Annexes to 'the Protein Puzzle', the consumption and production of meat, dairy and fish in the European Union

http://www.pbl.nl/en/publications/2011/meat-dairy-and-fish-options-for-changes-in-production-and-consumption

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Annex 3A Calculation of the intake of proteins and saturated fats

Using supply data of FAO for consumption

The food supply data from the food balance sheets are based on national accounts, reported to FAOstat each year. Supply is calculated as production plus imports minus exports and stock changes for each country. Data gaps are filled in by FAO, so a consistent time series of almost all countries is available.

The data cover basic food commodities, both vegetal and animal, from which the FAO calculated the supply of macro-nutrients such as protein and calories. The factors used in the calculations, such as the protein content of the commodities, are not listed in the FAOstat metadata, but can be derived from the data. For example, the factor for protein content is obtained by dividing the protein supply of a commodity by its supply quantity. Information can also be obtained via the FAOstat user forum.

The EU average protein content of commodities – based on the FAO balance sheets – matches well with the values found in (NEVO, 2010), except for pig meat, which has a relatively low protein content (13%) according to FAOstat. There are also significant differences between countries according to FAOstat data. When the FAO data on meat consumption are compared to Eurostat data, these correspond very well for the total of EU27 countries. For some specific countries, however, the difference is significant, such as for the United Kingdom (18%) or the Benelux countries (more than 20%). All in all, the FAOstat food balance sheets are considered the best complete time series available.

Calculation of intake of protein

In this report, the FAO data are taken as a basis for estimating the actual intake of protein. The amount of protein per capita per day for the EU27 as a whole (taken from the FAOstat site) was 106 grams in 2007, of which 62 grams was from animal products. A total retail and household loss of 20% was assumed, so the actual intake was 84.5 grams per capita per day, of which 50 grams was from animal products. This corresponds to 31 kilograms per capita per year, of which 18 kilograms was from animal products. As it is based on supply data, this average applies to the whole population.

An overview of the protein intake of the adult population in most EU27 countries, obtained from consumer surveys, is presented in (Elmadfa, 2009). The population weighted average protein intake is 31.5 kilograms per capita, per year. When corrected for the share of children and elderly people in the EU population, this is almost 29 kilograms per capita per year, for the whole population. This corresponds reasonably well with the FAO-based intake, as consumer surveys do underreport.

Saturated Fatty Acids (SFA)
In this report, the FAO data are taken as a basis for estimating the actual intake of SFA. The amount of fats per capita per day for the EU27 as a whole (taken from the FAOstat site) was 144 grams per capita per day in 2007, of which 77.5 grams was from animal products. A total retail and household loss of 20% was assumed, so the actual intake of fats was 115 grams per capita per day, of which 62 grams was from animal products. This corresponds to 42 kilograms in fats per capita per year, of which 22.6 kilograms was from animal products. When combined with a caloric value of fats of 9 kcal per gram (NEVO, 2010), these 42 kilograms form 37% of the energy (en%) in our diet. In (Schmidhuber, 2007) a value of 36en% is given for 2001/2003. These are totals, but can also be downloaded per animal product from the FAOstat site.

Animal fats are rich in SFA. Beef fat contains around 40% SFA, pig meat and chicken fat about 35%, butter fat 65%, and fish oil approximately 20% (NEVO, 2010; Voedingscentrum, 2008). Vegetable oils and fats also contain SFA, but less. Most vegetable oils contain 10% to 15% SFA. Palm oils, coconut cream and cacao butter are vegetable fats with higher percentages of SFA.

Multiplying the consumption of animal fats with the SFA percentages per product leads to an average intake of 10.9 kilograms of animal SFA per capita per year. From (Schmidhuber, 2007), the total intake of SFA is known for the EU (11.7en%, corresponding to 13.2 kilograms per capita per year when combined with the caloric supply from FAOstat (2 770 kcal per capita per day) and a caloric value of fats of 9 kcal per gram). This means that 13.2 to 10.9 = .3 kilograms SFA per capita per year originates from vegetal sources. Calculated in this way, animal fats contain 48% SFA, on average, and vegetal fats contain 12%. Total SFA intake is 13.2 kilograms per capita per year.

Annex 3B Consumption of animal products

consumption of meat per capita (supply, carcass weight)

	bovine kg/cap/y	pig kg/cap/y	poultry kg/cap/y	other meat kg/cap/y	total meat kg/cap/y
Austria	18	66	17	2	103
Belgium-Lux	20	34	26	4	85
Bulgaria	5	18	20	2	45
Cyprus	7	51	34	13	104
Czech Republic	8	47	25	6	86
Denmark	27	50	18	4	98
Estonia	14	27	17	1	59
Finland	19	34	17	2	73
France	27	32	21	9	89
Germany	13	56	16	3	88
Greece	18	27	14	16	76
Hungary	4,3	47	28	1	80
Ireland	24	36	25	7	93
Italy	24	45	16	7	92
Latvia	8	31	21	1	61
Lithuania	7	45	25	0	78
Malta	21	37	25	6	90
Netherlands	18	33	15	5	71
Poland	5	51	20	0	77
Portugal	18	45	25	4	93
Romania	8	32	19	4	63
Slovakia	6	33	18	2	59
Slovenia	21	41	20	2	84
Spain	15	62	28	7	112
Sweden	24	36	15	3	79
United Kingdom	22	28	29	7	86
EU-27	17	43	21	5	86
EU-15	20	43	21	6	90

consumption of other animal products per capita (supply)

