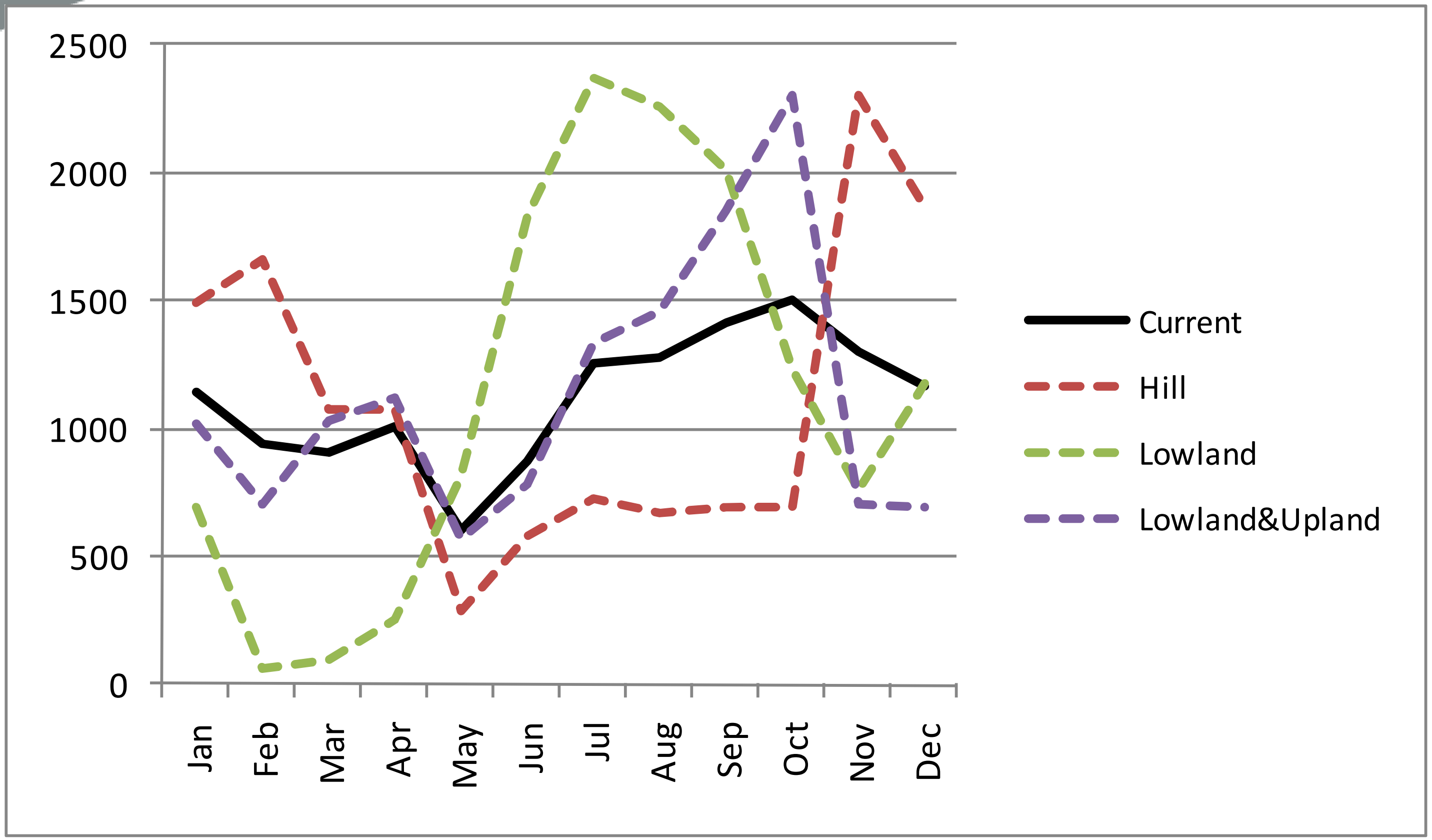

The matrix!

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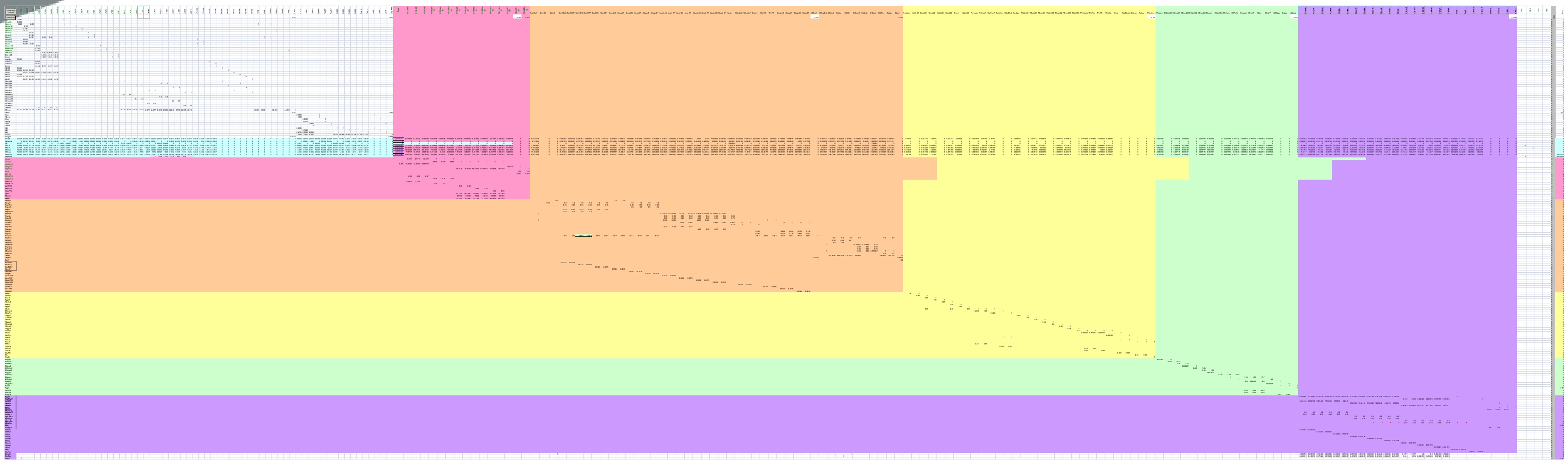

