The Nitrogen Footprint

Jan Willem Erisman
Louis Bolk Institute
VU Amsterdam
The Netherlands

Slides co-prepared by Allison Leach, Jim Galloway, and Andrew Greene

Assignment for today

- Estimate your N-footprint via the Beta-version at: www.N-Print.org
- Aim is to provide regional cost-effective solutions for the N impacts while feeding the growing world population in 2015
- As a group present your top three measures with costs, benefits and argumentation

Presentation outline

0 What is my background?

1 What is a nitrogen footprint?

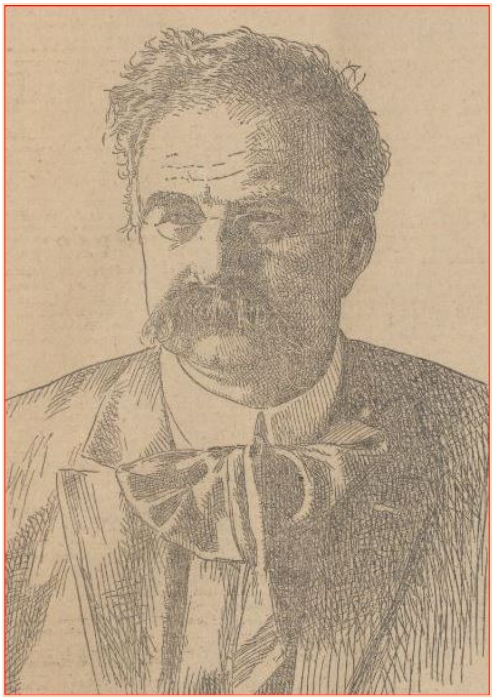
2 Personal N footprints

3 Options for reducing N footprints

4 Successful reductions

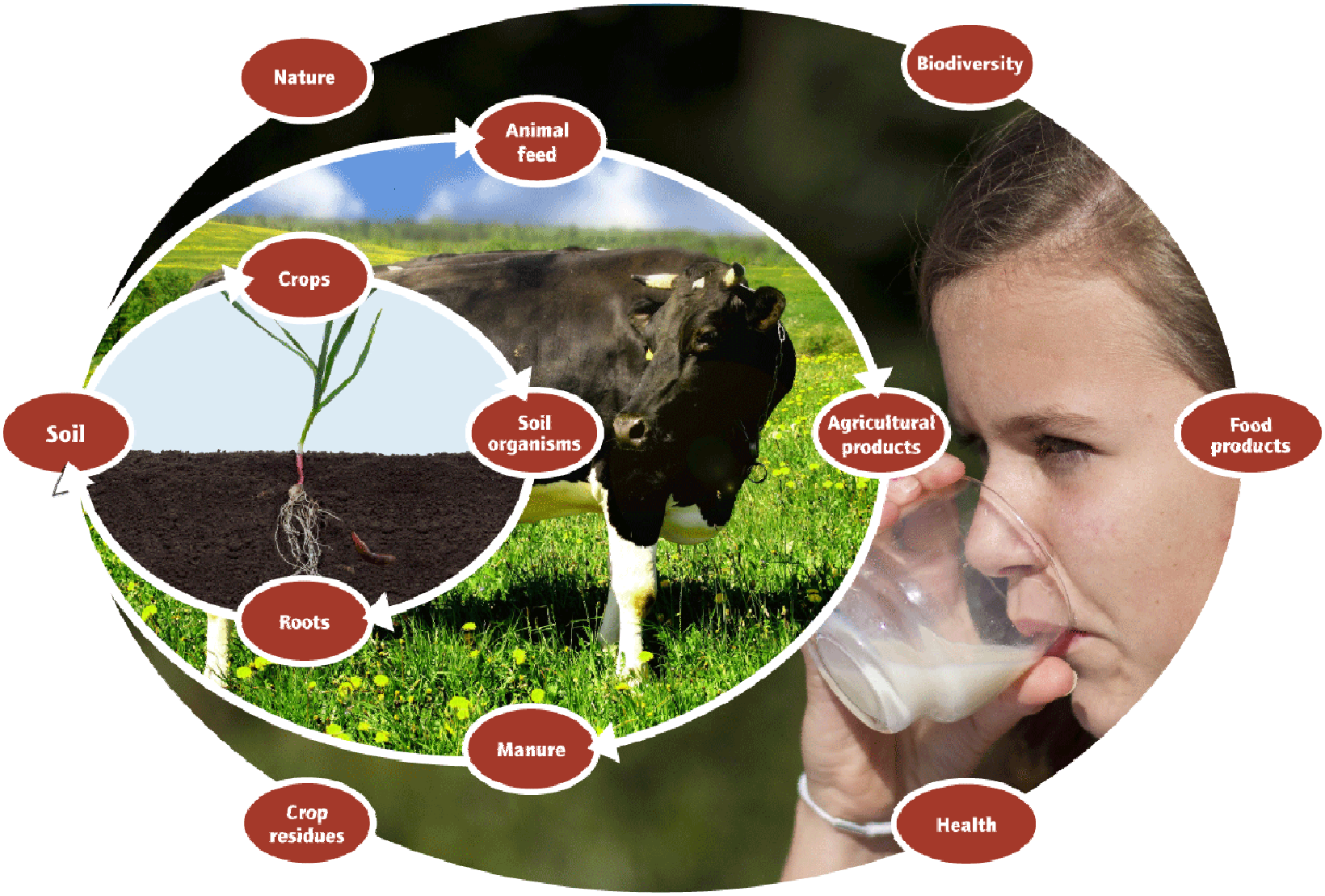
Louis Bolk (1866-1930)

"Our conception of life would be so much wider if we would be able to study life with a narrow glass"



LOUIS BOLK
INSTITUTE 40 YEARS

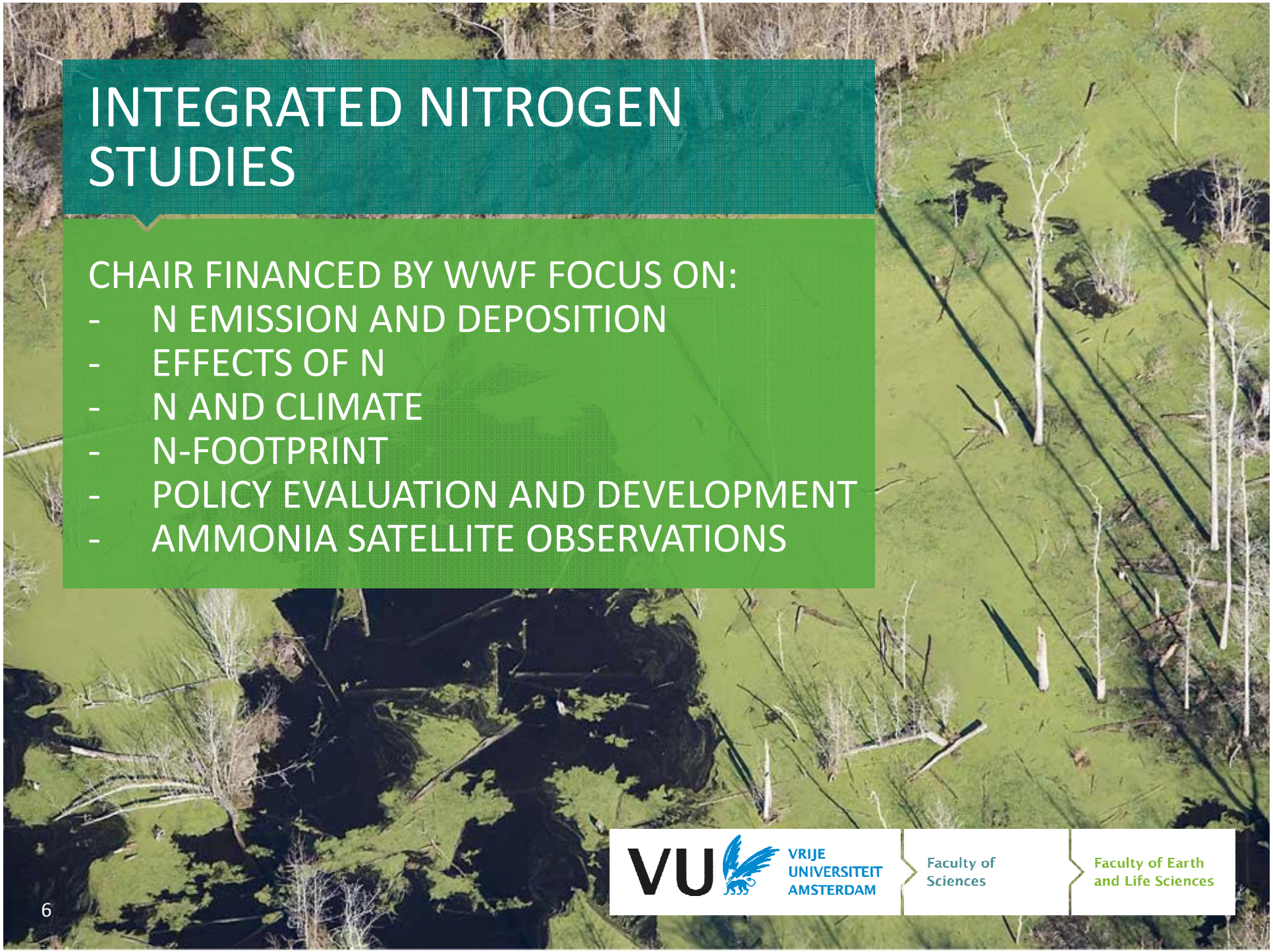
Louis Bolk Institute: for sustainable agriculture, nutrition and health



INTEGRATED NITROGEN STUDIES

CHAIR FINANCED BY WWF FOCUS ON:

- N EMISSION AND DEPOSITION
- EFFECTS OF N
- N AND CLIMATE
- N-FOOTPRINT
- POLICY EVALUATION AND DEVELOPMENT
- AMMONIA SATELLITE OBSERVATIONS



VU VRIJE UNIVERSITEIT AMSTERDAM | Faculty of Sciences | Faculty of Earth and Life Sciences

Infrared Atmospheric Sounding Interferometer (IASI)

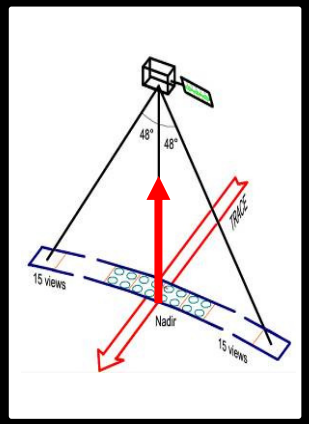
MetOp

Polar orbiting satellite

IASI

Thermal IR nadir sounder

Key points :



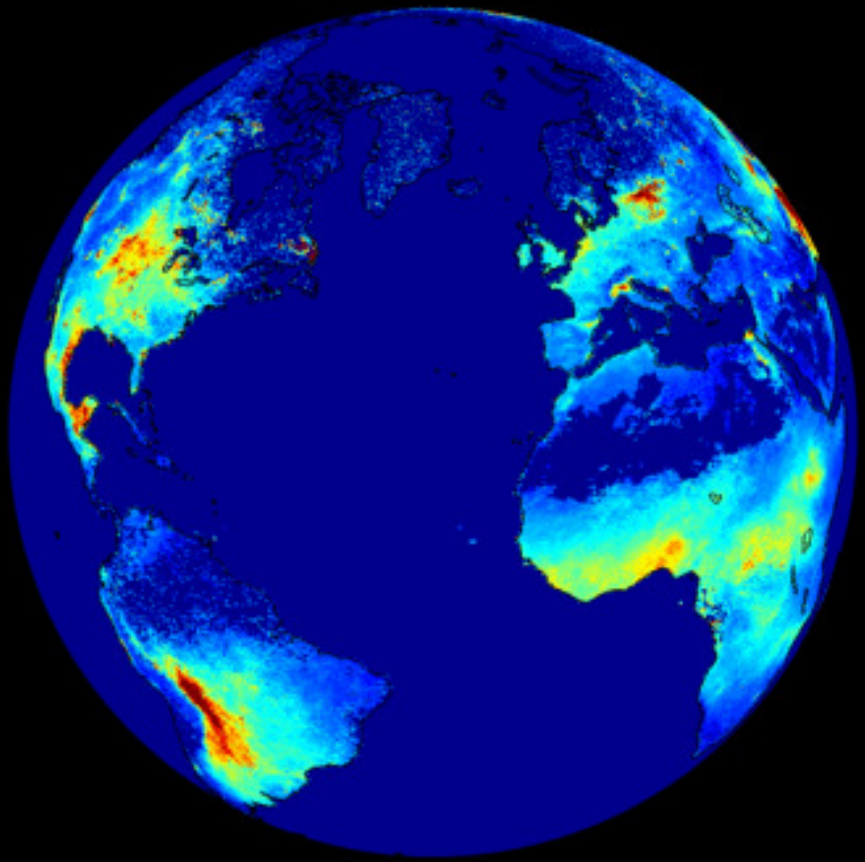
SAMPLING

- **Relatively small pixel size**: **12 km on-ground at nadir**
- **Global coverage & high sampling**: **global measurements twice daily**

INSTRUMENTAL

- Broad spectral range : 645-2760 cm^{-1} , without gaps
- Relatively high spectral resolution: 0.5 cm^{-1} apodized
- Low noise: 0.1 – 0.2 K in the regions of interest

