Past, present and future of the global N cycle: from 1960 to 2050

Nitrogen use in the global agro-food system

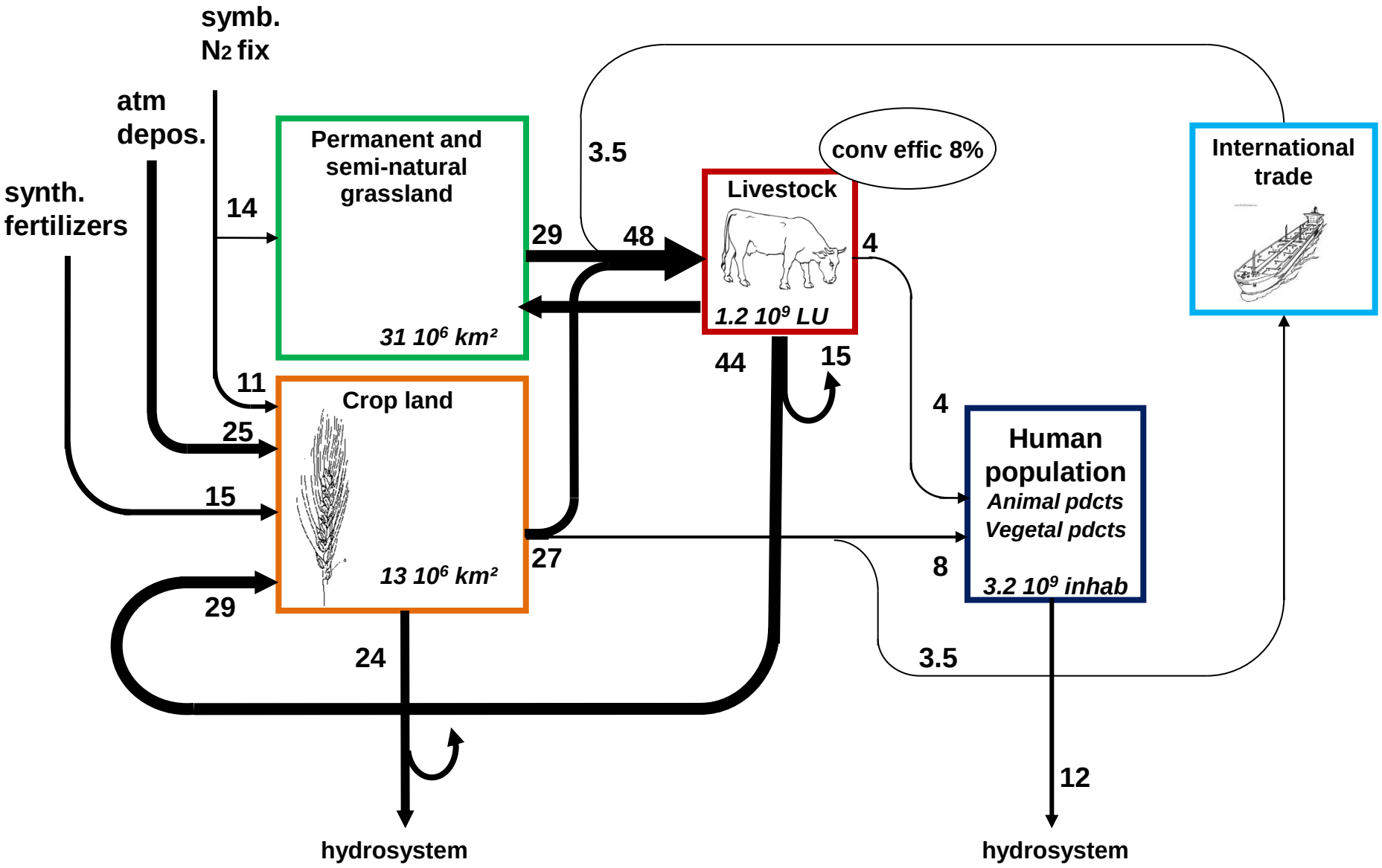
School of Advanced Science on nitrogen cycling, environmental sustainability and climate change

Luis Lassaletta

31 July – 10 August 2016, São Pedro, Sao Paulo – Brazil

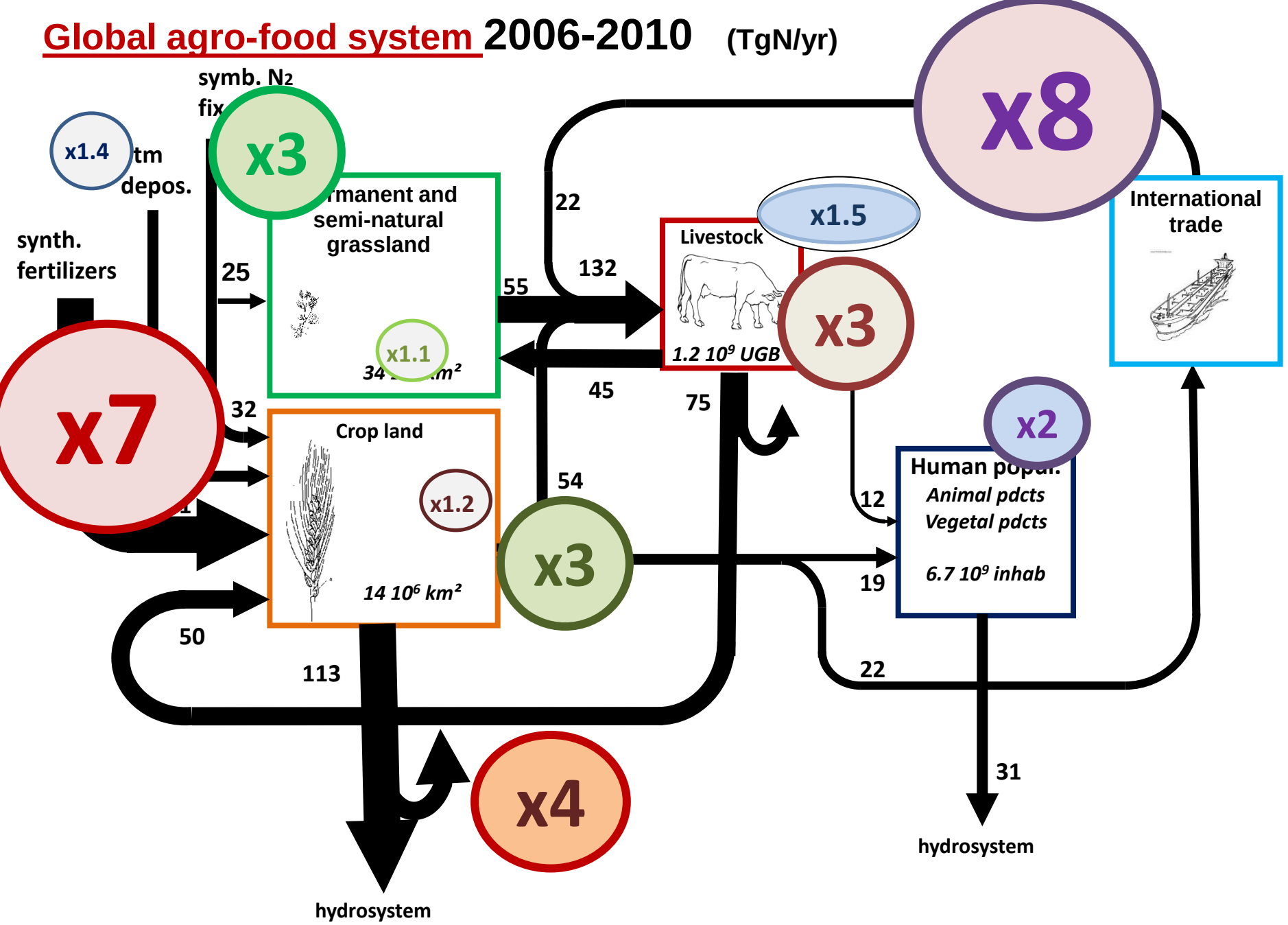
PBL Netherlands Environmental Assessment Agency

Global agro-food system 1961-1965 (TgN/yr)



Billen et al. 2014 (Global Food Security)

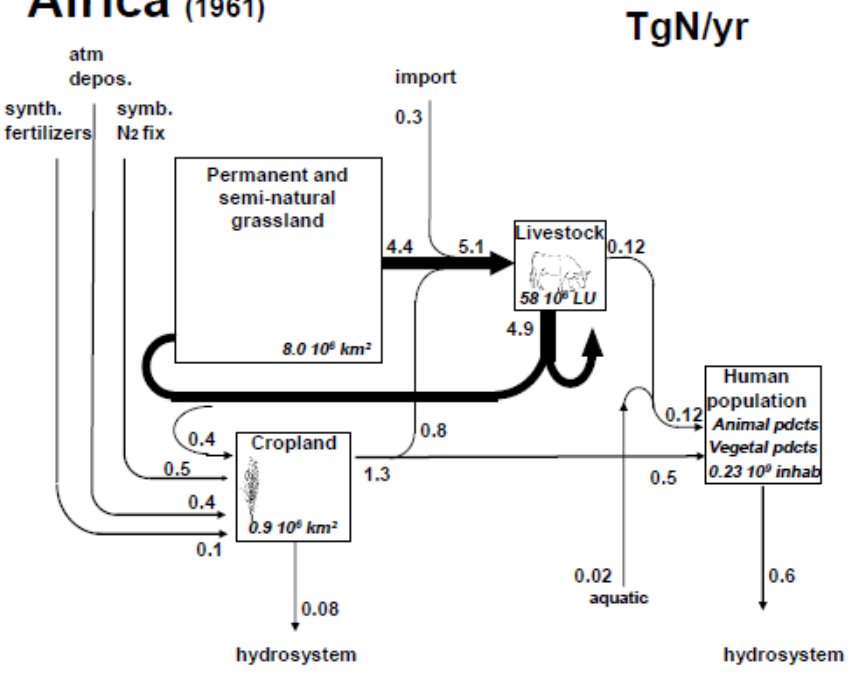
Global agro-food system 2006-2010 (TgN/yr)



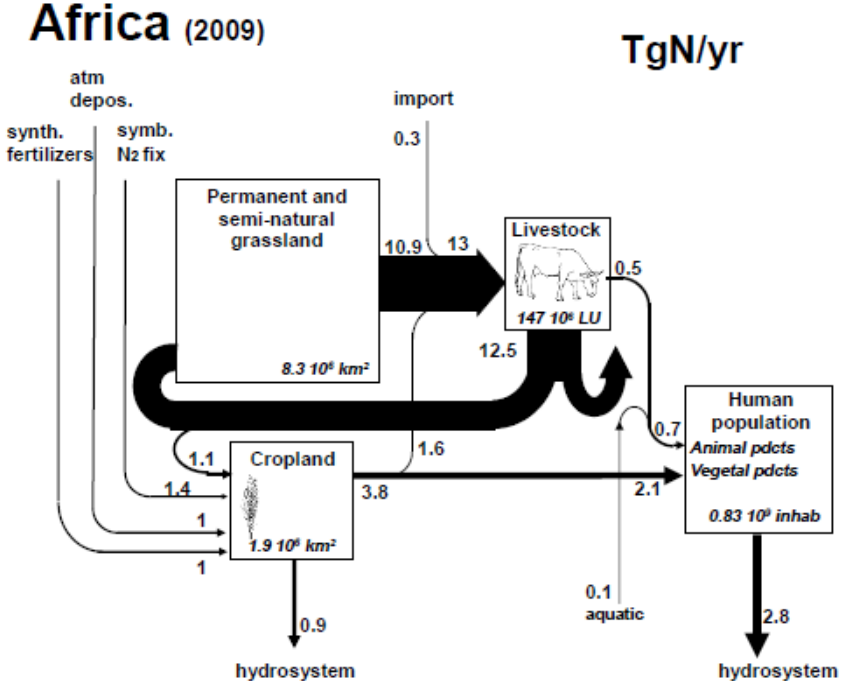
Billen et al. (Global Food Security)

Regional approaches

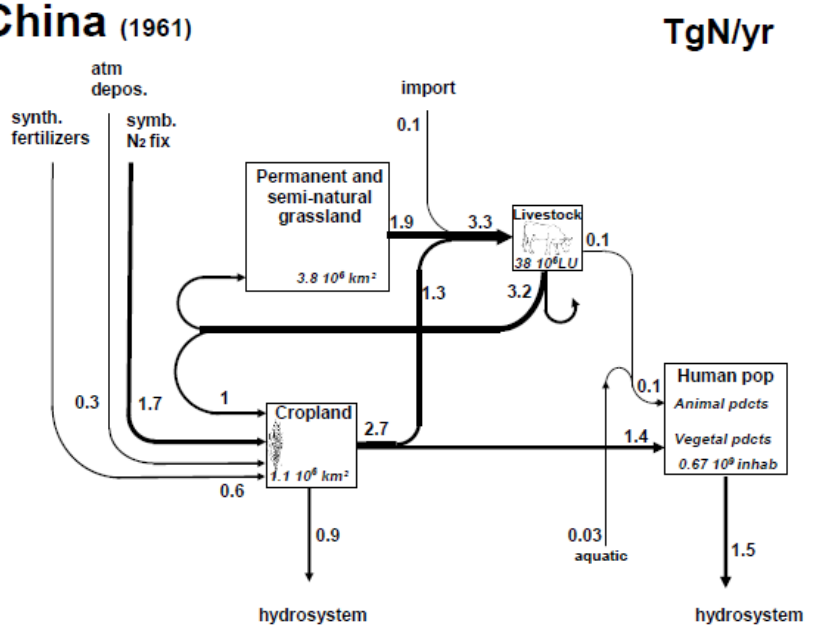
Africa (1961)



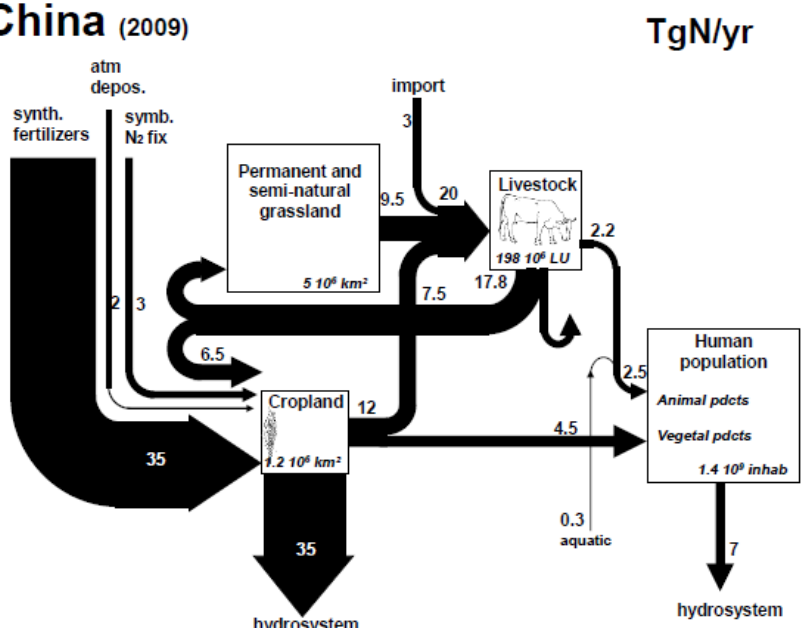
Africa (2009)



China (1961)

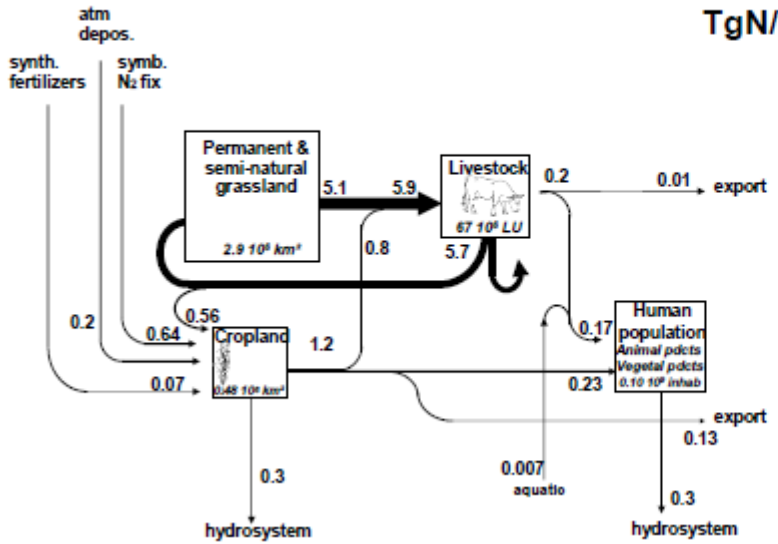


China (2009)



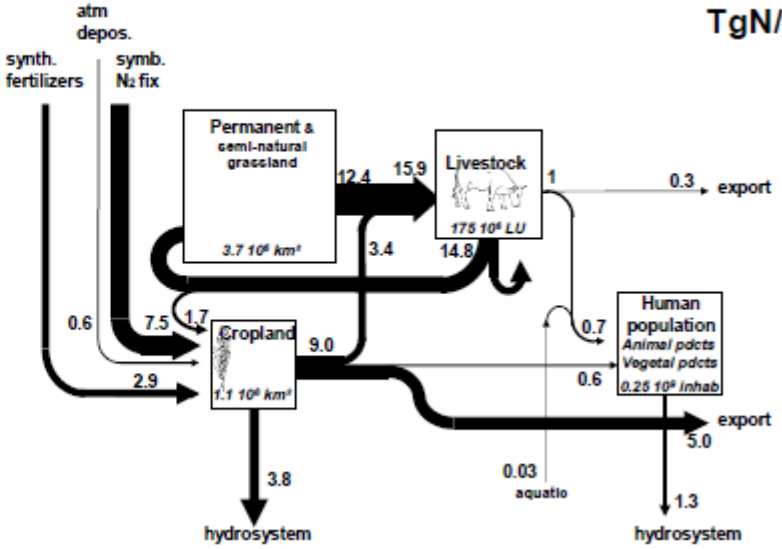
South American Soy countries (1961)

TgN/yr



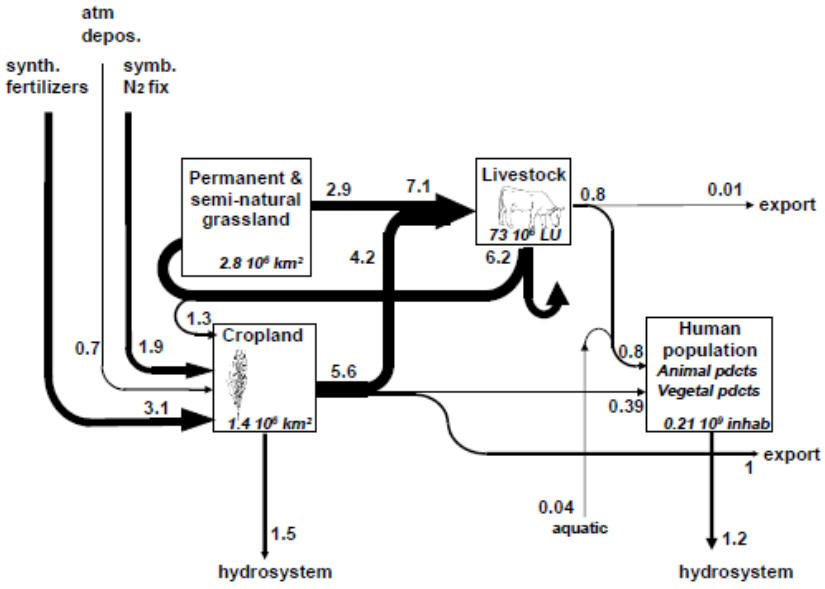
South American Soy countries (2009)

TgN/yr



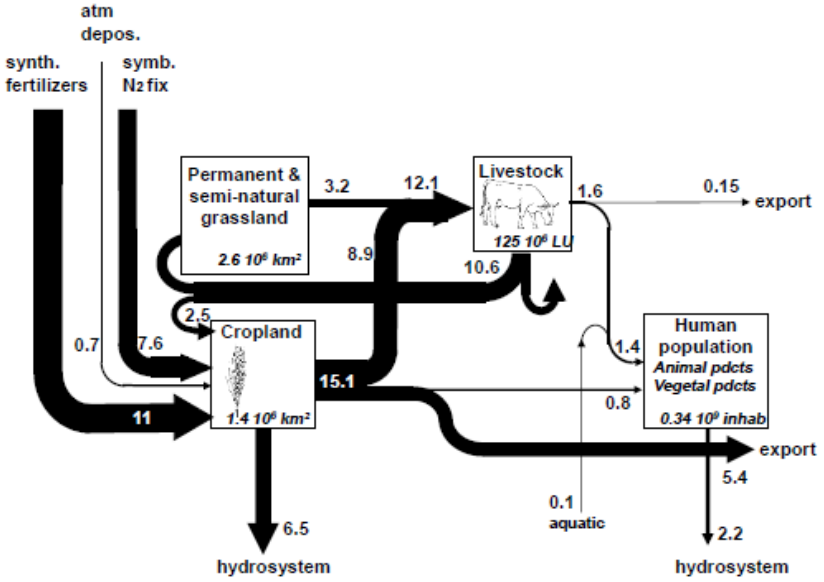
North America (1961)

TgN/yr



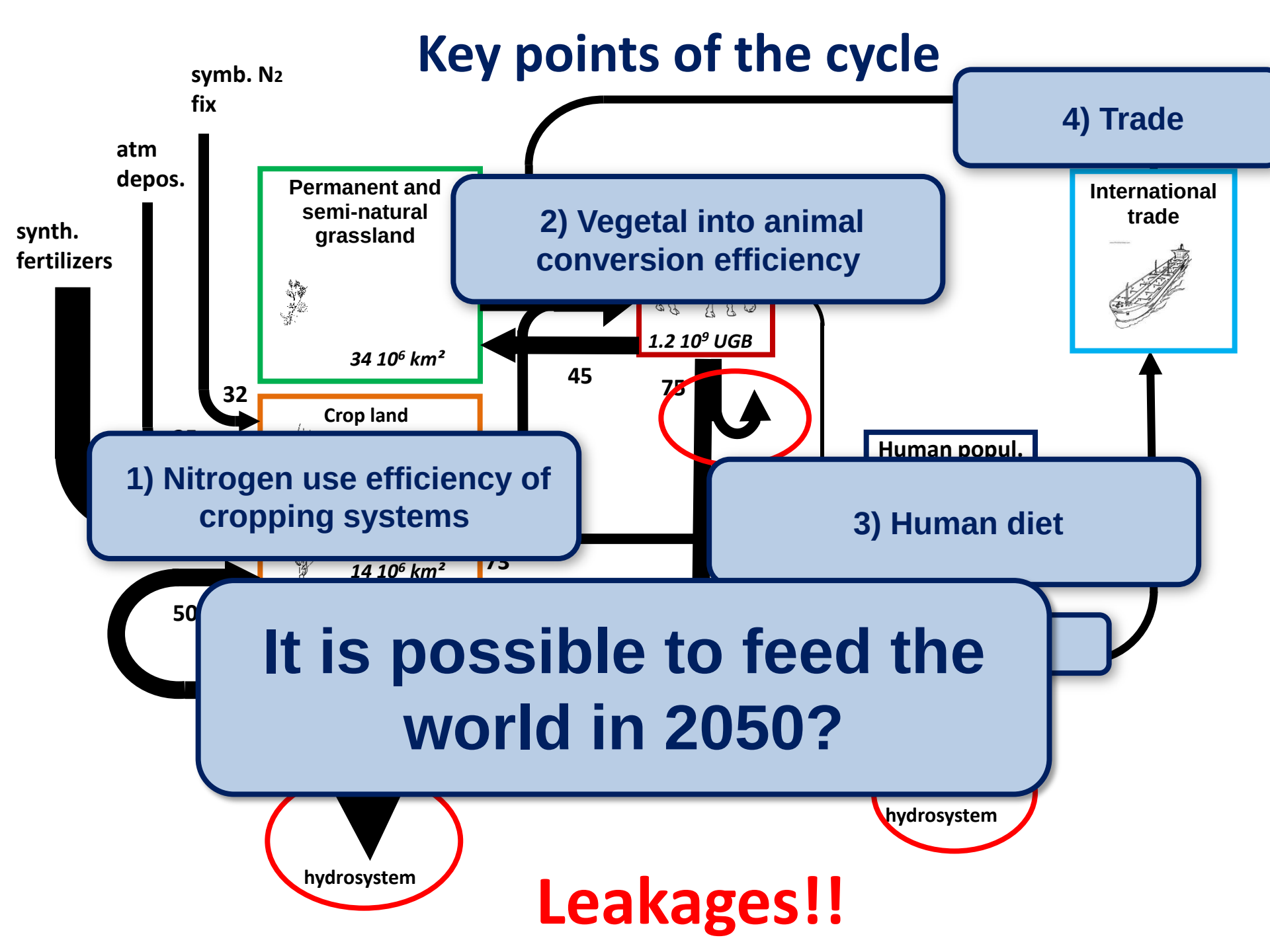
North America (2009)

TgN/yr



Lassaletta et al (Under review) Env. Res. Letters

Key points of the cycle



1) Nitrogen use efficiency of cropping systems

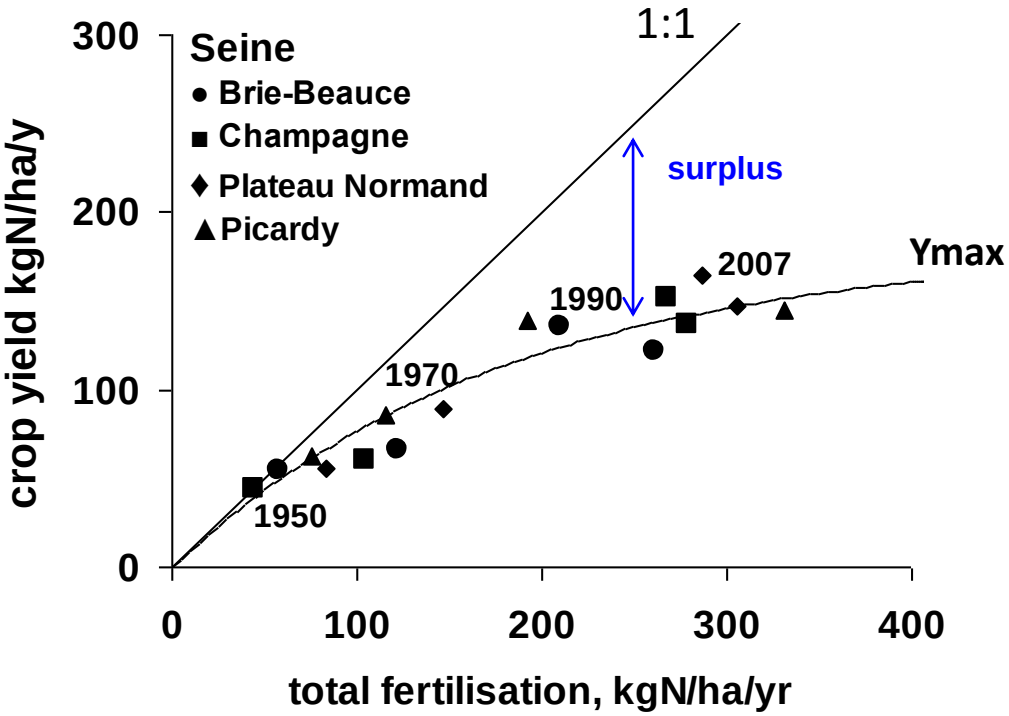
Crop production vs total fertilization relationship

$$\text{Crop prod} = Ymax\,[fert / (fert + Ymax)]$$

Integrated over the whole crop rotation cycle

Total fertilization

Max yield



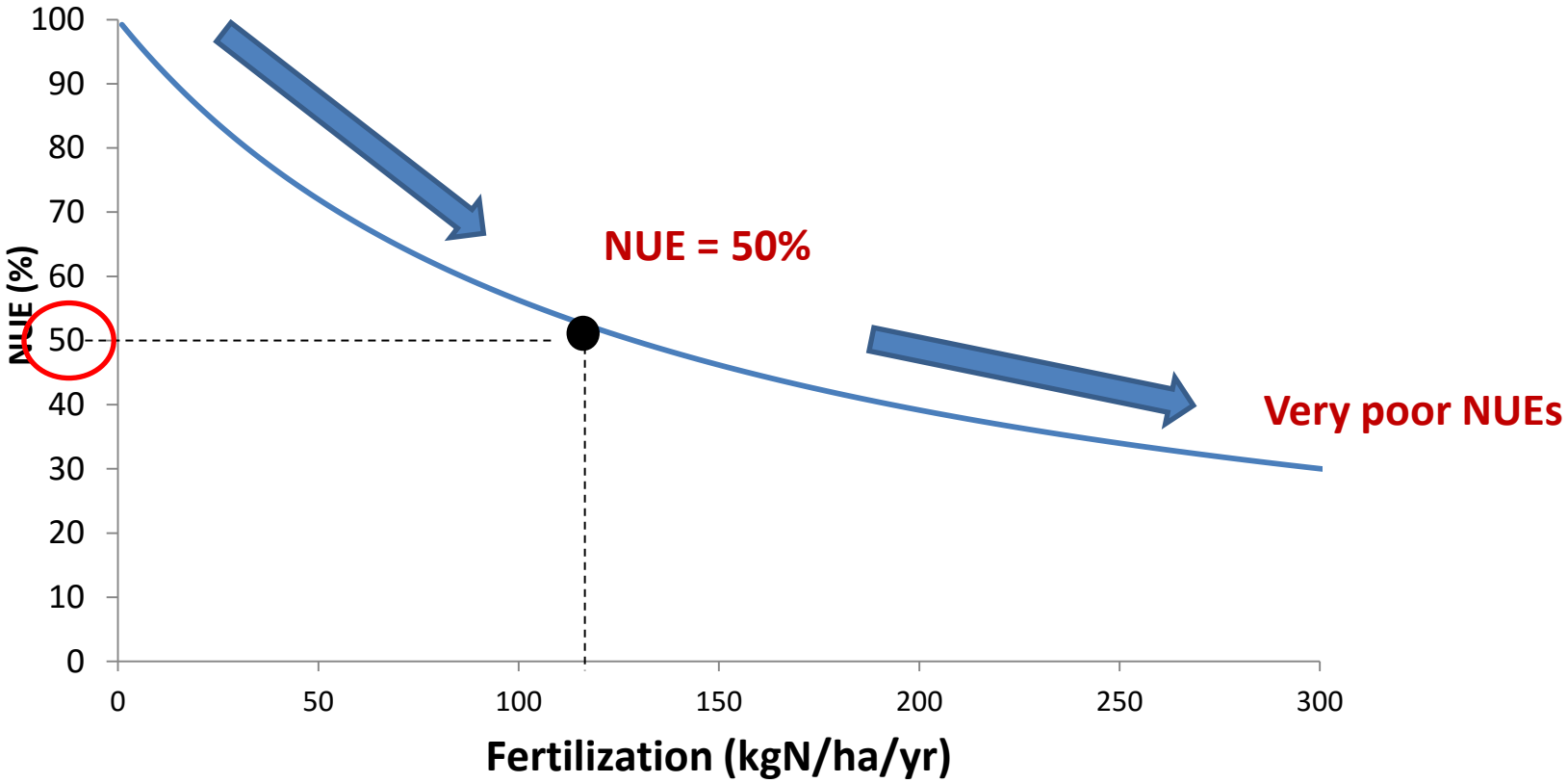
Billen et al. (Phil Trans Roy Soc B)