	fish&seafood	offals	milk, excl butter	butter&ghee
	kg/cap/y	kg/cap/y	kg/cap/y	kg/cap/y
Austria	13,4	1,33	235,1	5,3
Belgium-Lux	24,6	1,78	251,1	5,9
Bulgaria	4,2	4,57	151,8	0,3
Cyprus	23,1	4,75	162,5	0,8
Czech Republic	10,5	4,14	196,9	4,4
Denmark	24,5	0,81	295,6	1,8
Estonia	16,4	4,98	238,9	1,8
Finland	31,7	1,54	361,2	3,8
France	34,8	7,15	260,5	8,3
Germany	14,8	0,90	247,2	6,4
Greece	21,1	3,59	314,7	1,1
Hungary	5,1	2,36	175,6	1,0
Ireland	21,4	6,70	247,2	2,6
Italy	24,4	3,15	256,1	2,8
Latvia	12,6	6,38	208,7	1,7
Lithuania	37,6	5,72	273,9	1,4
Malta	30,2	2,31	188,6	0,7
Netherlands	19,0	1,79	320,2	3,3
Poland	9,5	2,65	198,5	4,2
Portugal	54,8	6,08	222,9	1,8
Romania	5,3	4,95	266,2	0,5
Slovakia	8,0	1,61	130,1	1,7
Slovenia	9,4	5,72	246,4	2,7
Spain	40,0	2,01	177,5	1,0
Sweden	28,5	1,38	355,9	2,7
United Kingdom	20,3	2,79	241,5	3,1
EU-27	22,1	3,15	241,7	3,9
EU-15	25,6	3,03	250,9	4,3

Annex 3C Intake of proteins

	animal protein kg/cap/y	vegetal protein kg/cap/y	total protein kg/cap/y
Austria	18,8	12,7	31,5
Belgium-Lux	17,3	10,9	28,2
Bulgaria	10,5	11,6	22,1
Cyprus	17,5	10,9	28,4
Czech Rep	16,0	11,6	27,5
Denmark	21,0	10,9	31,9
Estonia	14,6	12,4	26,9
Finland	19,4	12,1	31,4
France	21,3	11,6	33,0
Germany	17,8	11,7	29,5
Greece	18,7	16,0	34,8
Hungary	13,7	12,2	25,8
Ireland	18,9	12,6	31,5
Italy	17,8	14,7	32,5
Latvia	14,9	10,8	25,8
Lithuania	20,5	13,9	34,3
Malta	18,5	16,8	35,3
Netherlands	19,9	10,6	30,6
Poland	15,5	14,5	30,0
Portugal	20,8	12,8	33,6
Romania	16,2	15,9	32,1
Slovakia	9,8	11,2	21,0
Slovenia	16,7	12,9	29,6
Spain	20,5	11,5	32,0
Sweden	20,6	10,5	31,1
United Kingdom	17,4	13,1	30,5
EU-27	18,1	12,7	30,8
EU-15	19,0	12,4	31,4

	meat protein kg/cap/y	dairy protein kg/cap/y	eggs protein kg/cap/y	fish&seafood protein kg/cap/y	total protein kg/cap/y
Austria	10,9	5,8	1,3	0,8	18,8
Belgium-Lux	8,8	6,1	1,2	1,4	17,3
Bulgaria	5,1	4,0	1,1	0,3	10,5
Cyprus	11,1	4,0	1,0	1,3	17,5
Czech Republic	9,4	5,0	0,9	0,6	16,0
Denmark	10,5	7,4	1,8	1,4	21,0
Estonia	6,5	6,1	1,0	1,0	14,6
Finland	7,8	9,0	0,8	1,8	19,4
France	10,5	7,2	1,5	2,2	21,3
Germany	9,5	6,3	1,1	0,9	17,8
Greece	8,5	8,2	0,8	1,3	18,7
Hungary	8,0	4,1	1,4	0,3	13,7
Ireland	10,4	6,5	0,7	1,3	18,9
Italy	9,3	6,1	1,0	1,3	17,8
Latvia	7,0	5,6	1,5	0,8	14,9
Lithuania	9,3	7,6	1,2	2,4	20,5
Malta	10,2	5,0	1,5	1,8	18,5
Netherlands	8,3	8,7	1,8	1,2	19,9
Poland	8,6	5,2	1,1	0,6	15,5
Portugal	10,6	5,9	1,0	3,3	20,8
Romania	7,4	7,2	1,3	0,3	16,2
Slovakia	5,6	2,9	0,9	0,4	9,8
Slovenia	9,1	6,2	0,8	0,5	16,7
Spain	12,2	4,5	1,4	2,3	20,5
Sweden	8,7	9,2	1,1	1,7	20,6
United Kingdom	9,2	6,1	1,0	1,2	17,4
EU-27	9,5	6,2	1,2	1,3	18,1
EU-15	9,9	6,4	1,2	1,5	19,0

Annex 3D Intake of saturated fats

	beef kg/cap/y	pork kg/cap/y	dairy kg/cap/y	other animal kg/cap/y	vegetal kg/cap/y	total kg/cap/y
Austria	0,6	3,8	7,1	1,0	2,7	15,2
Belgium-Lux	0,7	2,3	8,7	1,5	2,6	15,7
Bulgaria	0,2	1,2	3,5	1,2	1,8	7,9
Cyprus	0,2	2,6	3,0	2,0	2,7	10,4
Czech Republic	0,2	2,4	5,2	0,9	2,4	11,1
Denmark	1,1	3,6	8,1	1,6	1,1	15,5
Estonia	0,4	1,3	4,5	0,8	1,4	8,4
Finland	0,7	2,2	9,6	1,1	1,4	14,9
France	0,9	2,0	9,7	1,7	2,4	16,7
Germany	0,4	3,1	7,5	0,9	2,2	14,0
Greece	0,5	1,3	5,3	1,7	3,3	12,0
Hungary	0,2	3,9	5,4	1,7	2,3	13,4
Ireland	0,7	2,1	5,8	1,5	2,4	12,4
Italy	0,7	2,4	5,7	1,0	3,1	12,9
Latvia	0,3	2,0	5,2	1,2	1,9	10,6
Lithuania	0,2	2,3	5,1	1,1	1,4	10,1
Malta	0,8	2,4	4,3	1,6	1,6	10,7
Netherlands	0,6	1,9	7,5	1,1	2,1	13,3
Poland	0,2	3,1	6,1	0,9	1,4	11,6
Portugal	0,6	2,7	5,2	1,6	2,2	12,3
Romania	0,2	1,9	5,2	1,2	1,7	10,2
Slovakia	0,3	2,5	4,2	1,1	1,7	9,8
Slovenia	0,7	2,3	5,7	0,9	1,9	11,4
Spain	0,4	2,9	3,0	1,5	3,2	10,9
Sweden	0,7	1,8	6,9	0,9	1,9	12,2
United Kingdom	0,8	1,8	6,8	1,9	2,3	13,6
EU27	0,6	2,5	6,5	1,3	2,3	13,2
EU-15	0,7	2,7	7,4	1,5	2,2	14,5