Ammonia satellite observations



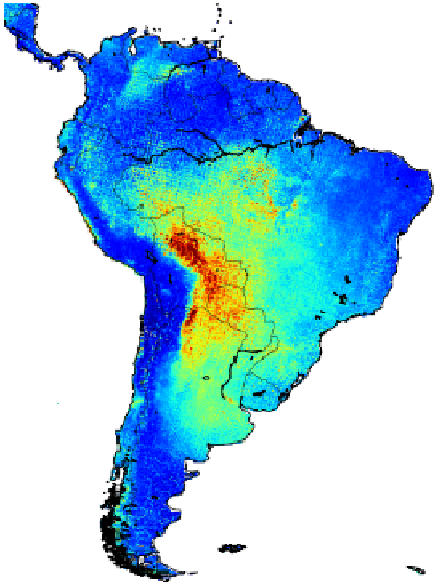
2011 NH_3 distribution

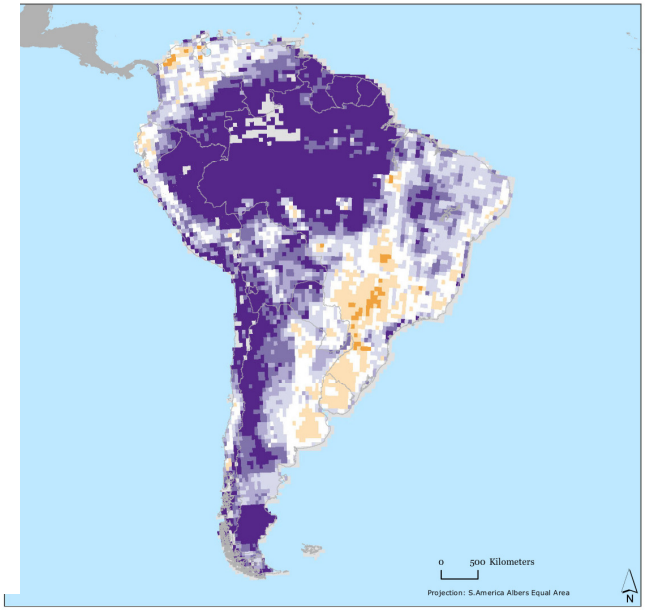
Van Damme et al. 2014

VU UNIVERSITY AMSTERDAM

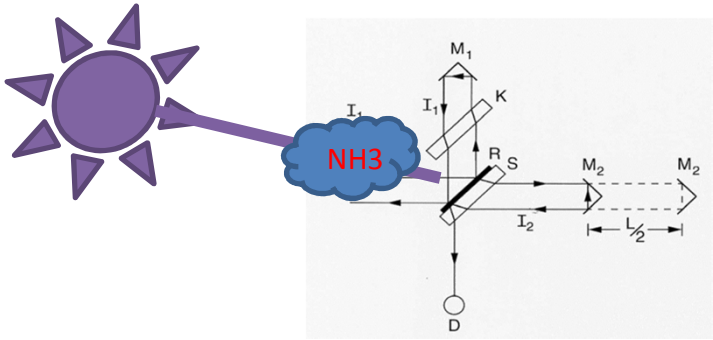
LOOKING FURTHER

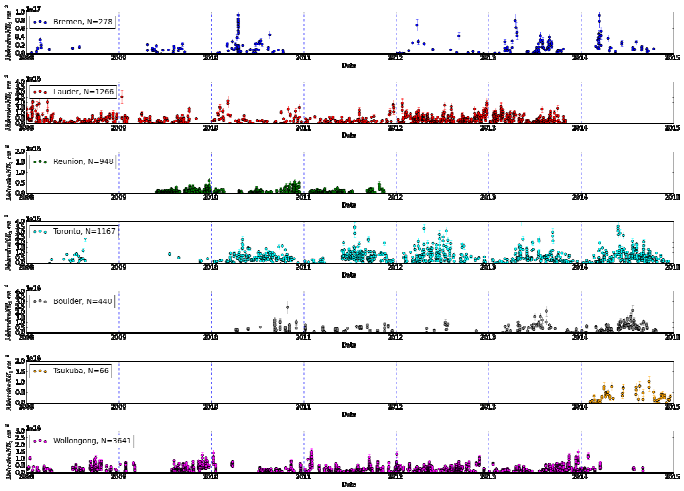
Ammonia satellite validation



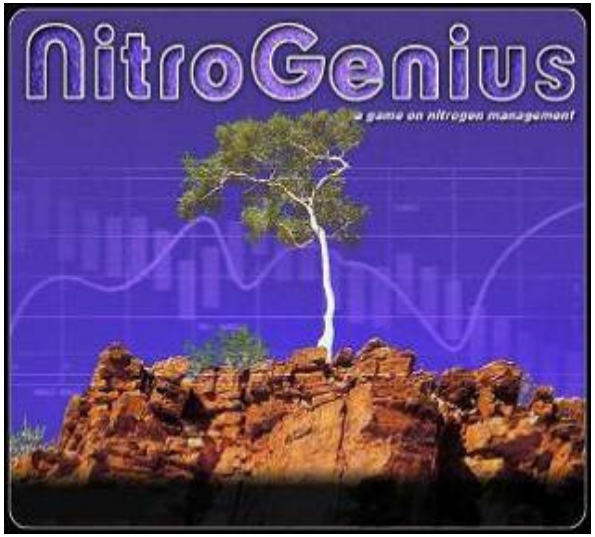


Enrico Dammers





N-tools: to simplify a complex issue



www.initrogen.org
www.nine-esf.org
www.n-print.org

Presentation outline

1. What is a nitrogen footprint?

2. Personal N footprints

3. Options for reducing N footprints

4. Successful reductions

Carbon Footprint

Measures the emission of gases that contribute to global warming

Water Footprint

Measures the consumption and contamination of freshwater resources

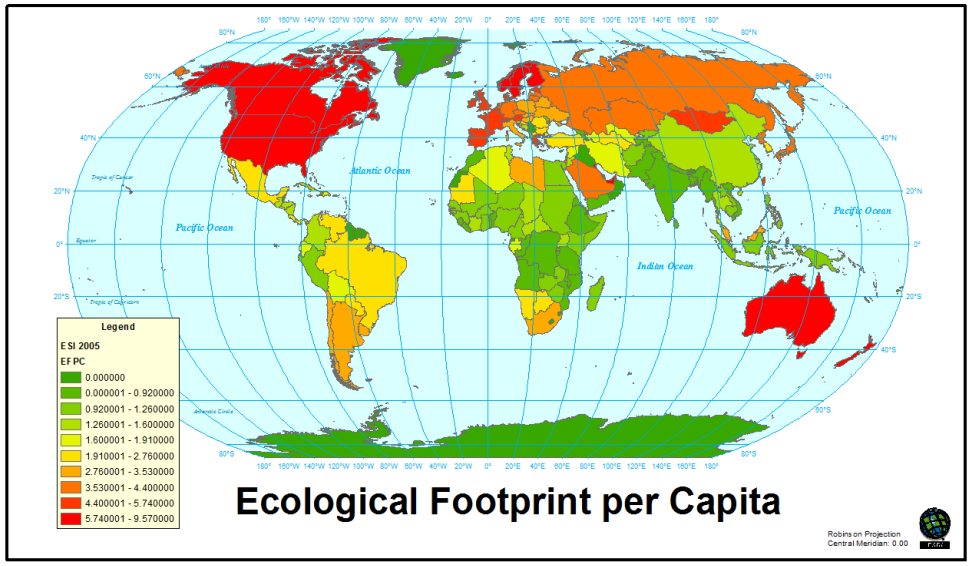
Activities, products and consumption patterns that affect Earth's natural resources and carrying capacity

Ecological Footprint

Measures the use of bio-productive space

Nitrogen Footprint

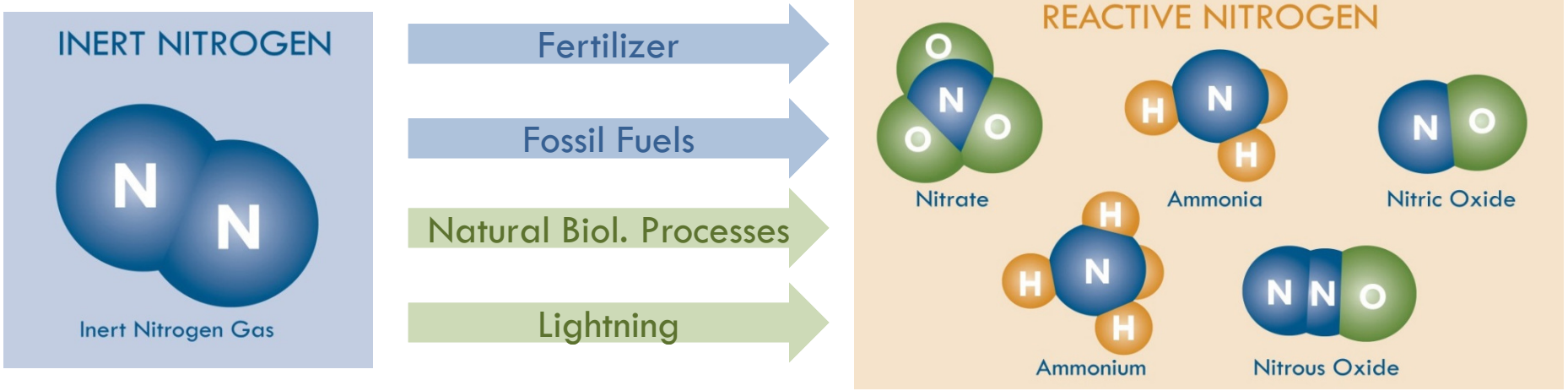
Measures the amount of nitrogen released into the environment in relation to consumption



Ecological Footprint per Capita

1 What is a nitrogen footprint?

What is REACTIVE NITROGEN ?



Reactive nitrogen is all species of nitrogen except the unreactive N_2 in the atmosphere. Reactive nitrogen is created by natural processes, but its creation is now dominated by human activities.

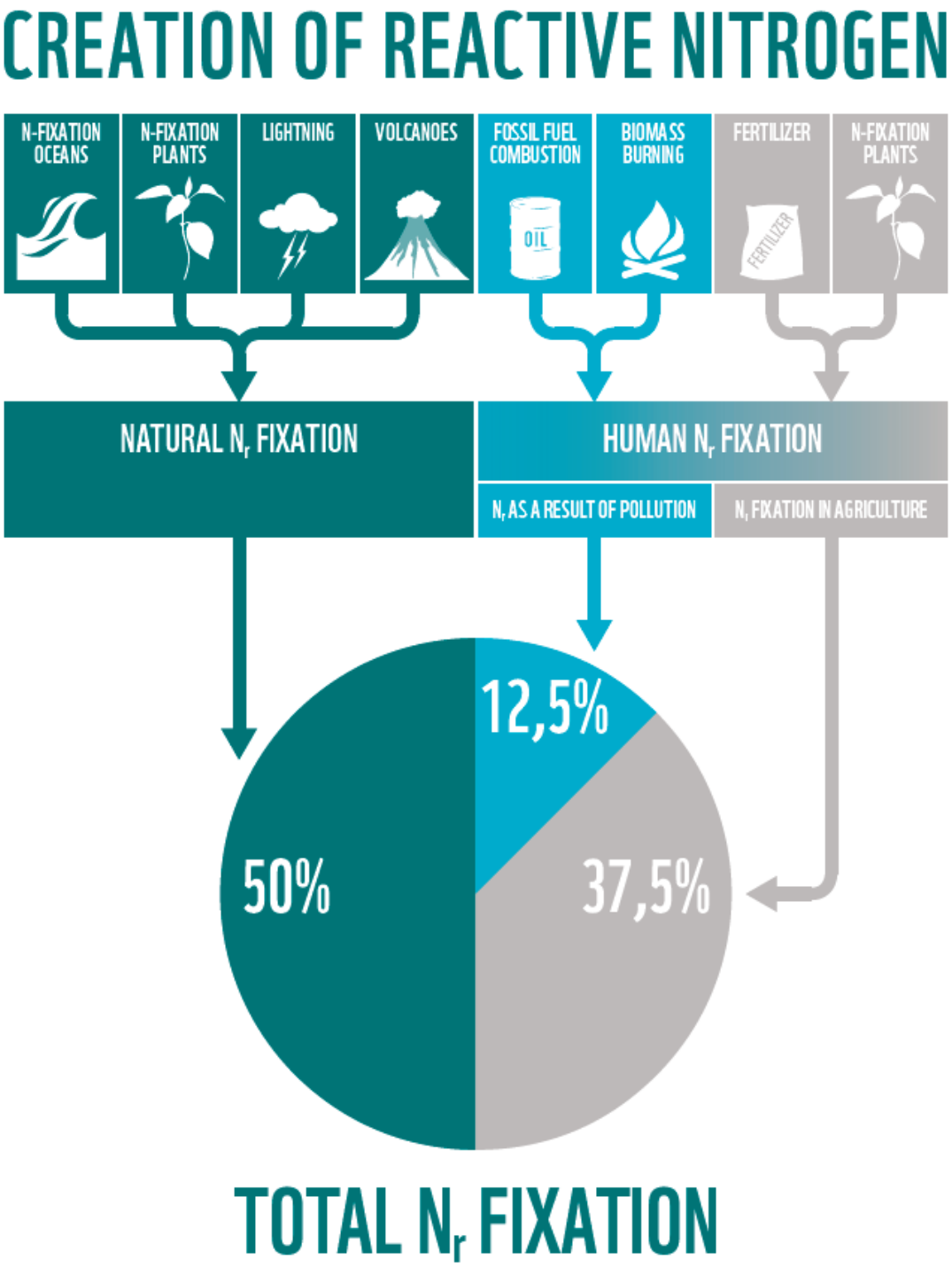
Reactive N is Created By:

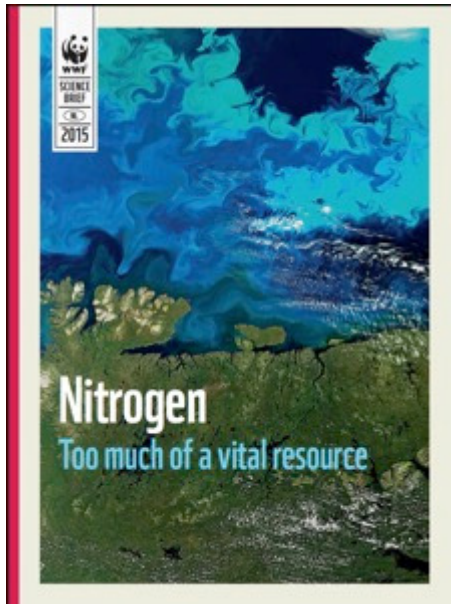
Natural processes:

- Nitrogen fixation by microbes
- Also: lightning

Man-made processes:

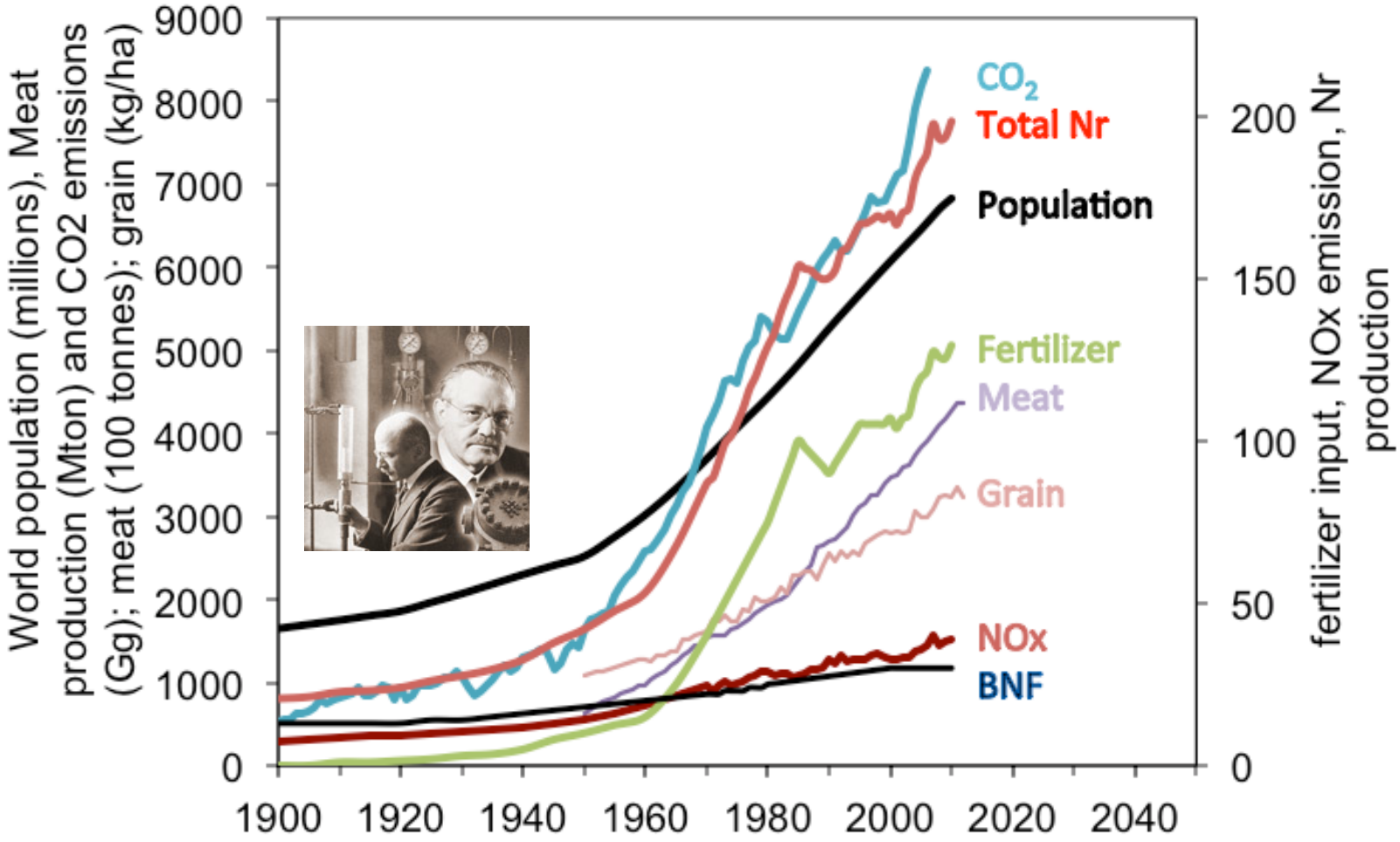
- Fossil fuel combustion
- **Haber Bosch process**