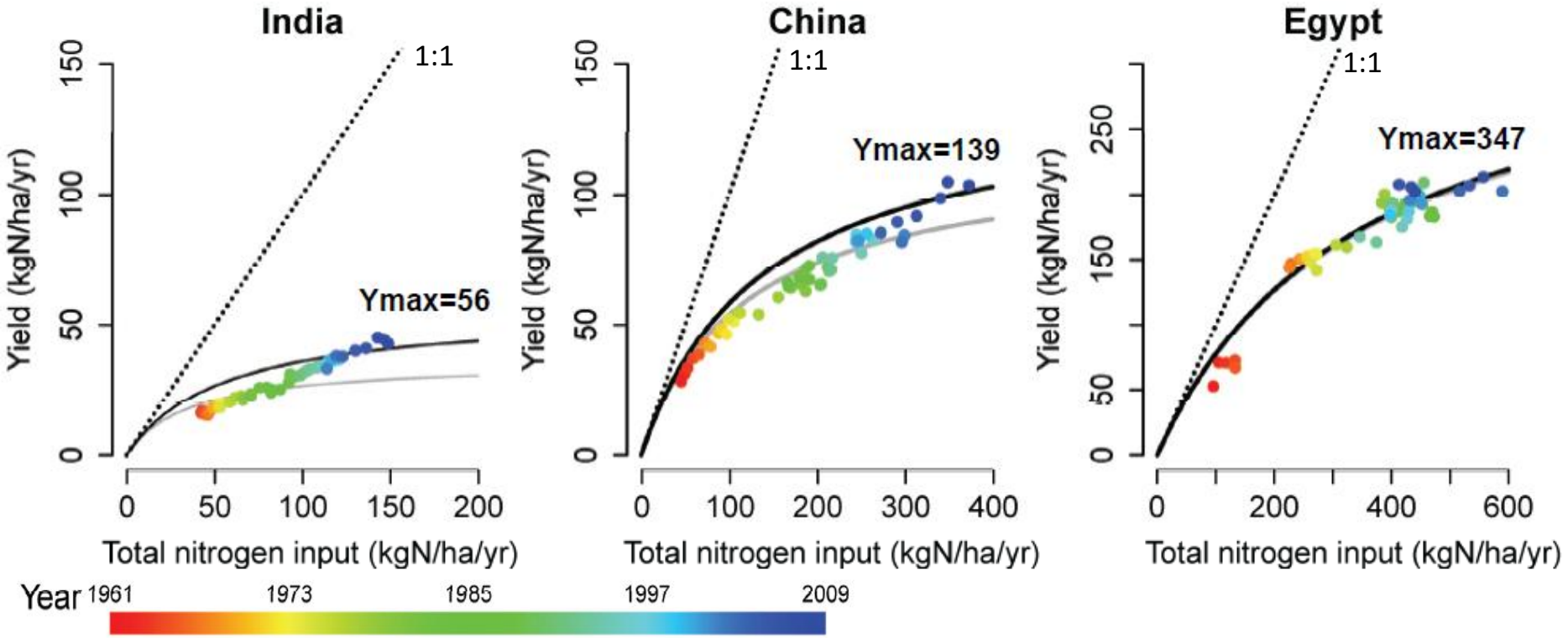
Total fertilization
- Synthetic ferlizer
- Crop N fixation
- Manure
- Atmospheric deposition

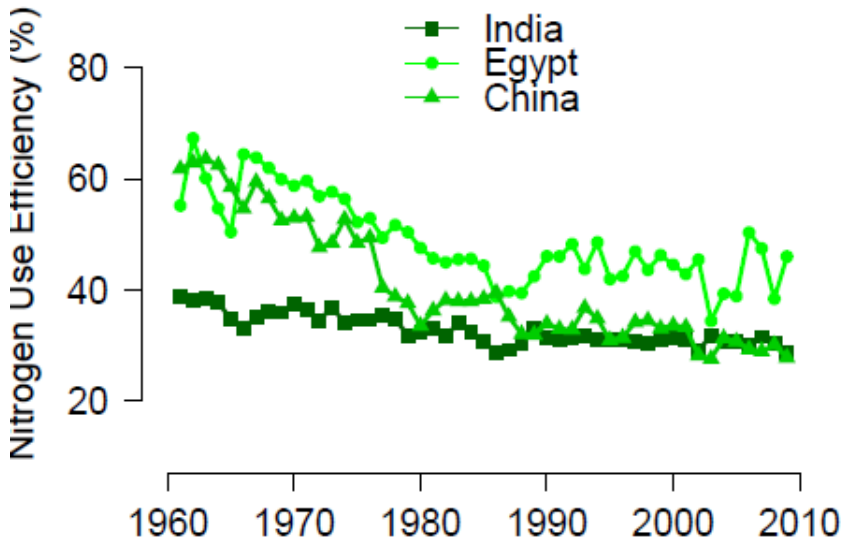
Outputs: kgN/ha

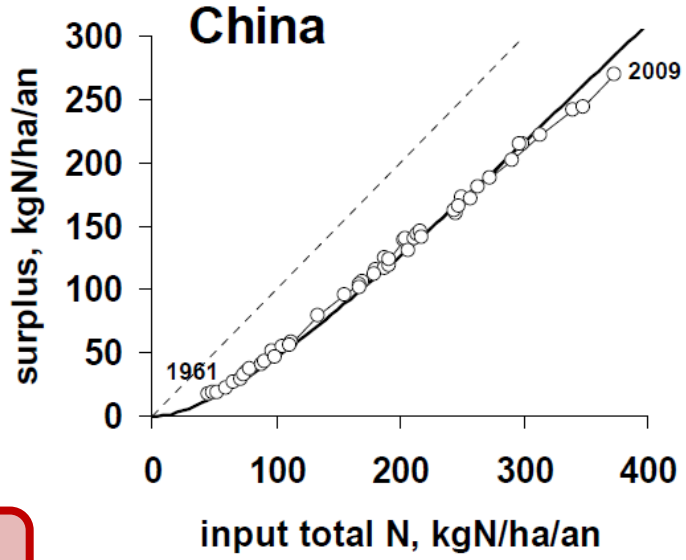
Surpluses: kgN/ha

N.U.E. = Nitrogen exported from field in crop products / Nitrogen fertilization


100
90
80
70
60
50
40
30
20
10
0
NUE (%)
0
50
100
150
200
250
300
Fertilization (kgN/ha/yr)
NUE = 50%
Very poor NUEs

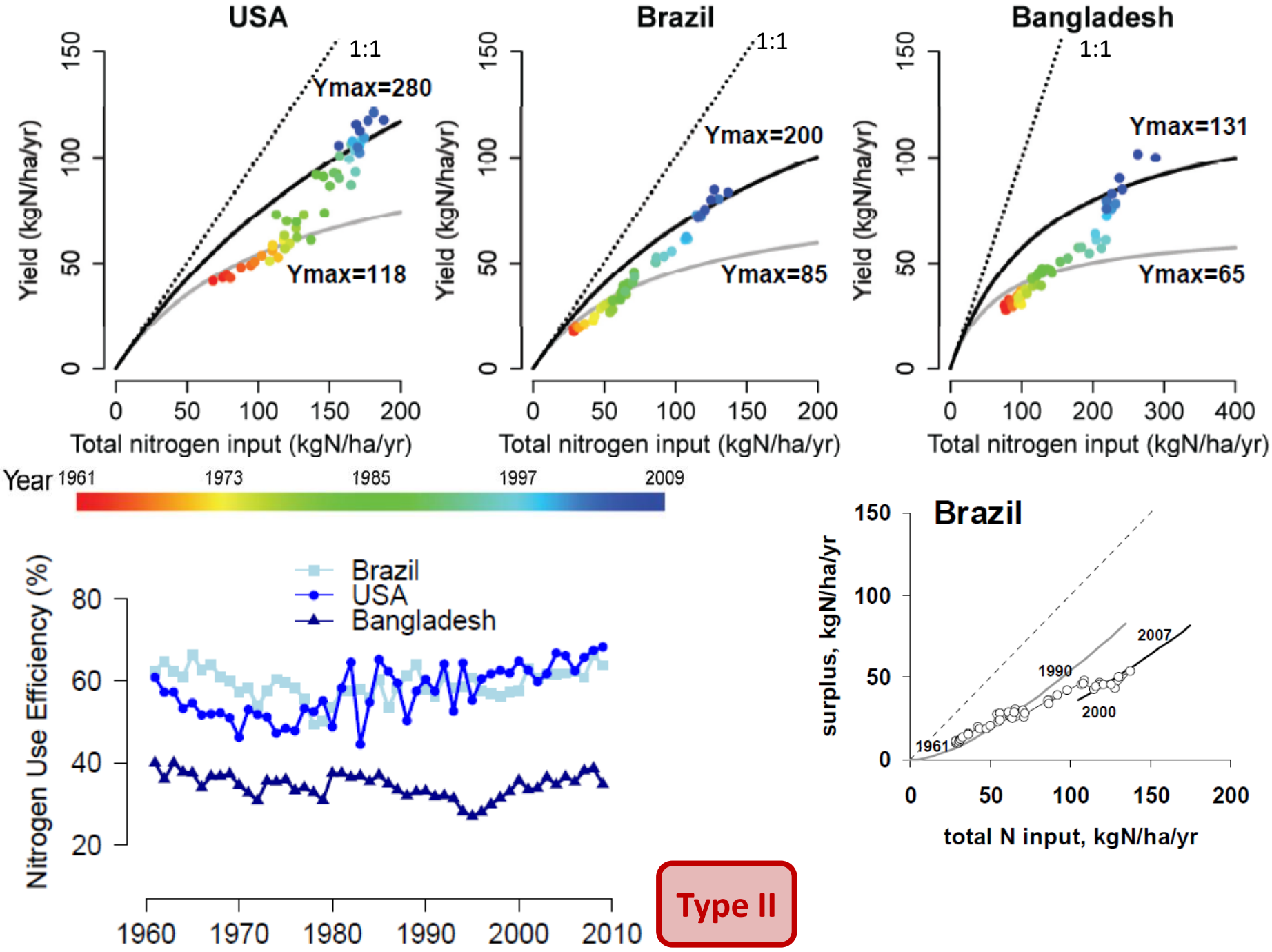


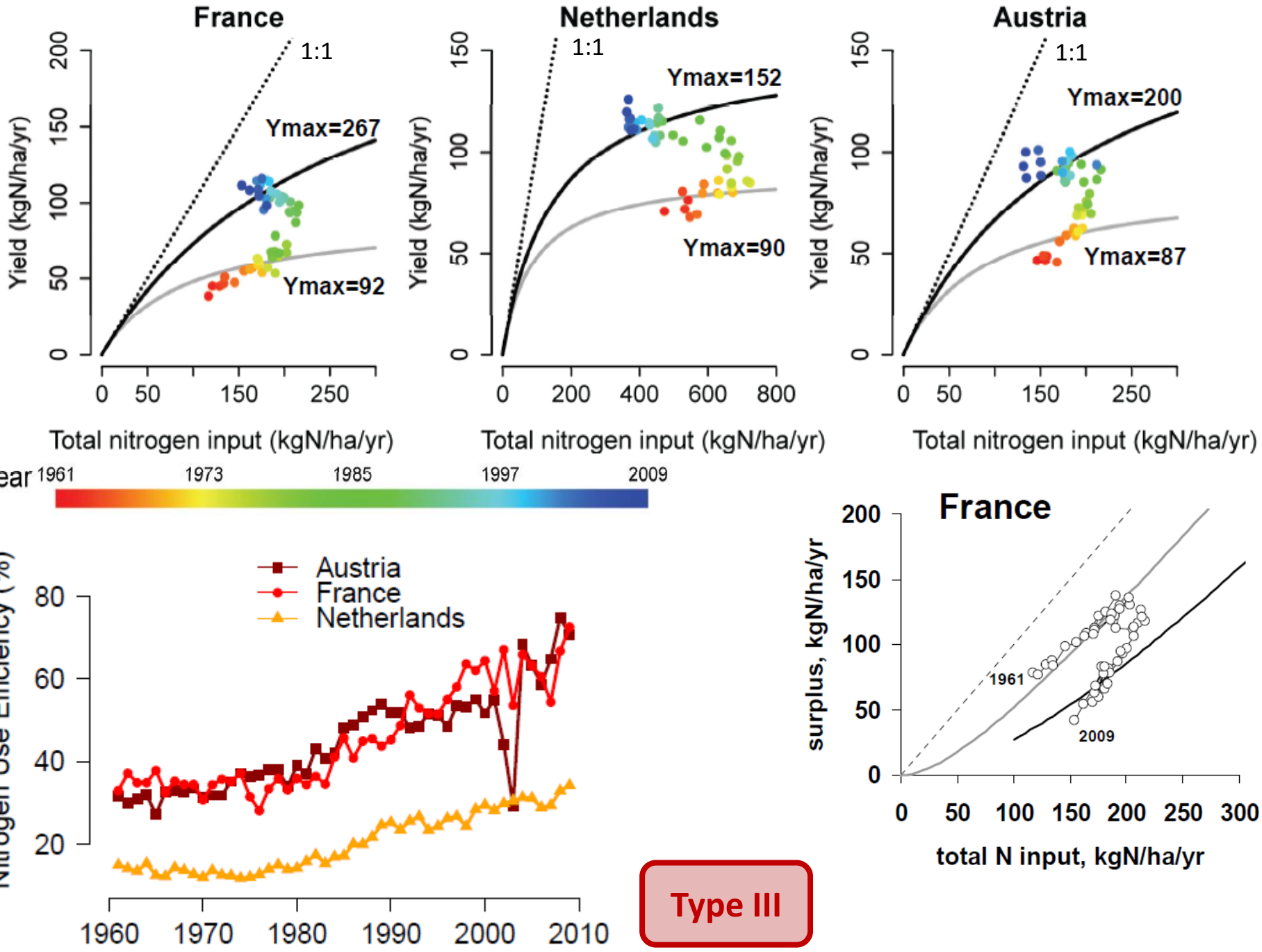


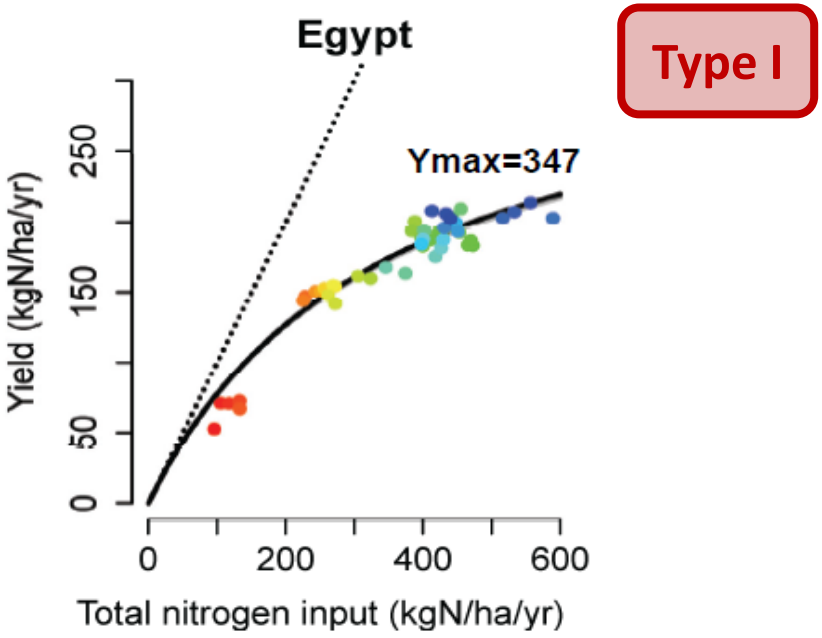


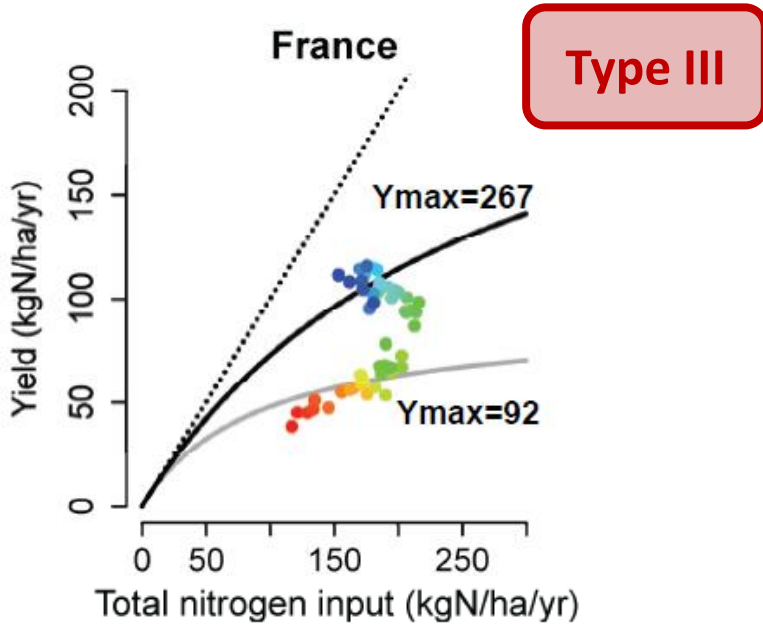
Type I

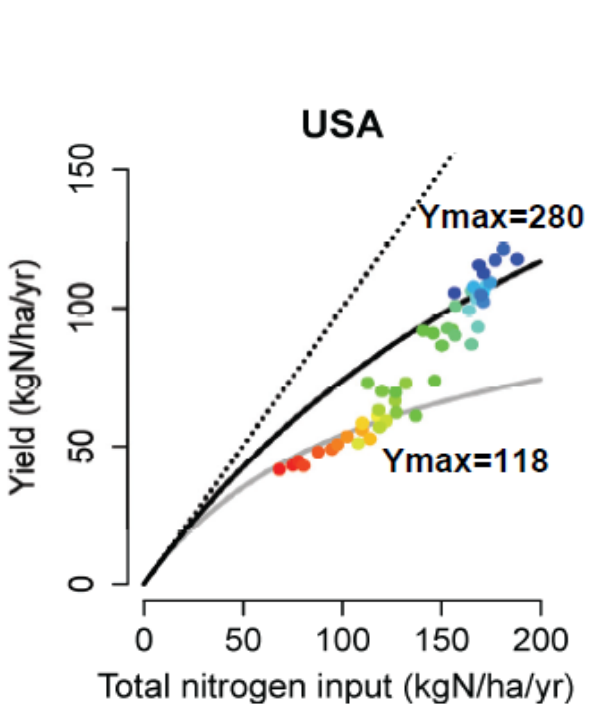
Lassaletta et al. 2014 (Env. Res. Letters)

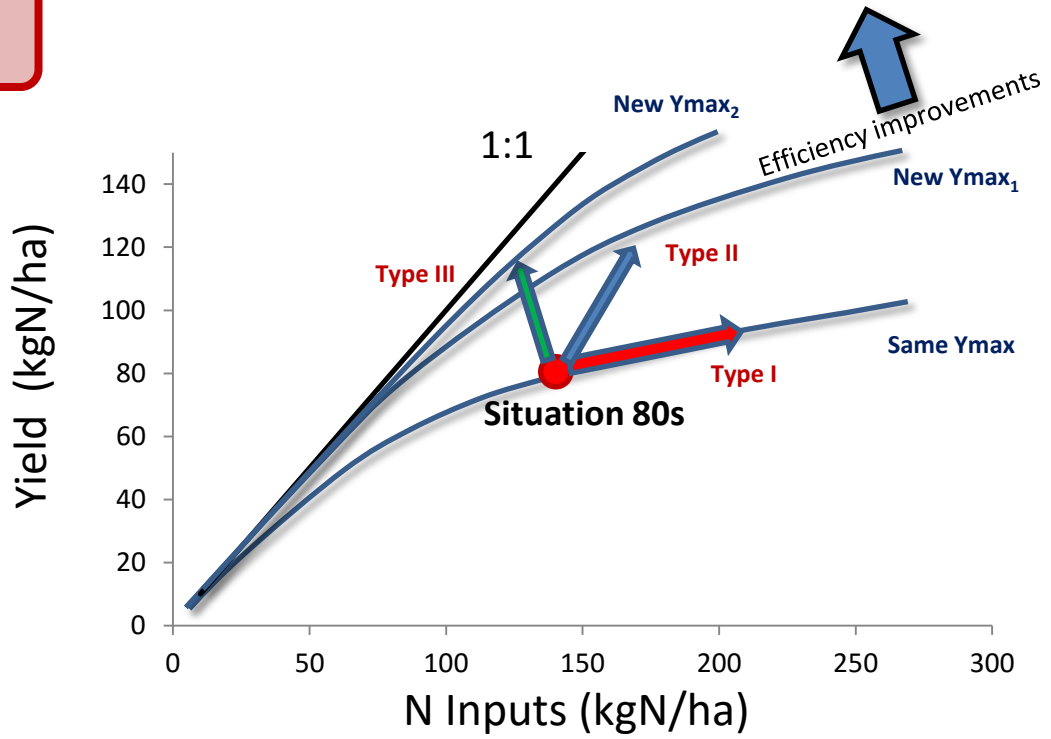

USA
Brazil
Bangladesh
1:1
Ymax=280
Ymax=118
Ymax=200
Ymax=85
Ymax=131
Ymax=65
Yield (kgN/ha/yr)
Total nitrogen input (kgN/ha/yr)
Year
1961
1973
1985
1997
2009
Nitrogen Use Efficiency (%)
Brazil
USA
Bangladesh
surplus, kgN/ha/yr
total N input, kgN/ha/yr
1961
1990
2000
2007
Type II

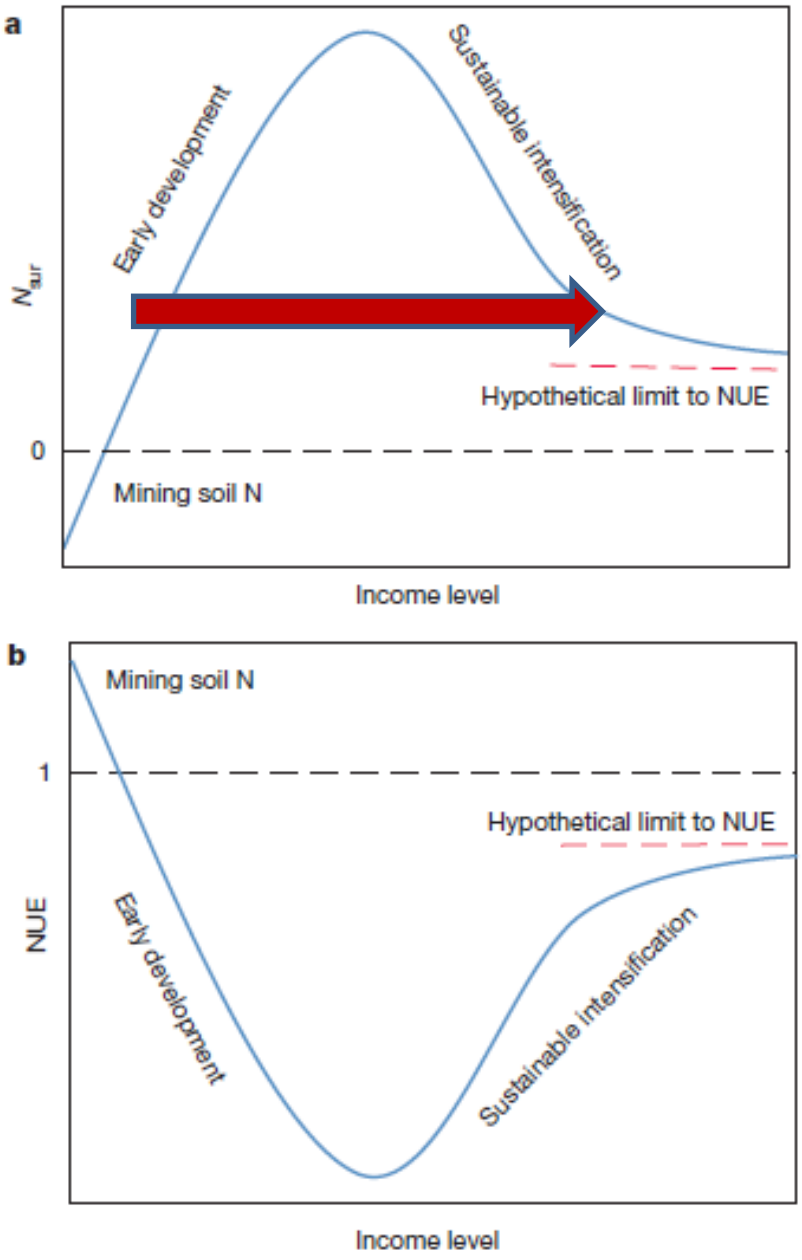

France
1:1
Ymax=267
Ymax=92
Yield (kgN/ha/yr)
Total nitrogen input (kgN/ha/yr)
Netherlands
1:1
Ymax=152
Ymax=90
Yield (kgN/ha/yr)
Total nitrogen input (kgN/ha/yr)
Austria
1:1
Ymax=200
Ymax=87
Yield (kgN/ha/yr)
Total nitrogen input (kgN/ha/yr)
Year 1961 1973 1985 1997 2009
Austria
France
Netherlands
Nitrogen Use Efficiency (%)
France
1961
2009
surplus, kgN/ha/yr
total N input, kgN/ha/yr
Type III


Egypt
Type I
Ymax=347
Yield (kgN/ha/yr)
0
50
150
250
0
200
400
600
Total nitrogen input (kgN/ha/yr)