Annex 3E Saturated fats in animal products compared to vegetal products

	Fat %w/w	Saturated fatty acids %w/w	Saturated fat in fat %w/w	Protein %w/w	Saturated fat/kg protein g/kg
Beef					
Rump steak	2	0.7	47	24	29
Stewing steak	10	4.4	45	21	212
Minced meat	15	6.8	47	19	356
Braising steak, marbled	17	7.2	43	20	362
Pig meat					
Tenderloin	3	1.2	39	23	53
Ham	4	1.4	39	22	64
Loin chop	7	2.6	39	23	115
Minced meat	14	5.5	39	19	293
Bacon	29	10	36	17	629
Poultry products					
Fillet	2	0.5	29	23	23
Drumsticks	8	2.3	29	19	120
Broiler whole	16	4.7	29	18	257
Eggs	9	3.0	33	12	242
Sheep meat					
Lean mutton	9	4.2	48	21	205
Minced lamb	13	5.8	45	19	301
Lamb chop	19	8.5	45	19	443
Dairy products					
Skimmed milk	0	0.1	65	4	18
Semi-skimmed milk	2	1.0	67	3	294
Raw milk	4	2.9	66	3	853
Mozzarella	18	12	67	20	605
Goat cheese fresh	17	11	64	13	799
Gouda cheese average	30	21	68	23	899
Brie 60+	33	22	67	17	1 306
Whipping cream	36	20	57	2	8 870
Fish					
Pollack	1	0.1	20	17	6
Tilapia	3	1.0	30	20	50
Mussels	3	1.0	32	17	58
Fish fingers	6	1.2	20	13	92
Salmon	14	3.0	21	20	150
Herring	15	3.3	22	16	206
Mackerel	31	7.4	24	18	411
Meat substitutes					
Mince substitute	3	0.5	17	18	28
Substitute crumbed	9	0.5	6	13	38
Vegetal burger	6	0.8	13	18	45
Sausage	20	2.1	11	18	117
Vegetal burger	11	2.0	19	11	182

	Fat	Saturated fatty acids	Saturated fat in fat	Protein	Saturated fat/kg protein
	%w/w	%w/w	%w/w	%w/w	g/kg
Vegetal products					
Common dry beans	2	0.3	15	20	15
Dry soy beans	19	2.8	15	36	78
Soy milk	2	0.3	14	4	81
Soy curd	7	1.0	14	12	83
Other products					
Butter	81	53	66	1	
Margarine	80	19	23		
Sunflower oil	100	12	12		
Olive oil	100	14	14		
Peanut oil	100	15	15		
Coconut cream	69	52	76		

Annex 7A Overview of reviewed LCA studies and their outcomes

	country	representation	Production type	GHG kgCO2-eq/ kg product	Land use m2/kg product	protein content %	GHG kgCO2-eq/ kg protein	Land use m2/kg protein
Beef and veal								
Feedlot systems								
Peters et al 2009	Australia	1 farm	grass-feedlot	14		20%	71	
Phetteplace et al 2001	US	2 farms	conventional, beef cattle, feedlot	14	15	20%	71	75
Pelletier et al 2010	US	model, 3 systems	conventional, beef cattle, feedlot	40		20%	201	
Dairy calves/mixed systems								
Blonk et al 2008	NL	model	conventional, beef cattle	16	15	20%	80	75
Nguyen et al 2010	EU	model	conventional, beef cattle, dairy calves	26	29	20%	130	143
Ogino et al 2007	Jap	model	conventional, beef cattle	36		20%	182	
Verge et al 2008	Canada	Canadian sector	conventional, feedlot and grassfed	27		20%	137	
Edward-Jones et al 2009	Wales UK	1 farm	conventional, intensive lowland, beef cattle	42		20%	209	
Flachowsky & Hachenberg 2009	D	model	conventional, beef cattle, stable conc feed	9		20%	45	
Flachowsky & Hachenberg 2009	D	model	conventional, beef cattle, stable grassfed	14		20%	69	
Hirschfeld et al 2008	D	model	conventional, beef cattle, dairy calves	12		20%	62	
Meadow systems, suckler herds								
Casey & Holden 2006	Ire	5 farms	conventional, beef cattle	35		20%	177	
Williams et al 2006	UK	model	conventional	23	33	20%	114	164
Nguyen et al 2010	EU	model	conventional, beef cattle, suckler herd calves	39	61	20%	194	307
Phetteplace et al 2001	US	5 farms	conventional, beef cattle, suckler herd calves	50	158	20%	251	788
Blonk et al 2008	Ire	model	conventional, beef cattle	38	60	20%	192	300
Flachowsky & Hachenberg 2009	D	model	conventional, beef cattle, meadow	28		20%	140	
Hirschfeld et al 2008	D	model	conventional, beef cattle, suckler calves	24		20%	122	
Pelletier et al 2010	US	model	conventional, beef cattle, pasture	52		20%	260	