Erisman et al. (2015)

Global trends in human population, N_r, CO_2 and grain and meat production



48% of the global population eat because of fertilizers

Erisman et al. 2008

Uneven distribution

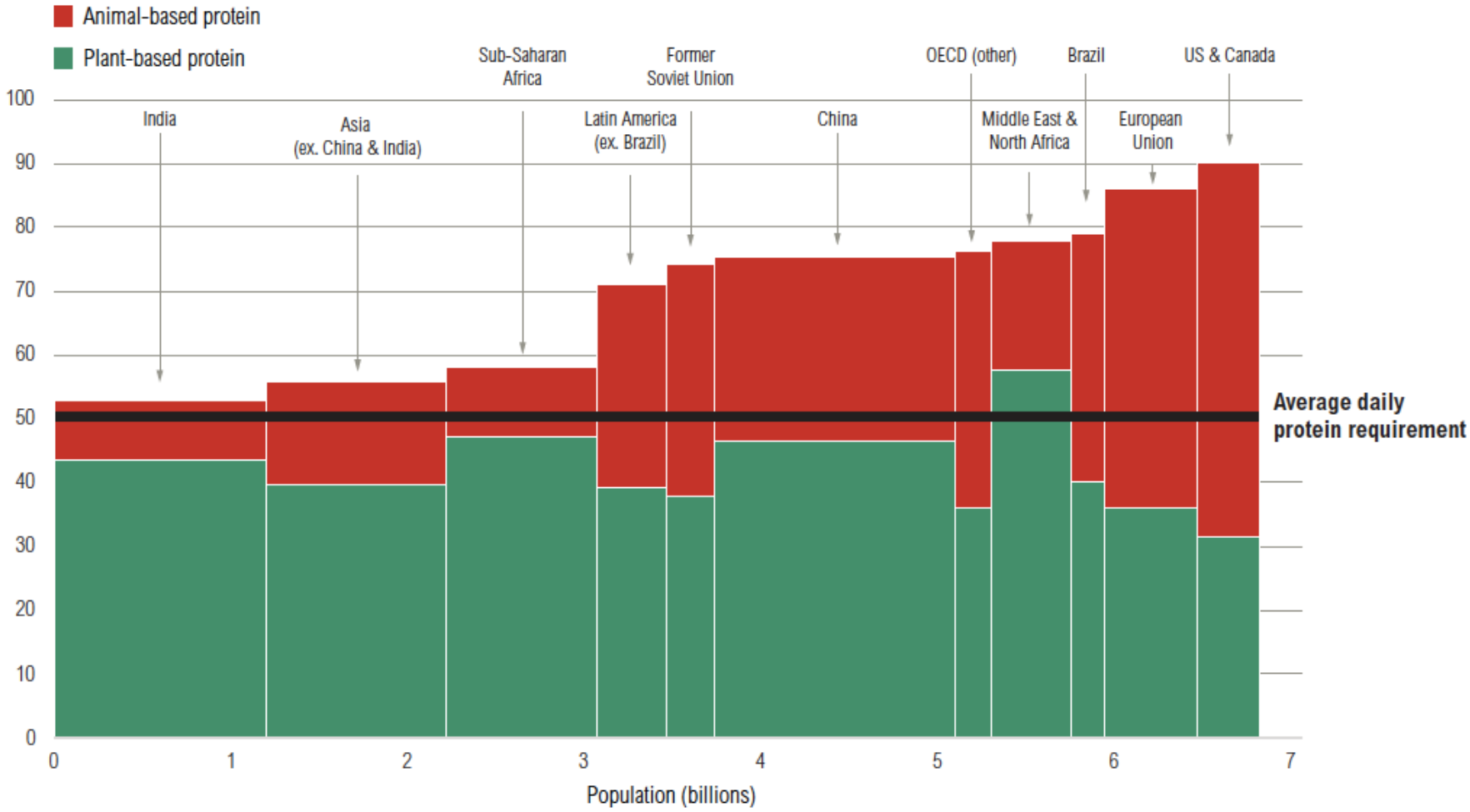
- More than 2 billion people in the world suffer from (micro) **nutrient deficiency**, especially in developing countries. Most critical are **protein-nitrogen**, phosphorus, calcium, zinc, iron, iodine
- An increasing number of people is **obese**
- Probably 20% of the population **'eats' 80% of the fertilizer**

United States, The Revis family
$341.98/week

Chad The Aboubakar family
$1.23

Photo's: Peter Menzel, Faith D'Aluisio

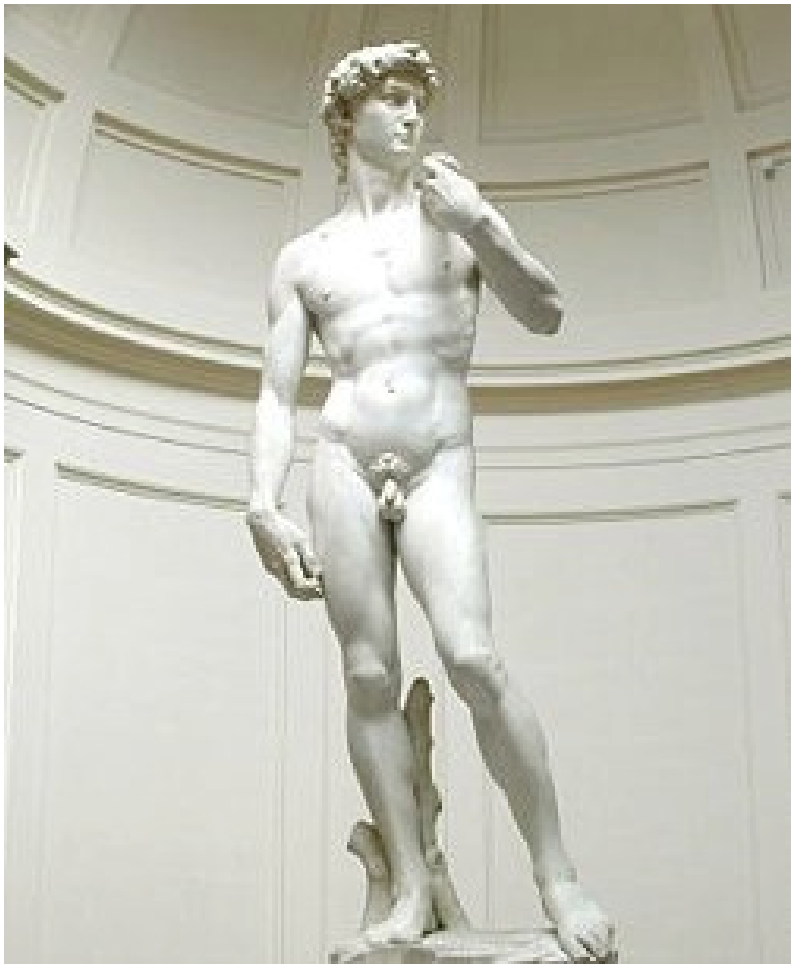
Protein consumption is worldwide above the recommended level …..



…. with many consequences for health (costs)

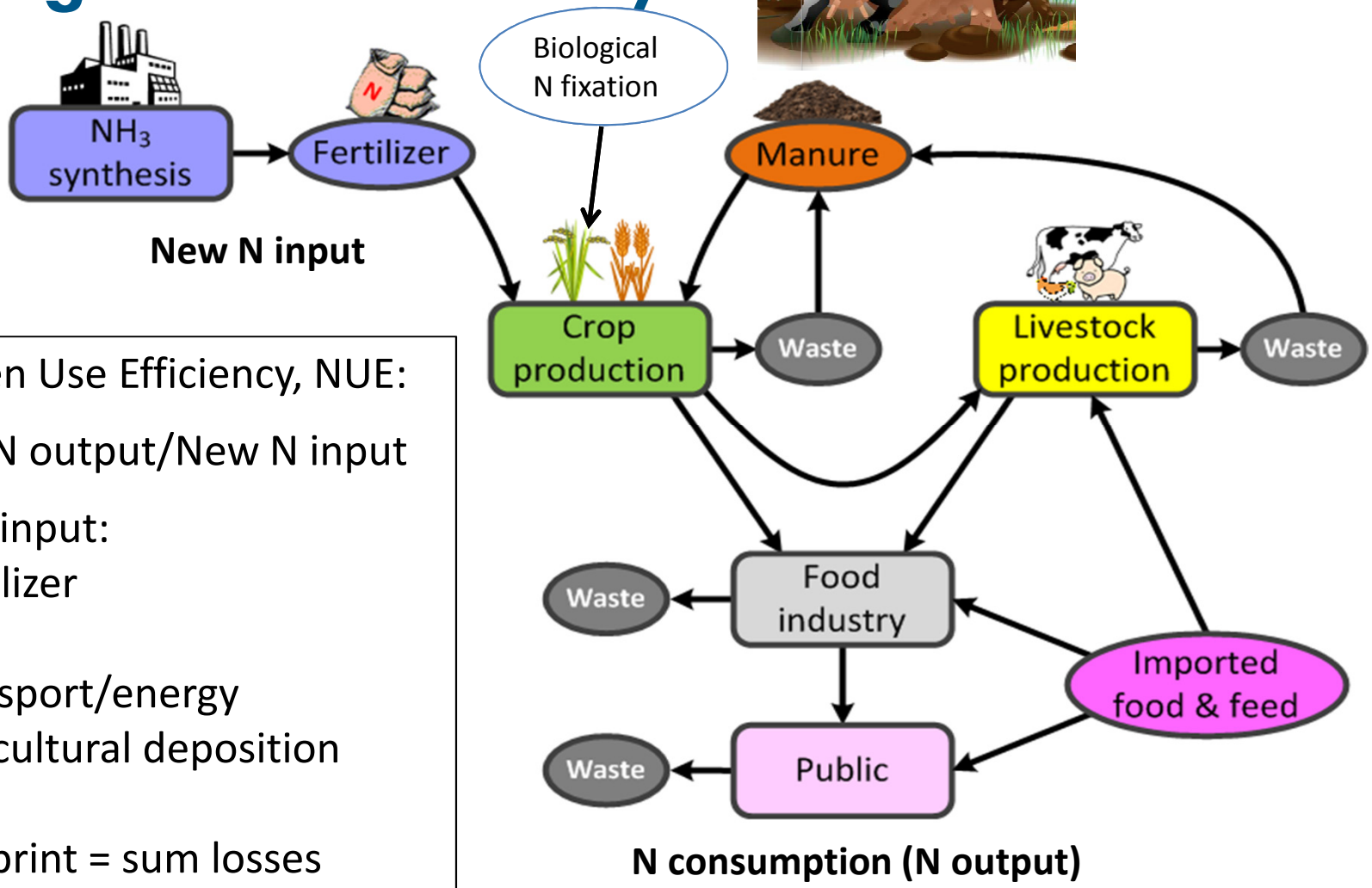
WRI, 2016

Nitrogen stimulates all growth



David,
Michelangelo Buonarroti (1475 - 1564)

Major N issue is the nitrogen use efficiency



Nitrogen Use Efficiency, NUE:

NUE = N output/New N input

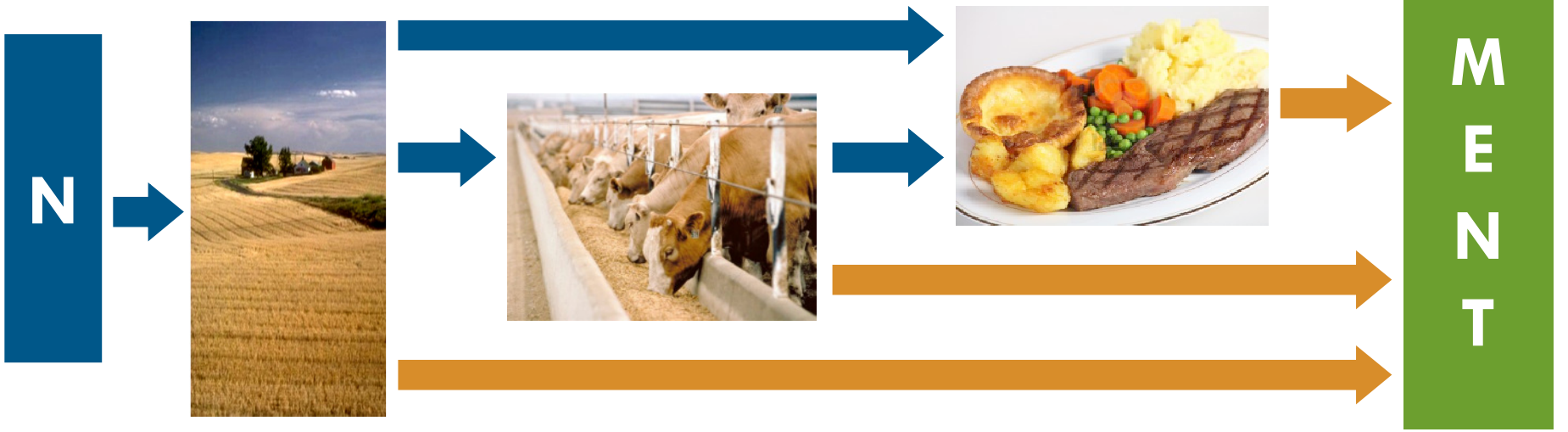
New N input:

- Fertilizer
- BNF
- Transport/energy
- Agricultural deposition

N Footprint = sum losses

Energy Production: NUE = 0%

Food Production: NUE = 10 – 50%



ENVIRONMENT

Too Much Nitrogen: In a Cascade

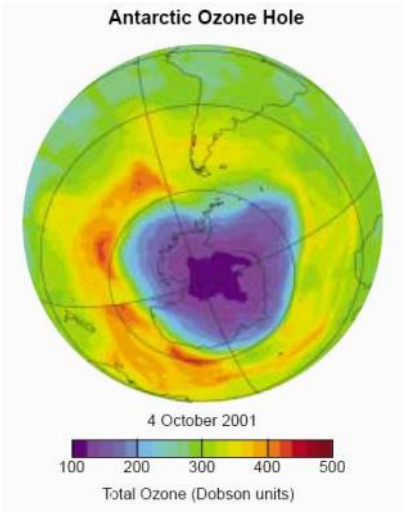
Smog, Haze

Forest Dieback

Acidification

Dead zones

Global Warming



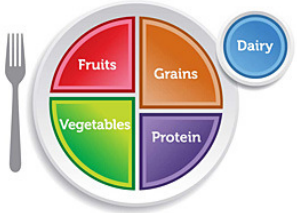
Ozone Hole

HUGE VARIATION IN N FLOWS AND SYSTEMS

The Nitrogen Dilemma:

Benefits

Necessary for life
Synthetic N fertilizer provides increased food supply



Drawbacks

Negative impacts to environmental, climate & human health

Challenge:

Optimize the use of nitrogen, while minimizing the negative impacts

Addressing the nitrogen challenge

1. Technology

2. Policy

3. Personal/institutional Action

What is a nitrogen footprint?