France
Type III
Ymax=267
Ymax=92
Yield (kgN/ha/yr)
0
50
100
150
200
0
50
150
250
Total nitrogen input (kgN/ha/yr)

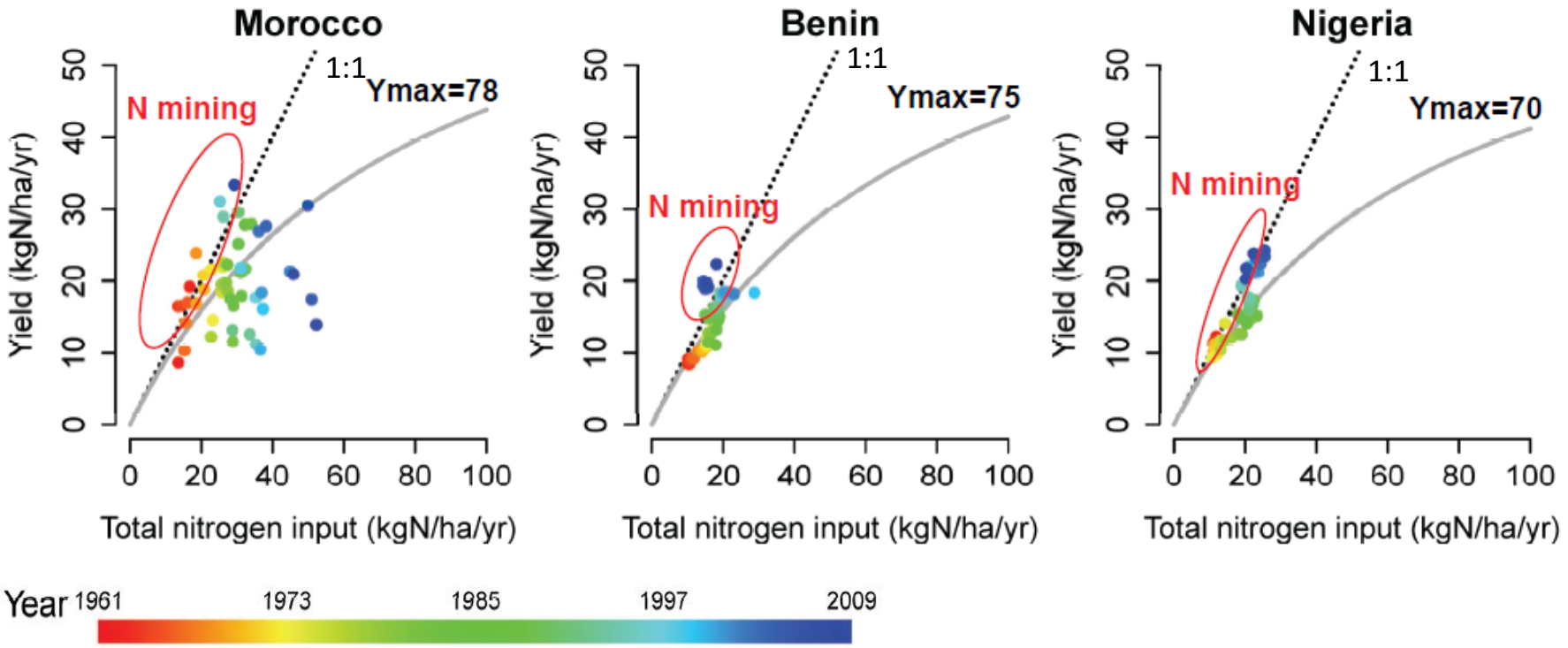

USA
Type II
Ymax=280
Ymax=118
Yield (kgN/ha/yr)
0
50
100
150
0
50
100
150
200
Total nitrogen input (kgN/ha/yr)


1:1
New Ymax2
Efficiency improvements
New Ymax1
Type III
Type II
Same Ymax
Type I
Situation 80s
Yield (kgN/ha)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
N Inputs (kgN/ha)



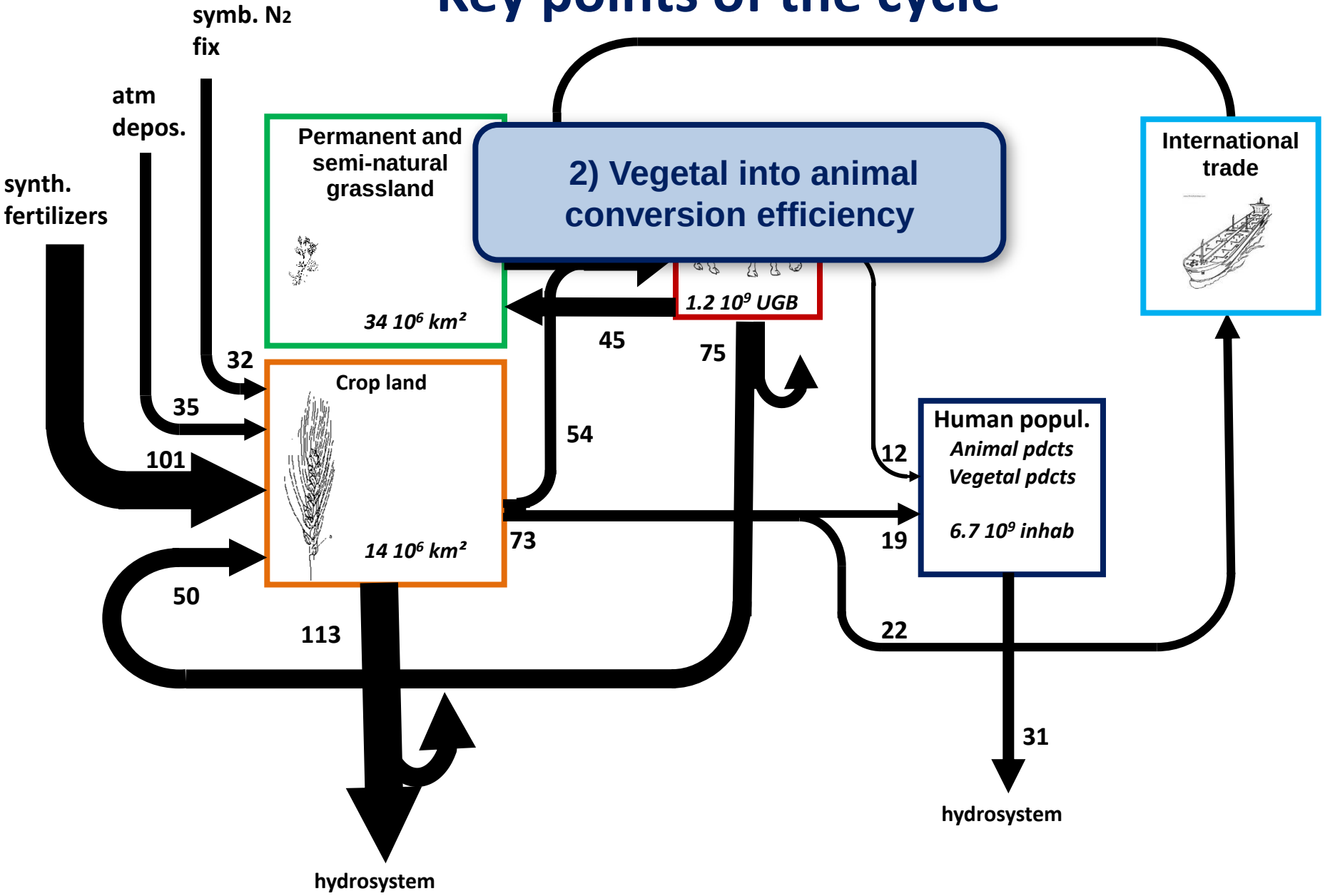
Is it posible to build the tunnel???

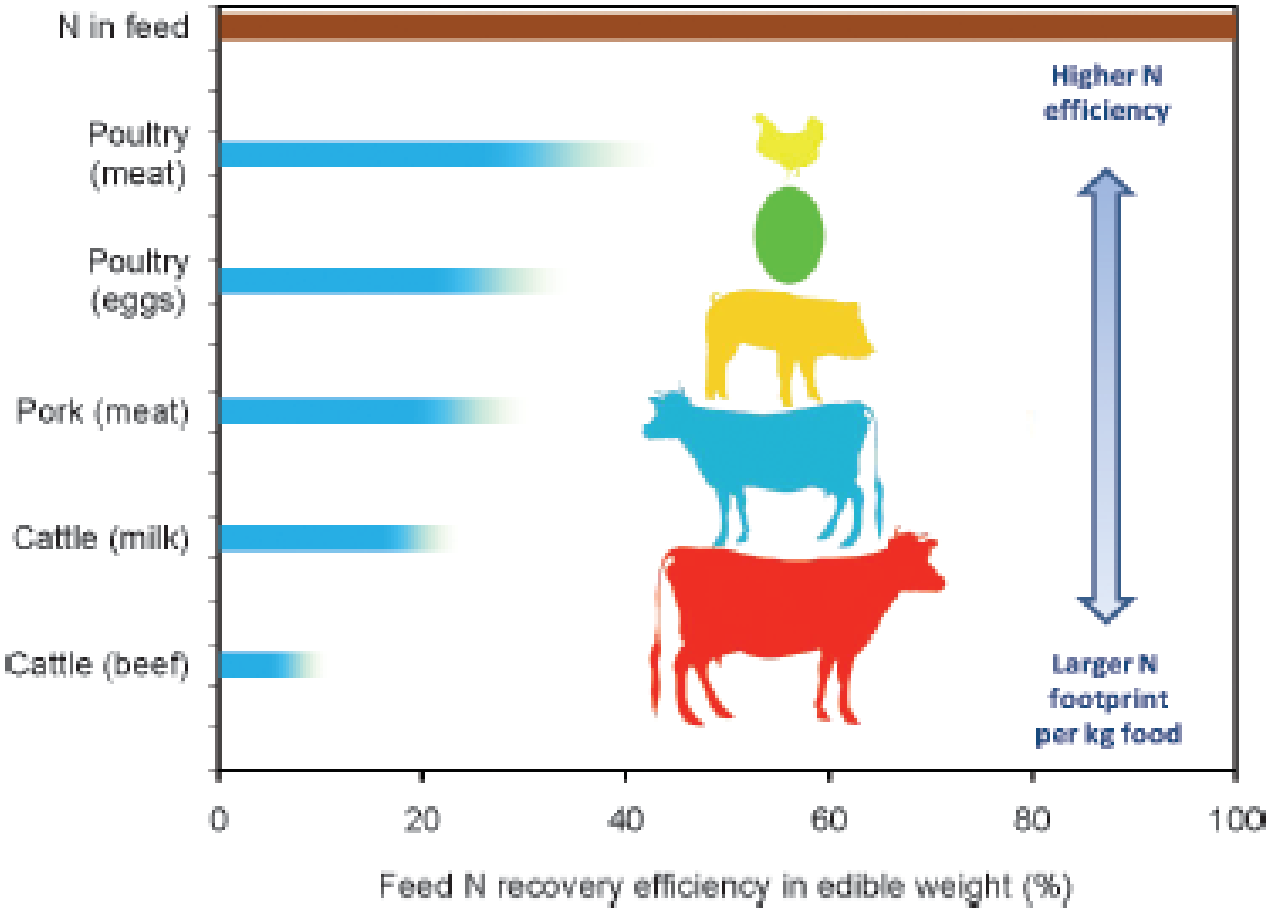
Zhang et al. 2016 (Nature)


Morocco
1:1
Ymax=78
N mining
Yield (kgN/ha/yr)
Total nitrogen input (kgN/ha/yr)
Benin
1:1
Ymax=75
N mining
Yield (kgN/ha/yr)
Total nitrogen input (kgN/ha/yr)
Nigeria
1:1
Ymax=70
N mining
Yield (kgN/ha/yr)
Total nitrogen input (kgN/ha/yr)
Year 1961 1973 1985 1997 2009

Type IV

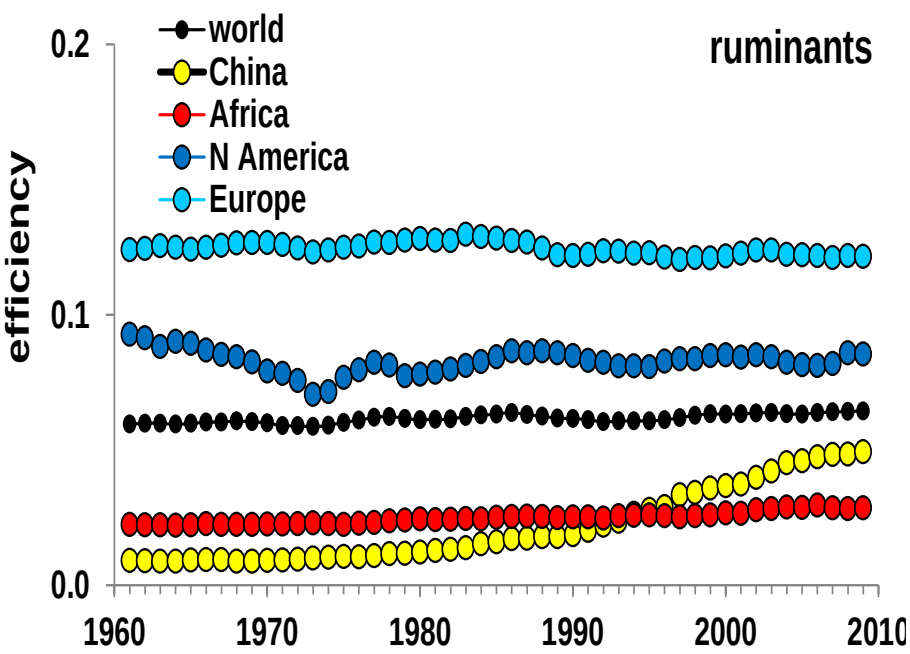
Key points of the cycle

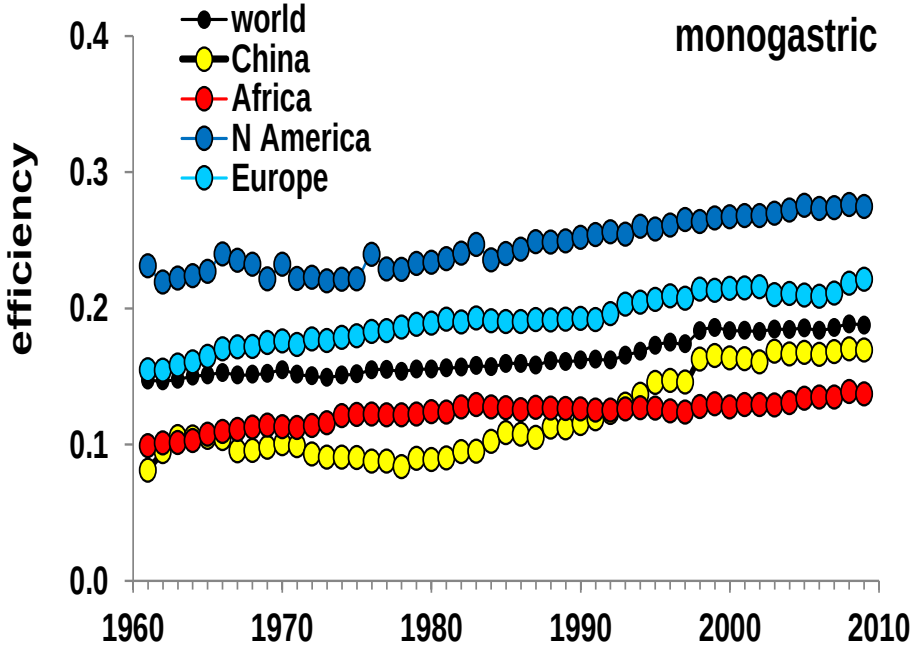




European Nitrogen Assessment (2011)

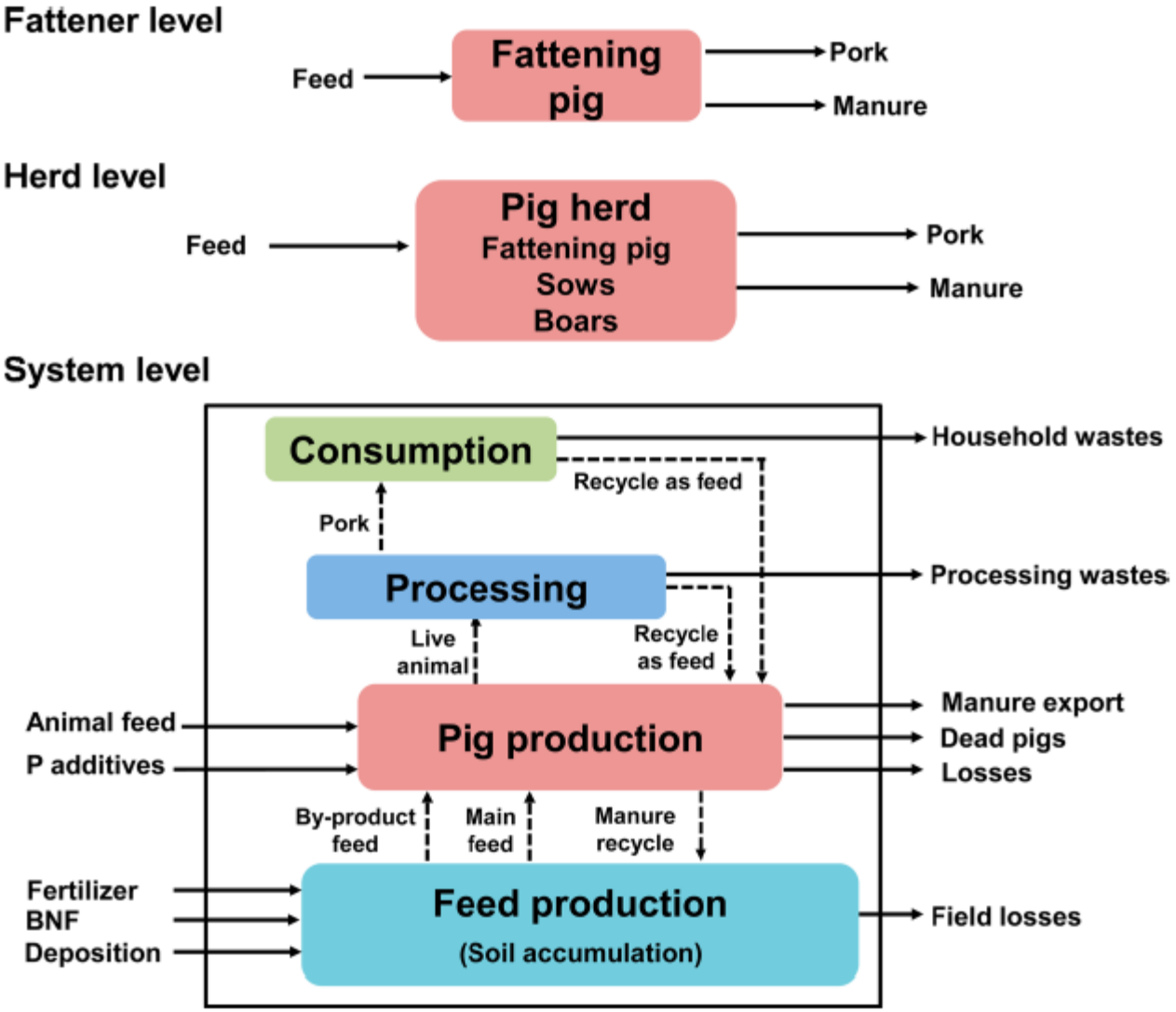
Nitrogen use efficiency of world livestock systems





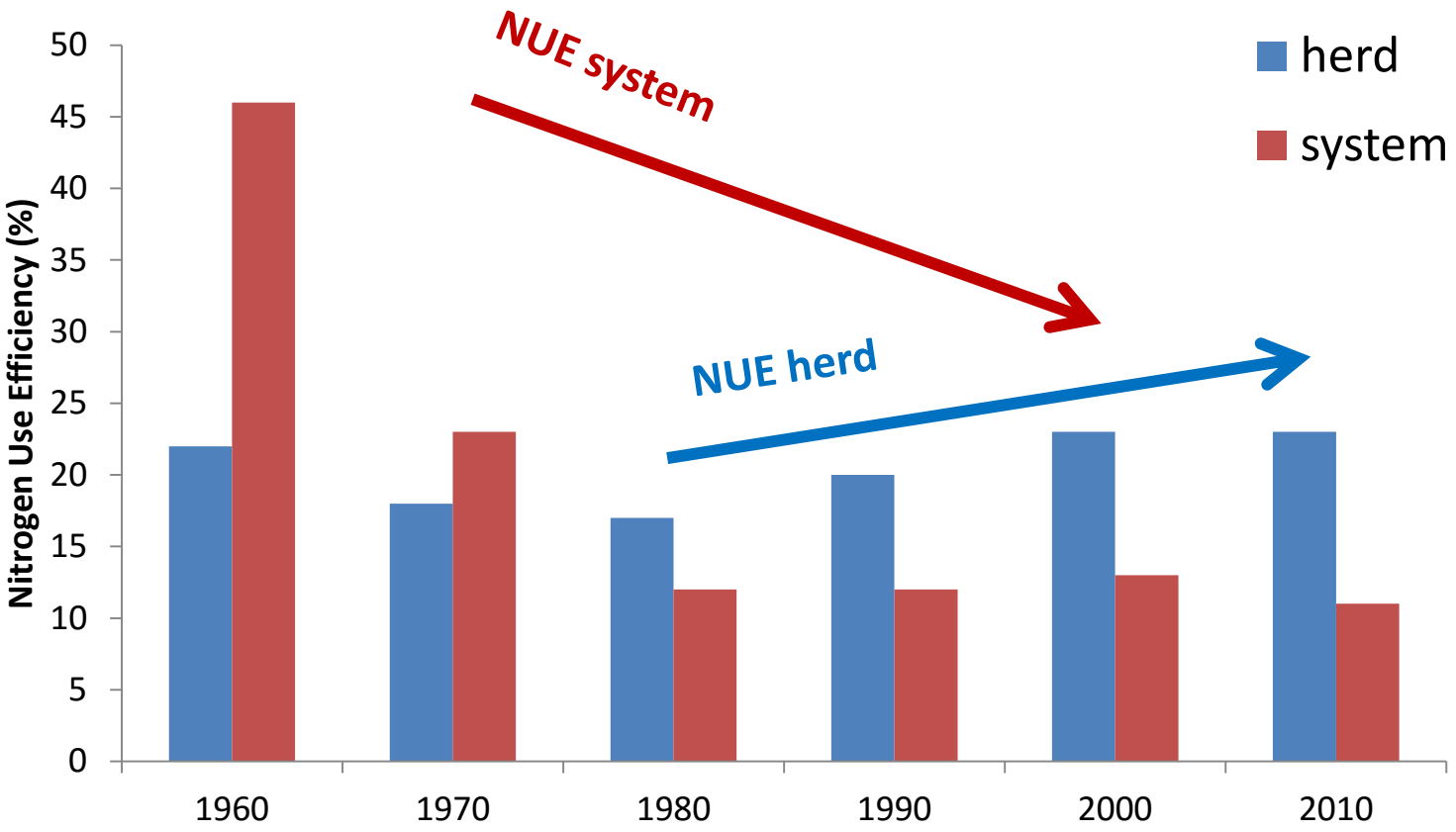
Lassaletta et al (Under review) Env. Res. Letters