So we will look at it in bits

The concept – current livestock structure

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	Pig	Poultry	Beef	Sheep	Dairy	Layers	CO_2	CH_4	N_2O		RHS
OBJ	1.55	0.90	2.27	2.38	2.53	0.83	0	0	0		
CO2k	2.55	1.83	3.21	3.13	2.50	1.98	-1	0	0	=	0
CH4k	0.06	0.00	0.33	0.35	0.21	0.01	0	-1	0	=	0
N2O	2.88	3.30	12.59	14.25	6.22	3.56	0	0	-1	=	0
sumGHG	0.00	0.00	0.00	0.00	0.00	0.00	1	23	0.296	<	22.15
NH3	36.72	17.69	70.44	27.77	40.52	29.37	0	0	0	<	109.48
Pig_prod	1	0	0	0	0	0	0	0	0	>	0.45
Poul_prod	0	1	0	0	0	0	0	0	0	>	1.03
Beef_prod	0	0	1	0	0	0	0	0	0	<	0.44
Shp_prod	0	0	0	1	0	0	0	0	0	<	0.22
Dairy_prod	0	0	0	0	1	0	0	0	0	>	0.89
Eggs_prod	0	0	0	0	0	1	0	0	0	>	0.30
LU_G1max	0.00	0.00	0.00	0.00	0.03	0.00	0	0	0	<	0.07
LU_G2max	0.00	0.00	0.05	0.08	0.21	0.00	0	0	0	<	0.68
LU_G3max	0.00	0.00	0.09	0.26	0.40	0.00	0	0	0	<	2.98
LU_G3amax	0.00	0.00	0.82	1.44	0.00	0.00	0	0	0	<	2.71
LU_G4max	0.00	0.00	0.66	1.16	0.00	0.00	0	0	0	<	2.36
LU_G5max	0.00	0.00	1.41	2.87	0.00	0.00	0	0	0	<	1.26
Grassland	0.00	0.00	3.03	5.82	0.65	0.00	0	0	0	>	0.65
Total_land	0.69	0.62	3.58	6.08	1.03	0.57	0	0	0	<	10.06
LU_G1<100	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	>	0.00
LU_G2<100	0.00	0.00	0.05	0.08	0.00	0.00	0	0	0	>	0.01
LU_G3<100	0.00	0.00	0.09	0.26	0.00	0.00	0	0	0	>	0.03
Beefdairytie	0.00	0.00	2.02	0.00	-0.80	0.00	0	0	0	=	0.00

The concept – current livestock structure - emissions

	Pig	Poultry	Beef	Sheep	Dairy	Layers
OBJ	1.55	0.90	2.27	2.38	2.53	0.83
CO2k	**2.55**	**1.83**	**3.21**	**3.13**	**2.50**	**1.98**
CH4k	**0.06**	**0.00**	**0.33**	**0.35**	**0.21**	**0.01**
N2O	**2.88**	**3.30**	**12.59**	**14.25**	**6.22**	**3.56**
sumGHG	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
NH3	**36.72**	**17.69**	**70.44**	**27.77**	**40.52**	**29.37**
Pig_prod	1	0	0	0	0	0
Poul_prod	0	1	0	0	0	0

Objective

- Total energy (tends to favour fatty production)
- Total protein (ignores non-protein in eggs and milk)
- Total economic value
  - Tends to combine all the above and added value of vitamins and minerals
  - BUT also includes social factors such as food-scare effects (eggs!!)