A **nitrogen footprint** is the amount of **reactive nitrogen** released to the environment as a result of an entity's resource consumption

What major sectors are commonly included in a nitrogen footprint?

Food*

Utilities

Transport

**Food consumption and production*

Food N footprint: Definitions

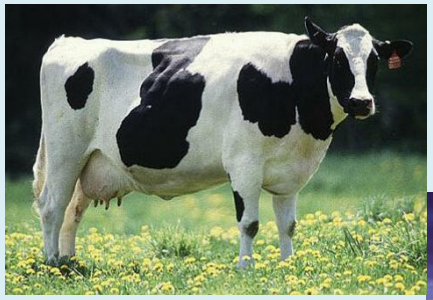
Food consumption

= N that enters human mouth

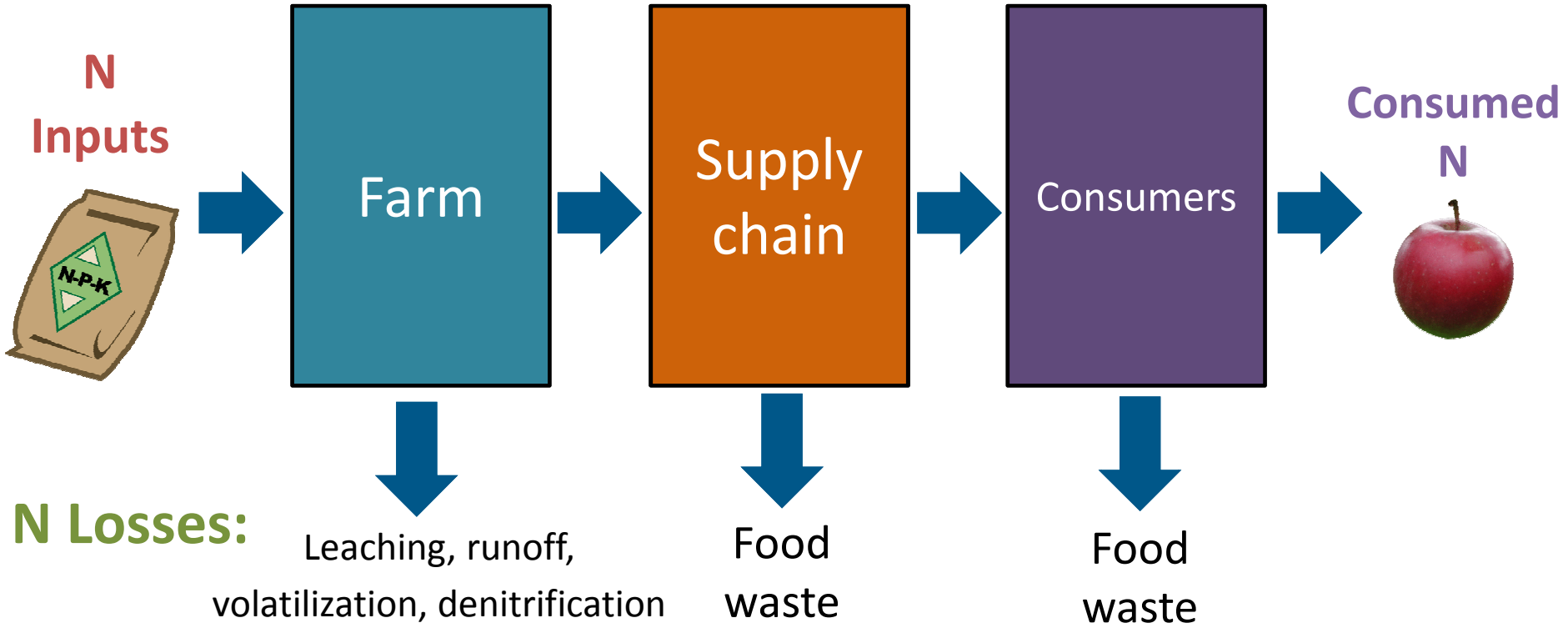
Virtual N

= **Food production N**

= N lost to the environment during the food production process



N efficiency over the food chain

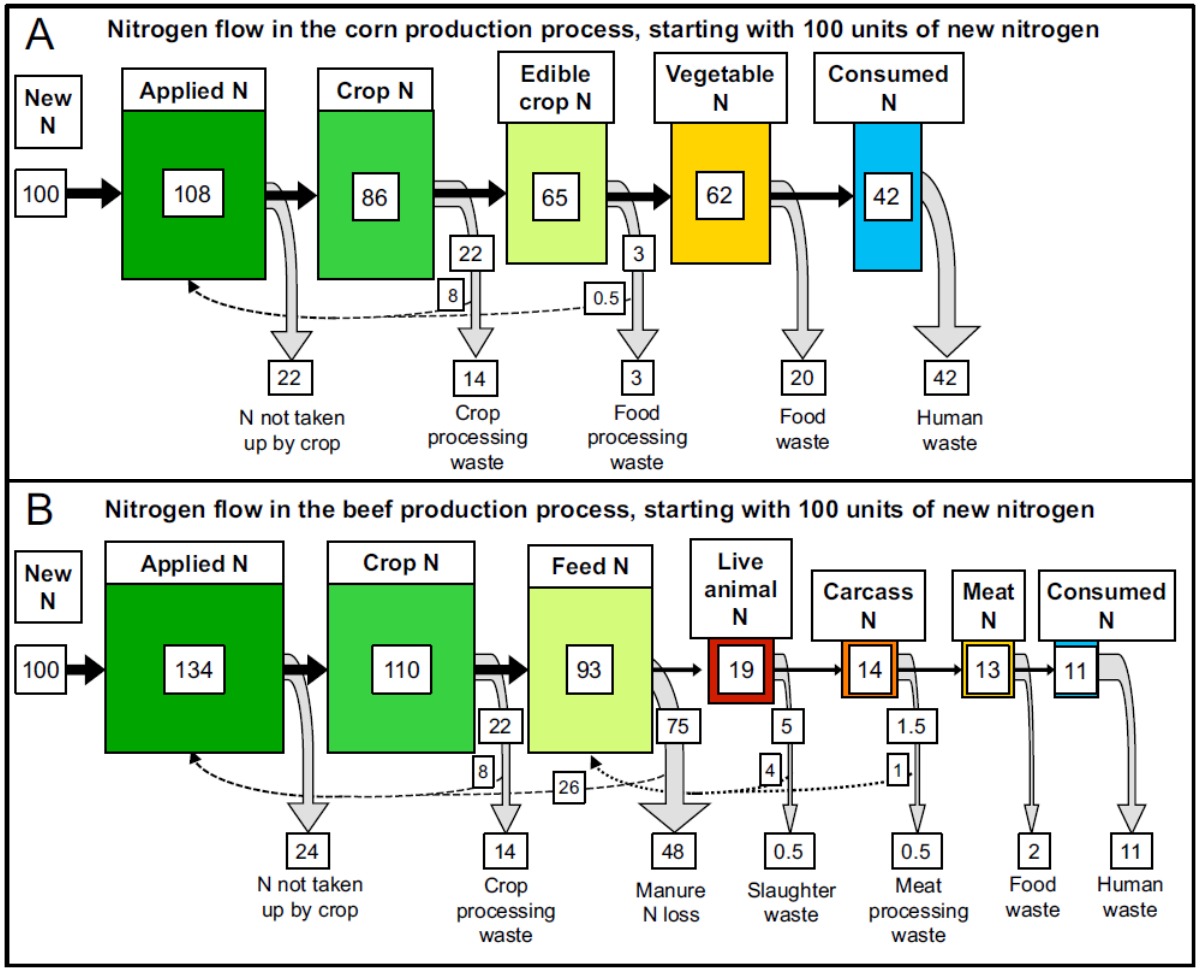


N Surplus = N Inputs – Consumed N = ∑ N Losses

$$\text{NUE} = \frac{\text{Consumed N}}{\text{N Inputs}}$$

$$\text{Virtual N Factor} = \frac{\sum \text{N Losses}}{\text{Consumed N}}$$

Virtual Nitrogen factors are region dependent



Corn

VNF ≃ 1.4

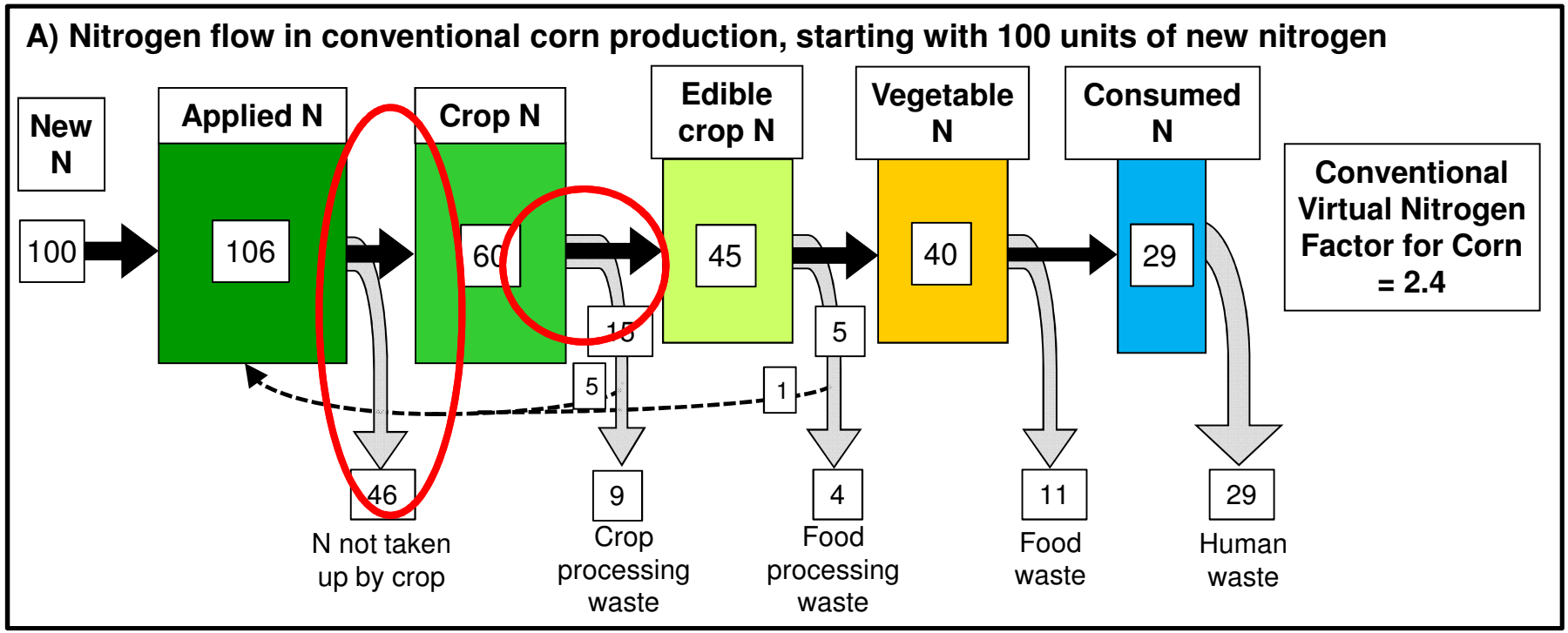
Beef

VNF ≃ 7.9

The virtual N factor (VNF) is a unit-less ratio of Nr released to the environment per unit of Nr consumed.

Leach et al. 2012

Food production N footprint is calculated with VIRTUAL NITROGEN FACTORS



Cattell Noll et al. (in prep) developing VNFs for **ORGANIC FOOD** and updating the circled factors

The impact of FOOD CHOICES on a N footprint

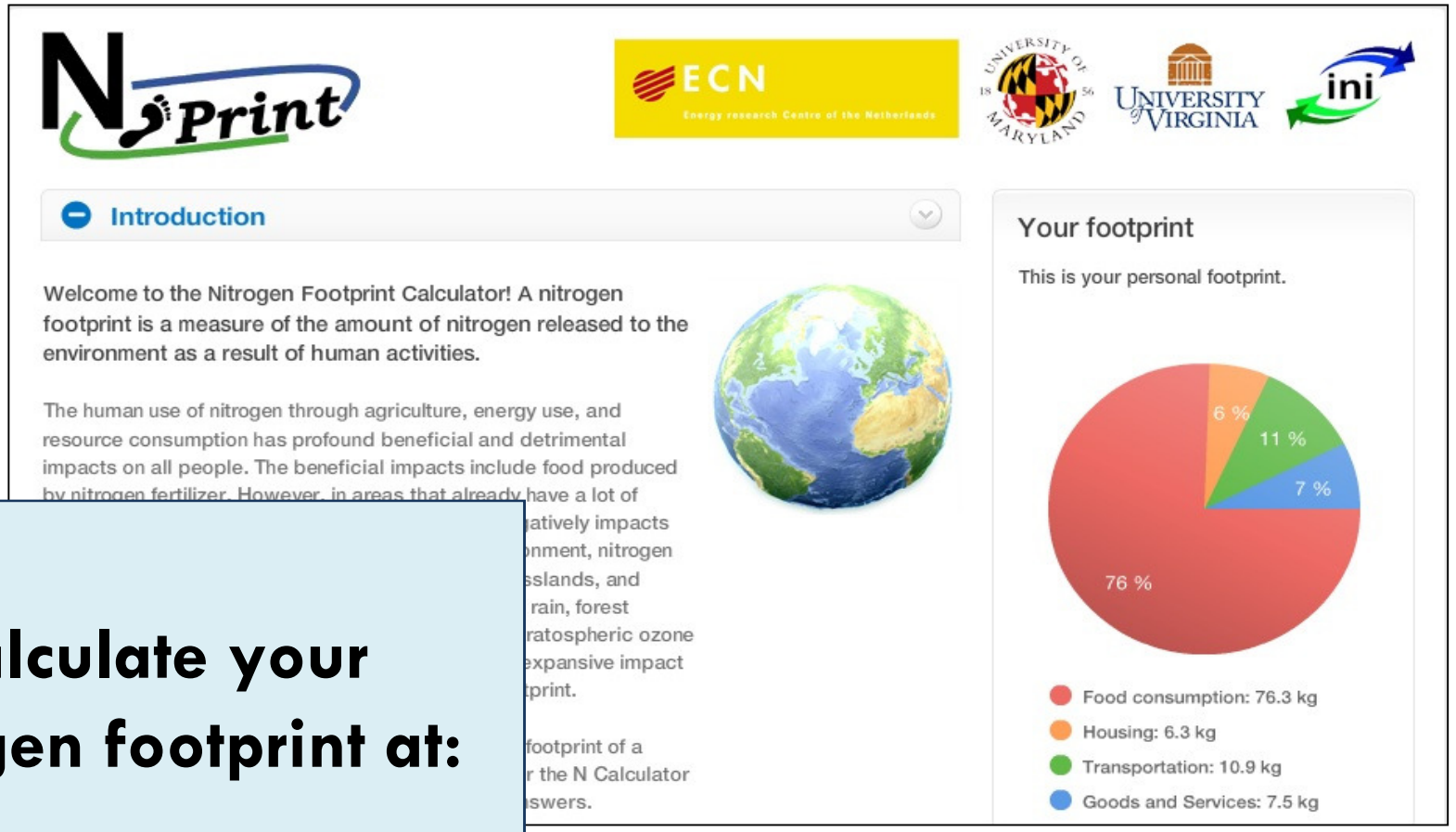
ENVIRONMENT

ENVIRONMENT

½ cup beans
15 g protein

3 oz steak
15 g protein

2 Personal N footprints



Calculate your nitrogen footprint at:

www.N-Print.org

New N-Calculator in development!