	country	representation	Production type	GHG kgCO2-eq/ kg product	Land use m2/kg product	protein content %	GHG kgCO2-eq/ kg protein	Land use m2/kg protein
Extensive pastoral systems								
Edward-Jones et al 2009	Wales UK	1 farm	conventional, extensive upland, beef cattle	129		20%	643	
Blonk et al 2008	Braz	model	conventional, beef cattle	59	420	20%	295	2100
Peters et al 2009	Australia	1 farm	grass, organic	17		20%	86	
Posnioen et al 2010	Arg	model	conventional, beef cattle	43	286	20%	215	1429
Cederberg et al 2009	Braz	model	conventional, beef cattle	41	250	20%	205	1250
Culled dairy cows								
Blonk et al 2008	NL	model	conventional, culled dairy cattle	9	7	20%	45	37
Hirschfeld et al 2008	D	model	conventional, culled dairy cows	9		20%	45	
FAO 2011	W-Eur	sector	conventional	12		20%	62	
Pork								
Zhu-XueQin & van Ierland 2004	NL	model	conventional	10,6	11	20%	53	55
Basset-Mens & vander Werf 2005	F	model	good practice	4,4	10	20%	22	48
Williams et al 2006	UK	model	conventional	8,7	10	20%	44	49
Cederberg & Flysjo 2004b	S	model (scen C)	conventional	4,4	12	20%	22	62
Blonk et al 2008	NL	model	conventional	4,5	8	20%	23	39
Eriksson et al 2005	S	model	conventional, soyfed	4,6	15	20%	23	75
Kool et al 2009	NL	model	conventional	4,9		20%	25	
Kool et al 2009	UK	model	conventional	4,8		20%	24	
Kool et al 2009	DK	model	conventional	4,8		20%	24	
Kool et al 2009	D	model	conventional	5,0		20%	25	
Hirschfeld et al 2008	D	model	conventional	5,8		20%	29	

	country	representation	Production type	GHG kgCO2-eq/ kg product	Land use m2/kg product	protein content %	GHG kgCO2-eq/ kg protein	Land use m2/kg protein
Poultry								
Williams et al 2006	UK	model	conventional	6,1	8	20%	30	40
Verge et al 2009	Canada	Canadian industry	regular industry	2,1		20%	10	
Verge et al 2009	Canada	Canadian industry	regular industry (turkey)	2,9		20%	14	
Blonk et al 2008	NL	model	conventional	2,6	5	20%	13	23
Katajajuuri 2008	Fin	20 farms	conventional	3,7		20%	19	
Eggs								
Williams et al 2006	UK	model	conventional	5,5	6,7	13%	42	52
Verge et al 2009	Canada	Canadian industry	regular industry	1,7		13%	13	
Mollenhorst et al 2006	NL	16 farms	cage	3,9	4,5	13%	30	35
Mollenhorst et al 2006	NL	45 farms	free-range	4,3	5,2	13%	33	40
Blonk et al 2008	NL	model	conventional	2,0	4	13%	15	29
Sheepmeat								
Peters et al 2009	Australia	1 farm	grass	10		20%	51	
Edward-Jones et al 2009	Wales	1 farm	conventional, intensive lowland, grass	38		20%	190	
Edward-Jones et al 2009	Wales	1 farm	conventional, extensive upland, beef cattle	150		20%	749	
Williams et al 2006	UK	model	conventional	24	20	20%	118	100
Blonk et al 2008	NL	sector	conventional	16	33,0	20%	82	165
Milk								
Blonk et al 2008	NL	sector	conventional	1,2	0,9	3,5%	34	26
Verge et al 2007	Canada	sector	regular industry	1,1		3,5%	32	
Casey&Holden 2005	Ire	model/sector	conventional	1,4		3,5%	41	
Haas et al , 2001	D	6 farms	conventional, intensive	1,4		3,5%	41	
Haas et al , 2001	D	6 farms	conventional, extensive, semi alpine	1,1		3,5%	32	
Thomassen, et al 2008	NL	119 farms	conventional	1,5	1,3	3,5%	43	37
Williams et al 2006	UK	model	conventional	1,2	1,2	3,5%	34	34
Cederberg & Flysjo 2004	S	8 farms, intensive	conventional	1,0	1,5	3,5%	28	43
Cederberg & Flysjo 2004	S	8 farms, extensive	conventional	1,1	1,9	3,5%	32	54
Hirschfeld et al 2008	D	model	conventional	1,0		3,5%	28	
Weiske et al 2006	EU-15	model	conventional	1,5		3,5%	43	
Sheane 2011	Scotland	sector	conventional	1,4		3,5%	40	
FAO 2010	W-Eur	sector/model	conventional	1,3		3,5%	37	