Chinese pig production systems



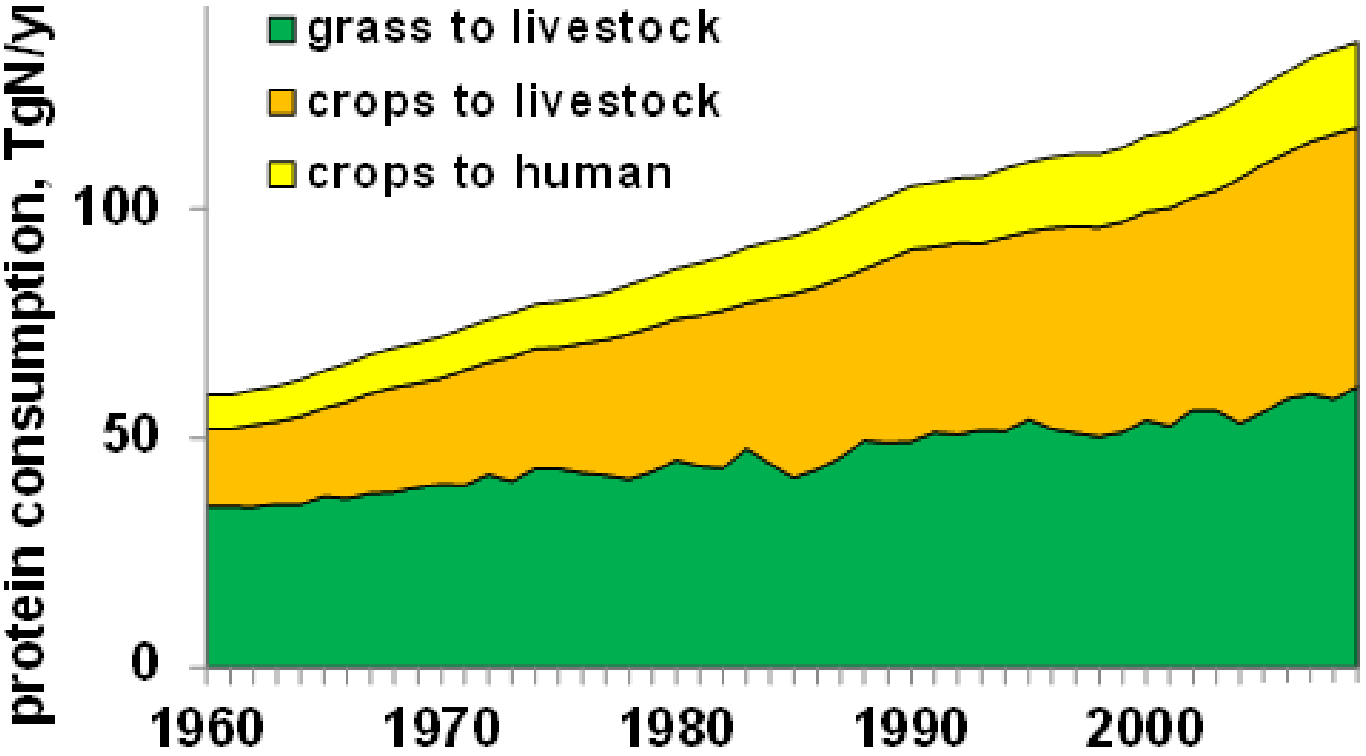
Bai et al. 2014 Envi. Scri Technol

Chinese pig production systems



Bai et al. 2014 Envi. Scri Technol

The fate of the protein produced by wolrd agricultural systems



ca. ¾ of the crop protein production is allocated to livestock systems

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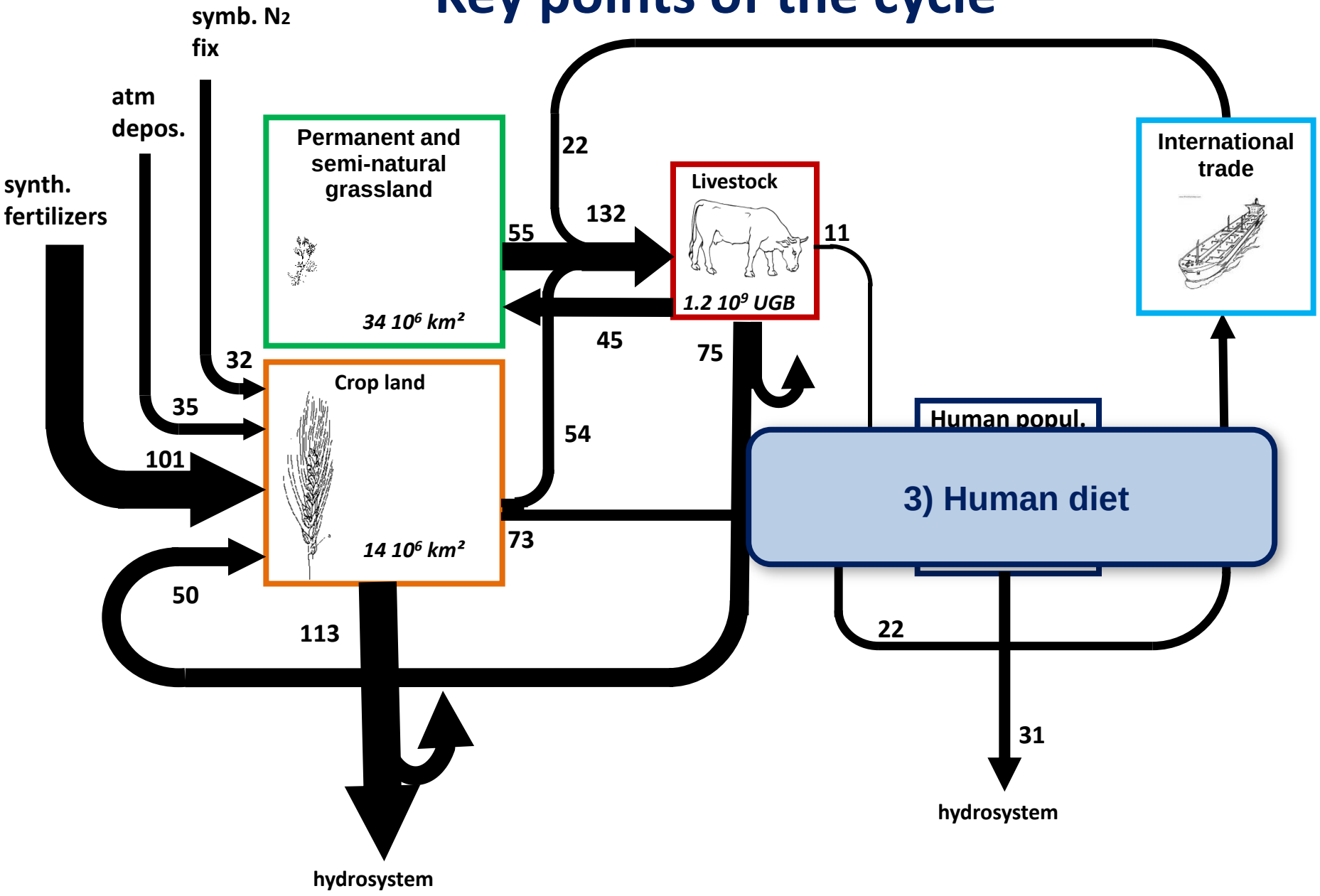
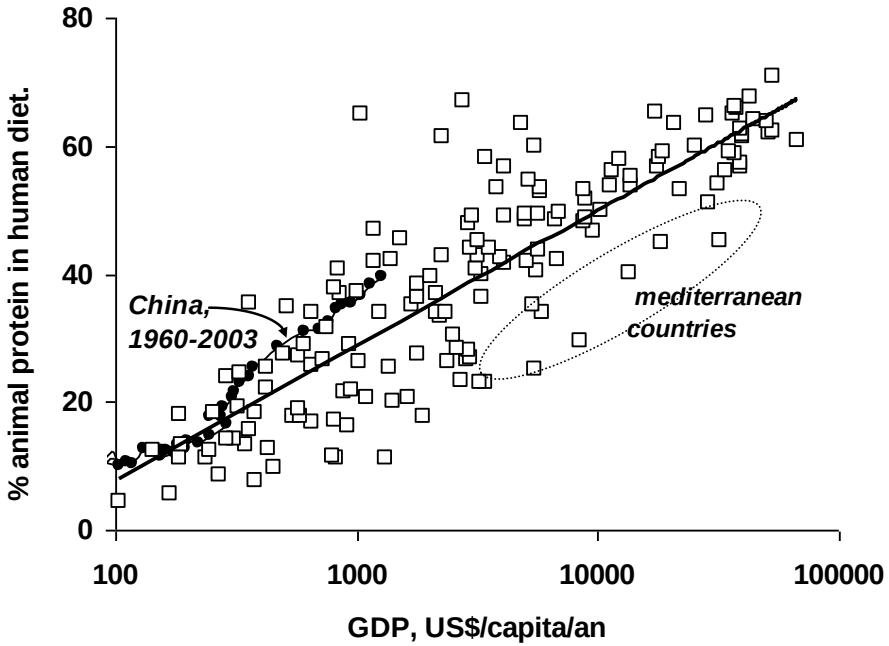
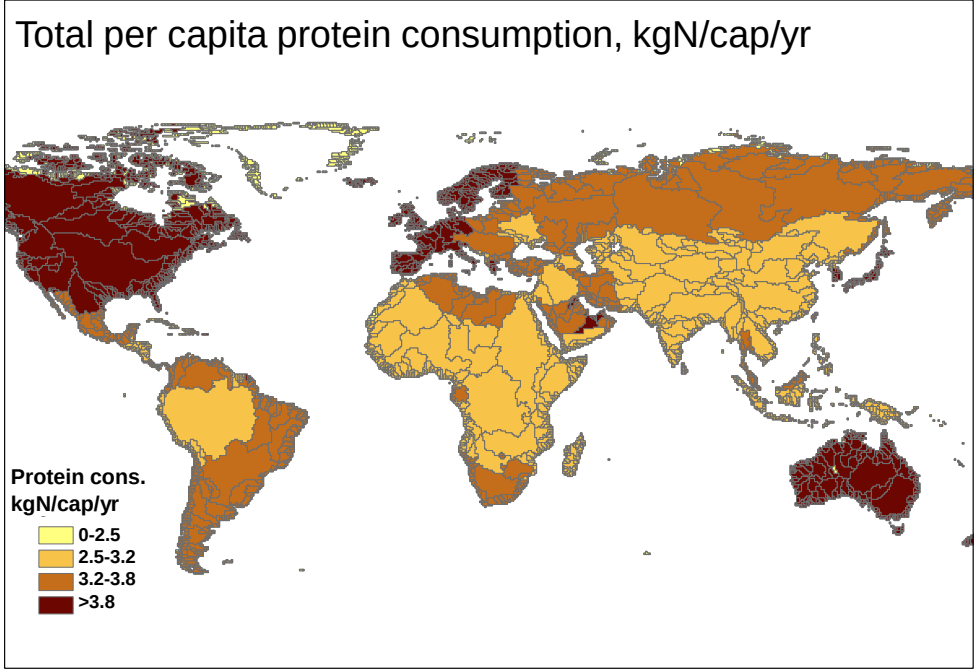
Key points of the cycle

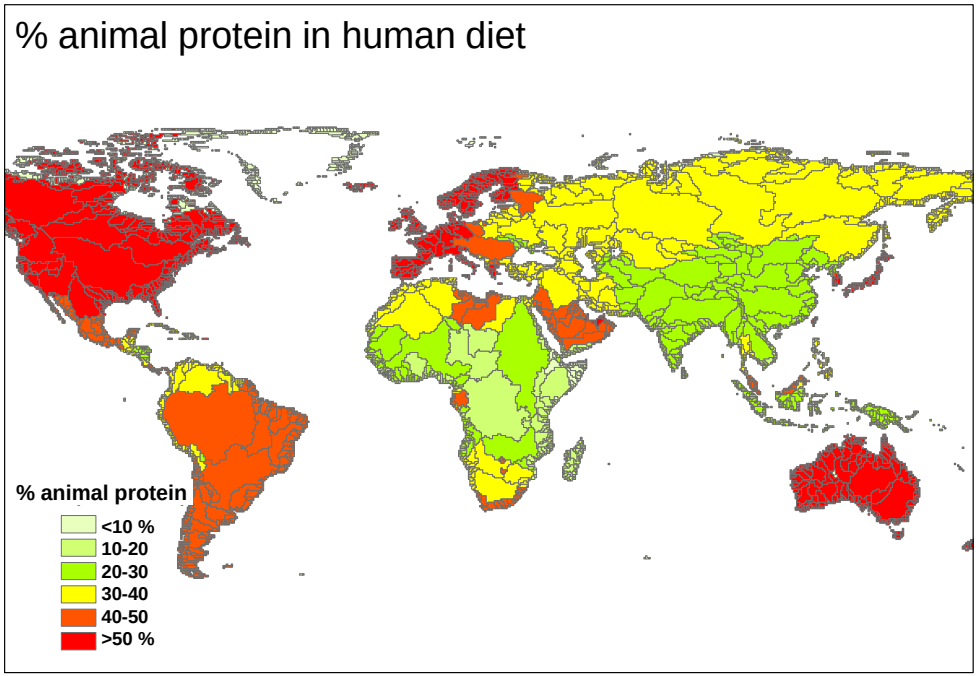


Diets of the world

World distribution and relationship with gross domestic product of the fraction of protein of animal origin in the human diet (FAOstat, 2003).

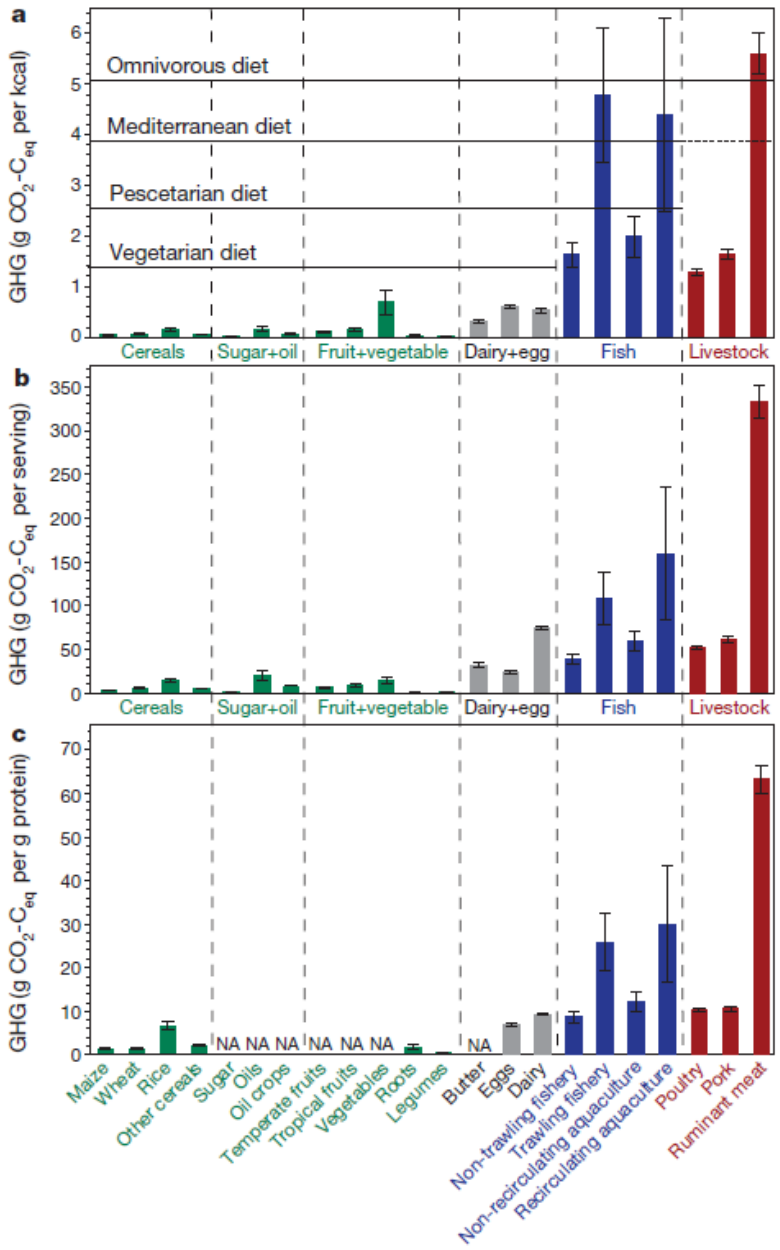




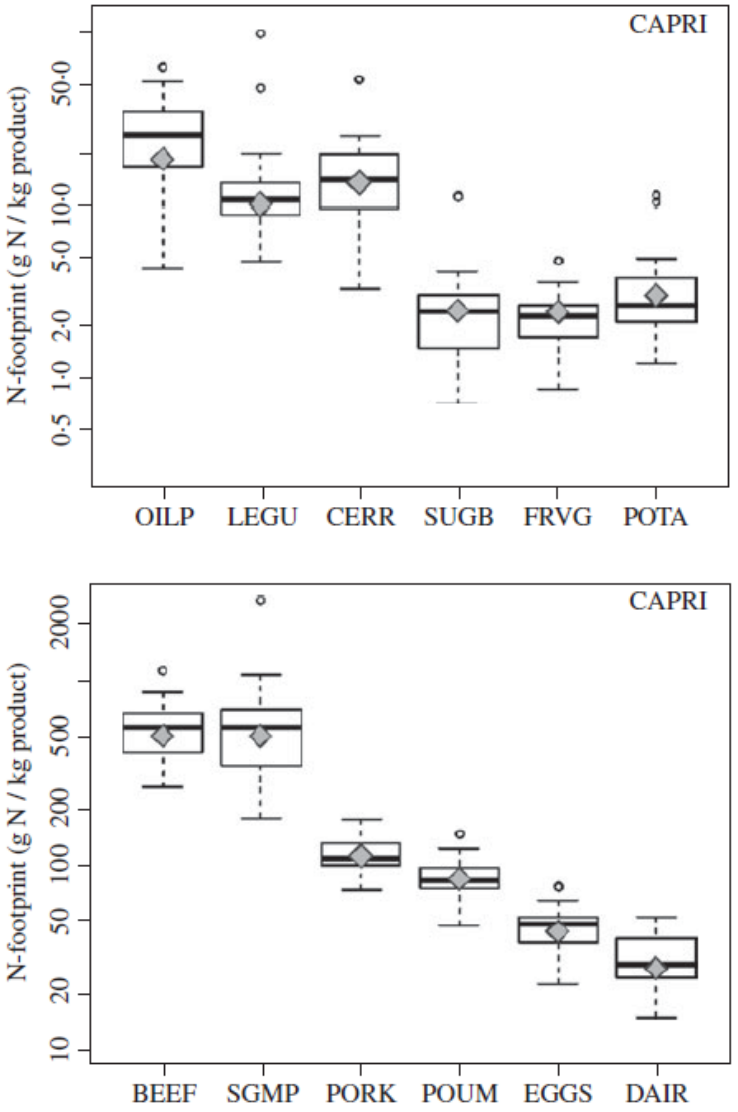


Billen et al. (2013) Phil Trans Roy Soc B

Food products footprints

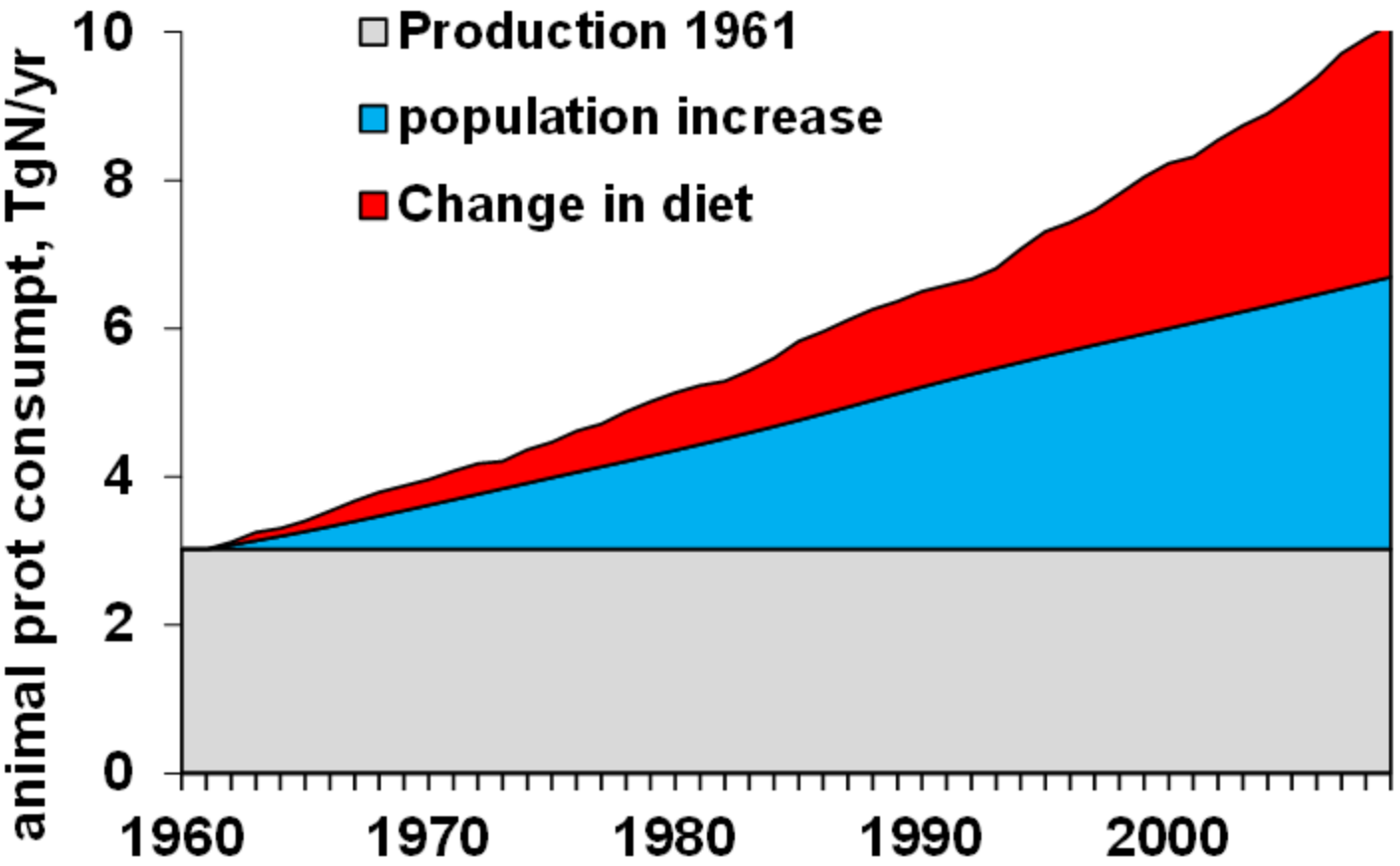


Tilman et al. 2014 (Nature)



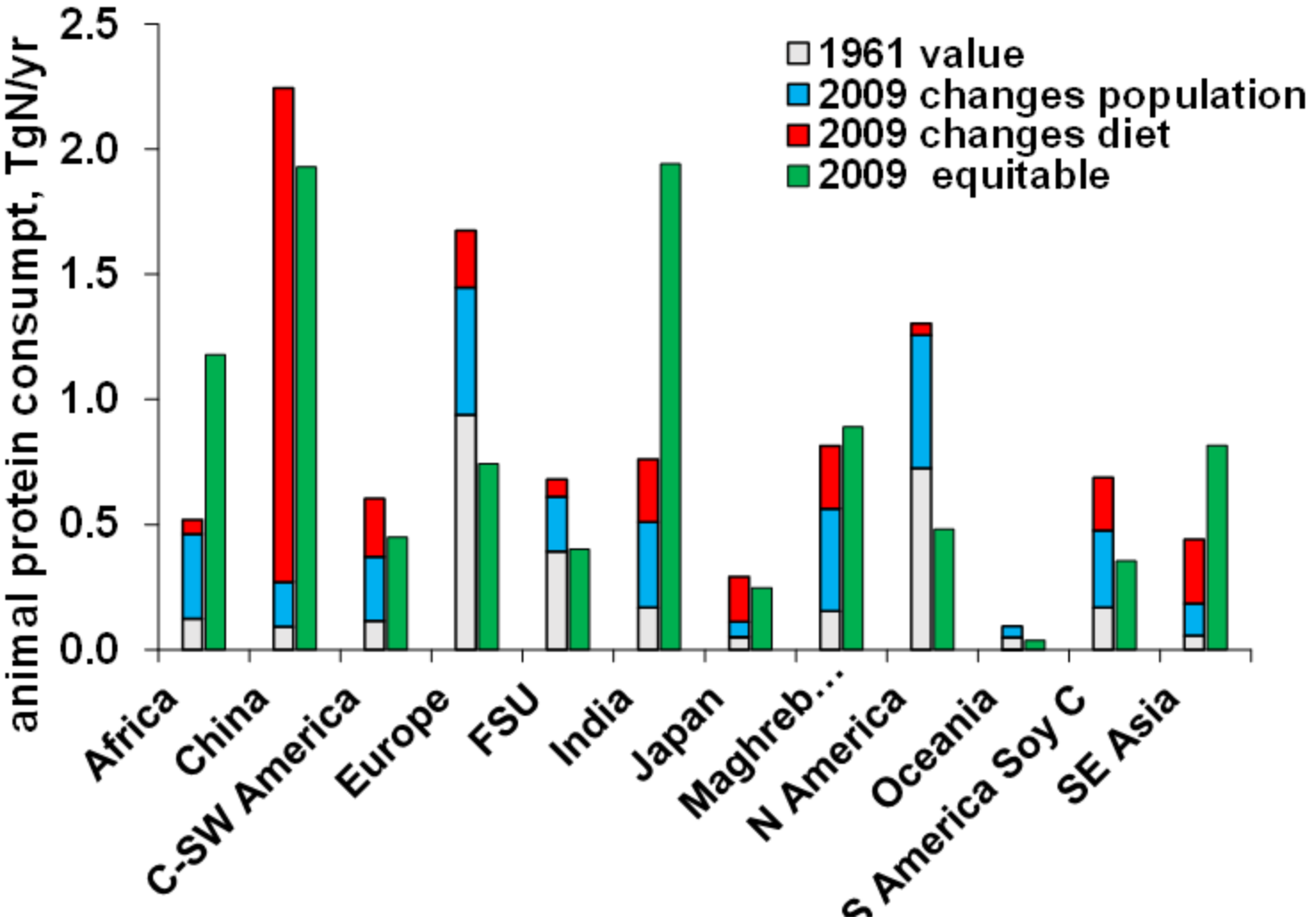
Leip et al. 2015 (J. Agr. Sci)

Reasons for the increase of the animal protein consumption



Lassaletta et al (Under review) Env. Res. Letters

Reasons for the increase of the animal protein consumption (regional)

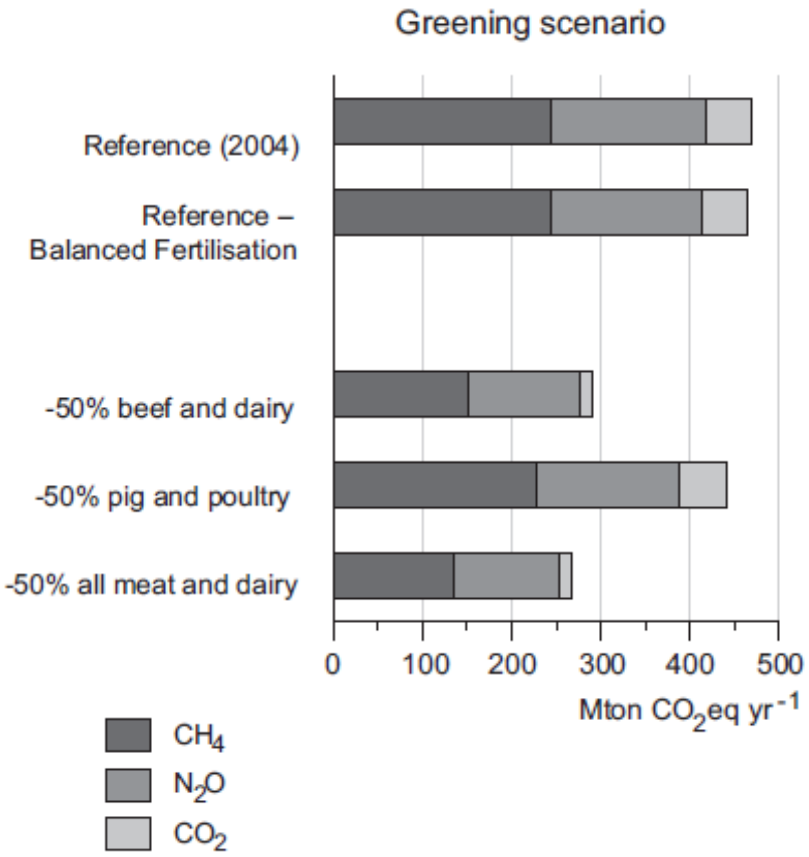


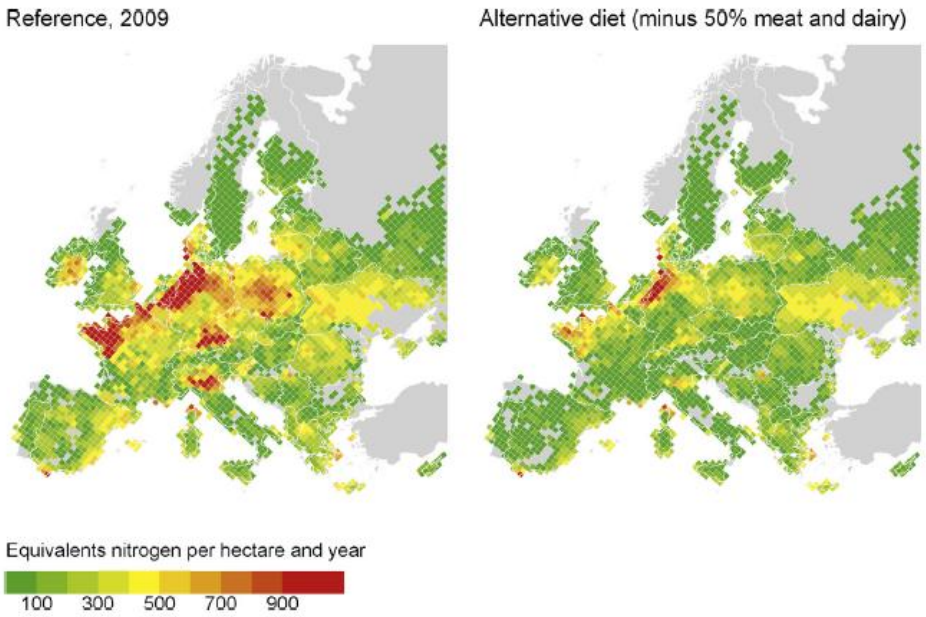
Equitable diet **= 1.6 kgN/cap/y animal protein**

40% Animal protein

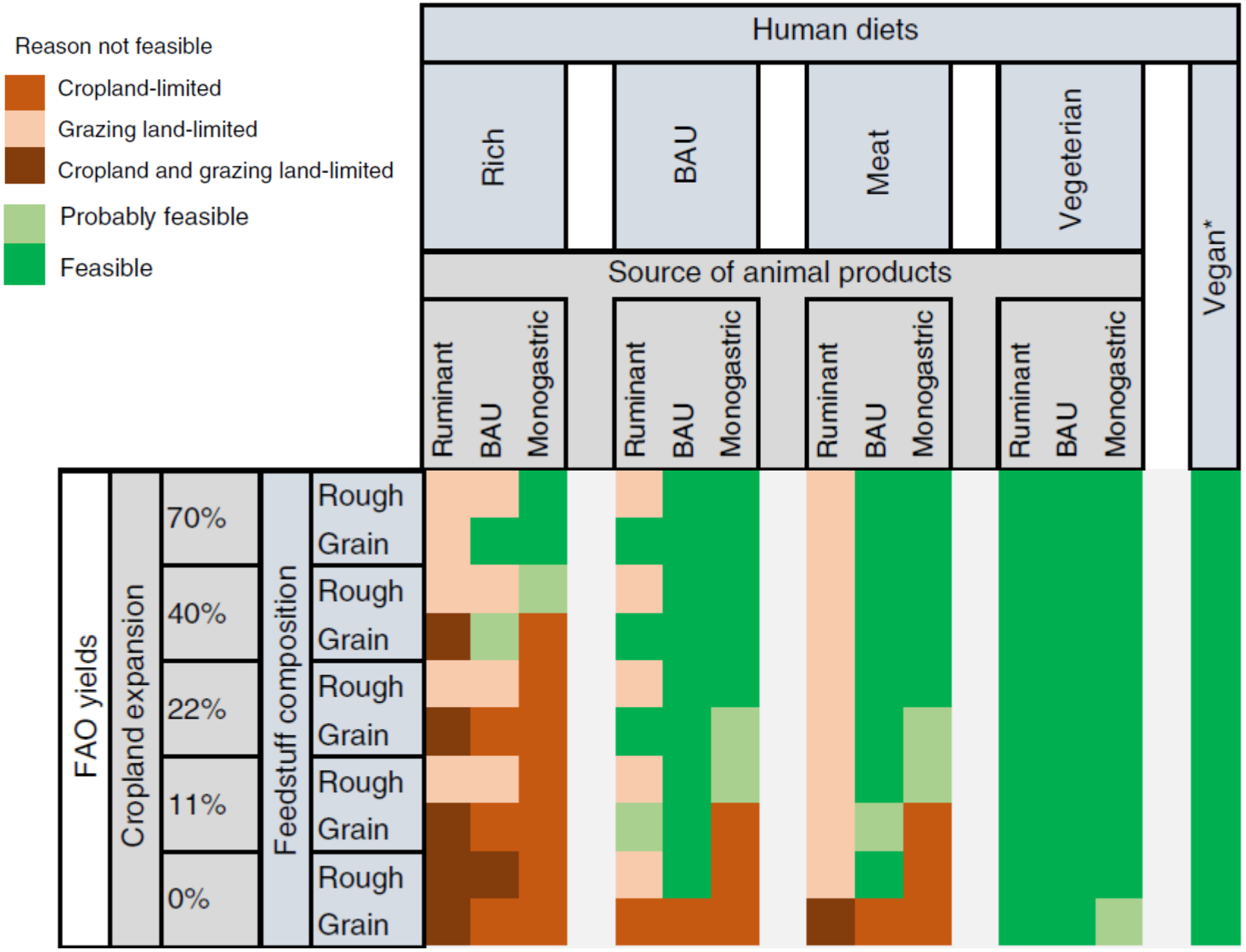
Lassaletta et al (Under review) Env. Res. Letters