Beta version at **www.N-Print.org**

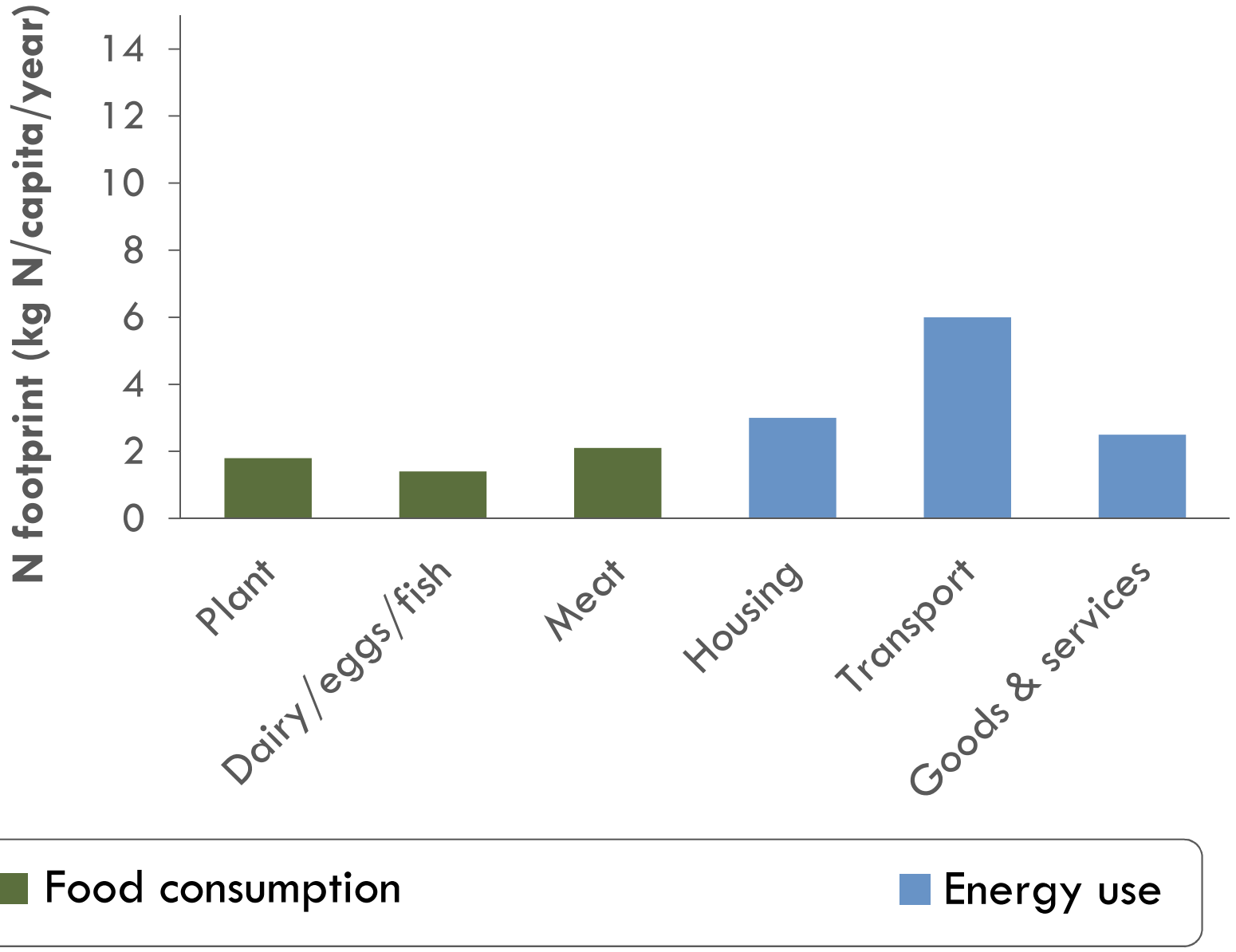
Many questions are needed to determine your footprint

Table 1
Overview of the N-Calculator questions for scaling the national average N footprints.

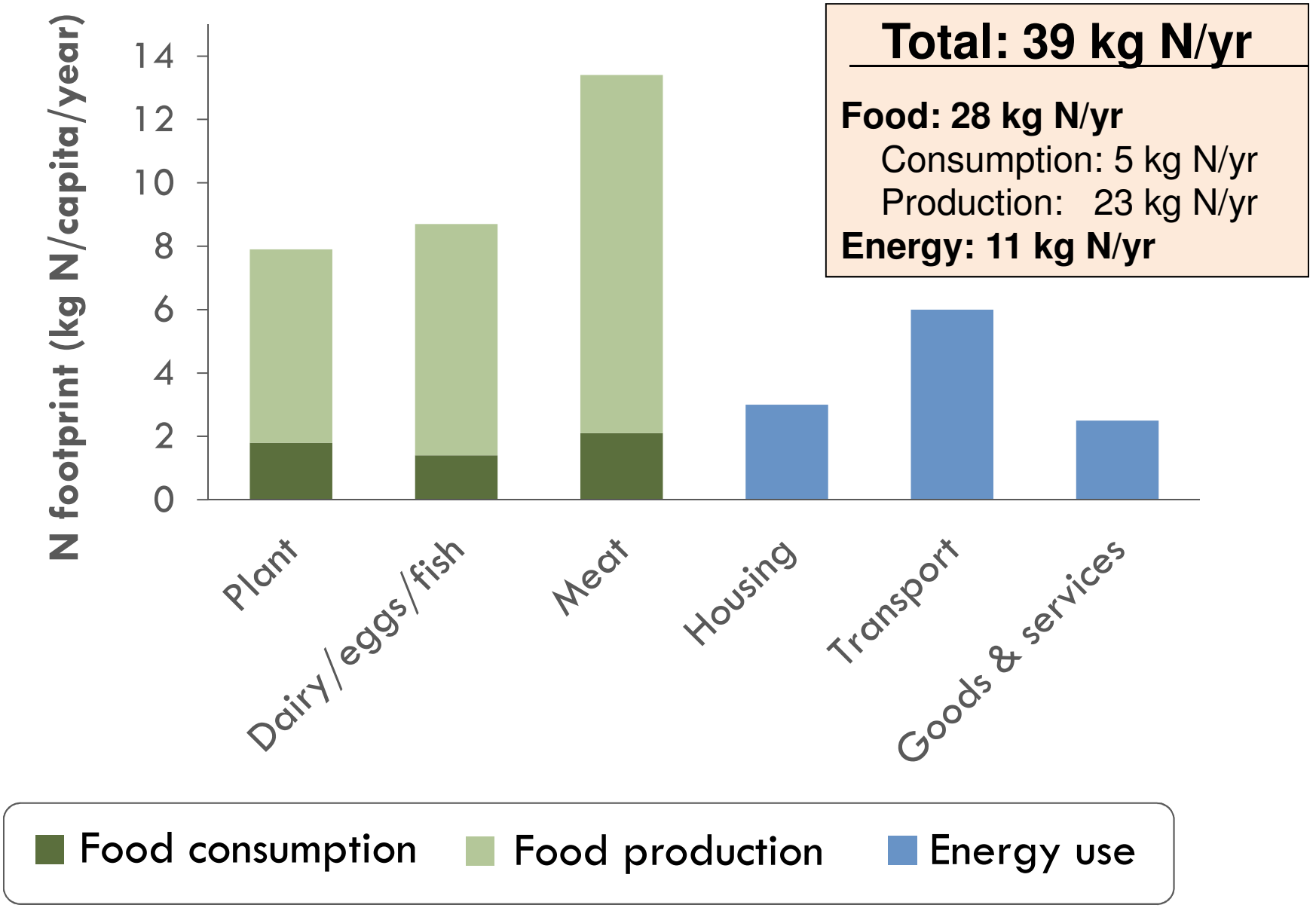
Topic	Question
Food	1. How many times a week do you consume different food types? Food categories[a] are the following: poultry, pigmeat, beef, fish and seafood, milk, cheese, eggs, cereals, rice, vegetables, beans and other legumes, starchy roots, nuts, stimulants, and alcoholic beverages 2. Is your house attached to a municipal sewer system with tertiary sewage treatment?
Energy	1. How many kWh of electricity does your household use each month? 2. How much natural gas does your household use to heat your home and to cook with each month? 3. How many people live in your household?
Transport	1. How many hours do you fly each year? 2. How far do you travel by bus or rail each week? 3. How far do you travel by car each week? 4. What kind of car do you drive?
Good and services	1. How would you describe your personal spending on goods and services?

Leach et al. (2012)

Personal N footprint in the US



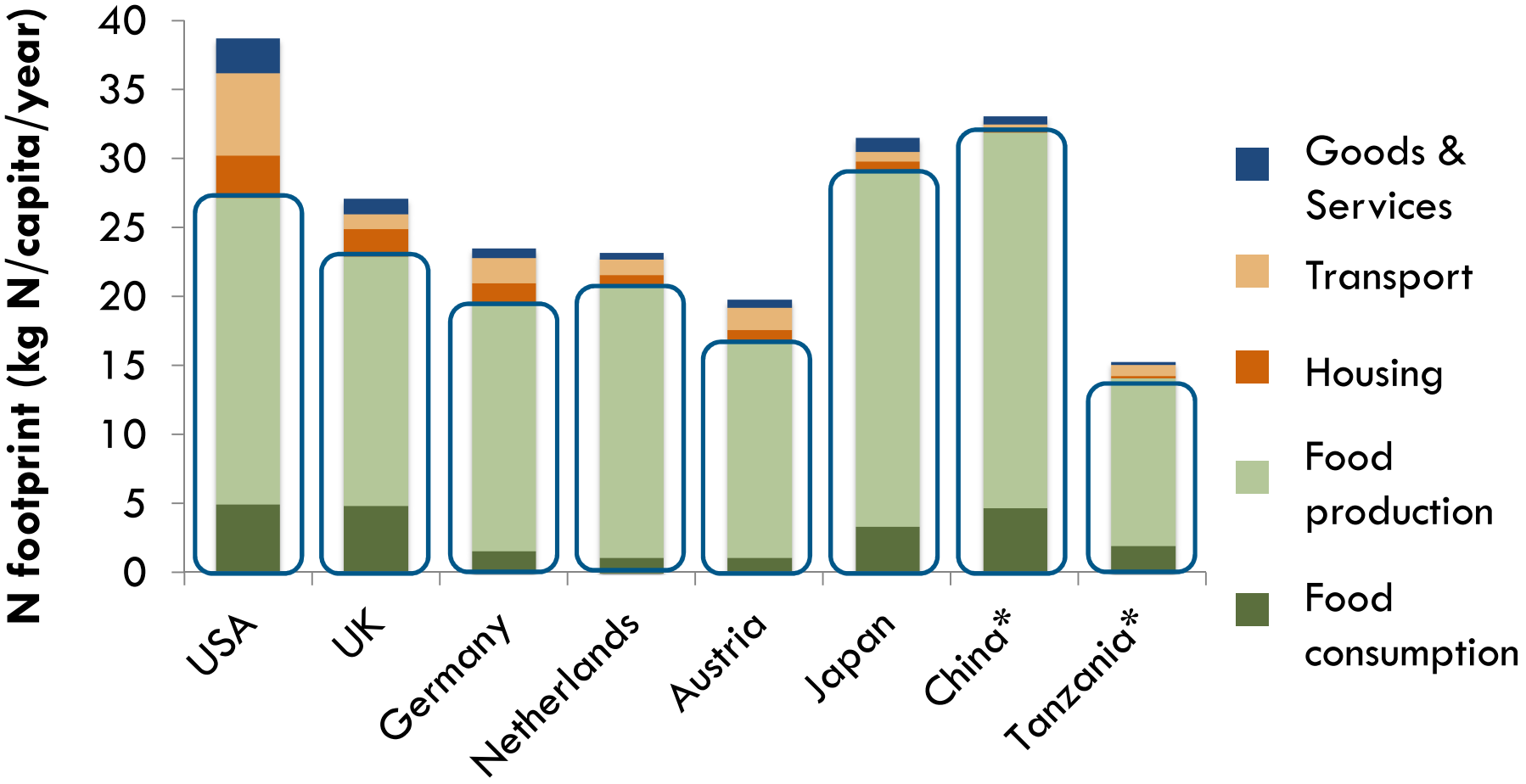
Personal N footprint in the US



Personal N footprint by country

*Preliminary

Personal N footprint by country



Food makes up more than 75% of a personal nitrogen footprint

**Preliminary*

Product N footprint for Austria

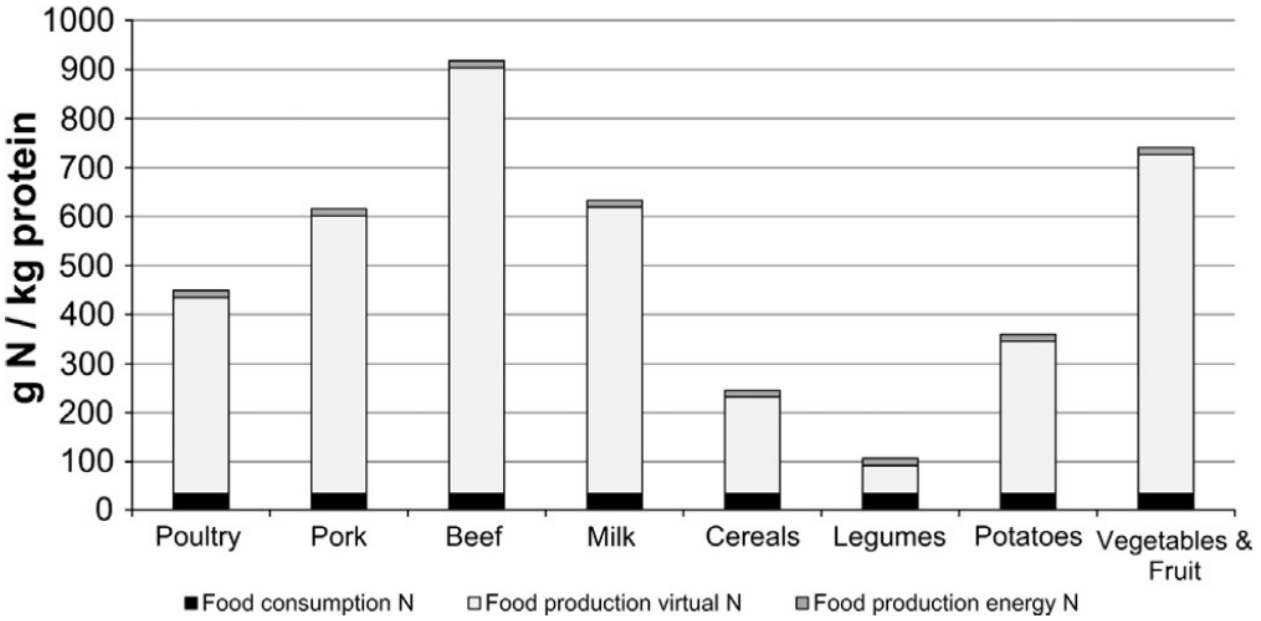


Fig. 2. Product N footprint g N/kg protein for different food items under average Austrian production conditions. The consumption part reflects the share of the N consumed and excreted by humans that is released to the environment (i.e., not denitrified in sewage treatment plants). Food production virtual N stands for real losses of Nr along the entire production chain, as derived by the application of the VNF, and food production energy N is the Nr released due to the use of energy along the production chain.