- We actually used all three – in many cases the solution turns out to be the same

The concept – current livestock structure

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	Pig	Poultry	Beef	Sheep	Dairy	Layers	CO_2	CH_4	N_2O		RHS
OBJ	1.55	0.90	2.27	2.38	2.53	0.83	0	0	0		
CO2k	2.55	1.83	3.21	3.13	2.50	1.98	-1	0	0	=	0
CH4k	0.06	0.00	0.33	0.35	0.21	0.01	0	-1	0	=	0
N2O	2.88	3.30	12.59	14.25	6.22	3.56	0	0	-1	=	0
sumGHG	0.00	0.00	0.00	0.00	0.00	0.00	1	23	0.296	<	22.15
NH3	36.72	17.69	70.44	27.77	40.52	29.37	0	0	0	<	109.48
Pig_prod	1	0	0	0	0	0	0	0	0	>	0.45
Poul_prod	0	1	0	0	0	0	0	0	0	>	1.03
Beef_prod	0	0	1	0	0	0	0	0	0	<	0.44
Shp_prod	0	0	0	1	0	0	0	0	0	<	0.22
Dairy_prod	0	0	0	0	1	0	0	0	0	>	0.89
Eggs_prod	0	0	0	0	0	1	0	0	0	>	0.30
LU_G1max	0.00	0.00	0.00	0.00	0.03	0.00	0	0	0	<	0.07
LU_G2max	0.00	0.00	0.05	0.08	0.21	0.00	0	0	0	<	0.68
LU_G3max	0.00	0.00	0.09	0.26	0.40	0.00	0	0	0	<	2.98
LU_G3amax	0.00	0.00	0.82	1.44	0.00	0.00	0	0	0	<	2.71
LU_G4max	0.00	0.00	0.66	1.16	0.00	0.00	0	0	0	<	2.36
LU_G5max	0.00	0.00	1.41	2.87	0.00	0.00	0	0	0	<	1.26
Grassland	0.00	0.00	3.03	5.82	0.65	0.00	0	0	0	>	0.65
Total_land	0.69	0.62	3.58	6.08	1.03	0.57	0	0	0	<	10.06
LU_G1<100	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	>	0.00
LU_G2<100	0.00	0.00	0.05	0.08	0.00	0.00	0	0	0	>	0.01
LU_G3<100	0.00	0.00	0.09	0.26	0.00	0.00	0	0	0	>	0.03
Beefdairytie	0.00	0.00	2.02	0.00	-0.80	0.00	0	0	0	=	0.00

The concept – current livestock structure- constraints

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	CO_2	CH_4	N_2O		RHS
OBJ	0	0	0		
CO2k	-1	0	0	=	0
CH4k	0	-1	0	=	0
N2O	0	0	-1	=	0
sumGHG	1	23	0.296	<	**22.15**
NH3	0	0	0	<	**109.48**
Pig_prod	0	0	0	>	**0.45**
Poul_prod	0	0	0	>	**1.03**
Beef_prod	0	0	0	<	**0.44**
Shp_prod	0	0	0	<	**0.22**
Dairy_prod	0	0	0	>	**0.89**
Eggs_prod	0	0	0	>	**0.30**
LU_G1max	0	0	0	<	0.07

The concept – current livestock structure

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	Pig	Poultry	Beef	Sheep	Dairy	Layers	CO_2	CH_4	N_2O		RHS
OBJ	1.55	0.90	2.27	2.38	2.53	0.83	0	0	0		
CO2k	2.55	1.83	3.21	3.13	2.50	1.98	-1	0	0	=	0
CH4k	0.06	0.00	0.33	0.35	0.21	0.01	0	-1	0	=	0
N2O	2.88	3.30	12.59	14.25	6.22	3.56	0	0	-1	=	0
sumGHG	0.00	0.00	0.00	0.00	0.00	0.00	1	23	0.296	<	22.15
NH3	36.72	17.69	70.44	27.77	40.52	29.37	0	0	0	<	109.48
Pig_prod	1	0	0	0	0	0	0	0	0	>	0.45
Poul_prod	0	1	0	0	0	0	0	0	0	>	1.03
Beef_prod	0	0	1	0	0	0	0	0	0	<	0.44
Shp_prod	0	0	0	1	0	0	0	0	0	<	0.22
Dairy_prod	0	0	0	0	1	0	0	0	0	>	0.89
Eggs_prod	0	0	0	0	0	1	0	0	0	>	0.30
LU_G1max	0.00	0.00	0.00	0.00	0.03	0.00	0	0	0	<	0.07
LU_G2max	0.00	0.00	0.05	0.08	0.21	0.00	0	0	0	<	0.68
LU_G3max	0.00	0.00	0.09	0.26	0.40	0.00	0	0	0	<	2.98
LU_G3amax	0.00	0.00	0.82	1.44	0.00	0.00	0	0	0	<	2.71
LU_G4max	0.00	0.00	0.66	1.16	0.00	0.00	0	0	0	<	2.36
LU_G5max	0.00	0.00	1.41	2.87	0.00	0.00	0	0	0	<	1.26
Grassland	0.00	0.00	3.03	5.82	0.65	0.00	0	0	0	>	0.65
Total_land	0.69	0.62	3.58	6.08	1.03	0.57	0	0	0	<	10.06
LU_G1<100	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	>	0.00
LU_G2<100	0.00	0.00	0.05	0.08	0.00	0.00	0	0	0	>	0.01
LU_G3<100	0.00	0.00	0.09	0.26	0.00	0.00	0	0	0	>	0.03
Beefdairytie	0.00	0.00	2.02	0.00	-0.80	0.00	0	0	0	=	0.00