	country	representation	Production type	GHG kgCO2-eq/ kg product	Land use m2/kg product	protein content %	GHG kgCO2-eq/ kg protein	Land use m2/kg protein
Rainbow trout								
Gronroos et al 2006	F	sector, typical system	net cages at sea (Baltic)	2,6		20%	13	
Gronroos et al 2006	F	model	landbased marine farm	7,4		20%	37	
Aubin et al 2009	Fr	1 farm, aquitaine	landbased freshwater farm	7,4		20%	37	
Salmon								
Silvenius & Gronroos 2003	N	sector, typical system	net cages at sea (Atlantic)	2,7		20%	14	
Blonk et al 2009	N	sector, typical system	net cages at sea (Atlantic)	2,7	2,5	20%	14	13
Ellingsen et al 2009	N	sector	marine aqua culture	3,0	6,0	20%	15	30
Pelletier et al 2009	N	major companies	marine aqua culture	4,5		20%	22	
Pelletier et al 2009	UK	major companies	marine aqua culture	8,2		20%	41	
Herring								
Silvenius & Gronroos 2003	F	sector	wild catch from Baltic sea	1,1		20%	5	
Cod iceland								
Blonk et al 2009	Iceland	sector	wild catch from NorthAtlantic	7,4		20%	37	
Ziegler et al 2003	S	sector, trawling and gilnet	wild catch from Baltic sea	6,0		20%	30	
Alaska pollack								
Blonk et al 2009	US	sector	wild catch from the Bering sea	2,5		20%	13	
Pangasius								
Blonk et al 2009	Vietnam	model	land based aquaculture	3,0	5,3	20%	15	27
Turbot								
Aubin et al 2009	Fr	typical farm	landbased marine farm	15,0		20%	75	
Sea-bass								
Aubin et al 2009	Greece	typical farm	net cages at sea (mediteranean)	9,0		20%	45	
Shrimp/prawn								
Ziegler 2009	Senegal	sector, trawl	wild catch from Atlantic	38,0		16%	238	
Ziegler 2009	Senegal	sector, artisanal	wild catch from Atlantic	7,8		16%	49	

	country	representation	Production type	GHG kgCO2-eq/ kg product	Land use m2/kg product	protein content %	GHG kgCO2-eq/ kg protein	Land use m2/kg protein
Mussels								
Irribarren et al 2010	E	open sea culture (rafts)	bay of Biskay	0,7		16%	4	
Lobster								
Ziegler 2008	N	sector	creel	18,7		17%	110	
Ziegler 2008	N	sector	conv trawl	86,2		17%	507	
Mackerel								
Vazquez-Rowe2010	E	Galician pelagic fishery	wild catch	3,3		20%	16	
Meat substitutes with eggs or milk protein								
Blonk et al 2008	NL	vegetal with milk protein	producer data	6,2	3,1	18%	34	17
Blonk et al 2008	NL	vegetal with egg protein	producer data	2,6	1,2	15%	17	8
Meat substitutes vegetal								
Blonk et al 2008	NL	tofu	producer data	2,0	3,0	12%	17	25
Blonk et al 2008	NL	tempeh	producer data	1,1	2,3	12%	9	19
Blonk et al 2008	NL	vegaburger	producer data	1,1	1,9	20%	6	10
Blonk et al 2008	NL	lupinebased	producer data	0,5	0,3	8%	7	4
Pulses								
Blonk et al 2008	NL	common beans	model	2,0	8,5	20%	10	43
Nemecek et al 2005	CH	peas	model	0,8	2,6	21%	4	13
Sheenan et al 1998	USA	soya	US production	0,8	3,8	35%	2	11

Annex 7B Elaboration on land use calculation

The land use was calculated by multiplying the apparent consumption in the EU-27 with land use intensities.

The apparent consumption (red) was calculated from Eurostat data (black) and FAO-stat data (blue), as listed in the table below

Table1; Trade balance of meat and dairy of the EU-27

	2009 Imports	production	apparent consumption	exports	unit
Beef	431	8000	8183	248	kt cwe
Pig meat	52	21238	18906	2384	kt cwe
Poultry	862	11130	10978	1014	kt cwe
Dairy (milk eq)	45729	134387	123138	56978	kt-milkeq
Eggs	30	6540	6421	149	kt egg-eq
Sheep&goat	412	1026	1230	208	kt cwe
Other (rabbit, duck, game, etc.)	596	1169	1433	332	kt cwe

The imports were split up to region of origin, based on Eurostat data (black), FAO-stat data (red) and assumptions (red). In the table below these are presented.

Table 2; Region of production of EU-imports

origin of imports	S-America	N-America	SE-Asia	Oceania	Africa	Other
Beef	83%	2%		8%	6%	1%
Pig meat	36%	12%				52%
Poultry	70%		20%			10%
Dairy (milk eq)	10%	10%		70%		10%
Eggs	80%		10%			10%
Sheep&goat				100%		
Other (rabbit, duck, game, etc.)	20%		20%	20%	20%	20%

The land use intensities were taken from several LCA studies. The land use intensities for products from the EU-27 were chosen in such a way that EU production multiplied with these data resulted in a land use that more or less matched EU agricultural land use statistics. The intensities for the EU were not averages from European LCA studies, but are situated in the higher end of the ranges, which were established by reviewing several LCA studies. As LCA land use data include land use for feed production we made a correction for the 130000 kha of soy fields that are used for the EU livestock feed consumption (Miterra). These hectares were allocated to South America (85%) and North America (15%).

Table 3; Land use intensities of products (m2/kg Carcass weight)

	S-America	N-America	SE-Asia	Oceania	Africa	Other	EU-27
Beef	250	95		95	400	95	95
Pigmeat	10	10				10	10
Poultry	7		7			7	7
Dairy (milk eq)	2	2		2		2	2
Eggs	7		7			7	7
Sheep&goat				40			40
Other (rabbit, duck, game, etc.)	35		35	35	35	35	35

This procedure resulted in the following land use per region:

Table 4; Land use of EU consumption of meat and dairy (kha)

	S-America	N-America	SE-Asia	Oceania	Africa	Other	EU27
Beef	10310	367		318	1004	40	71847
Pigmeat	3732	661				24	14488
Poultry and eggs	2375	353	105			53	8744
Dairy products	3999	1221		4377		625	14406
Other meat	599	46	339	1748	339	339	6526

Annex 7C Full reference list of LCA- studies

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ANNEX 8A - Description of the model suite