3 Options for reducing YOUR footprint

Calculate your N footprint: **www.N-PRINT.org**

Energy:

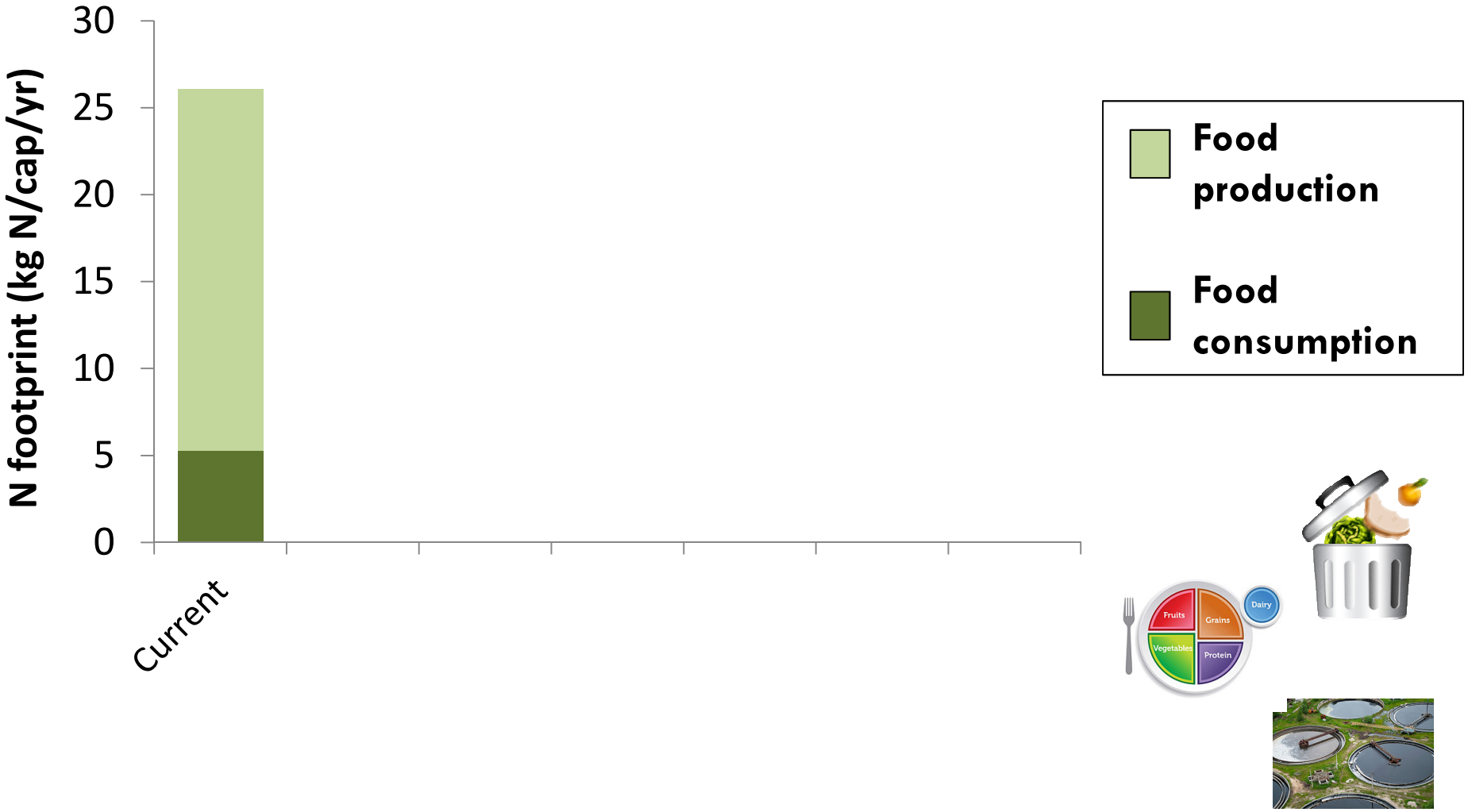
- Reduce utility usage
- Public transit
- Reduce, reuse, recycle!

Food:

- Recommended amount of protein
- Less animal protein
- Less N-intensive meat
- Food from sustainable farms
- Reduce food waste

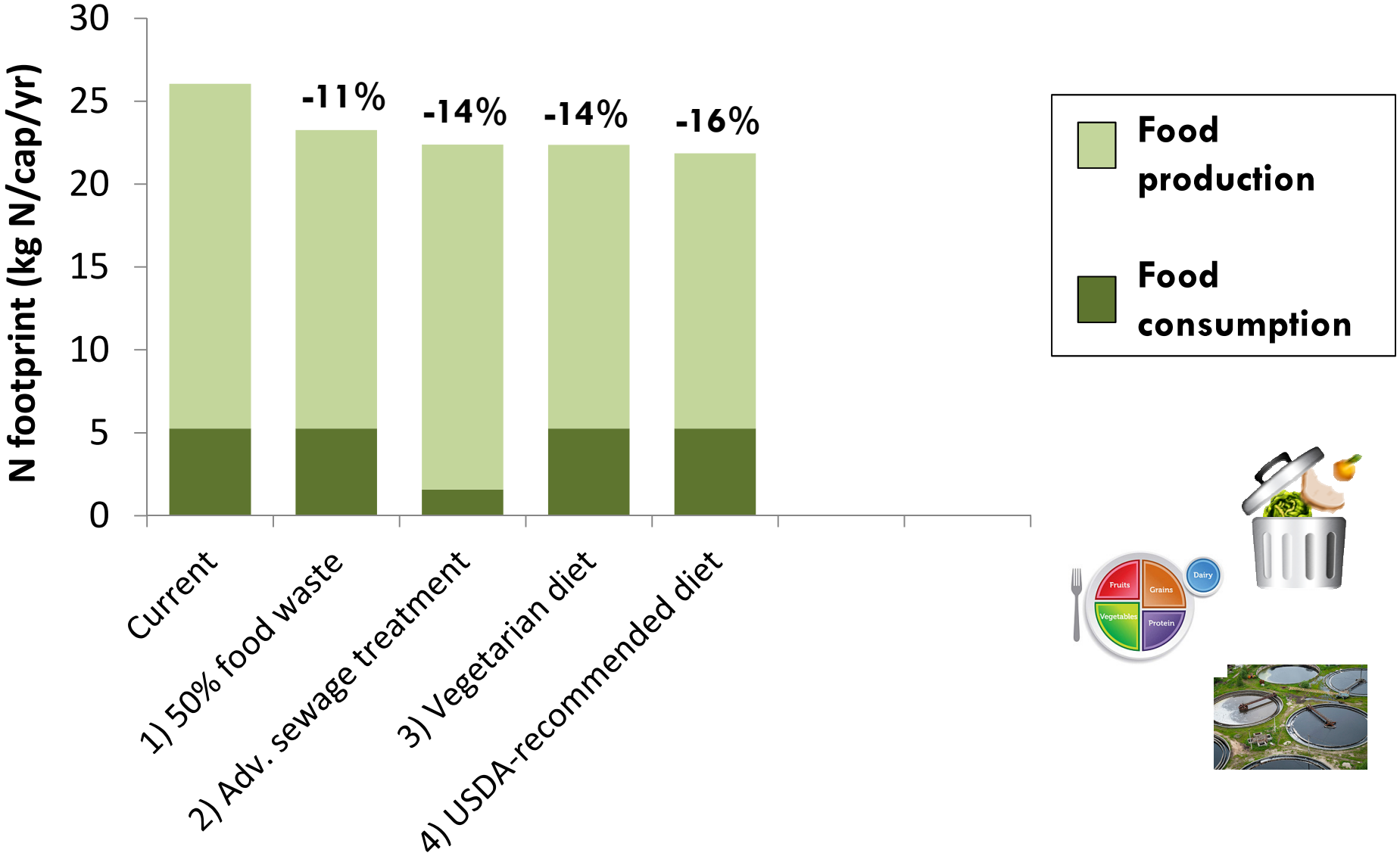
Scenarios: US personal N footprint

Current N consumption: 5.3 kg N/cap/yr
Recommended N consumption: 3.0 kg N/cap/yr



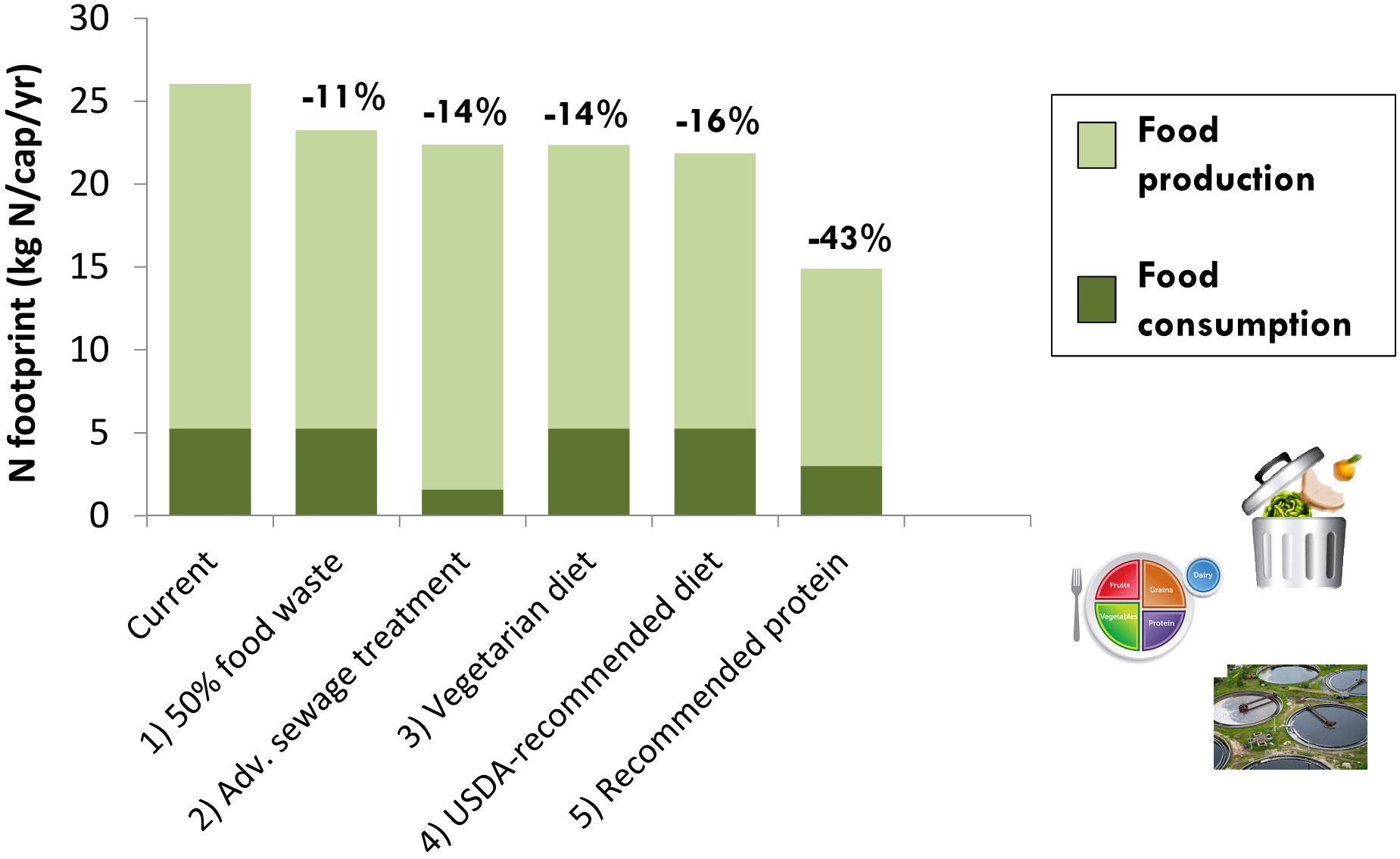
Scenarios: US personal N footprint

Current N consumption: 5.3 kg N/cap/yr
Recommended N consumption: 3.0 kg N/cap/yr



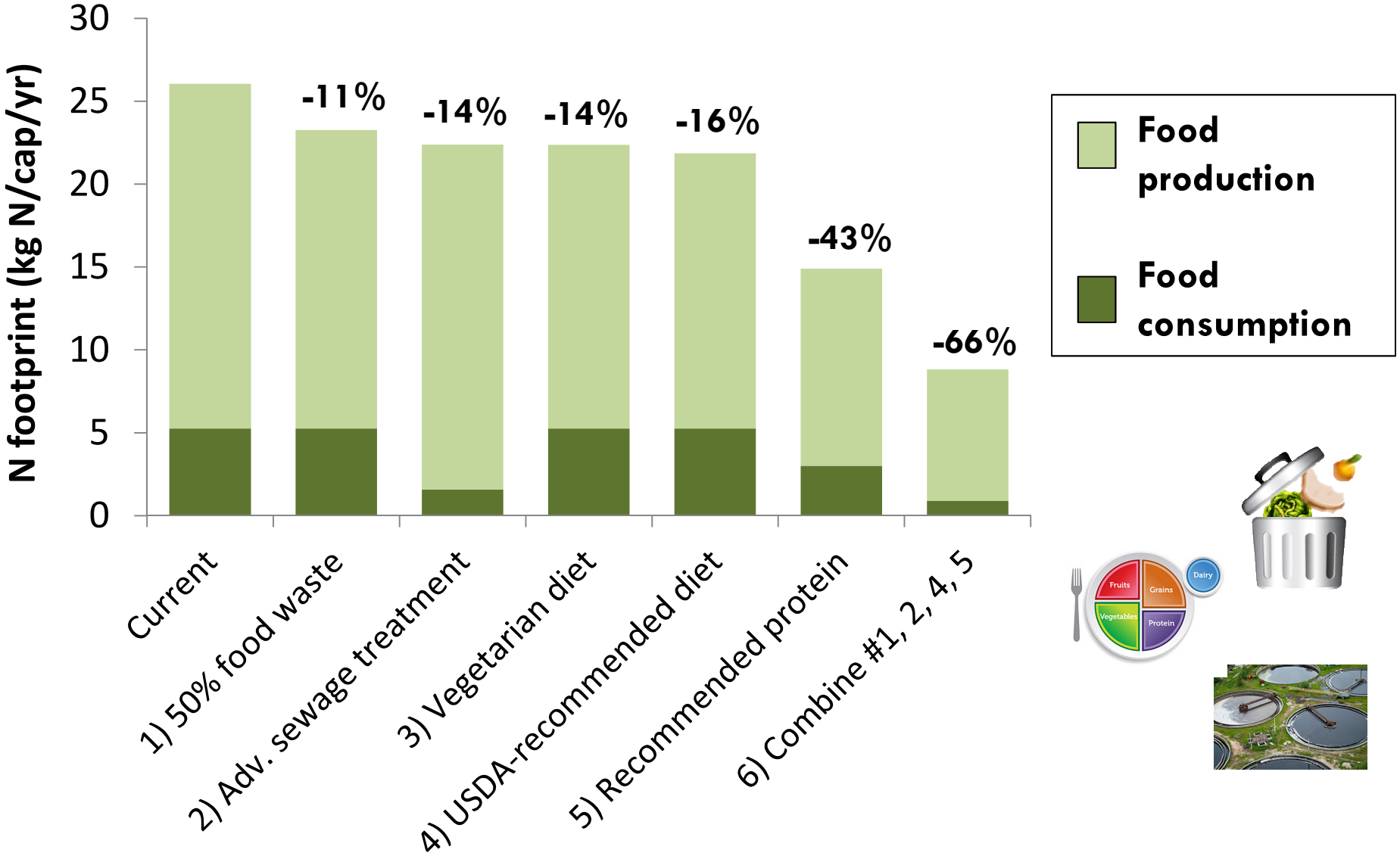
Scenarios: US personal N footprint

Current N consumption: 5.3 kg N/cap/yr
Recommended N consumption: 3.0 kg N/cap/yr