The concept – current livestock structure-internal

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	Pig	Poultry	Beef	Sheep	Dairy	Layers		RHS
OBJ	**1.55**	**0.90**	**2.27**	**2.38**	**2.53**	**0.83**		
LU_G5max	0.00	0.00	1.41	2.87	0.00	0.00	<	1.26
Grassland	**0.00**	**0.00**	**3.03**	**5.82**	**0.65**	**0.00**	>	**0.65**
Total_land	**0.69**	**0.62**	**3.58**	**6.08**	**1.03**	**0.57**	<	**10.06**
G1<100	0.00	0.00	0.00	0.00	0.00	0.00	>	0.00
G2<100	0.00	0.00	0.05	0.08	0.00	0.00	>	0.01
G3<100	0.00	0.00	0.09	0.26	0.00	0.00	>	0.03
Beefdairytie	**0.00**	**0.00**	**2.02**	**0.00**	**-0.80**	**0.00**	=	0.00

Some Results

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80% emissions: value (no structural change)

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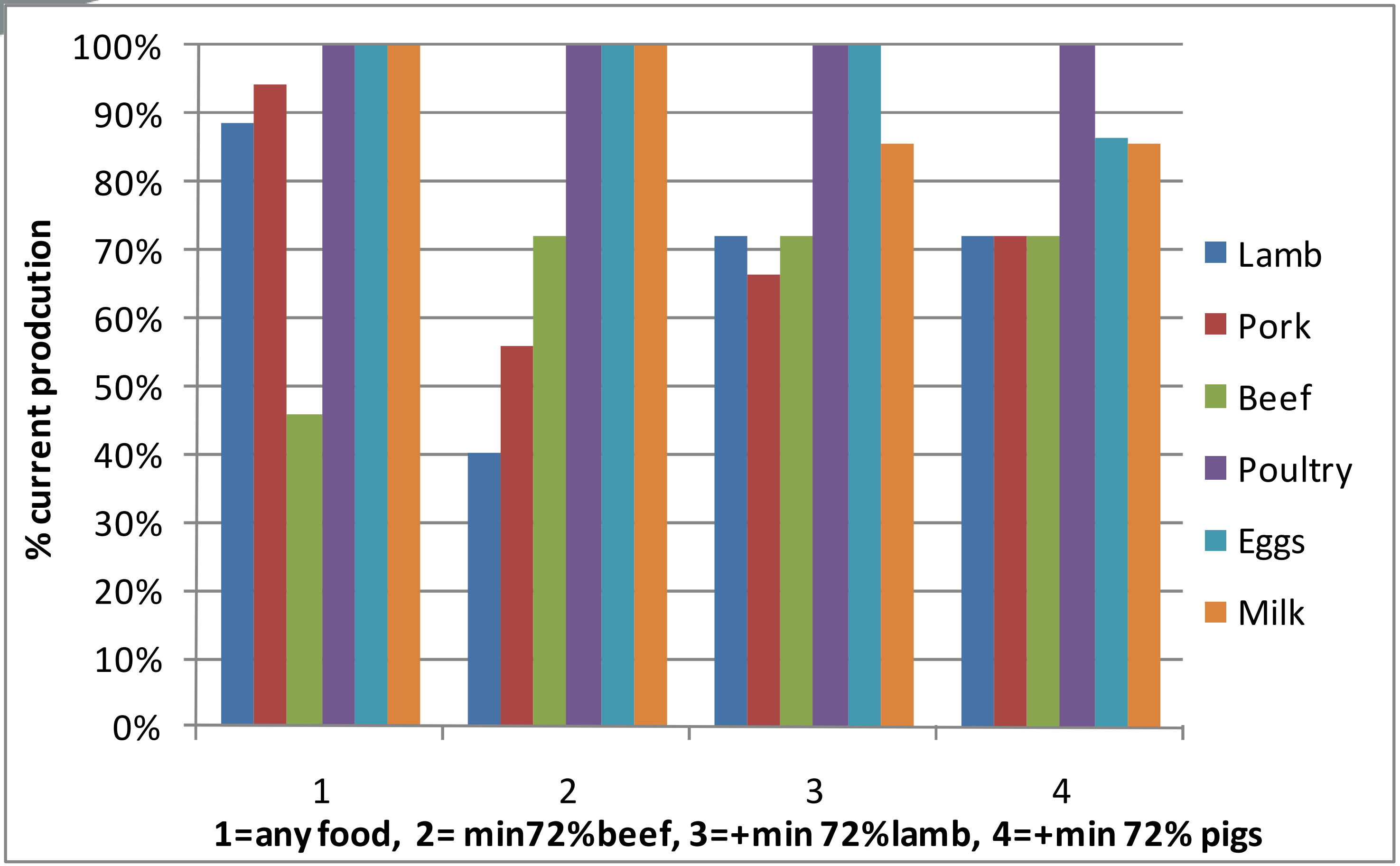
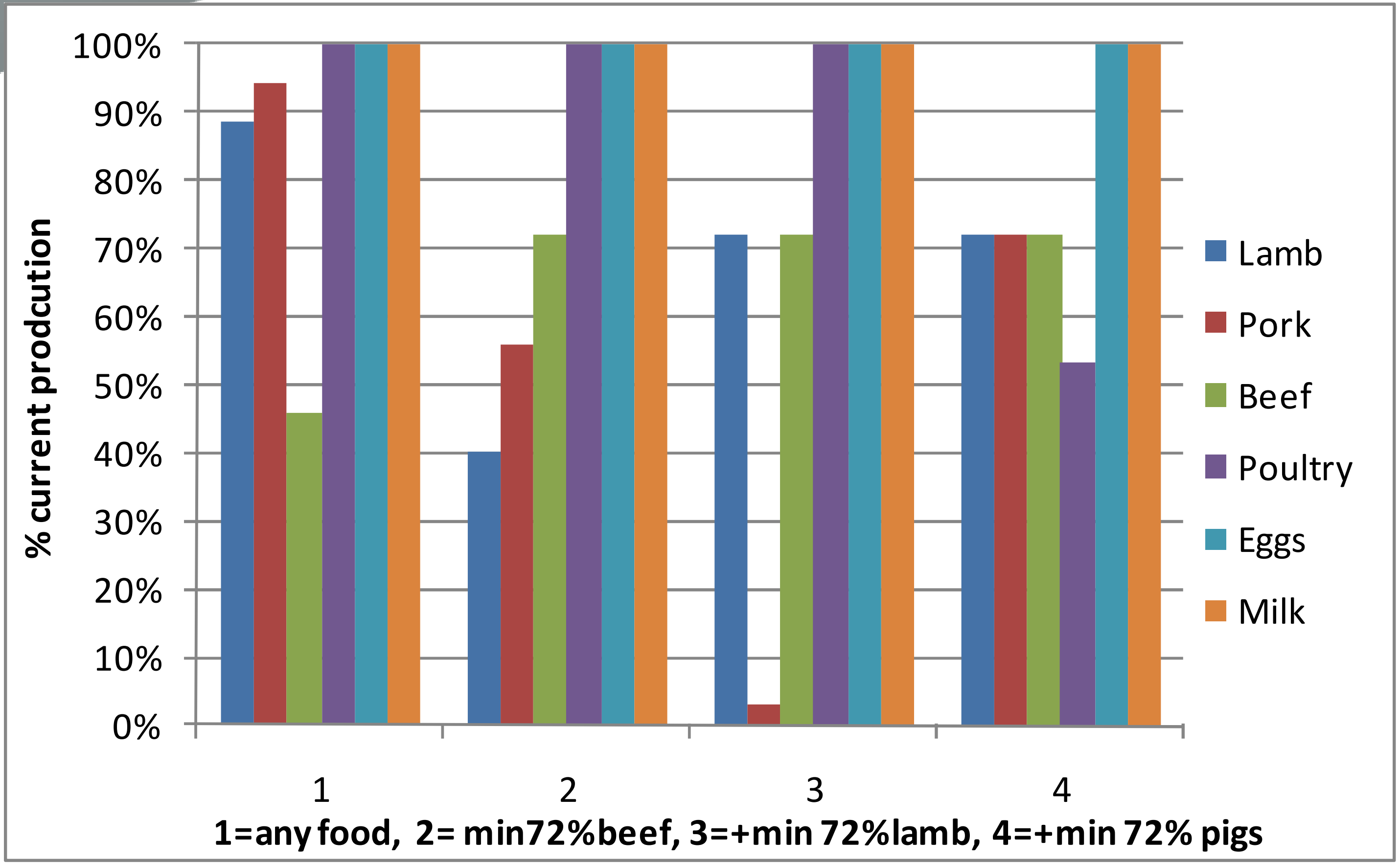
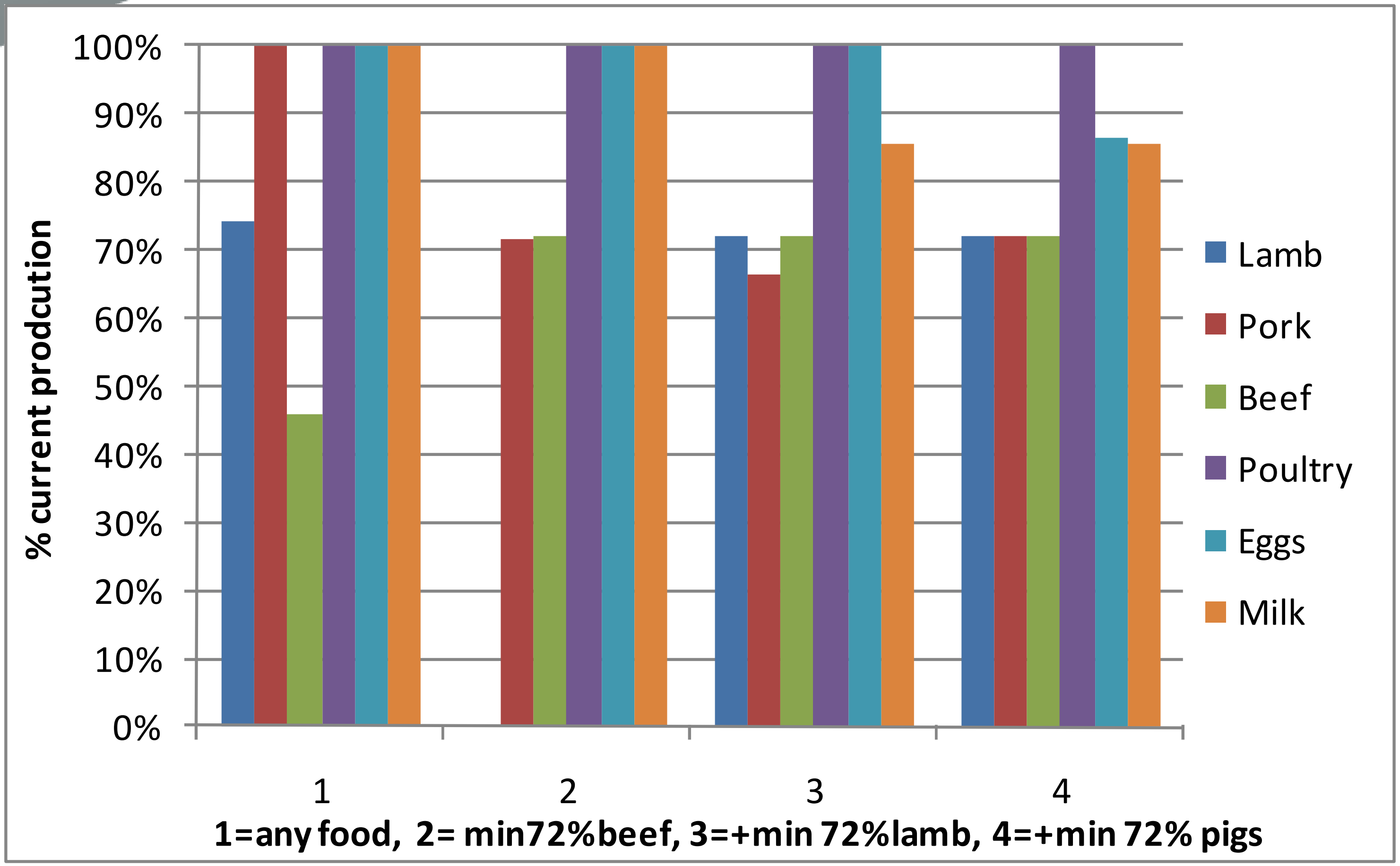