Overview

Two different agro-economic models were used for this study, being the IMPACT model of IFPRI (Rosegrant *et al.*, 2008), and the LEITAP model, a modified GTAP model and database (Meijl *et al.*, 2006). Both models were coupled to the integrated assessment model IMAGE (MNP, 2006).
The IMPACT and LEITAP models are driven by population growth and economic development, including both income growth and 'autonomous' technological progress (exogenous to the model), such as crop productivity increase and intensification in the livestock system. While population and income drive changes in demand, the supply side is determined by land and resource availability, and by technological progress. Trade and prices are the mediators to find a new equilibrium under these demand and supply changes. The regional production of agricultural commodities calculated by the two models, as well as the sectoral technological progress and endogenous intensification are passed to IMAGE (Figure 1). IMAGE allocates this production on a spatial grid, and calculates the resulting environmental impacts, land use and GHG emissions, and climate change under the respective scenario. IMAGE results are also passed on to the GLOBIO3 model (Alkemade *et al.*, 2009) to asses biodiversity according to the mean species abundance (MSA) indicator. A detailed description of the coupling between IMAGE and LEITAP can be found in Eickhout *et al.* (2009).

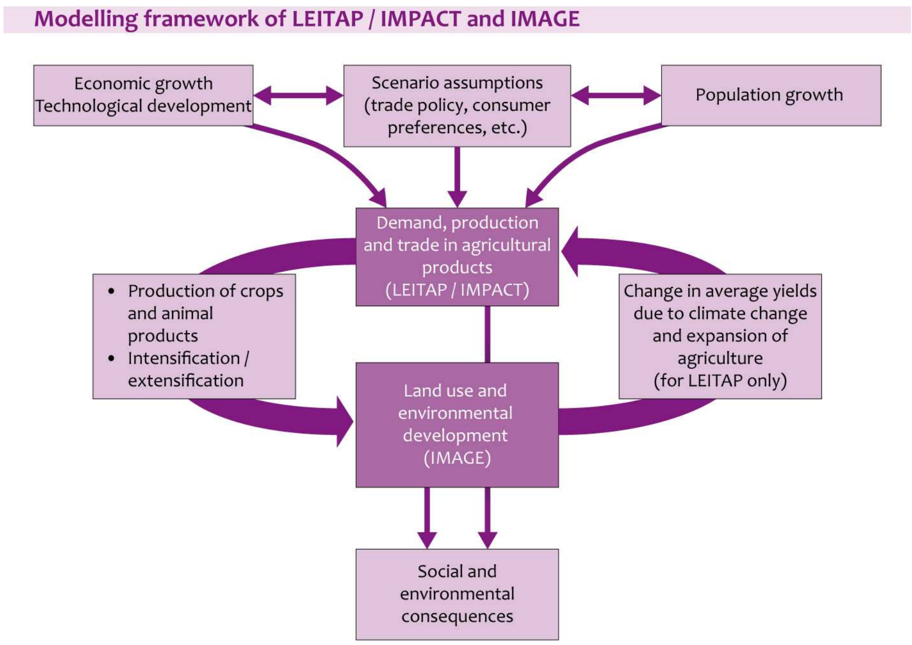

Figure 1. Schematic representation of the scenario analysis with IMPACT and LEITAP, coupled to the IMAGE model. (050s_dev10)

LEITAP

LEITAP (van Meijl *et al.*, 2006) is a further development of the GTAP model (Hertel, 1997), a multi-regional, static, applied computable general equilibrium (CGE) model based on neoclassical microeconomic theory. In the model, a representative producer for each sector of a country or region makes production decisions to maximise profit by choosing inputs of labour, capital, and intermediates. LEITAP additionally includes a dynamic land supply function (Eickhout *et al.*, 2009; van Meijl *et al.*, 2006), accounts for the different degrees of substitutability between types of land use (Huang *et al.*, 2004;

van Meijl *et al.*, 2006), and includes an imperfect mobility of capital and labour between agricultural and non-agricultural sectors (Hertel and Keening, 2003). The standard GTAP income elasticities are reduced for agricultural commodities consistent with FAO-estimates (Britz, 2003), and are made dynamically dependent on purchasing power parity corrected real GDP per capita. Additionally, the LEITAP model includes a great detail of international and EU agricultural policies (Helming *et al.*, 2010). As most other CGE models, LEITAP (and GTAP) applies the Armington assumption for international trade, according to which changes in relative prices (domestic versus international, or between different countries) determine the percentage change of import and export streams. (Armington, 1969). Recently, the LEITAP model was updated to include first generation biofuels (Banse *et al.*, 2008). For the purpose of this study, the calculations of the indirect demand for food (e.g. via the service sector), and the intensification of livestock have been improved, co-products from biofuels have been implemented, the feed sector (ofd) has been split out, and a first step towards handling of physical units next to economic units has been made. These changes are documented by Woltjer and Chen (2011, forthcoming).

IMPACT

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) was developed in the early 1990s to study the actions required to feed the world in the future, reduce poverty, and protect the natural resource base (Rosegrant *et al.*, 1995). The IMPACT model is a partial equilibrium model. This allows for exploration of the relationship of food demand, food production, resource availability, trade, commodity prices, and food security at various spatial scales (from river basins, countries, or regions, to the global level) and time horizons. The world is divided into 115 regions, which are intersected with 126 river basins, to represent the most significant climate and hydrologic variations. This intersection of countries and river basins gives rise to 281 spatial 'food-producing' units that enable the observation of economic and environmental policy response at the sub-country level. IMPACT has exogenous yield and area growth rates which are based on exogenous changes in crop productivity modelled for the IAASTD global assessment (IAASTD, 2009) and expert assessment of land availability changes for agricultural land.

Differences between LEITAP and IMPACT

There are numerous differences between the LEITAP and IMPACT models that arise from basic differences in model origins, development and the applications for which they are designed and used. Those considered to be most pertinent in explaining the differences of model results in this study are discussed in this paragraph.