Scenarios: US personal N footprint

Current N consumption: 5.3 kg N/cap/yr
Recommended N consumption: 3.0 kg N/cap/yr



4 Successful reductions

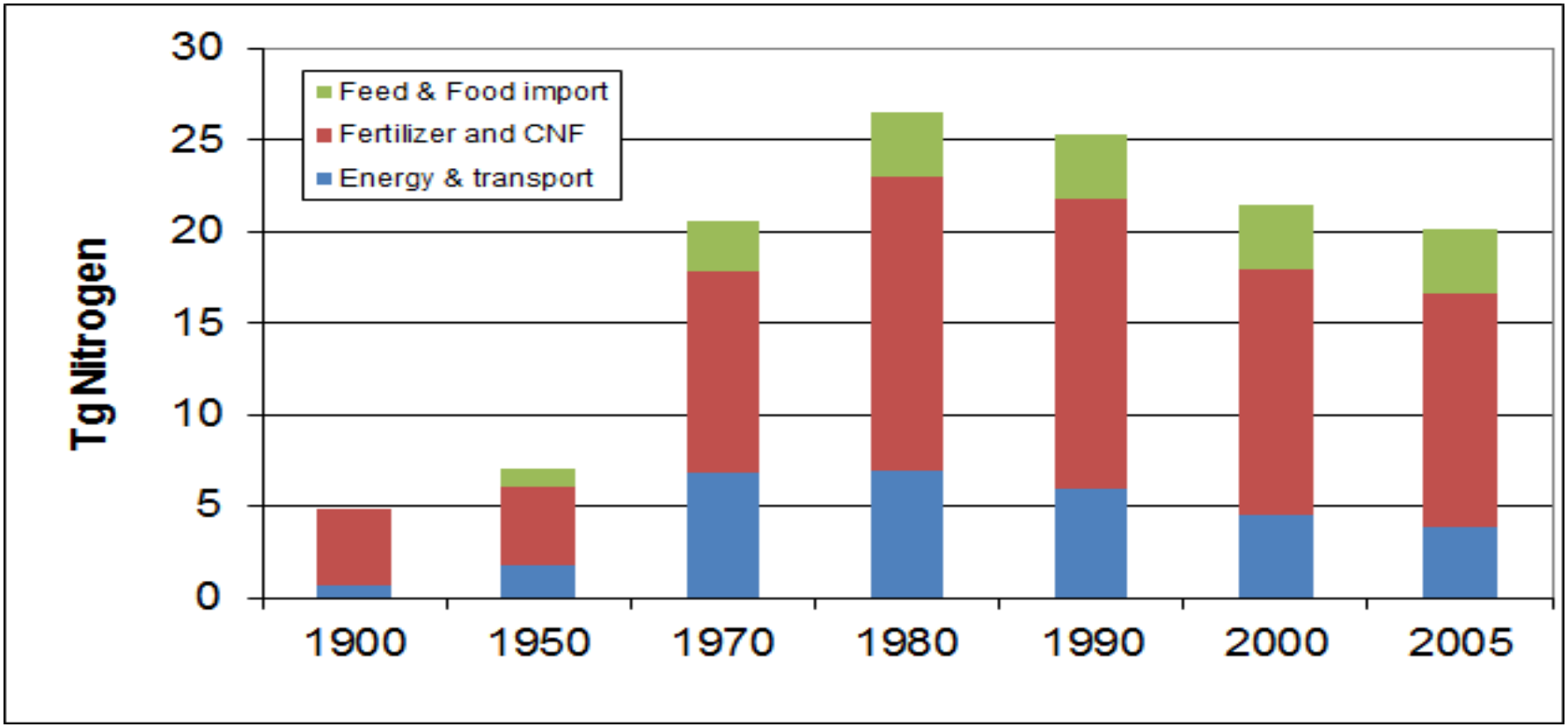
1. Technology

2. Policy

Most important policies:

- 1990's: stop fertilizer subsidies
- Common Agricultural Policy: farmers support and intensification
- Nitrate directive and Water framework Directive: limiting fertilization rates
- Air quality directive: implementing technology