80% emissions: energy



80% emissions: protein



Structural change

- Consider effect of changes within the commodity:
- Use pigs as an example as smallest
  - Sows, weaners, finishers
  - Indoor or outdoor
  - Manure or slurry
  - Light, medium or heavy finishing
  - Organic
- =13 options

	Rear	InUnitS	InUnitF	OutUnit	InWeanS	InWeanF	OutWean	FinLighS	FinLighF	FinMedS	FinMedF	FinHeavS	FinHeavF	Org	MeatOrg	Pigmeat	NH_3	N_2O	CH_4	CO_2		
Max																1.55						
piglets		21.1	21.1	22.0	-1	-1	-1														>	0
weaner	-1				0.95	0.95	0.97	-1	-1	-1	-1	-1	-1								>	0
Replacem	0.94	-0.4	-0.4	-0.4																	>	0
Organic														999	-1						>	0
Pigmeat								59.9	59.9	69.2	69.2	78.1	78.1		1	-1					>	0
pigtie																1					<	446
Land	0.04	0.16	0.16	0.16	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	1.27							>	0
NH_3-N	3.03	7.49	12.1	4.05	0.19	0.30	0.11	1.45	1.98	1.76	2.41	2.05	2.79	26.4			-1				=	0
N_2O-N	0.18	0.68	0.83	1.01	0.03	0.03	0.04	0.10	0.14	0.13	0.17	0.15	0.21	4.42				-1			=	0
CO_2	131	783	802	596	25	26	21	90	92	111	115	135	138	2401						-1	=	0
CH_4	1.9	8.6	13.3	5.2	0.4	0.2	0.0	1.8	1.3	2.2	1.6	2.6	1.8	26.8					-1		=	0
GWP_{100}	273	1331	1544	1205	49	46	39	184	194	228	240	274	288	5057							<	2321
Ammonia																	1				<	18.5
IndoorB		-0.33	-0.33	0.7																	=	0
IndoorW					-0.3	-0.3	0.75														=	0
Orgprop															1	-.01					E	0
SowFYM		-0.58	0.42																		E	0
WeanFYM					-0.5	0.5															E	0
LighFYM								-0.7	0.35												E	0
MedFYM										-0.7	0.35										E	0
HeavFYM												-0.7	0.35								E	0
Light								-40.	-40.	22.8	22.8	25.8	25.8								E	0
Medium								30.0	30.0	-35	-35	39.0	39.0								E	0
Heavy								10.2	10.2	11.8	11.8	-65	-65								E	0

Max	Rear	InUnitS	InUnitF	OutUnit	InWeanS	InWeanF	OutWean	FinLighS	FinLighF	FinMedS	FinMedF	FinHeavS	FinHeavF
piglets		21.1	21.1	22.0	-1	-1	-1						
weaner	-1				0.95	0.95	0.97	-1	-1	-1	-1	-1	-1
Replacem	0.94	-0.4	-0.4	-0.4									
Organic													
Pigmeat								59.9	59.9	69.2	69.2	78.1	78.1
pigtie													
Land	0.04	0.16	0.16	0.16	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04