The most important difference is that of a *general- versus a partial-equilibrium* modelling approach, and the amount to which processes are endogenized. In CGE models like LEITAP, all economy-wide interactions that connect consumers and their incomes to intermediate and primary production and trade are endogenous, assuming optimizing agents within a competitive market equilibrium. Disposable income is determined endogenously through changes in wages, returns to factor rents and direct transfers from the government; and the use and price of the production factors (land, labour, capital etc.) are endogenously determined. Income and productivity developments are directly related with each other.
Contrary, in a partial-equilibrium (PE) model like IMPACT, the changes in disposable income that drives the consumption of agricultural goods are determined by exogenous growth rates. Likewise, the prices of production factors remain (largely) fixed within PE models, as if the factors were limitless in supply (Wobst, 2000). The price of land, however, is also calculated internally in IMPACT, with land availability being largely exogenous, but modified as a feedback to demand.
This difference between general and partial equilibrium models leads to differences in how changes induced on the consumer side might be translated into changes on the supply side, and resulting price changes. As noted by (Wobst, 2000), the price impacts might tend to be larger in a partial-equilibrium framework, due to the rigidity of other supply-side factor markets.

For *trade*, CGE models tend to use a spatially-explicit, bilateral representation, with preferences for imports and domestic consumption being given by an Armington-based approach (Armington, 1969). IMPACT, like other PE models, has an 'integrated world markets' approach, that pools net trade at the global level and does not distinguish bilateral flows. This affects how production shocks translate into trade shifts and price changes in these models, and how changes in consumer preference are translated into market-mediated equilibrium shifts.

Another important difference is that the IMPACT model works mostly with *physical units*, while the LEITAP model, like all GTAP based models, performs all calculations on the basis of relative monetary values. Only when analyzing the results, or linking them to models like IMAGE, relative changes in economic volumes are translated to changes in physical units. However, this inevitably involves substantial uncertainty, as the heterogeneity of commodity groups is represented differently, and weighting for mass or economic values can make large differences.

Land availability in the LEITAP model is based on total productive land within a region according to the IMAGE model, and an economic land supply curve, relating the area of agricultural land and land price (van Meijl *et al.*, 2006). At present, there is no such market-based mechanism for shifting total available agricultural land in IMPACT. Changes in available arable area are primarily driven by exogenous shifts in the agricultural frontier (based on assumptions for IAASTD (2009)), which are further modified in response to commodity price changes. However, price-driven expansion of agriculture is relatively small compared to the exogenously-driven changes over time.

IMAGE

The Integrated Model to Assess the Global Environment (IMAGE version 2.4) was developed to explore the long-term dynamics of global change as a function of drivers such as demographic and economic development. Agricultural demand, production and trade are calculated by an agro-economic model like LEITAP or IMPACT (see above, and Eickhout *et al.*, (2009)). Environmental effects computed by the IMAGE ecosystem, crop and land-use models are calculated at a 0.5 by 0.5 degree resolution. Crop and grassland productivity are calculated based on the Agro-Ecological Zones (AEZ) approach (see Leemans and van de Born, (1994)). The amount of land needed depends on regional production (calculated by LEITAP or IMPACT) and changes in crop, grassland and livestock productivity. The regional production of agricultural goods is allocated to the grid on the basis of allocation rules considering crop productivity and socioeconomic factors such as distance to roads and water (Alcamo *et al*., 1998). If the increase in productivity in a certain region is slower than the increase in production, agricultural area is expanding into natural vegetation, resulting in conversion emissions of CO_2 and other emissions associated with biomass burning. If productivity increase is faster than production increase, abandonment of the agricultural area occurs.

Land-use for livestock systems. IMAGE describes two aggregated livestock production systems, known as pastoral systems, dominated by grazing ruminants, and mixed/landless systems. Ruminant production in mixed/landless systems is characterised by less grass and fodder consumption, but higher inputs of feed crops than in pastoral systems. Pork, poultry meat and eggs are assumed to be produced in mixed/landless systems only. The contribution of pastoral and mixed systems to ruminant production, and also feed requirements and feed composition for all livestock differ strongly between regions, and change over time, leading to very different efficiencies and land requirements (see Bouwman *et al.* (2005b) for more details).

GHG emissions from agricultural and livestock production systems. Land-related emissions of CO_2 (including the C exchange between terrestrial ecosystems and the atmosphere) are performed on grid cells of 0.5 by 0.5 degree, characterised by their climate (temperature, precipitation), soil and land cover

(natural ecosystems or agriculture). If natural vegetation is converted to agricultural land, aboveground carbon stocks are lost as CO_2, and also soil respiration increases, releasing CO_2 until a new equilibrium is reached. If natural vegetation re-grows after abandonment of agriculture, the carbon stock of natural vegetation gradually builds up. For more details see Van Minnen *et al.* (2000), and Klein Goldewijk *et al.* (1994).
Methane emissions from enteric fermentation are calculated in IMAGE from the total feed requirements and feed composition (Bouwman *et al.*, 2005b) and methane conversion rates (IPCC, 2006). Methane emissions from animal manure are based on Steinfeld *et al.* (2006). Nitrous oxide emissions from fertilizer application and animal manure management are based on IPCC data (IPCC, 2006). While emissions factors for e.g. fertilizer application and manure are assumed to be constant over time, future emissions per unit of product will change due to productivity improvements in both the crop and the livestock sector. Emissions from other sectors (production of fertilizers, transport), are not included here.