Effect of reduction of animal protein consumption in Europe



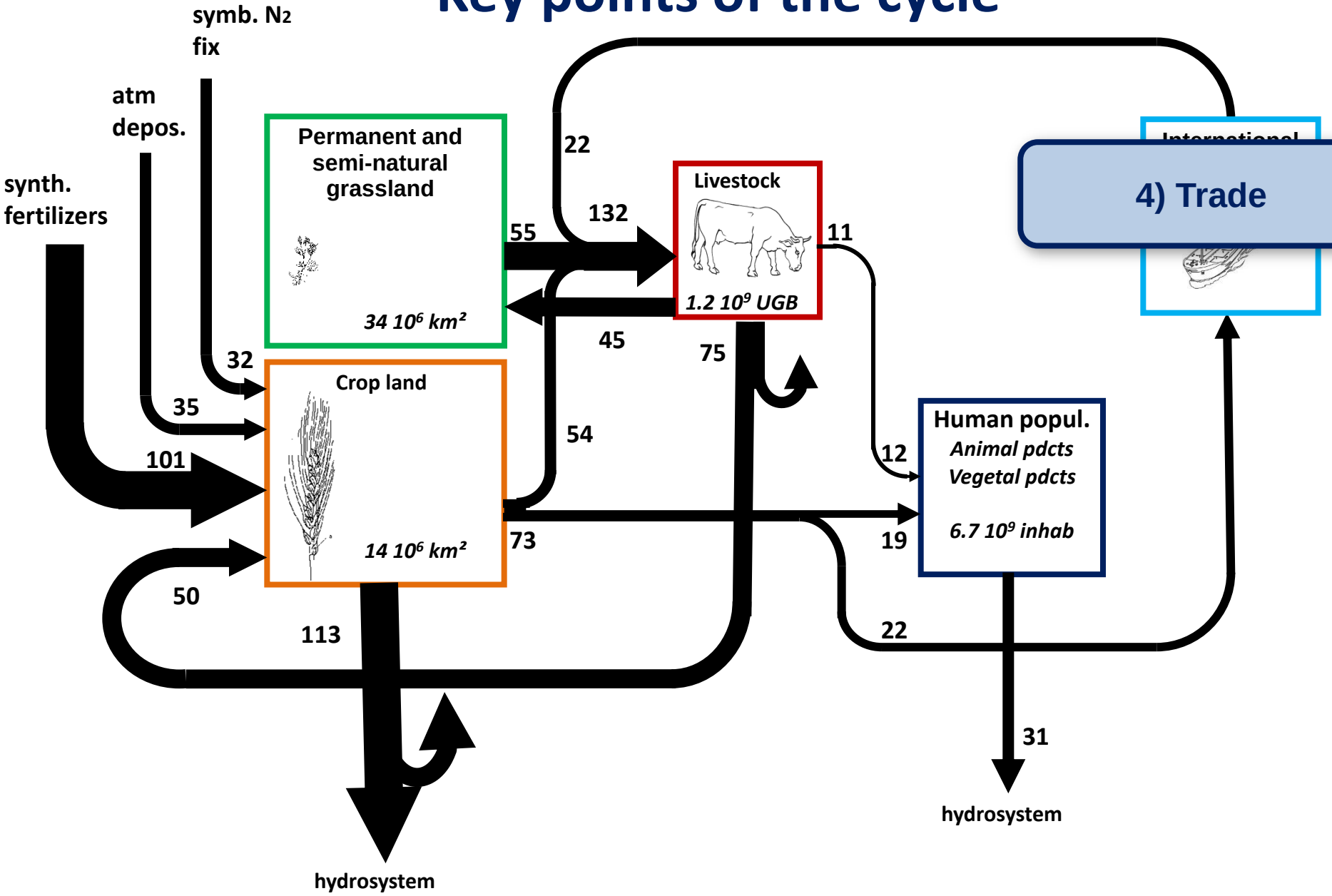


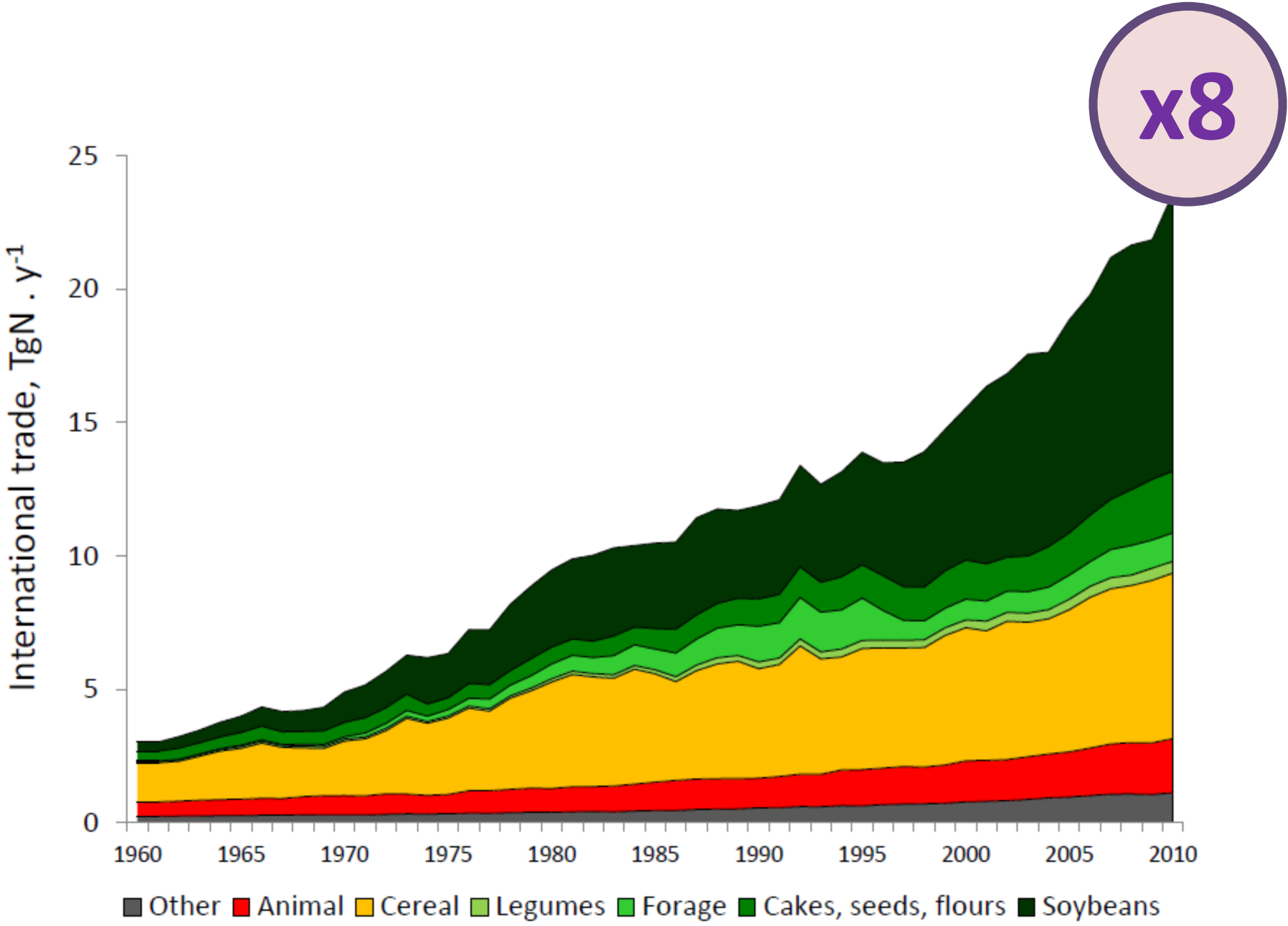
Westhoek (2014) Global Env. Change



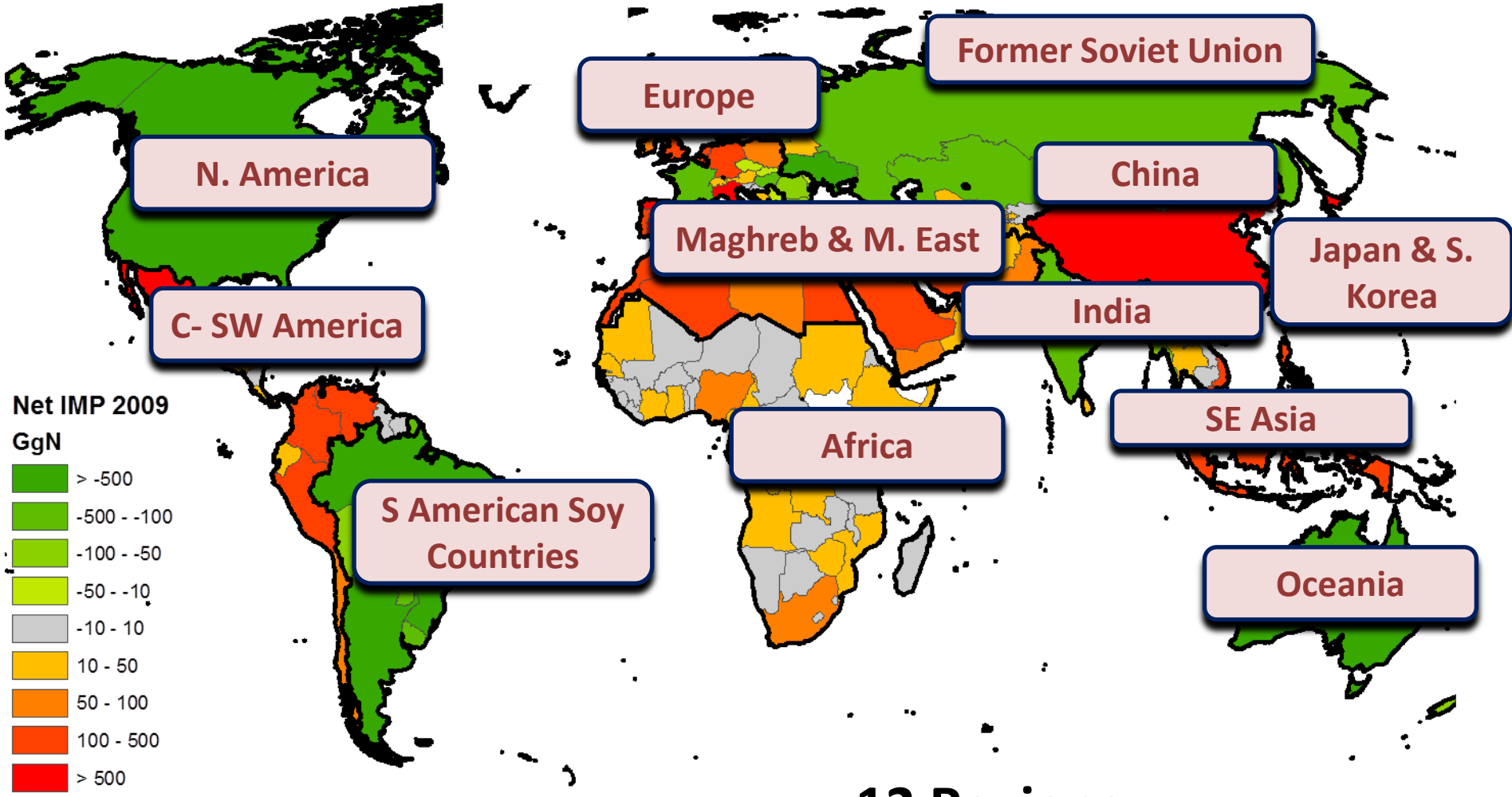
Erb et al. 2016 (Nature Com.)

Key points of the cycle

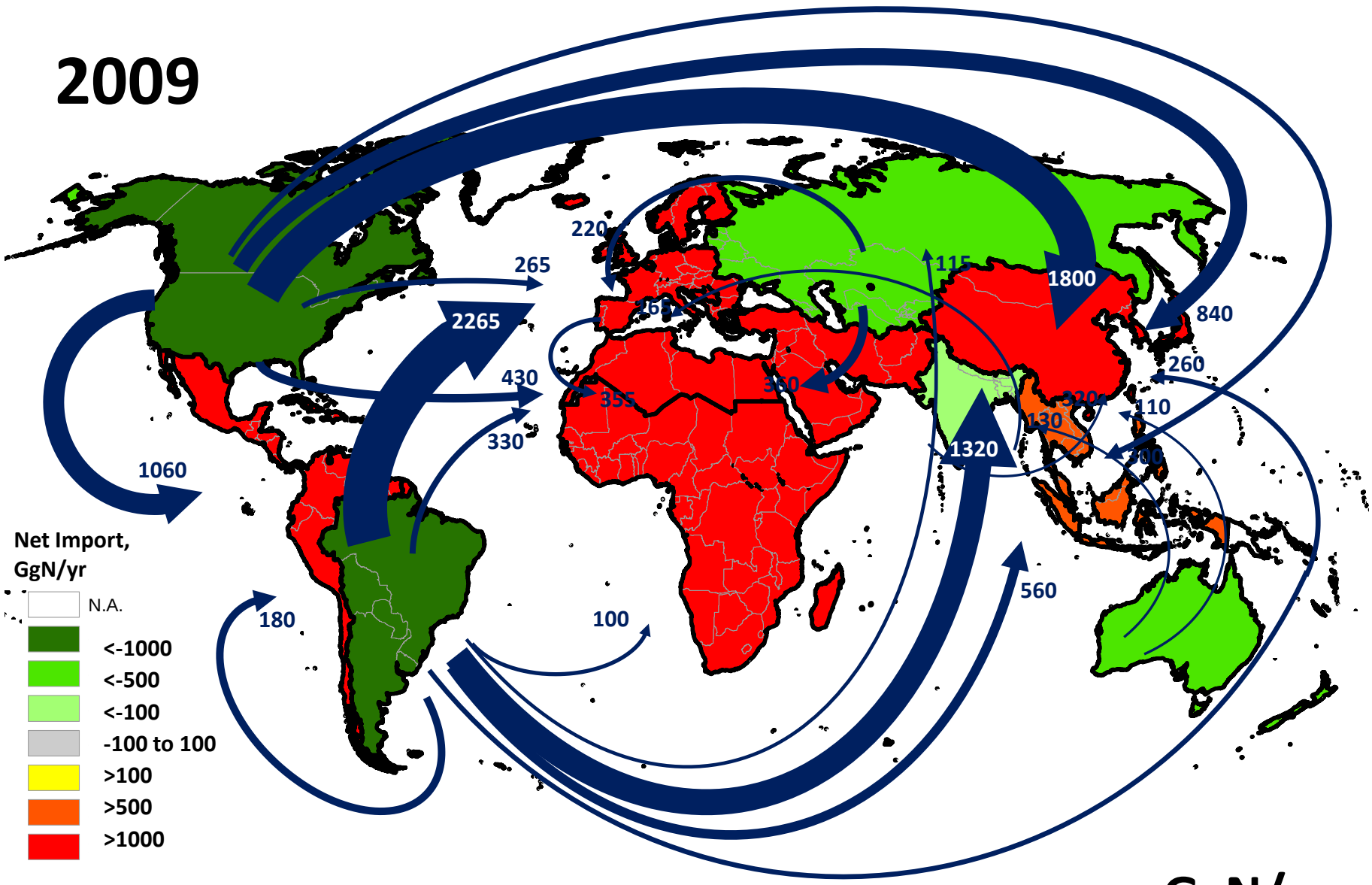




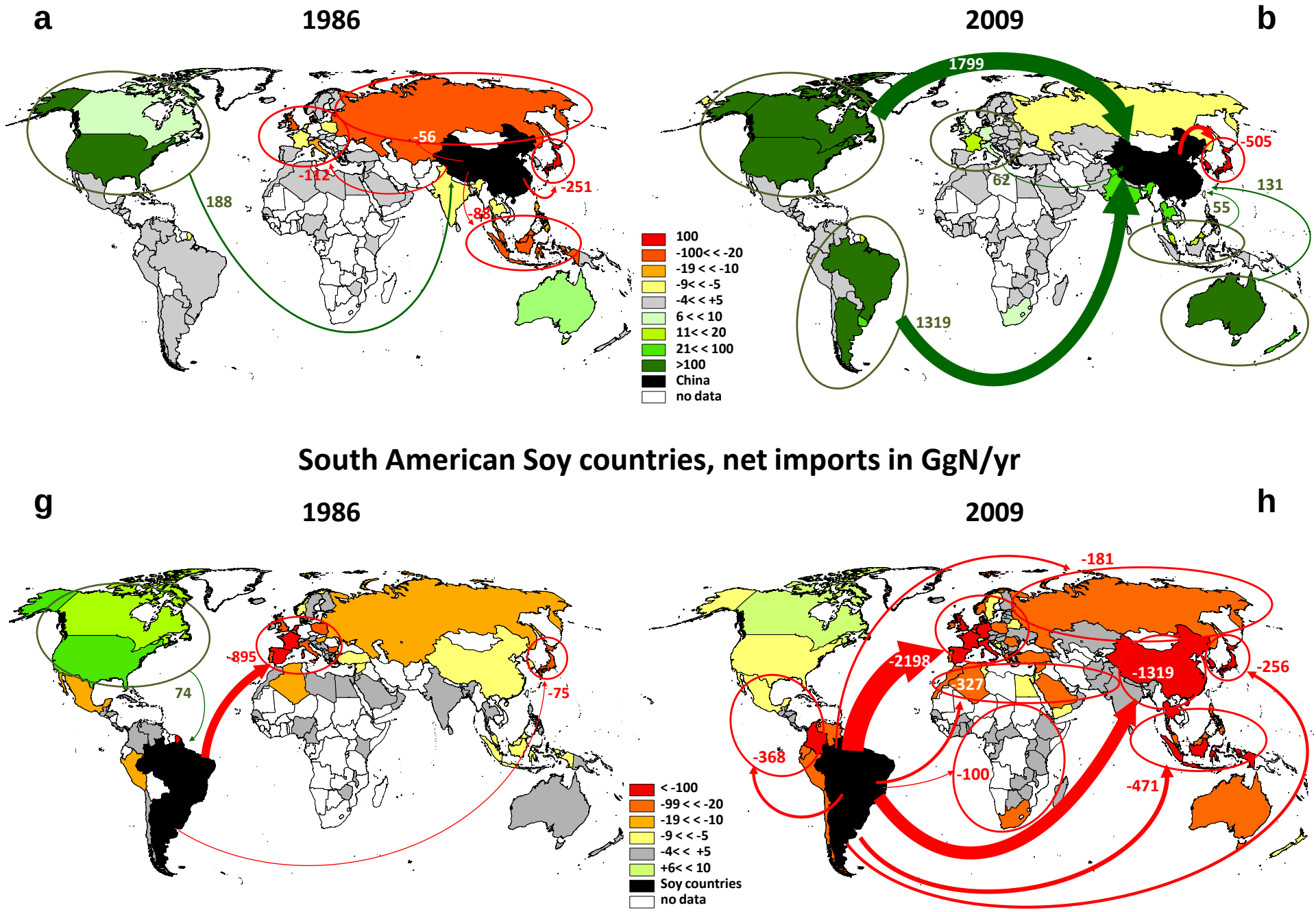
Lassaletta et al. (2013) Biogeochemistry


Former Soviet Union
Europe
N. America
China
Maghreb & M. East
Japan & S. Korea
India
C- SW America
SE Asia
Africa
S American Soy Countries
Oceania
Net IMP 2009
GgN
> -500
-500 - -100
-100 - -50
-50 - -10
-10 - 10
10 - 50
50 - 100
100 - 500
> 500

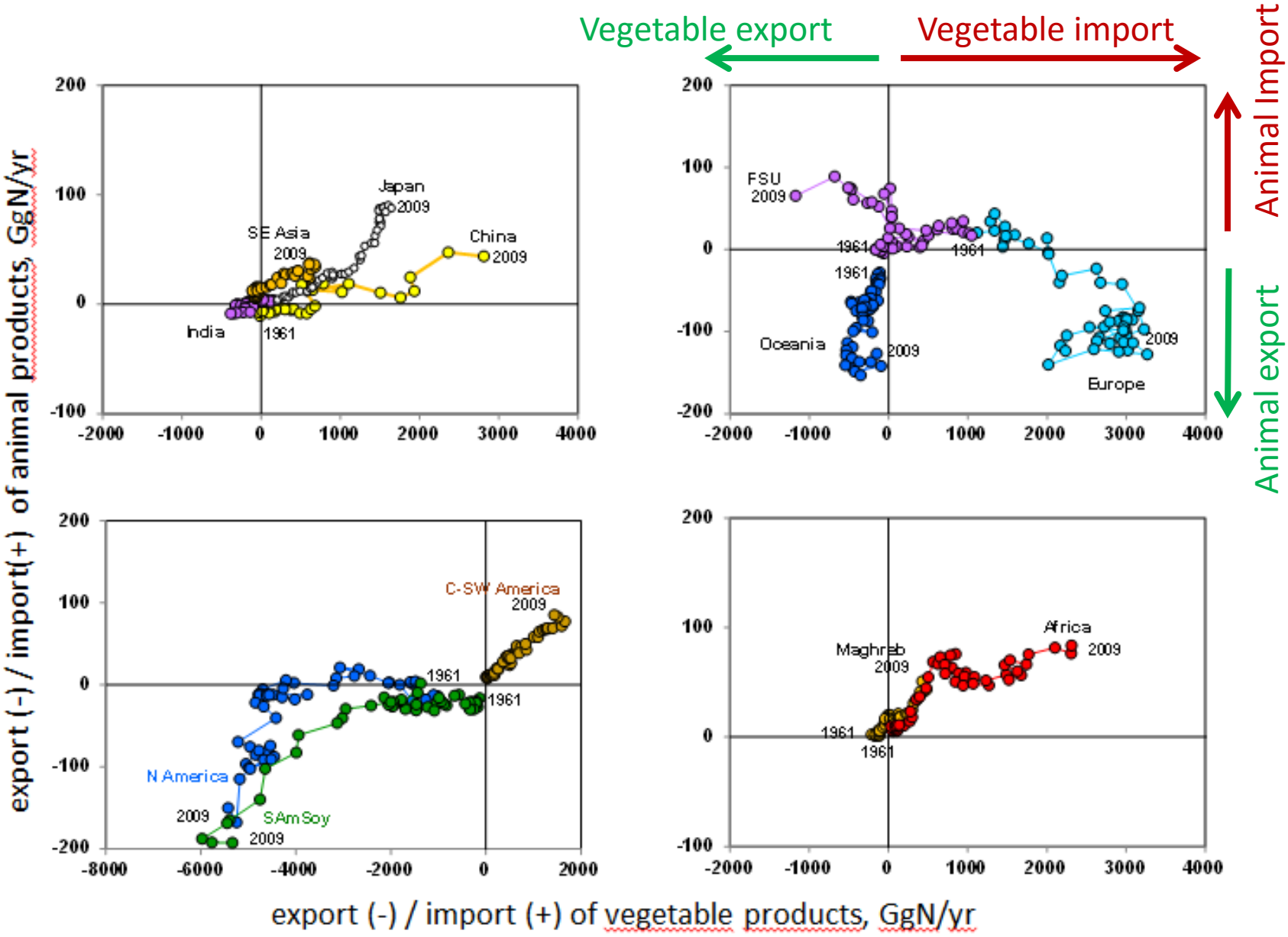
12 Regions



Lassaletta et al. (2014) Biogeochemistry


China, net imports in GgN/yr
a
1986
2009
b
188
-112
-56
-251
-88
1799
-505
62
131
55
1319
100
-100< < -20
-19 < < -10
-9< < -5
-4< < +5
6 < < 10
11< < 20
21< < 100
>100
China
no data
South American Soy countries, net imports in GgN/yr
g
1986
2009
h
74
-895
-75
-181
-2198
-1319
-256
-327
-368
-100
-471
< -100
-99 < < -20
-19 < < -10
-9 < < -5
-4< < +5
+6< < 10
Soy countries
no data

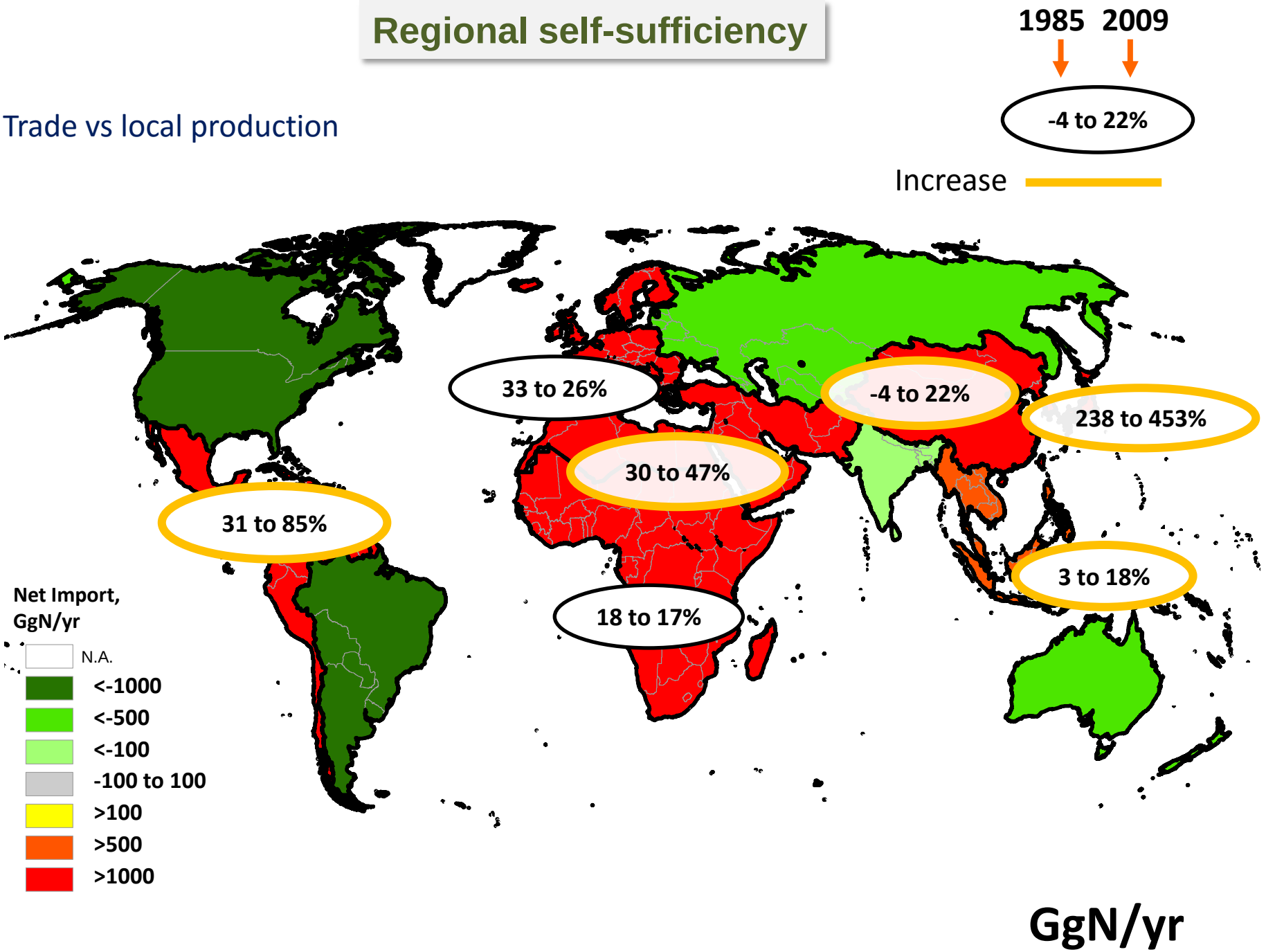
Regional trajectories of net import (animal and vegetal)