	Rear	InUnitS	InUnitF	OutUnit	InWeanS	InWeanF	OutWean	FinLighS	FinLighF	FinMedS	FinMedF	FinHeavS	FinHeavF	Org	MeatOrg	Pigmeat	NH_3	N_2O	CH_4	CO_2		
Max																1.55						
piglets		21.1	21.1	22.0	-1	-1	-1														>	0
weaner	-1				0.95	0.95	0.97	-1	-1	-1	-1	-1	-1								>	0
Replacem	0.94	-0.4	-0.4	-0.4																	>	0
Organic														999	-1						>	0
Pigmeat								59.9	59.9	69.2	69.2	78.1	78.1		1	-1					>	0
pigtie																1					<	446
Land	0.04	0.16	0.16	0.16	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	1.27							>	0
NH_3-N	3.03	7.49	12.1	4.05	0.19	0.30	0.11	1.45	1.98	1.76	2.41	2.05	2.79	26.4			-1				=	0
N_2O-N	0.18	0.68	0.83	1.01	0.03	0.03	0.04	0.10	0.14	0.13	0.17	0.15	0.21	4.42				-1			=	0
CO_2	131	783	802	596	25	26	21	90	92	111	115	135	138	2401						-1	=	0
CH_4	1.9	8.6	13.3	5.2	0.4	0.2	0.0	1.8	1.3	2.2	1.6	2.6	1.8	26.8					-1		=	0
GWP_{100}	273	1331	1544	1205	49	46	39	184	194	228	240	274	288	5057							<	2321
Ammonia																	1				<	18.5
IndoorB		-0.33	-0.33	0.7																	=	0
IndoorW					-0.3	-0.3	0.75														=	0
Orgprop															1	-.01					E	0
SowFYM		-0.58	0.42																		E	0
WeanFYM					-0.5	0.5															E	0
LighFYM								-0.7	0.35												E	0
MedFYM										-0.7	0.35										E	0
HeavFYM												-0.7	0.35								E	0
Light								-40.	-40.	22.8	22.8	25.8	25.8								E	0
Medium								30.0	30.0	-35	-35	39.0	39.0								E	0
Heavy								10.2	10.2	11.8	11.8	-65	-65								E	0

Rear	InUnitS	InUnitF	OutUnit	InWeanS	InWeanF	OutWean	FinLighS	FinLighF	FinMedS	FinMedF	FinHeavS	FinHeavF
IndoorB	-0.33	-0.33	0.7									
IndoorW				-0.3	-0.3	0.75						
Orgprop												
SowFYM	-0.58	0.42										
WeanFYM				-0.5	0.5							
LighFYM							-0.7	0.35				
MedFYM									-0.7	0.35		
HeavFYM											-0.7	0.35
Light							-40.	-40.	22.8	22.8	25.8	25.8
Medium							30	30	-35	-35	39	39
Heavy							10.2	10.2	11.8	11.8	-65	-65

	Rear	InUnitS	InUnitF	OutUnit	InWeanS	InWeanF	OutWean	FinLighS	FinLighF	FinMedS	FinMedF	FinHeavS	FinHeavF	Org	MeatOrg	Pigmeat	NH_3	N_2O	CH_4	CO_2		
Max																1.55						
piglets		21.1	21.1	22.0	-1	-1	-1														>	0
weaner	-1				0.95	0.95	0.97	-1	-1	-1	-1	-1	-1								>	0
Replacem	0.94	-0.4	-0.4	-0.4																	>	0
Organic														999	-1						>	0
Pigmeat								59.9	59.9	69.2	69.2	78.1	78.1		1	-1					>	0
pigtie																1					<	446
Land	0.04	0.16	0.16	0.16	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	1.27							>	0
NH_3-N	3.03	7.49	12.1	4.05	0.19	0.30	0.11	1.45	1.98	1.76	2.41	2.05	2.79	26.4			-1				=	0
N_2O-N	0.18	0.68	0.83	1.01	0.03	0.03	0.04	0.10	0.14	0.13	0.17	0.15	0.21	4.42				-1			=	0
CO_2	131	783	802	596	25	26	21	90	92	111	115	135	138	2401						-1	=	0
CH_4	1.9	8.6	13.3	5.2	0.4	0.2	0.0	1.8	1.3	2.2	1.6	2.6	1.8	26.8					-1		=	0
GWP_{100}	273	1331	1544	1205	49	46	39	184	194	228	240	274	288	5057							<	2321
Ammonia																	1				<	18.5
IndoorB		-0.33	-0.33	0.7																	=	0
IndoorW					-0.3	-0.3	0.75														=	0
Orgprop															1	-.01					E	0
SowFYM		-0.58	0.42																		E	0
WeanFYM					-0.5	0.5															E	0
LighFYM								-0.7	0.35												E	0
MedFYM										-0.7	0.35										E	0
HeavFYM												-0.7	0.35								E	0
Light								-40.	-40.	22.8	22.8	25.8	25.8								E	0
Medium								30.0	30.0	-35	-35	39.0	39.0								E	0
Heavy								10.2	10.2	11.8	11.8	-65	-65								E	0

Pig systems for 20% reduction

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- Same structure, only permits 80% production of pig meat.
- Allowing optimum manure system (but maintaining the same proportions of indoor and outdoor conventional rearing), enables this to be increased to 85%. This requires the use of slurry for sows, farmyard manure for weaners and slurry for finishers.
- Allowing optimum choice of indoor or outdoor, increases this to 86%, by the use of outdoor sows and weaners. (Finishing is only allowed to be indoor)
- Allowing choice of light, medium or heavy finishing systems, only increase this to 87%. This involves dropping the heavy systems.