Nitrogen

The annual soil N budget includes the N inputs and outputs for 0.5 by 0.5 degree grid cells (Bouwman *et al.*, 2009). N inputs include biological N fixation (N_{fix}), atmospheric N deposition (N_{dep}), application of synthetic N fertilizer (N_{fert}) and animal manure (N_{man}). N outputs include N withdrawal from the field by crop harvesting, hay- and grass-cutting, and grass consumption by grazing animals (N_{withdr}). The soil N budget (N_{budget}) is calculated as follows:

$$N_{\text{budget}} = N_{\text{fix}} + N_{\text{dep}} + N_{\text{fert}} + N_{\text{man}} - N_{\text{withdr}} \qquad (1)$$

The soil N budget is calculated following a steady-state approach, which ignores N accumulation by soil organic matter build-up in case of a positive budget, and soil organic matter decompositon and mineralization, which is an internal cycle. With no accumulation, a positive nutrient budget is subject to NH_3 volatilization, denitrification, surface runoff and leaching. Negative budgets indicate N depletion due to soil organic matter loss. In case of soil erosion, a negative budget may be underestimated. The calculation of the individual terms of the N budget are discussed in detail elsewhere (Beusen *et al.*, 2008; Bouwman *et al.*, 2005a; Bouwman *et al.*, 2006; Bouwman *et al.*, 2009; Bouwman *et al.*, 2005b). Bouwman *et al.*, (2009) found good agreement between the budget calculations for the year 2000 and detailed country estimates for the member states of the Organisation for Economic Cooperation and Development (OECD) (OECD, 2008).

For the construction of the reference scenario, we used historical country data from FAO (2008) on total synthetic fertilizer consumption and crop production and N fertilizer use by crop from the International Fertilizer Industry Association/International Fertilizer Development Center/Food and Agriculture Organization (IFA/IFDC/FAO) (2003). For crops and grass, we used the concept of fertilizer N use efficiency (NUE), which represents the production in kg dry matter per kg of fertilizer N. This is the broadest measure of N use efficiency, also called the partial factor productivity of the applied fertilizer N (Dobermann and Cassman, 2005). NUE incorporates the contribution of indigenous soil N, fertilizer uptake efficiency and the efficiency with which the N uptake is converted into the harvested product. NUE varies between countries because of differences in the crop mix, their attainable yield potential, soil quality, amount and form of N application and management. For example, very high values in many African and Latin American countries reflect current low fertilizer application rates; in many industrialized countries with intensive high-input agricultural systems the NUE values are much lower. Following the analysis of Dobermann and Cassman (2005), we excluded animal manure N in the NUE values.

For constructing the reference scenario, we used data from Bruinsma (2003) as a guide. We divided the world into countries with inputs exceeding the crop uptake (positive balance or surplus) and countries with current deficit. Generally, farmers in countries with a surplus (industrialized countries, China, India, North Africa) are motivated to be increasingly efficient (generally 10-20% higher NUE) in the use of fertilizers. In deficit countries (Sub-Saharan Africa, Central and South America), we assume that NUE for upland crops will gradually decrease to a varying degree (Figure 1). In contrast, countries in Eastern Europe and the former Soviet Union had a rapid decrease in fertilizer use after 1990, causing a strong apparent increase in the fertilizer use efficiency; here we assumed an increase of fertilizer use between 2000 and 2030, and a decrease of NUE.

The other scenarios assume the same NUE as the reference, except the high crop yield scenario. For high crop yields we assumed that the yield increase is partly due to better management, and partly due to improved crop varieties, which both may influence the NUE. Better management includes split applications to reduce losses such as ammonia volatilization, leaching and denitrification. Also, improved crop varieties may be developed for improving the N uptake. We calculated the mean crop yield increase for all crops, and simply assumed that the increase in NUE is half the increase of the crop yield in the high yield scenario relative to the baseline. Hence, if crop yields in the high yield scenario are 40% higher than in the baseline, the NUE in the high yield scenario would be 20% higher than in the baseline.

For the high livestock efficiency scenario we assumed that the N excretion is 15% less than in the baseline. This represents the effect of the improved feed conversion in this scenario.

GLOBIO3

According to the Convention on Biological Diversity (CBD), biodiversity encompasses the overall variety found in the living world and includes the variation in genes, populations, species and ecosystems. Several complementary indices are used within the CBD framework. In the GLOBIO3 model (Alkemade *et al.,* 2009) biodiversity loss is expressed for each biome by the mean relative abundance of the original species (MSA). In this index, the abundances of individual species are compared to their abundances in the natural or low-impacted state. Therefore, this aggregated indicator can be interpreted as a measure of ‘naturalness’ or ‘intactness’, and is similar to the Biodiversity Intactness Index BII (Scholes and Biggs, 2005).

Mean species abundance is not an absolute measure of biodiversity. If the indicator value is 100%, the biodiversity is similar to the natural state. If the indicator value is 50%, the average abundance of original species is 50% of the natural state, and so on. By definition, the abundance of exotic or invasive species is not included in the indicator, but their impact shows by the decrease in the abundance of the original species they replace.
One of the advantages of ‘mean species abundance’ is that it can be measured and modeled relatively easily. In a straightforward multiplicative approach, the GLOBIO3 model (Alkemade *et al.*, 2009) combines estimates for key pressures on biodiversity, based on data from approximately 500 peer-reviewed studies. The pressures on biodiversity considered include land cover change, land use intensity, atmospheric nitrogen deposition, infrastructure development, fragmentation and climate change.
For land-use change, the MSA value of a human influenced land-cover type depends on the local pristine or reference situation. For instance, a forest converted to intensively used grassland has a lower remaining MSA than a natural grassland converted to the same land-cover, as the converted grassland resembles the original situation more. The fragmentation effect is related to the size of natural continuous land-cover types, and their capacity to sustainably house viable populations of species. The combination of the multiple impacts results in estimates for changes in species abundance and extent of natural areas on a spatial grid of 0.5 x 0.5 degree, conform to IMAGE.

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