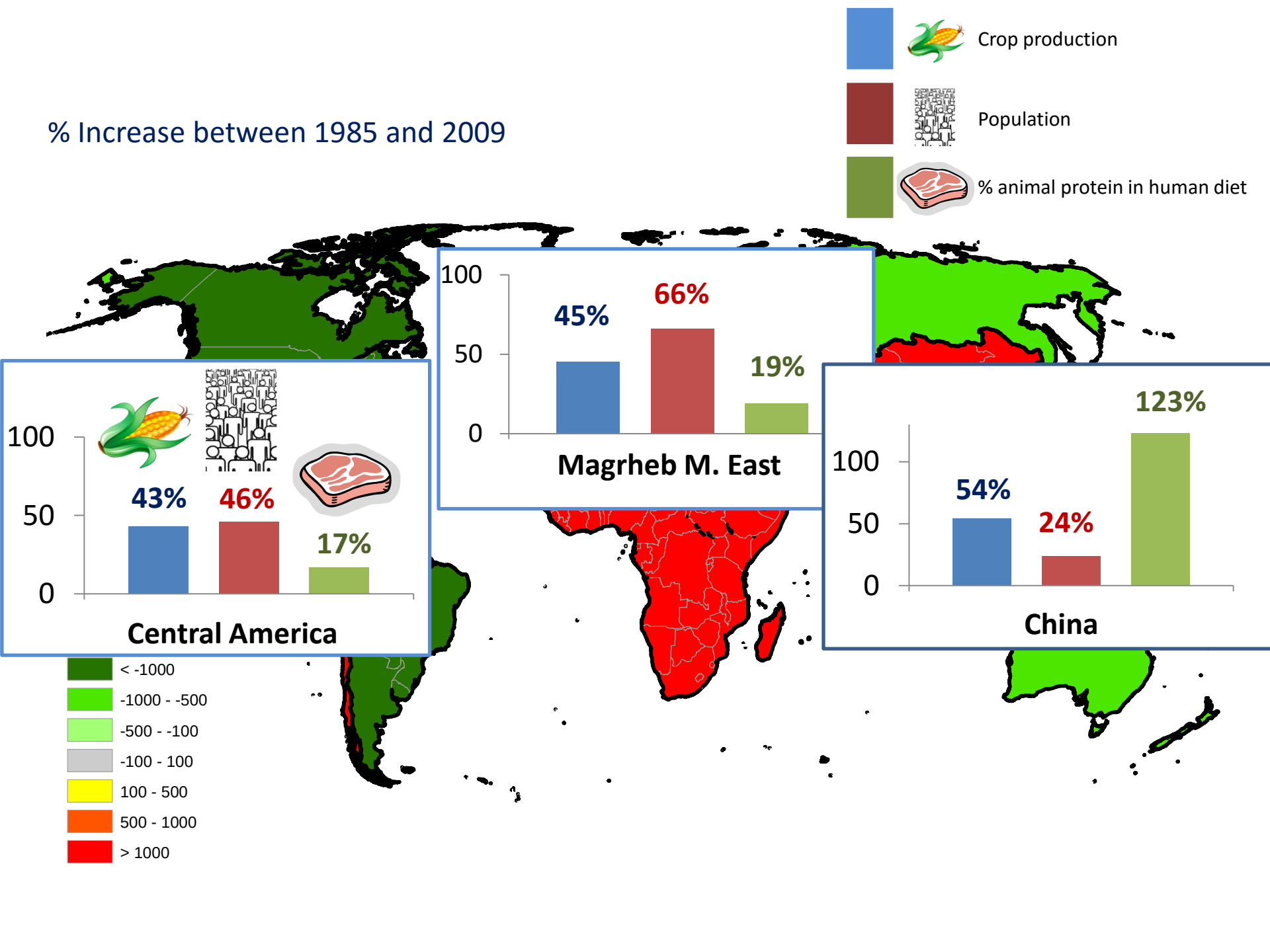


Lassaletta et al (Under review) Env. Res. Letters

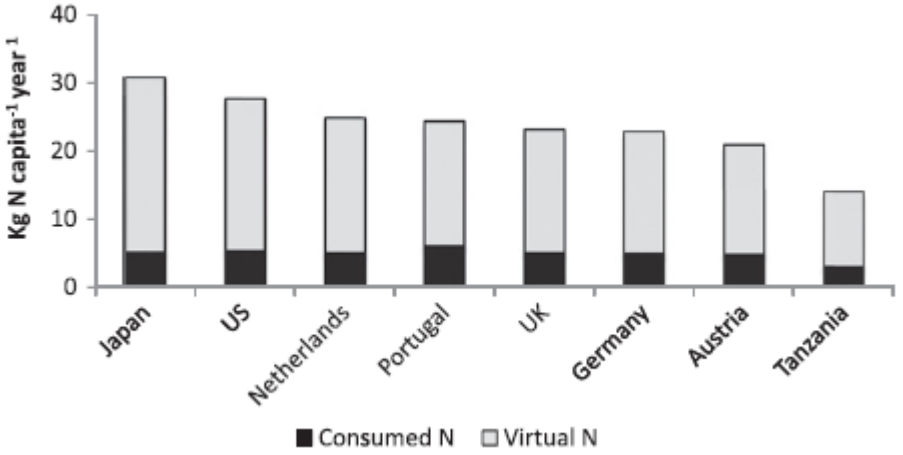
Regional self-sufficiency

Trade vs local production

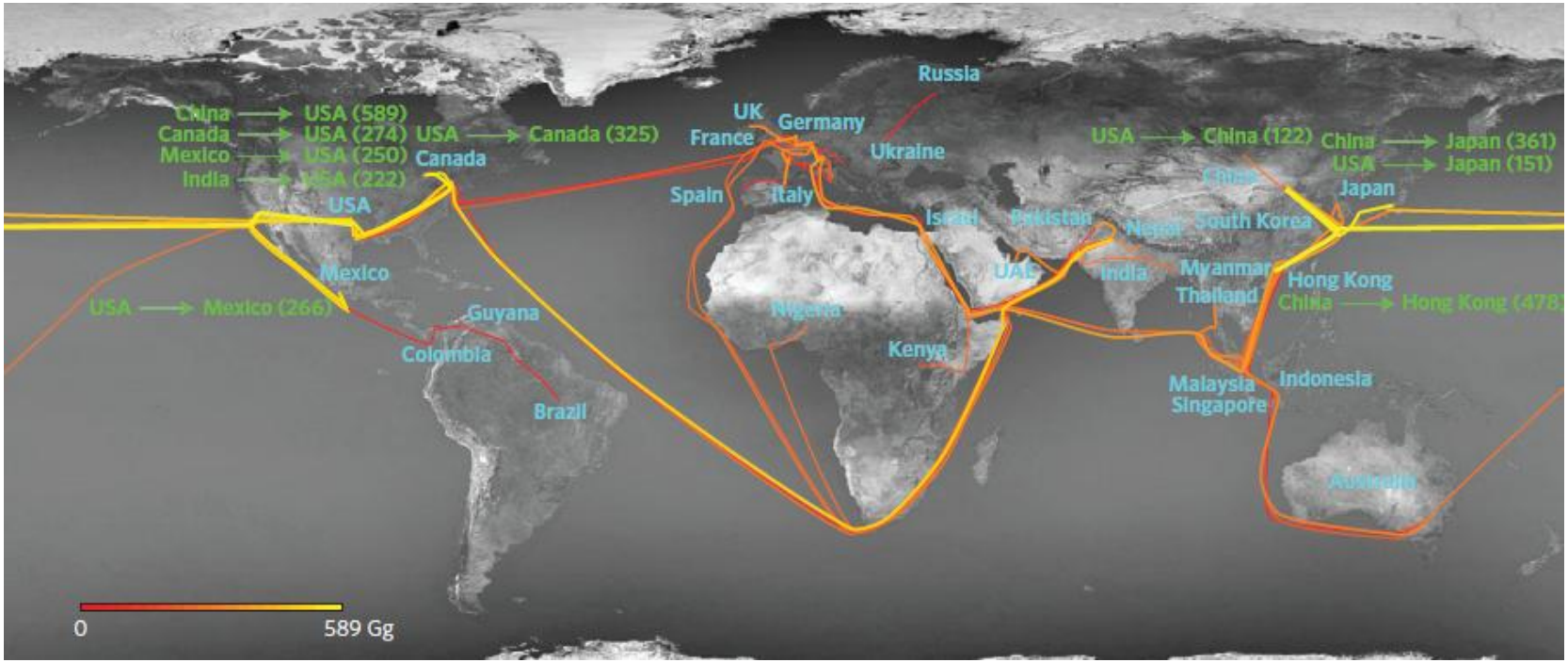



% Increase between 1985 and 2009
Crop production
Population
% animal protein in human diet
100
50
0
43%
46%
17%
Central America
100
50
0
45%
66%
19%
Magrheb M. East
100
50
0
54%
24%
123%
China
< -1000
-1000 - -500
-500 - -100
-100 - 100
100 - 500
500 - 1000
> 1000

Virtual N transfers



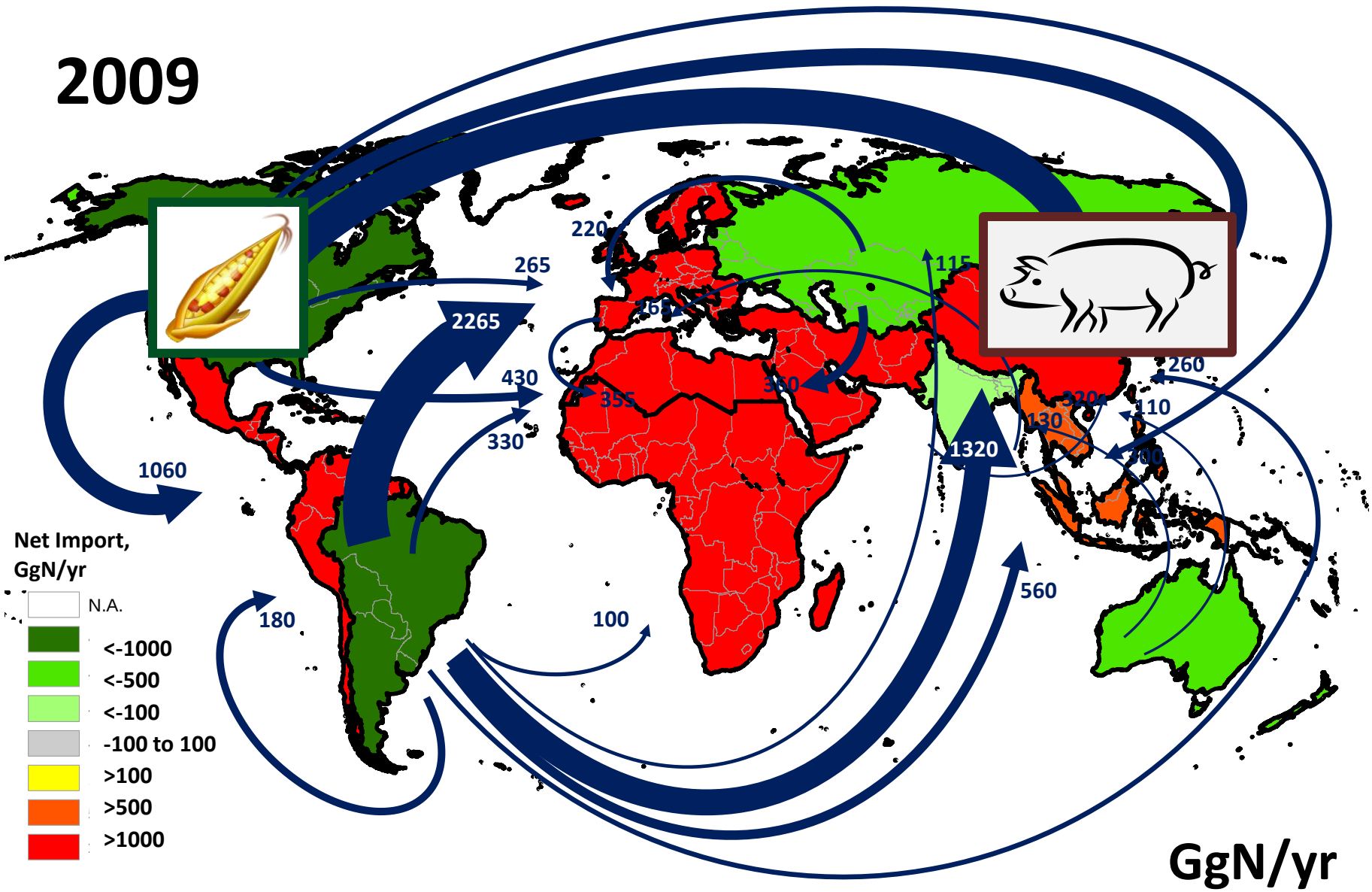
Galloway et al. 2012 (Env. Res Letters)



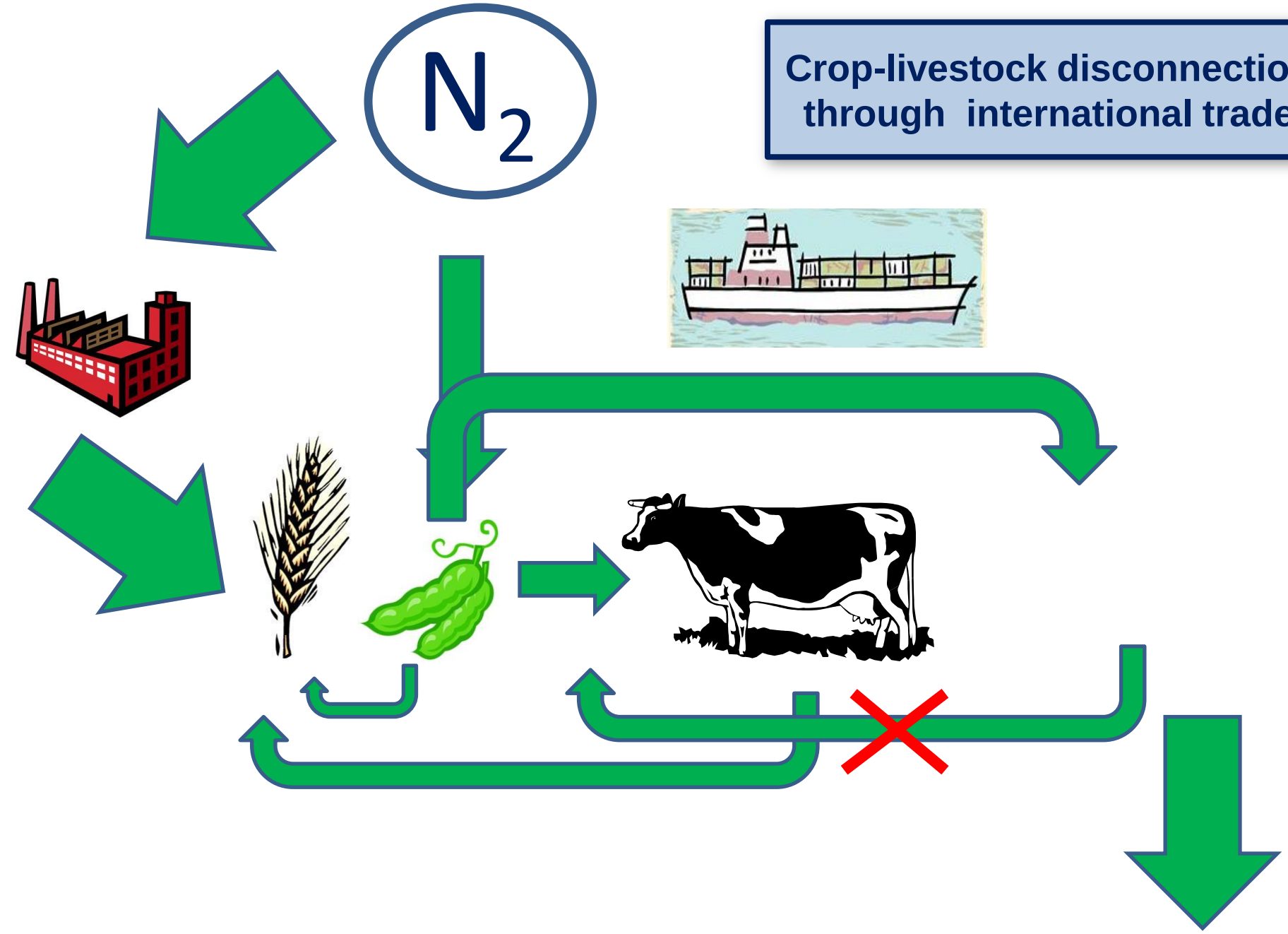
International flows of embodied nitrogen emissions

Oita et al 2016 Nature Geosciences

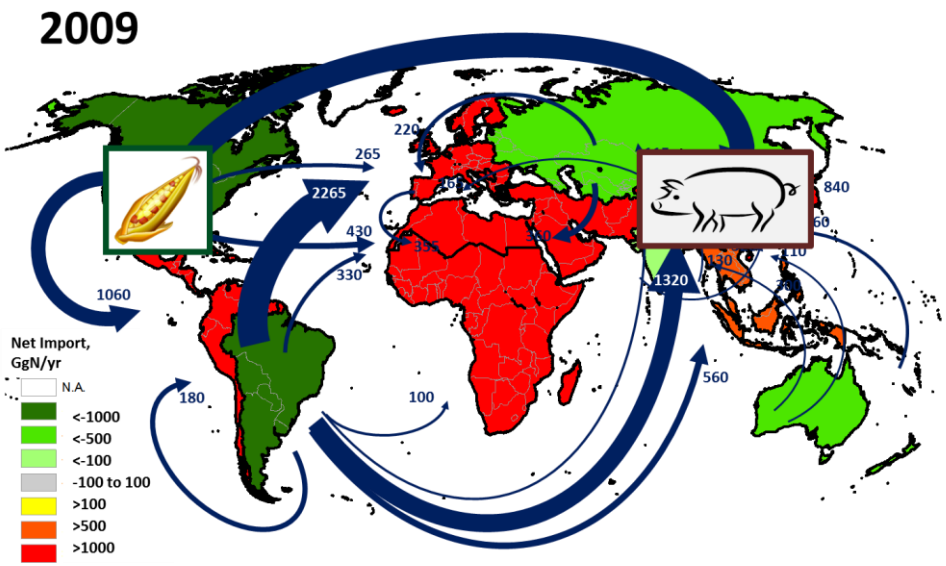
Crop-livestock disconnection

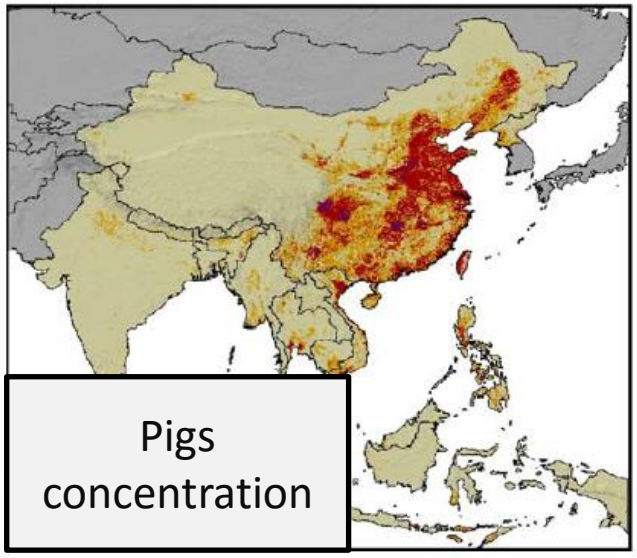


Crop-livestock disconnection through international trade



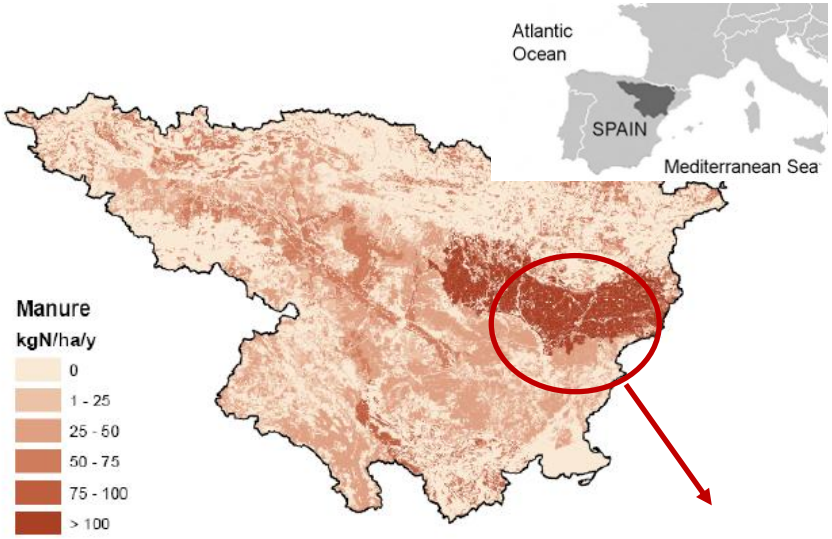
Consequences of disconnection





Pigs concentration

Gerber & Menzi 2006 (Int. Cong. Ser.)

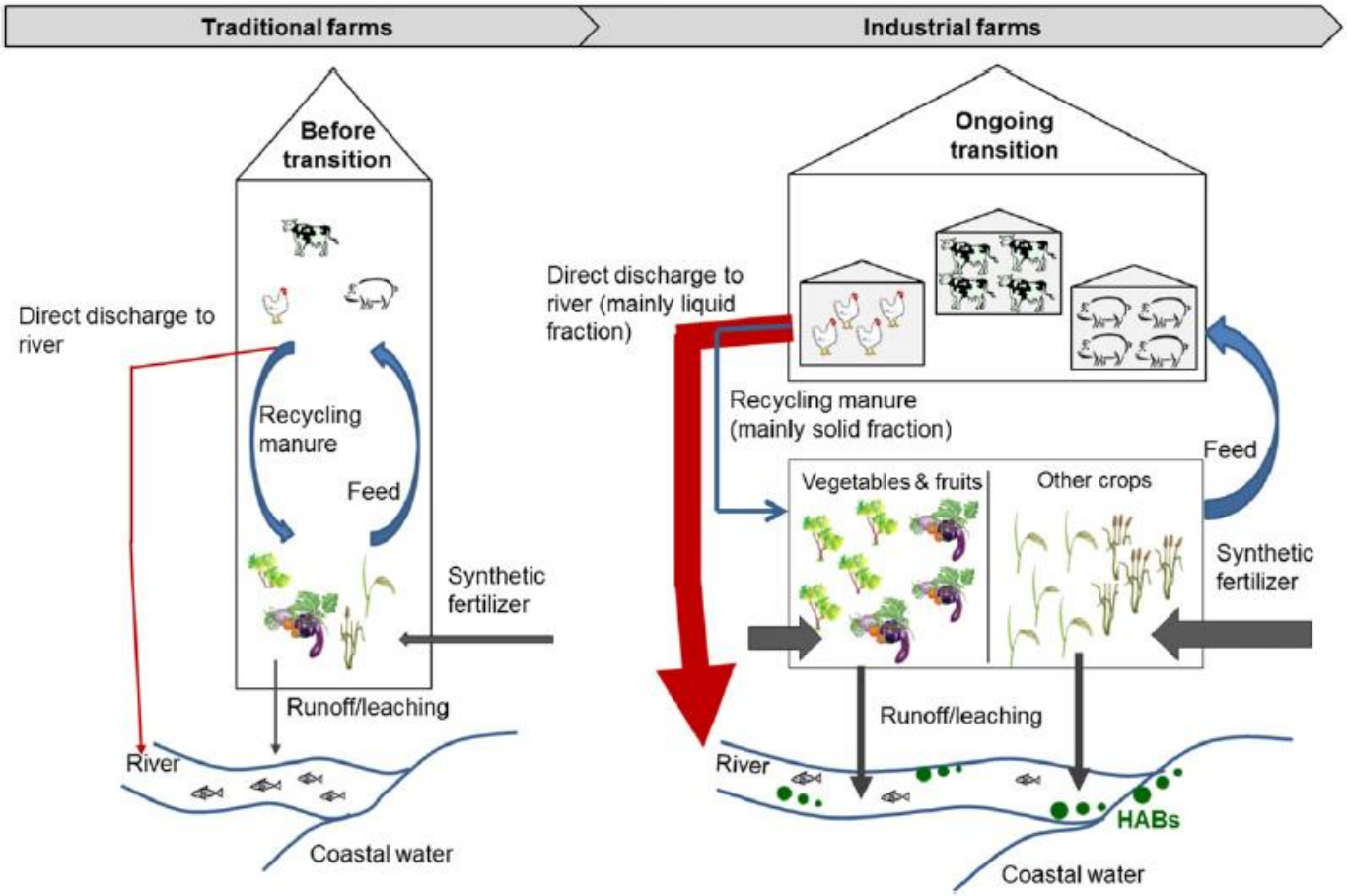


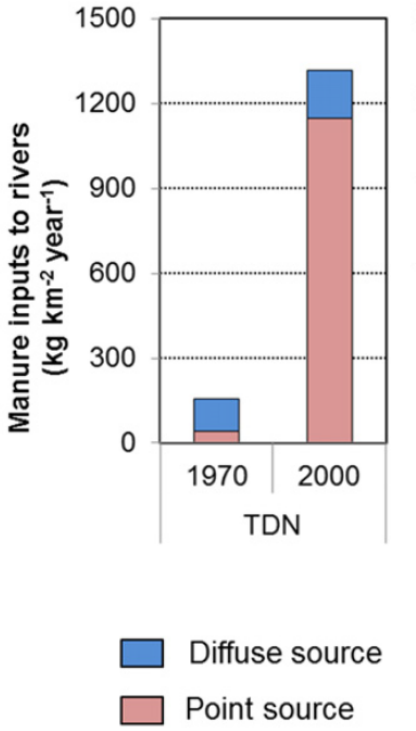
400 kgN/ha

Lassaletta et al. 2012 (Biogeosciences)

Use of crop residues

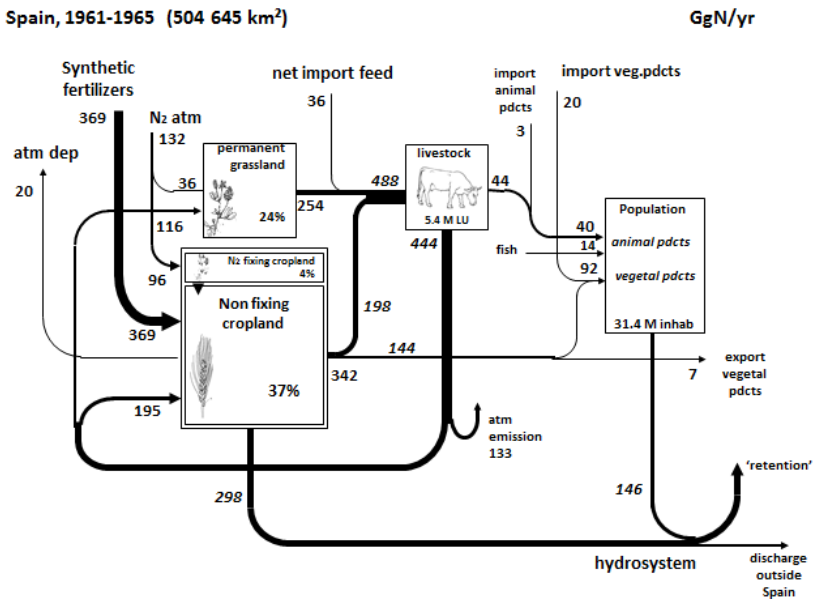
Disconnetion in China



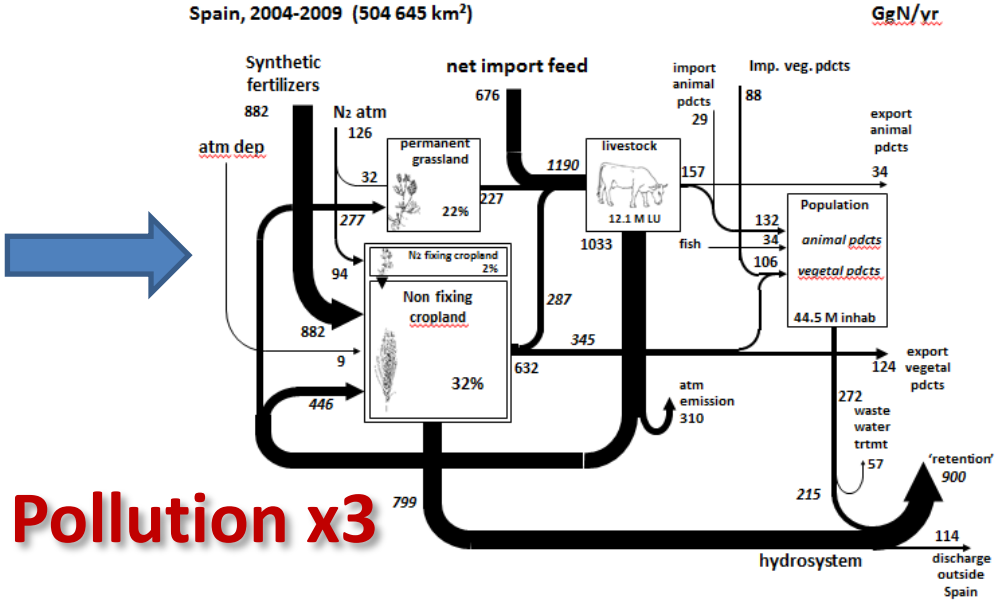


Strokal et al. 2016 (Env. Res. Letters)