- With ammonia abatement measures (cover, ploughing in immediately, injecting, drying,…) this can be increased to 88%
- In all cases the limiting factor is GWP. Ammonia is always reduced to less than the 20% reduction and in all cases is actually better than a 40% reduction.

Beef production systems

	RearBrdF	DairyXS	DairyS	Beef18S	Beef18F	CerealdS	CerealdF	Lsuck-AS	Usuck-SF	Hsuck	WinFiS	WinFiF	Beef		
OBJ													2.27		
Dairy-w			1	-1	-1									=	0
Dairy-X		1				-1	-1							=	0
Replace	1							0.13	0.15					=	0
Sucklera	-1							0.90			-1	-1		=	0
Sucklers									0.89	0.88				=	0
Winterf										0.18				=	0
Finished				275	275	286	286				315	315	-1	=	0
DairyTie		-0.3	0.7											=	0
Prop18				0.55	0.55									=	0
PropUp								-0.36	0.64	-0.36				=	0
PropHill								-0.25	-0.25	0.75				=	0
Prime													1	<	749
Arable	0.0			0.1	0.1	0.4	0.4	0.0	0.0	0.0	0.1	0.0		>	0
Land	0.2	0.0	0.0	0.2	0.2	0.0	0.0	0.6	0.5	0.1	0.1	0.1		>	0
Hill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0		>	0
NH3-N	0.8	0.0	0.0	13.4	8.4	18.0	11.4	23.1	12.8	1.8	12.5	7.6		=	0
N2O-N	0.8	0.0	0.0	1.6	1.6	1.5	1.5	3.2	2.8	2.0	0.8	0.8		=	0
CO2	80	0	0	649	656	1044	1054	435	421	315	383	390		=	0
CH4	16.6	0.0	0.0	41.2	48.7	36.6	46.5	67.8	67.6	50.8	23.4	30.7		=	0
GWP100	880	0	0	2474	2647	2688	2918	3709	3481	2660	1370	1540		<	11902
Ammonia														<	49
Beef18SF				0.7	-0.3									=	0

Beef production systems

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- 20% reduction in emissions – 80% production of beef.
- Choice of slurry or FYM – NO CHANGE. Some slurry, some FYM but total production and emissions unchanged.
- Choice of dairy calves or sucklers. If 10% more of the calves came from dairy, then 85% production level. At 100% dairy, GWP is 64% of current!
- Choice of Hill/Upland/Lowland – 87% production level with much less than ammonia limit,
  - **BUT need over 4x as much Hill land!!**
- Limit to 30% increase in Hill land – 81% production level, chooses lowland sucklers (just), but only Upland autumn sucklers worse.
- Improved Nitrogen Use Efficiency allows 81% production (NH_3 not GWP)
- 95% methane emissions allows 83% production

And so on

- The same can be done for each livestock commodity
- Conclusion of problem:
  - can't be done if eat same amount of meat
  - abatements have concentrated on ammonia
- LCA Conclusion:
  - Having a model-based LCA enables the calculation of impacts from any (future) system
  - Differences are systemic and so not subject to uncertainty of observation

Distribution of emissions

CO2	Fertiliser -N	Fertiliser -non N	Machinery	Fuel (diesel /elec)	Direct emission	Overseas	TOTAL
Pig meat	143	-9	287	1,763	0	312	2,496
Poultry	135	34	180	1,277	0	200	1,827
Beef	732	75	363	1,684	2	113	2,969
Sheep	796	119	253	1,413	0	149	2,730
Milk	442	36	202	1,554	0	267	2,501
Eggs	107	-5	263	1,409	0	217	1,991

- In LCA world is life cycle emissions
- In UK world is emissions in UK
- In Department of Agriculture policy world is in THEIR inventory
- (machinery and fertiliser are Industry, fuel is Transport)
    - Production versus Consumption Inventory

Is more calves from dairy possible?

	50% calves female			**100% calves female**			
Dairy cows	2065	2065	2065	2065	2065	2065	**3000**
Lactations	3.8	**5**	**7**	3.8	**5**	**7**	**7**
Male dairyX killed	9%	9%	9%				
From dairy							
Male	880	892	903	658	723	782	1136
Female	386	516	634	658	723	782	1136
From beef - beef herd reduced to produce same total calves							
Male	796	698	621	752	675	603	164
Female	485	425	378	458	411	367	100
% from dairy herd	50%	56%	61%	52%	57%	62%	90%