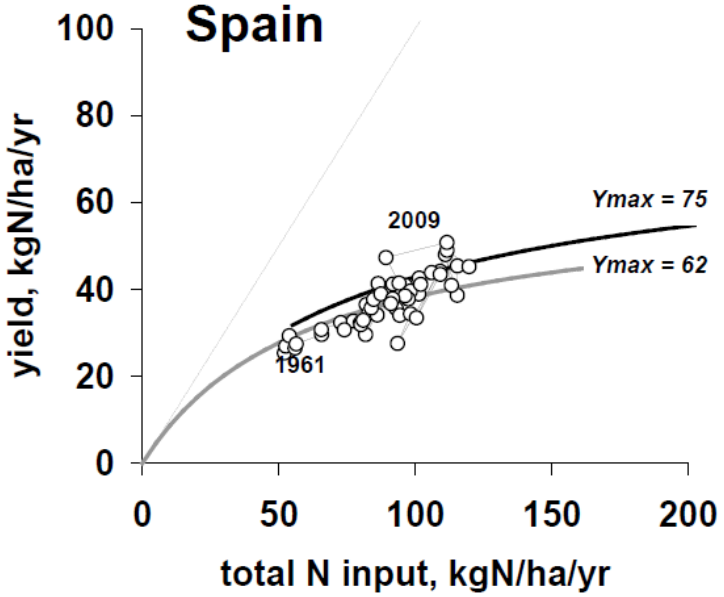
Spain 1961-65



Spain 2005-2009

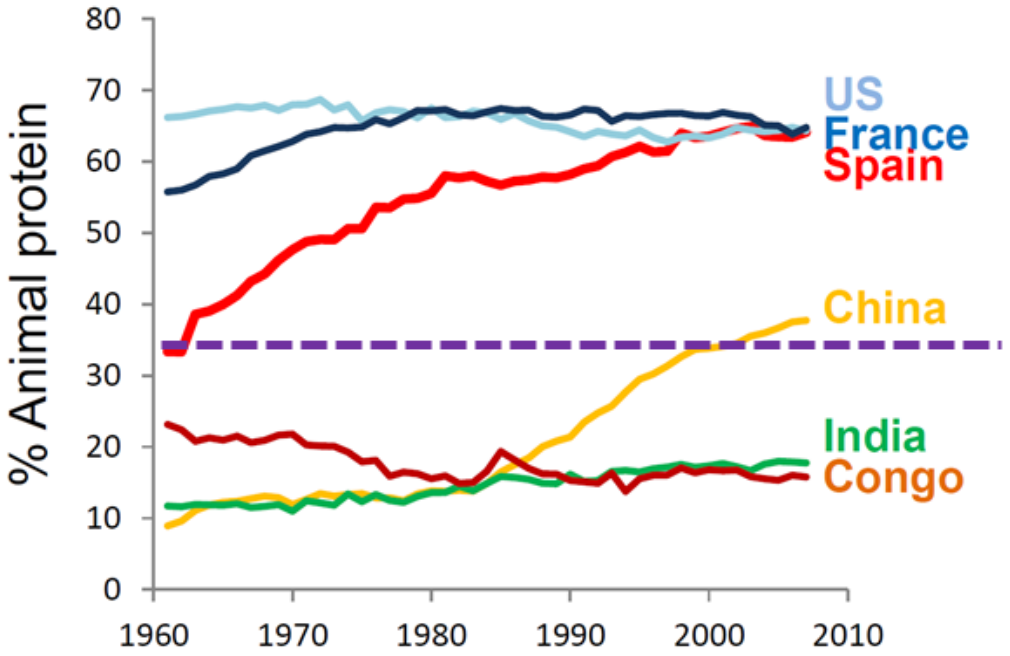


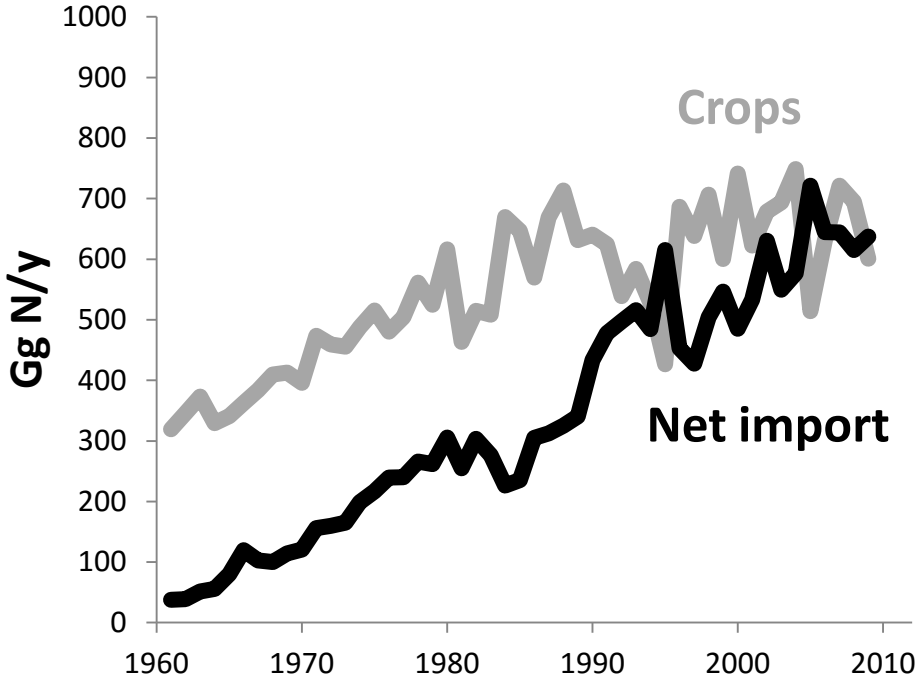
Pollution x3

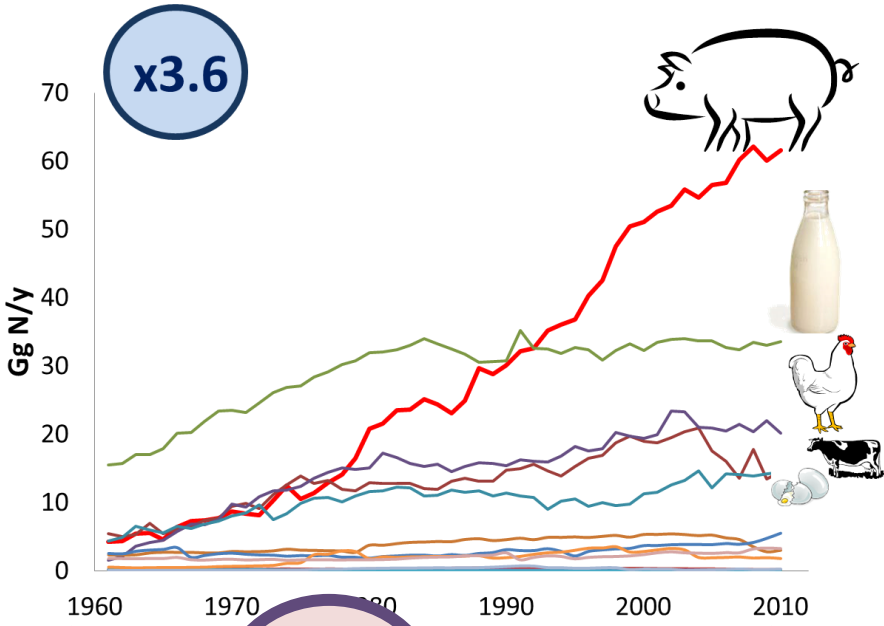


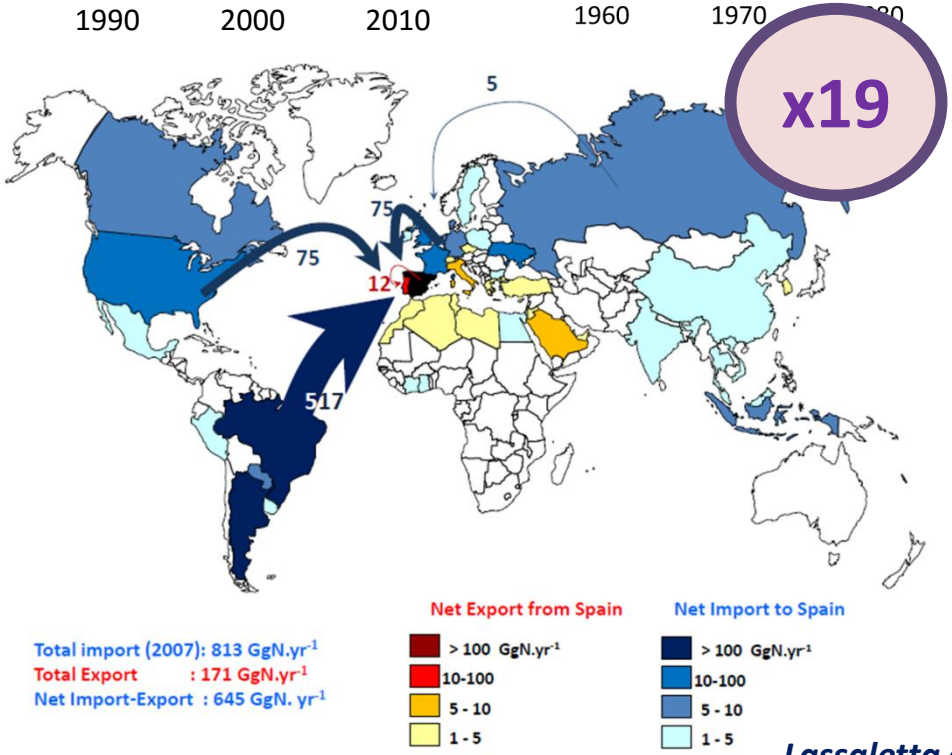
Moderate increase in productivity

Moderate drop of effciency

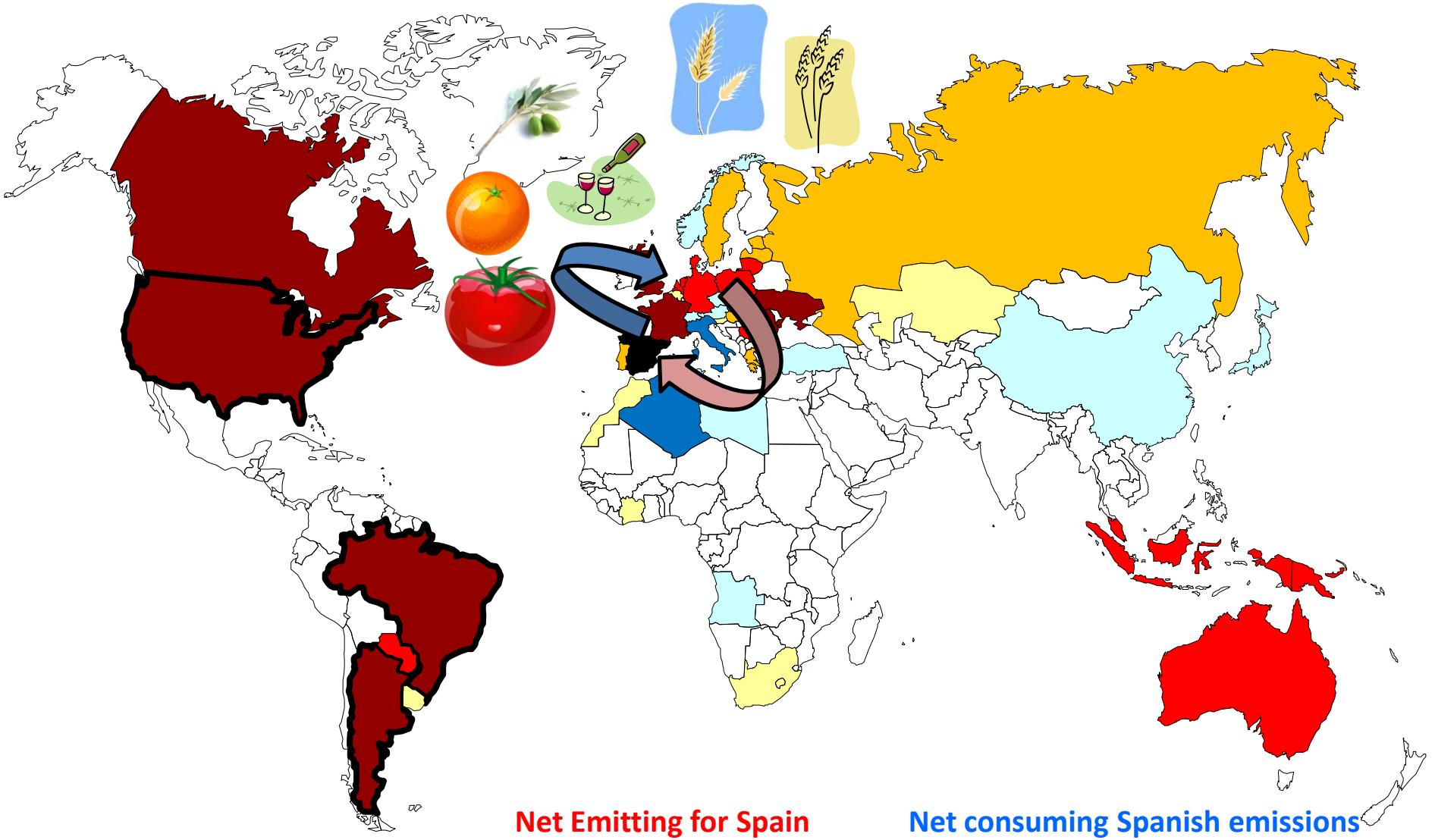








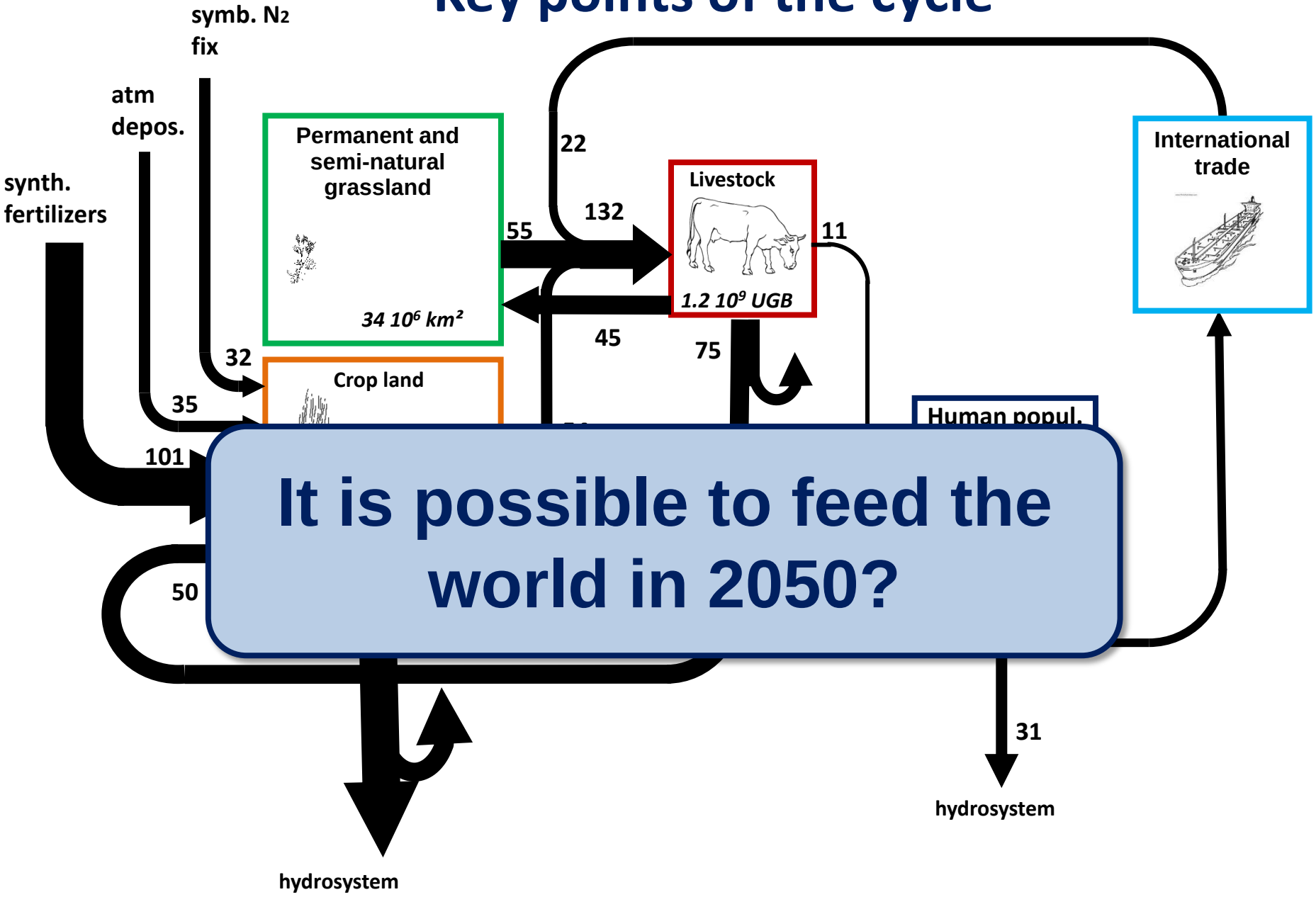
Lassaletta et al. 2014 (Reg Env Change)



Virtual fluxes

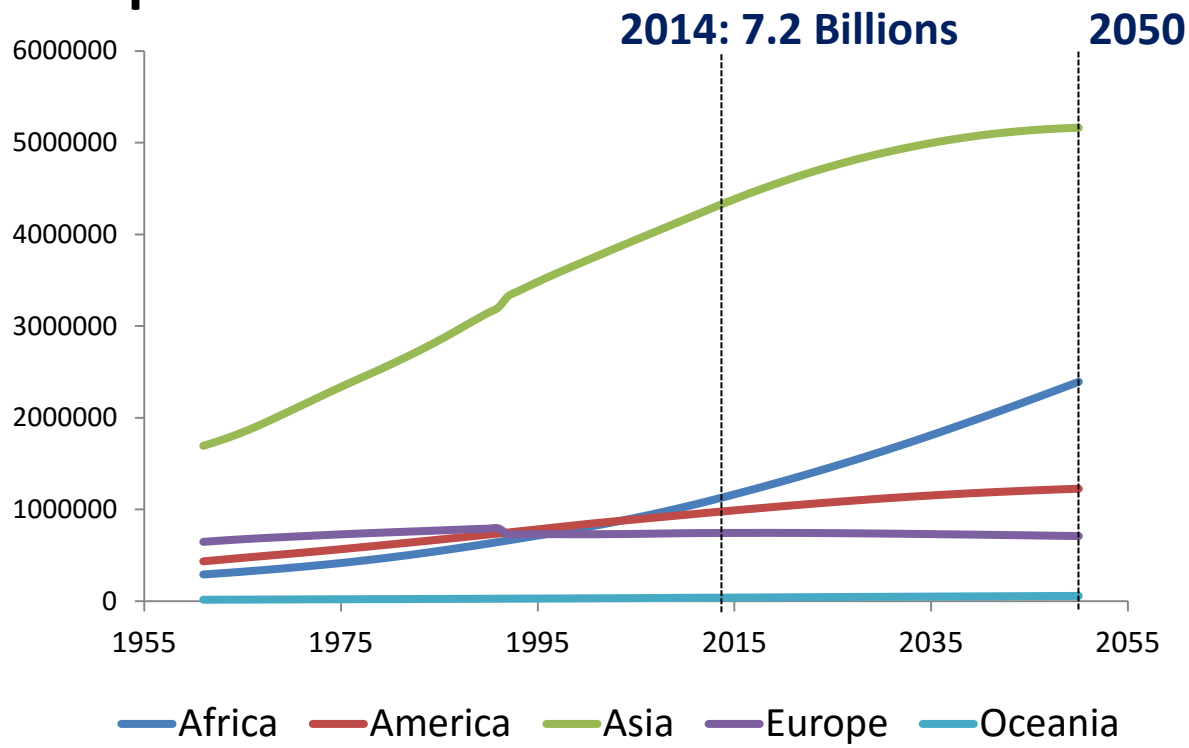
Lassaletta et al. 2014 (Mitigat Adapt Strat Global Change)

Key points of the cycle



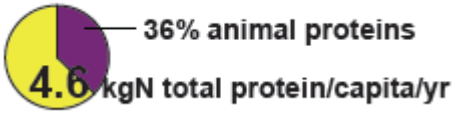
It is possible to feed the world in 2050?

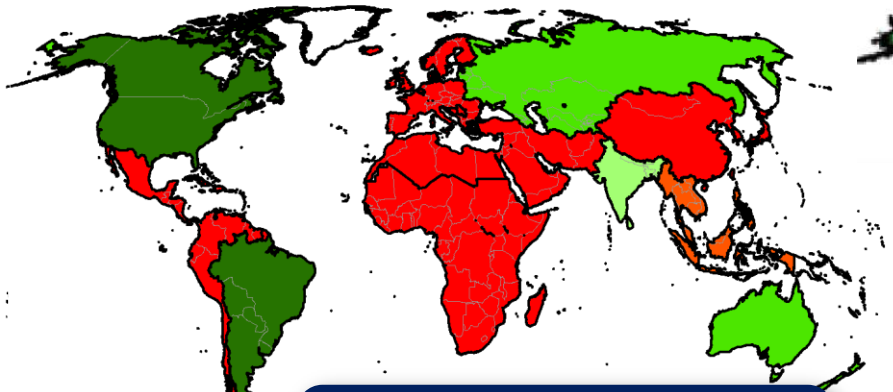
Population



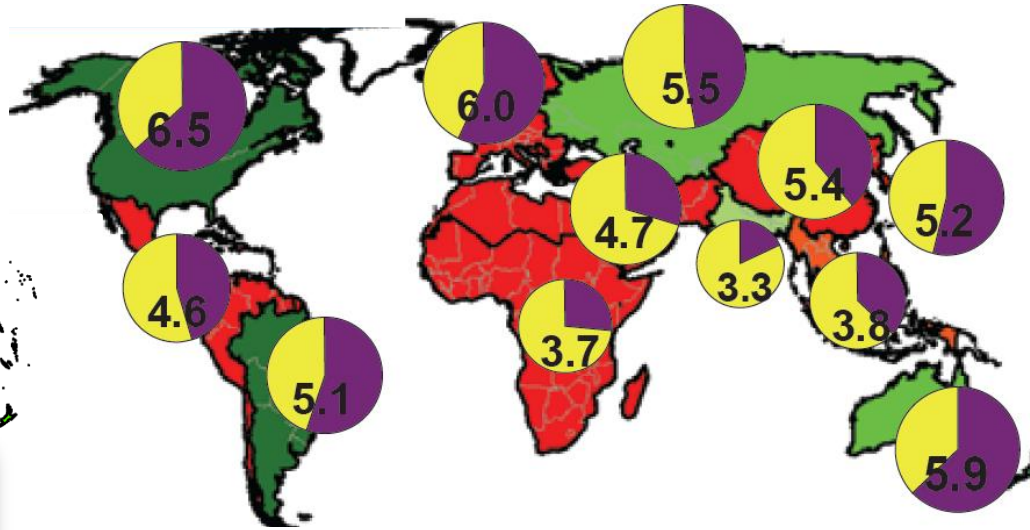
FAOStat (2014)

Diet?





12 regions

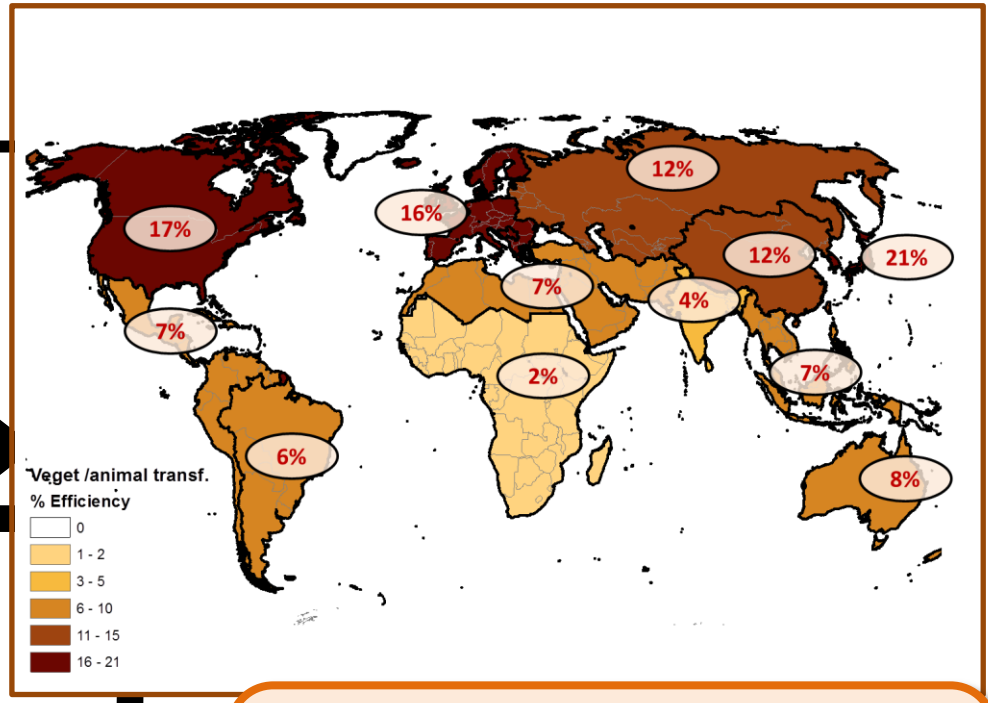


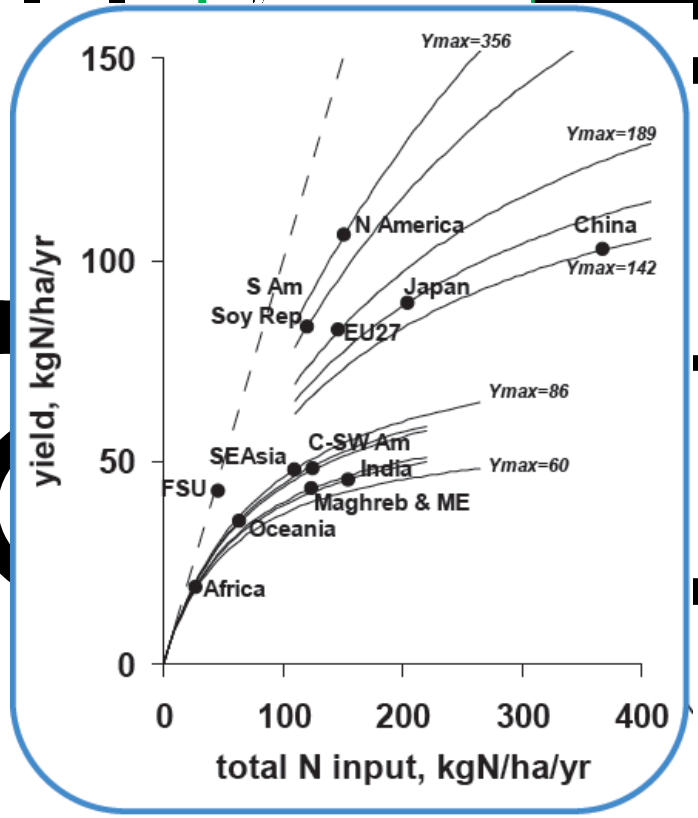
Fertilizer/yield relationship constant

depos.

synth. fertilizers

Permanent and semi-natural grassland





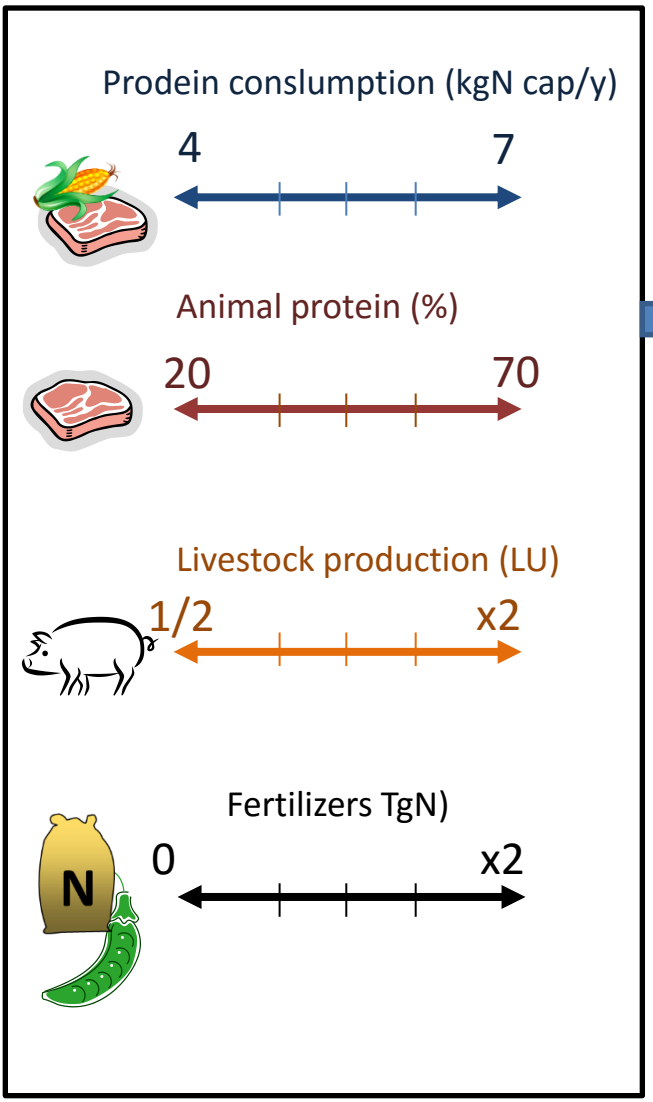
Vegetal into animal conversion efficiency constant

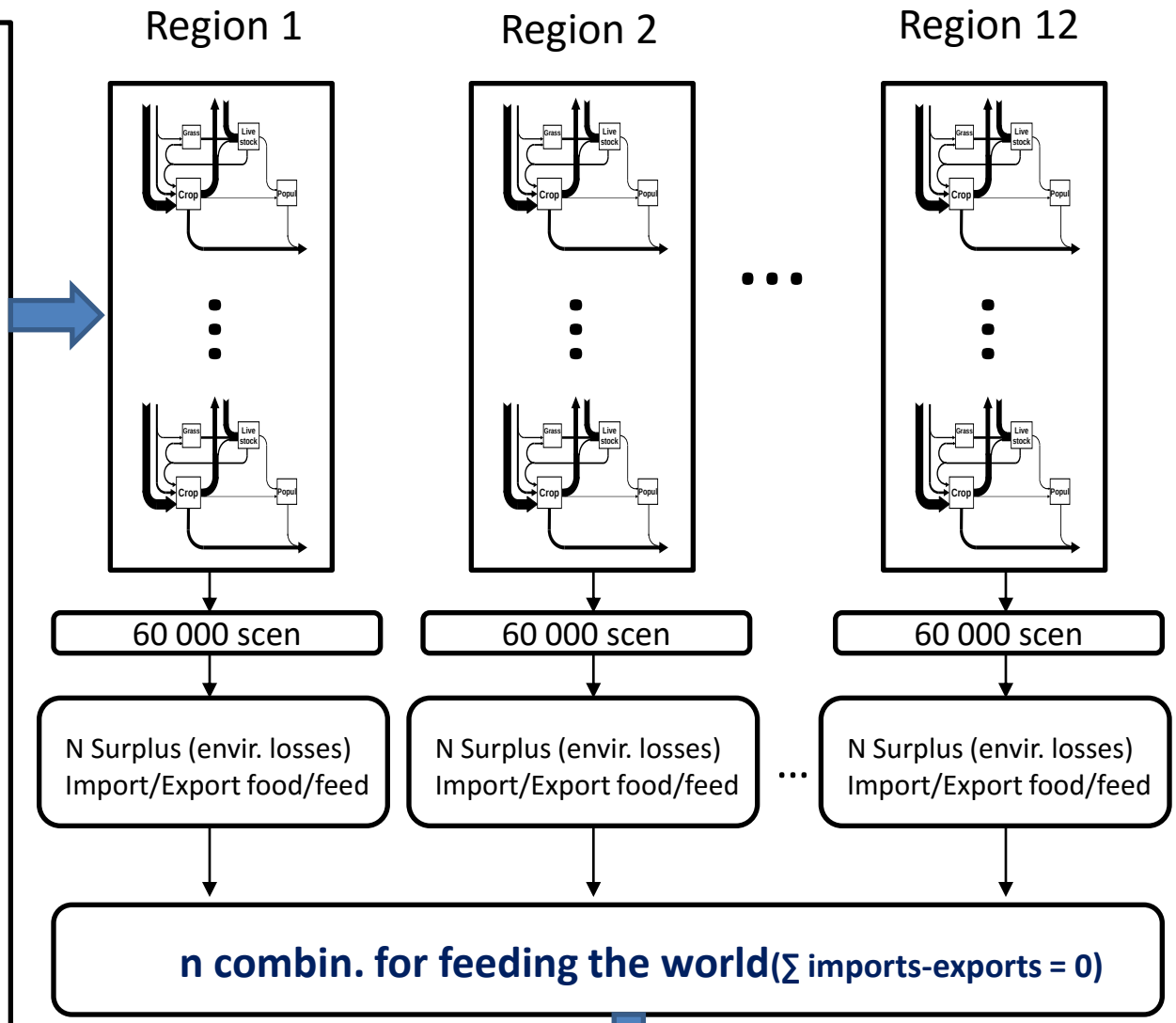
Agricultural land surface constant

hydrosystem

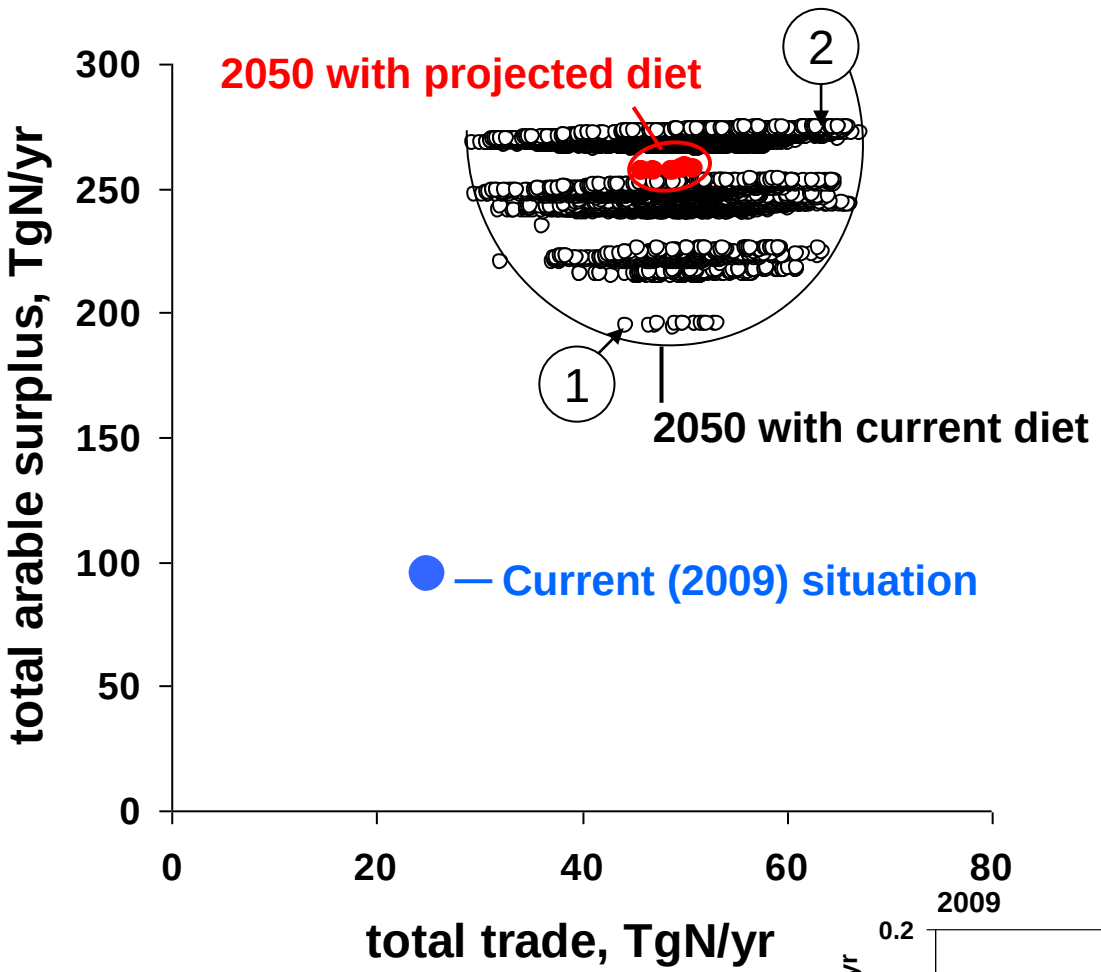
Total nitrogen input (kgN/ha/yr)

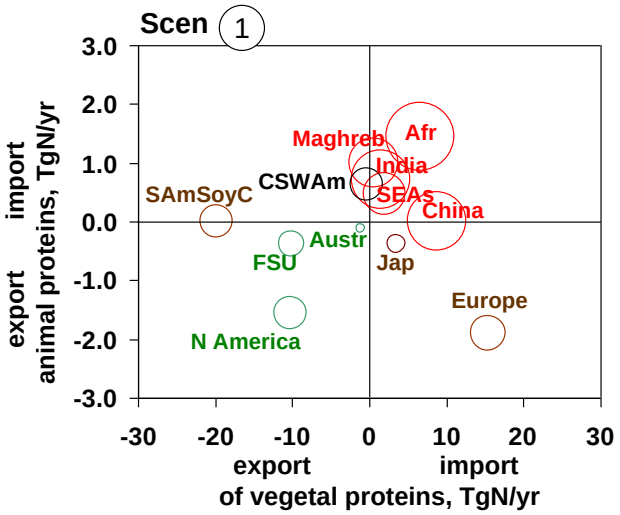
Modelling the realm of possibilities for feeding the world

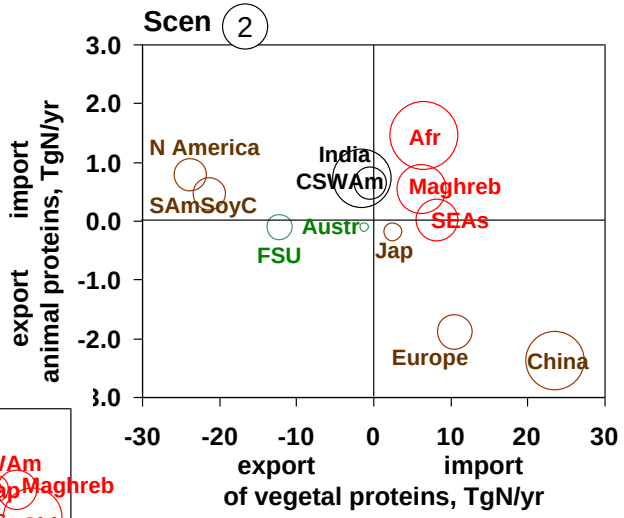


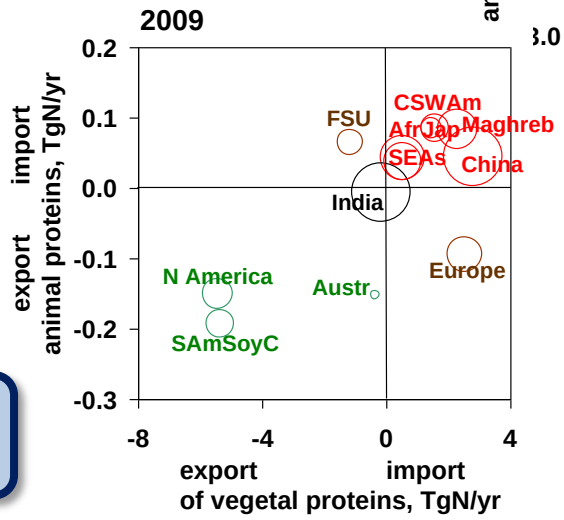


Billen et al. 2015 (Env. Res Lett)

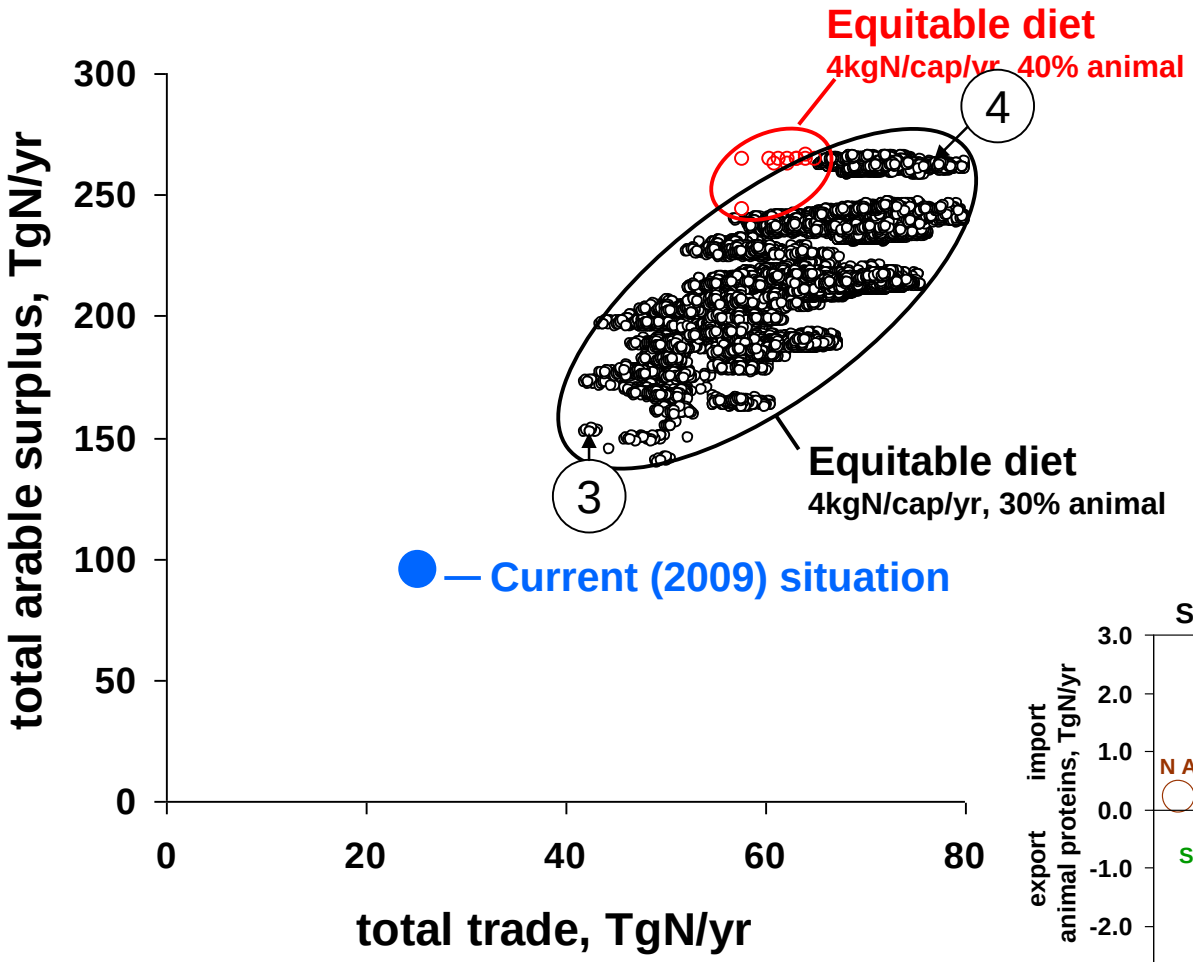


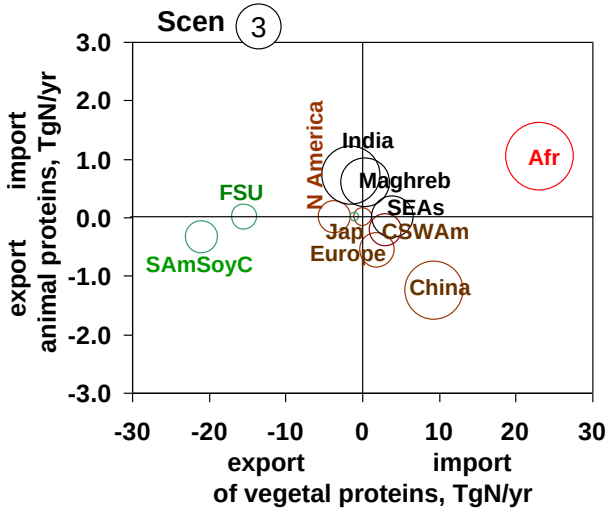


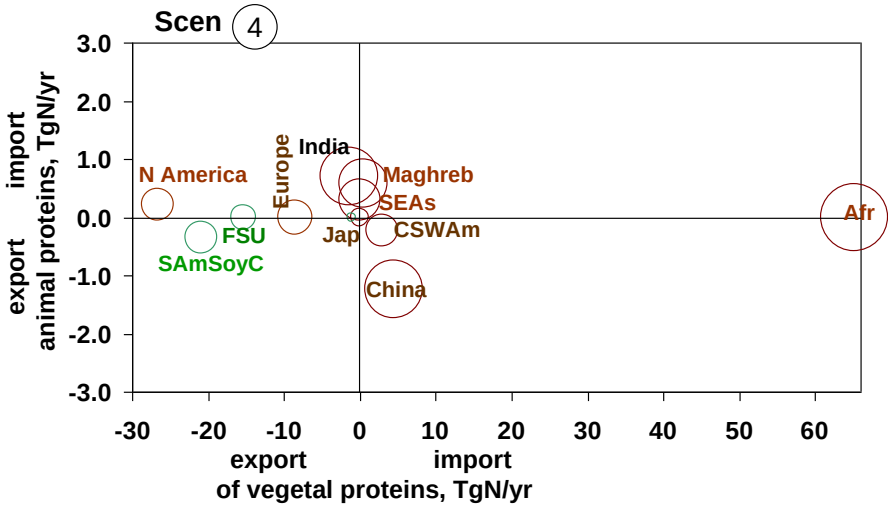




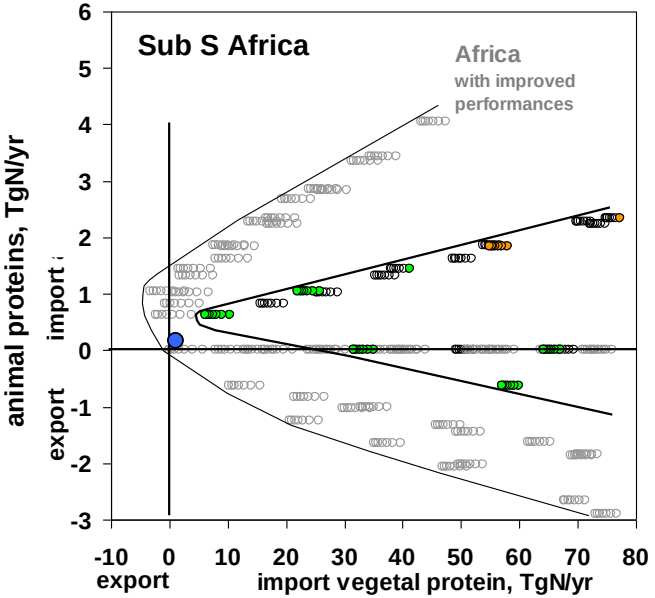
Global: current diet

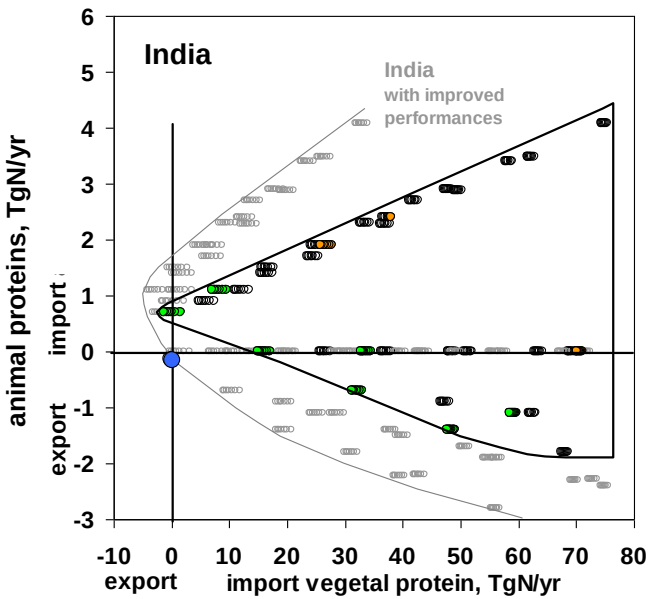


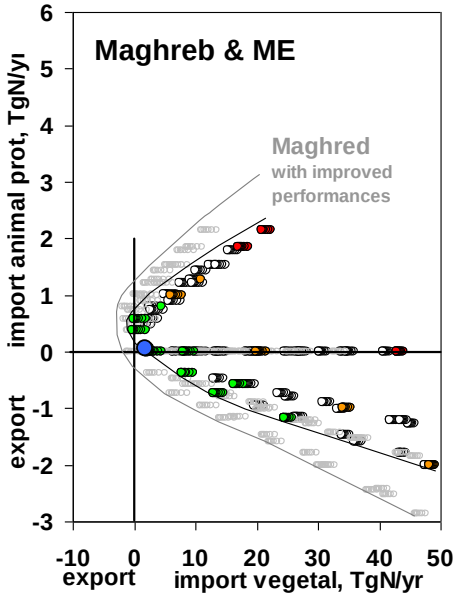




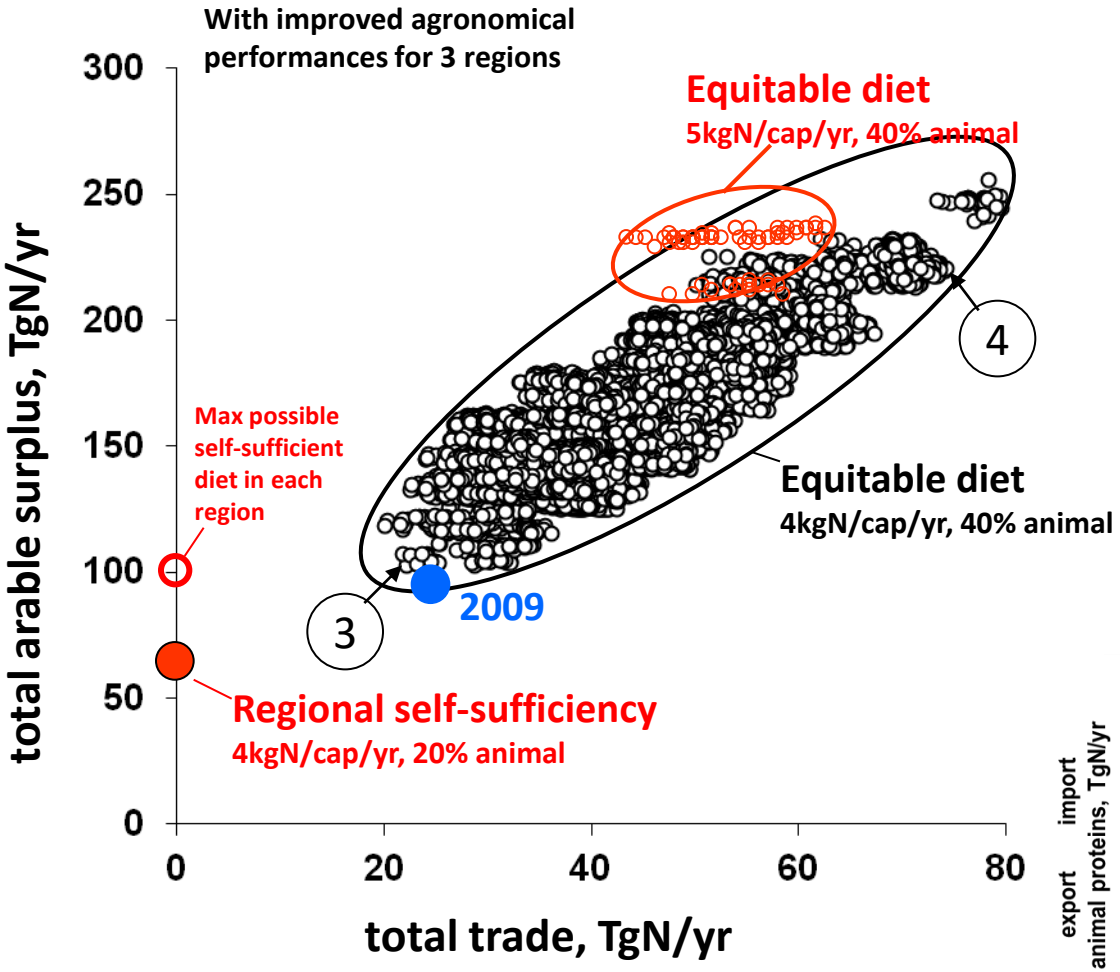
Global: Equitable diet

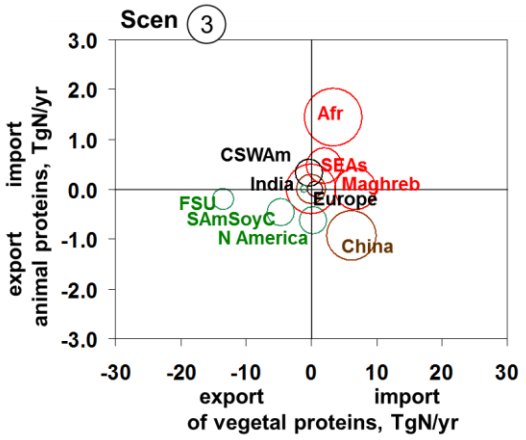


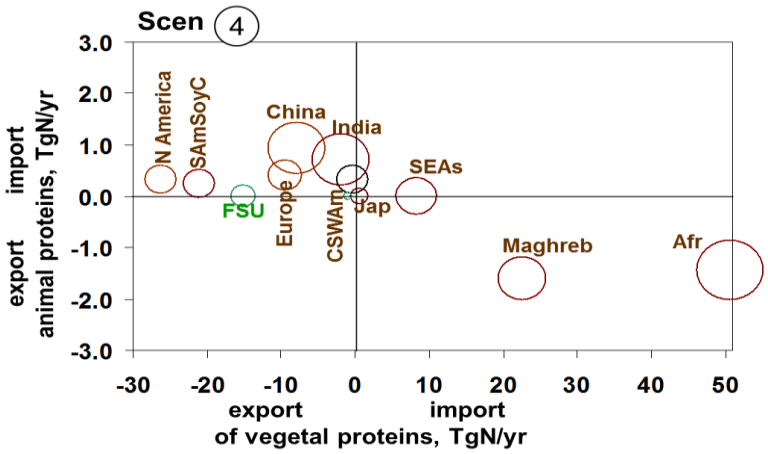




Global: Agronomical improvements in India, Africa







Global: Agronomical improvements in India, Africa

CONCLUSIONS

1. Today, to analyze the N cycle the **global system** is necessary to **take into account the local particularities** of the world regions, similarly, to understand the country scale we need to take the global scale.

2. The keys drivers for a sustainable N use can be found both in the **supply** (NUE of cropping systems, vegetal into animal transformation efficiency, crop-livestock disconnection) in the **demand side** (human diet, food waste).

3. To produce **enough quality food** for an increasing world population is not only depending on closing the yield gaps. There is a large amount of options to **feed the world in 2050** with different levels of pollution and international interdependency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