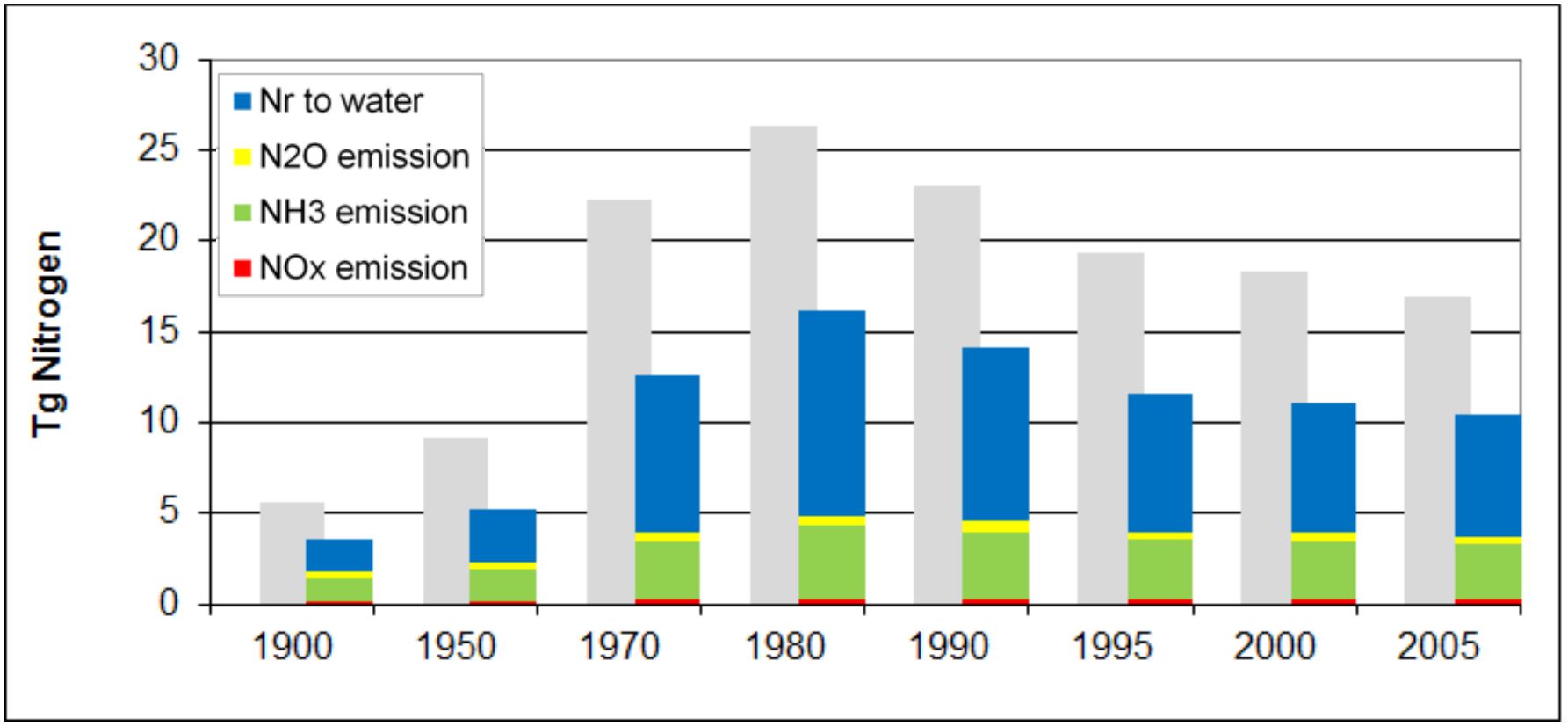
N sources EU27 – share agriculture 80%



IMAGE, 2012

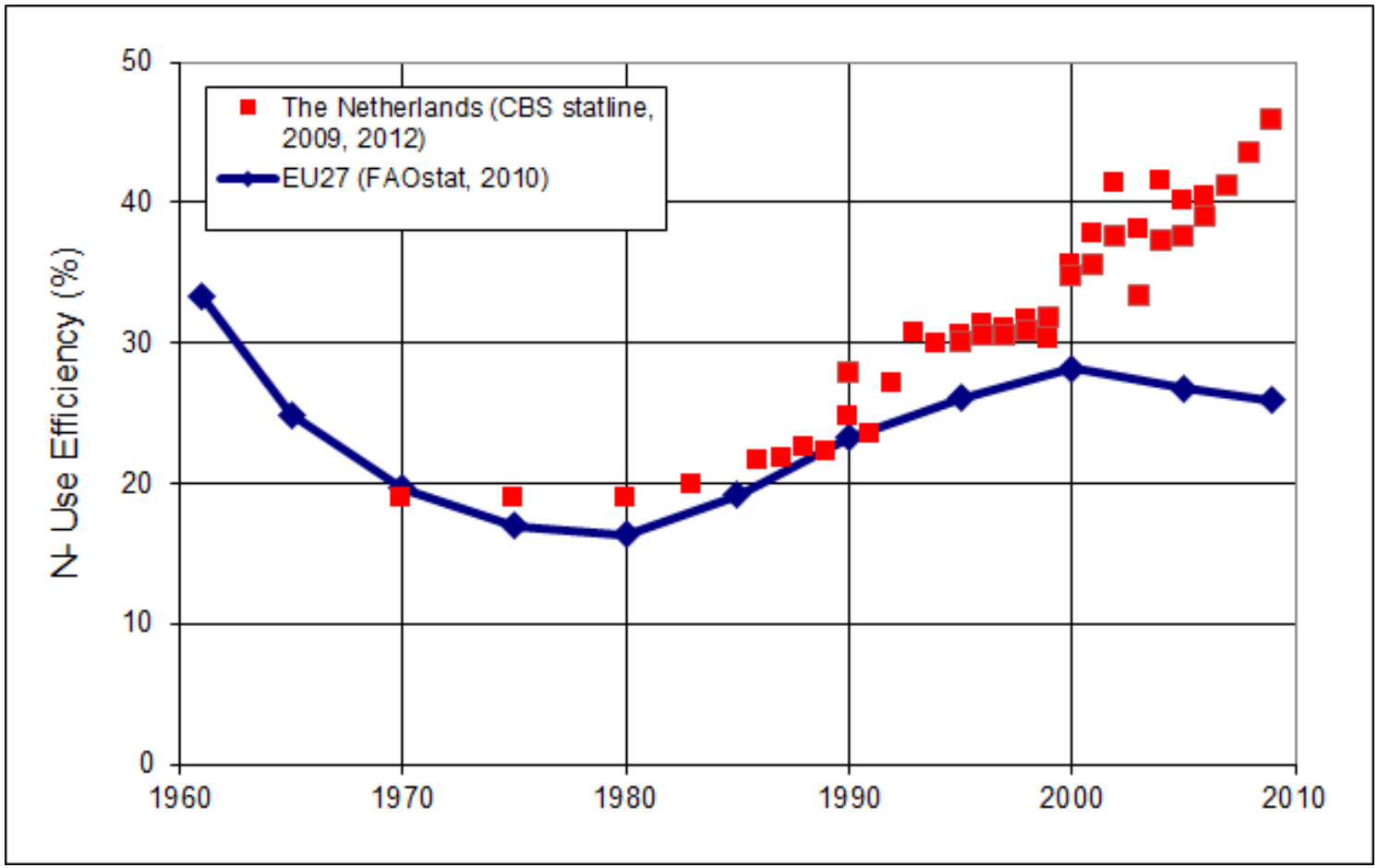
Nitrogen emissions EU27

≈60% agriculture



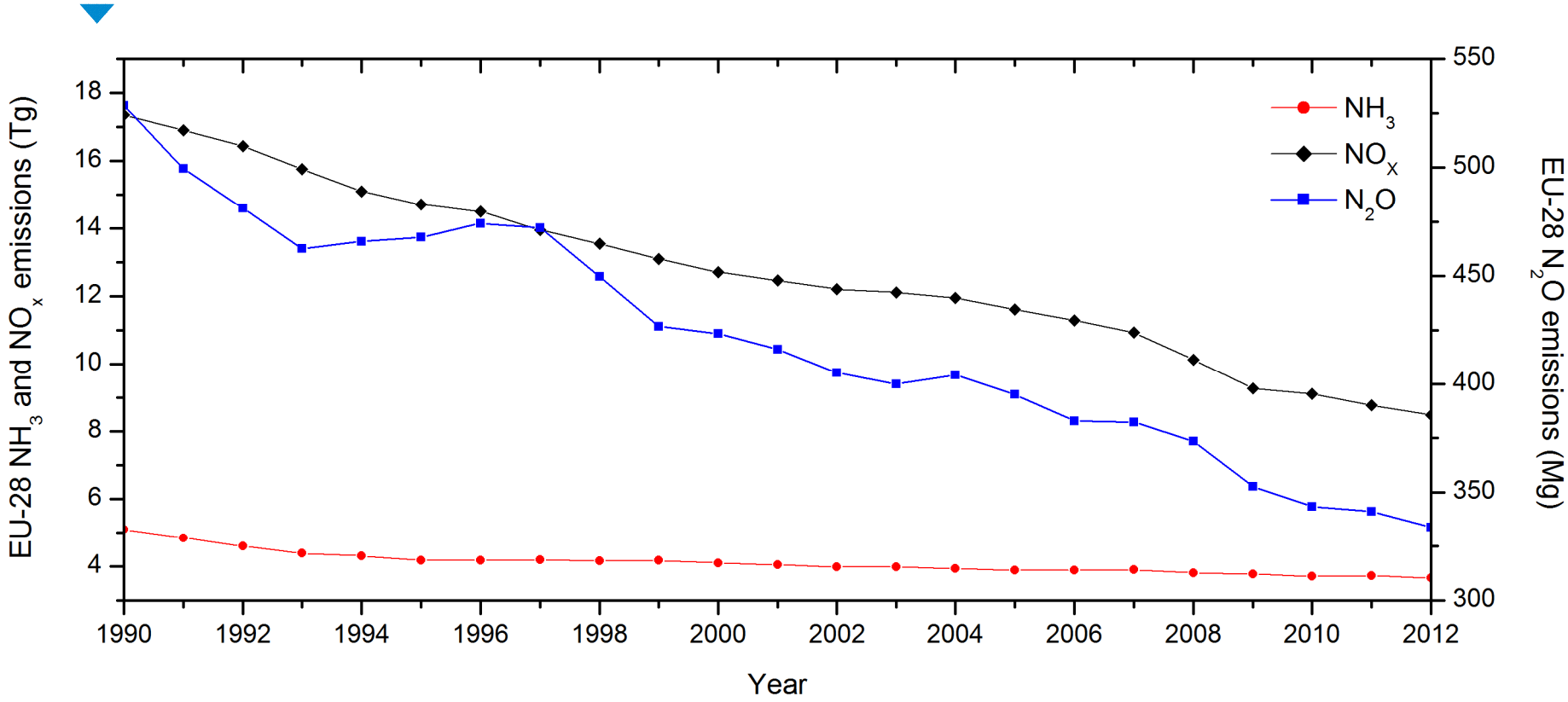
IMAGE, 2012

N Use Efficiency responds to N fertilizer use



FAOstat, CBS

Nitrogen emissions in Europe



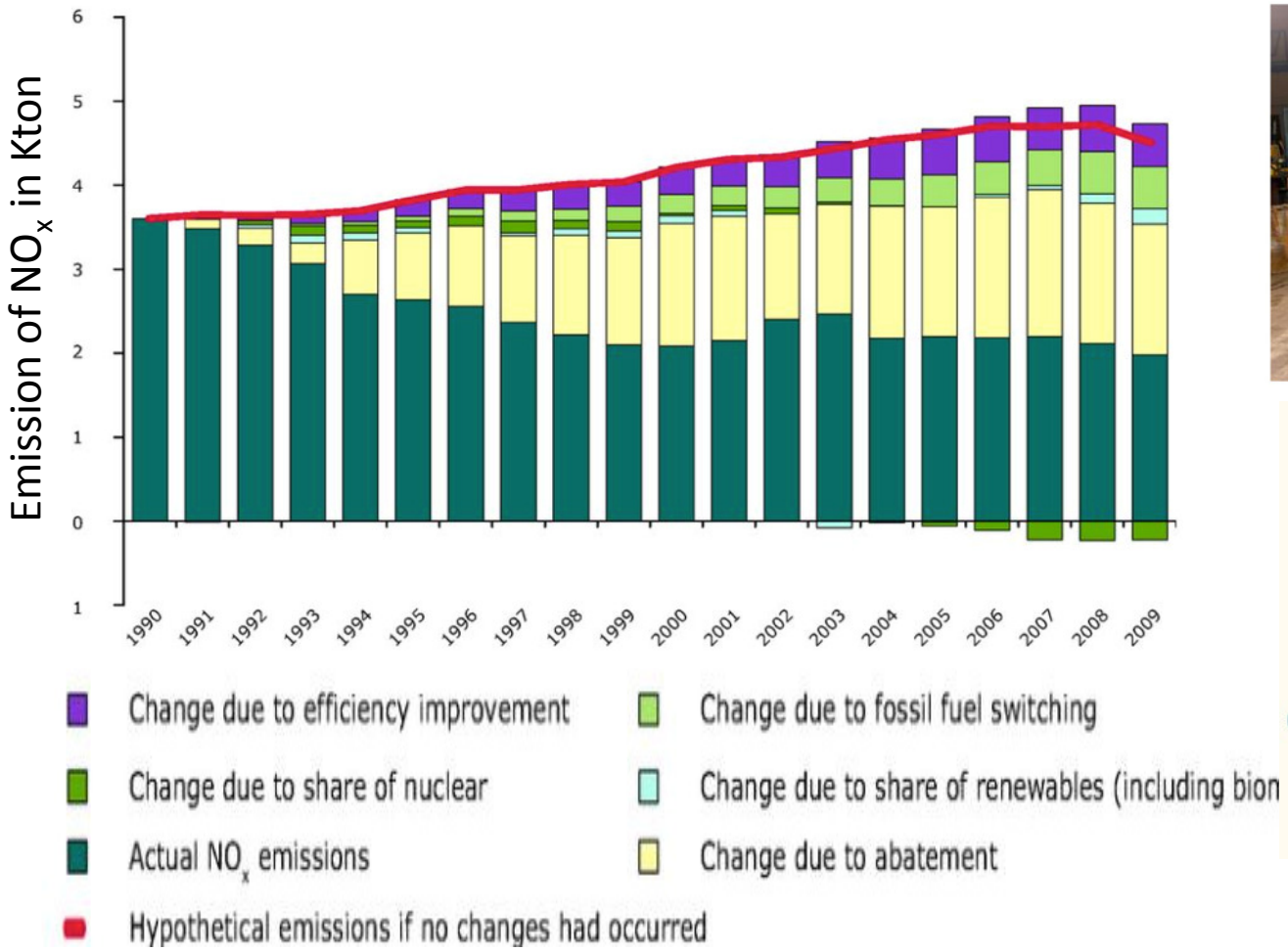
Between 1980 and 2011 EU28 emissions decreased for:

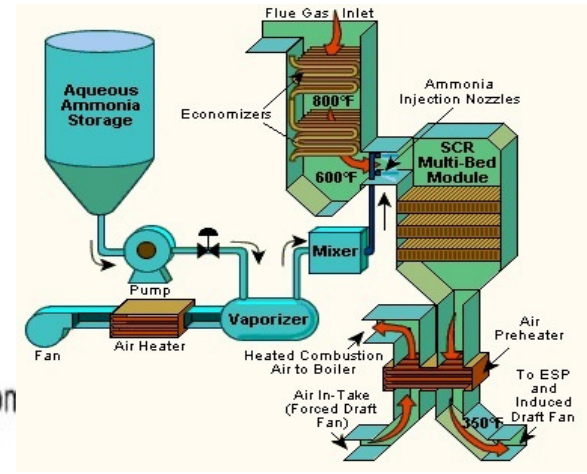
NOx by 49%,

N_2O by 19%

NH_3 by 18%

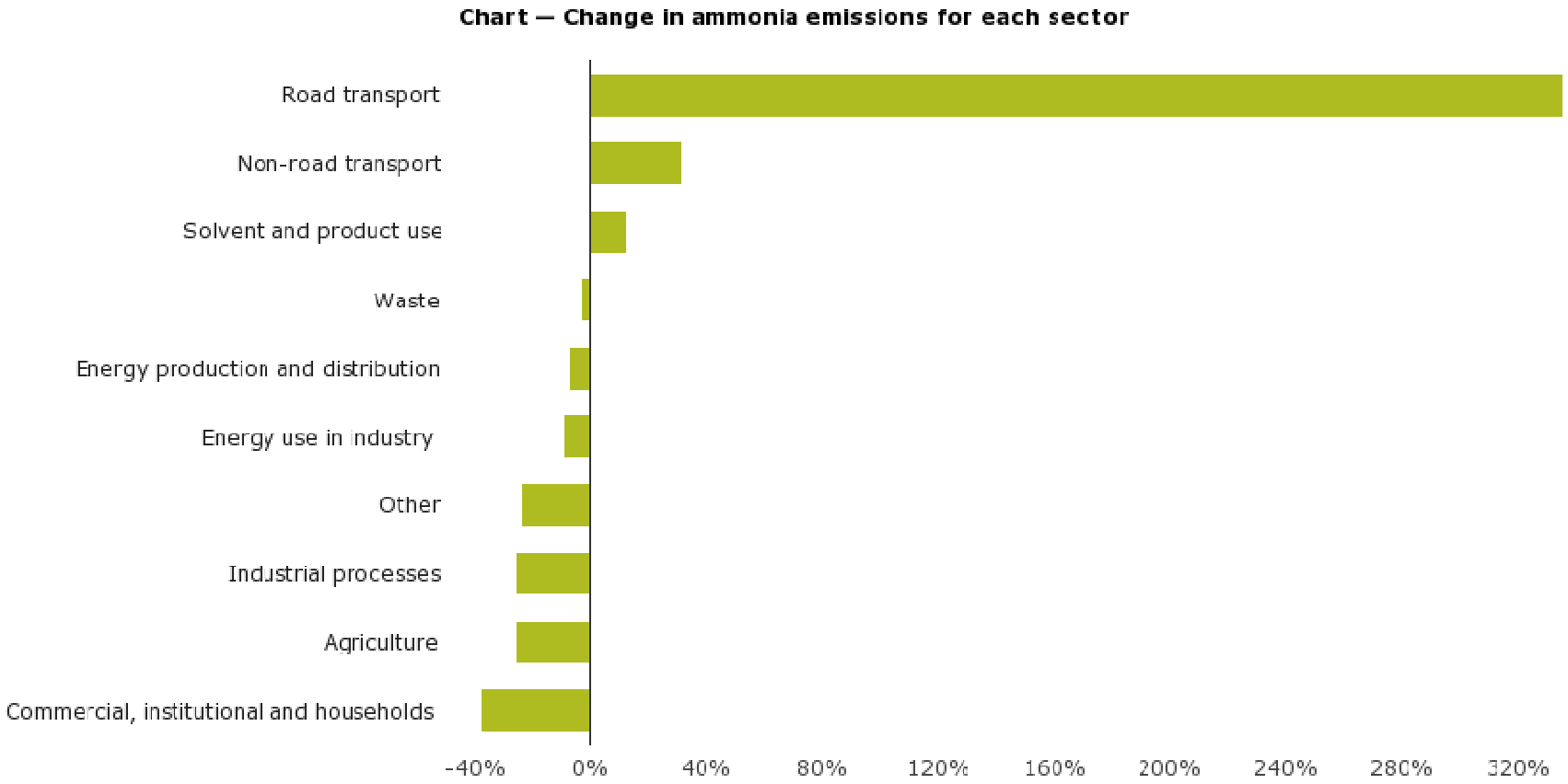
NO_x emissions in Eu decreased by 49% relative to 1990





SCR system

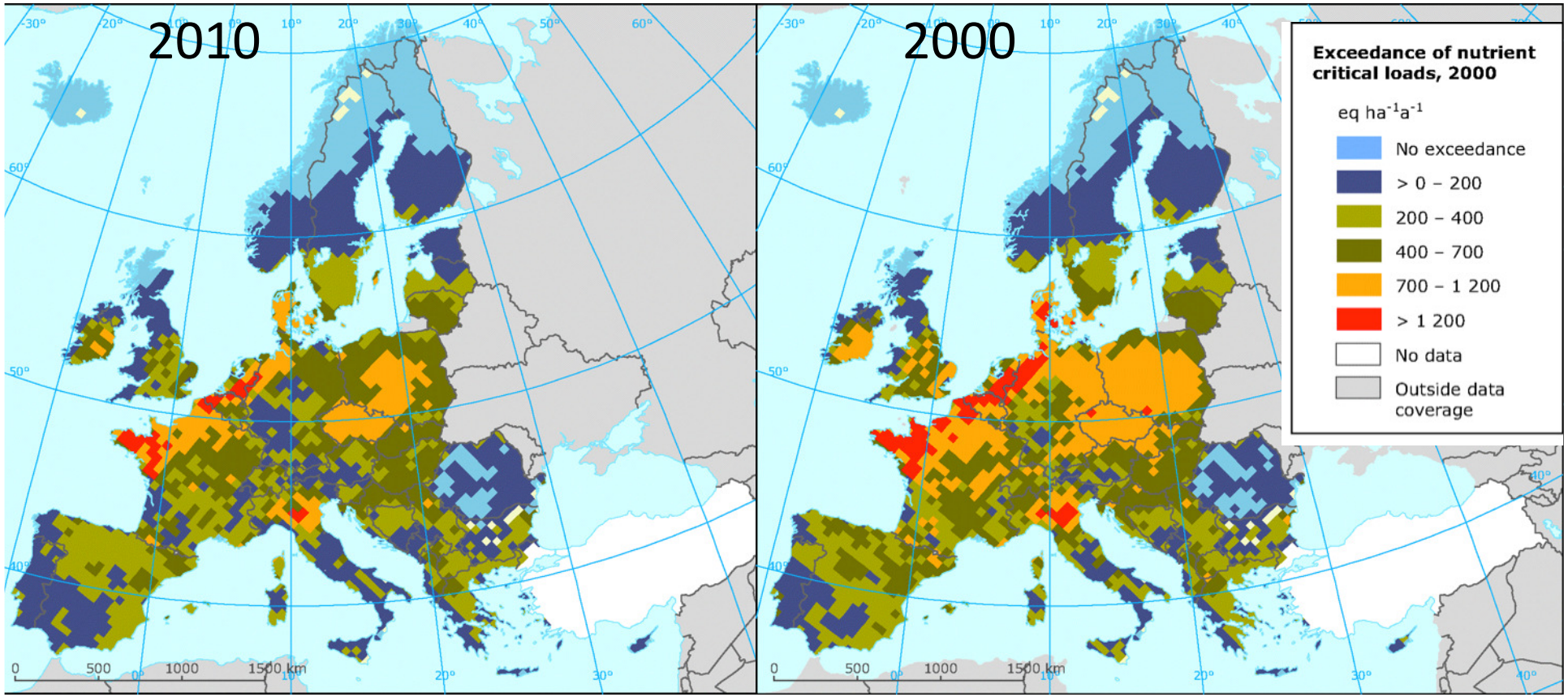
Contribution per sector to NH_3 emission reduction (1990-2010)



European Environment Agency

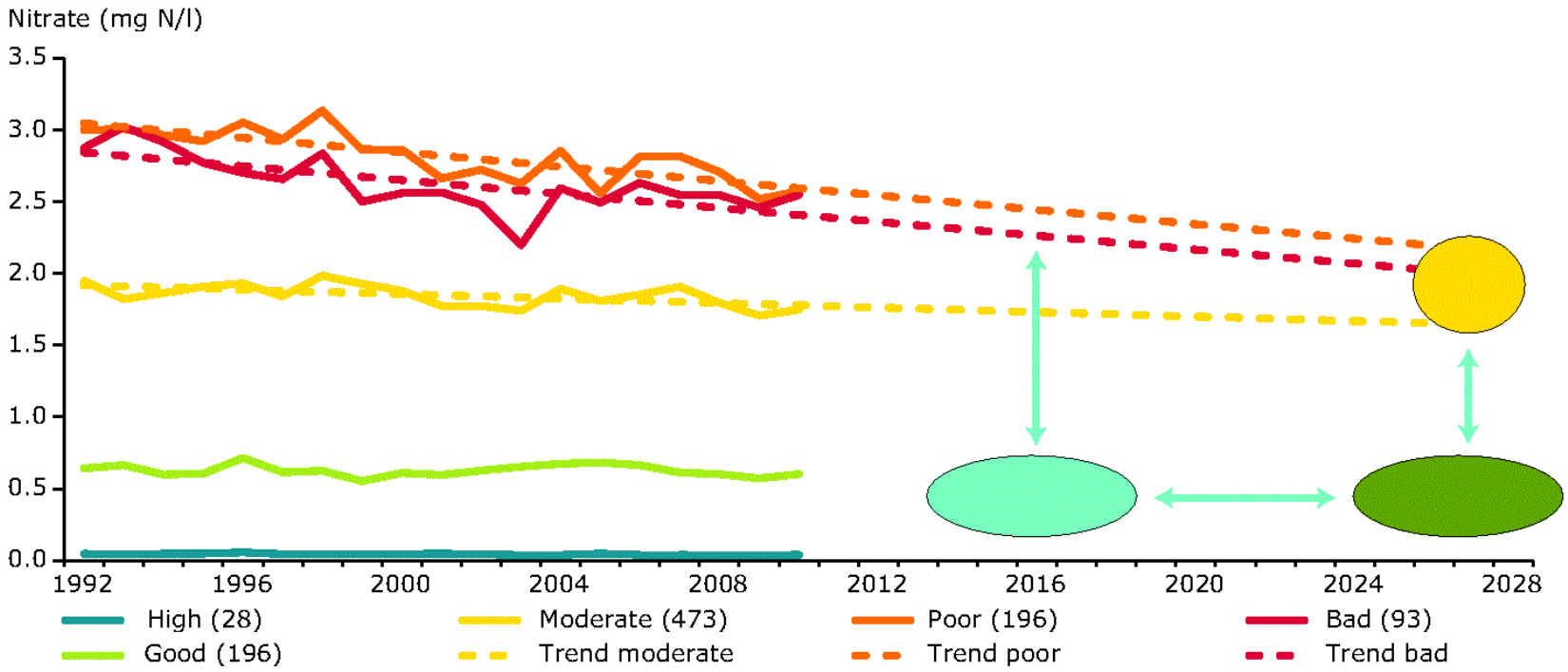
VU

Exceedance of nutrient critical loads 2000 - 2010

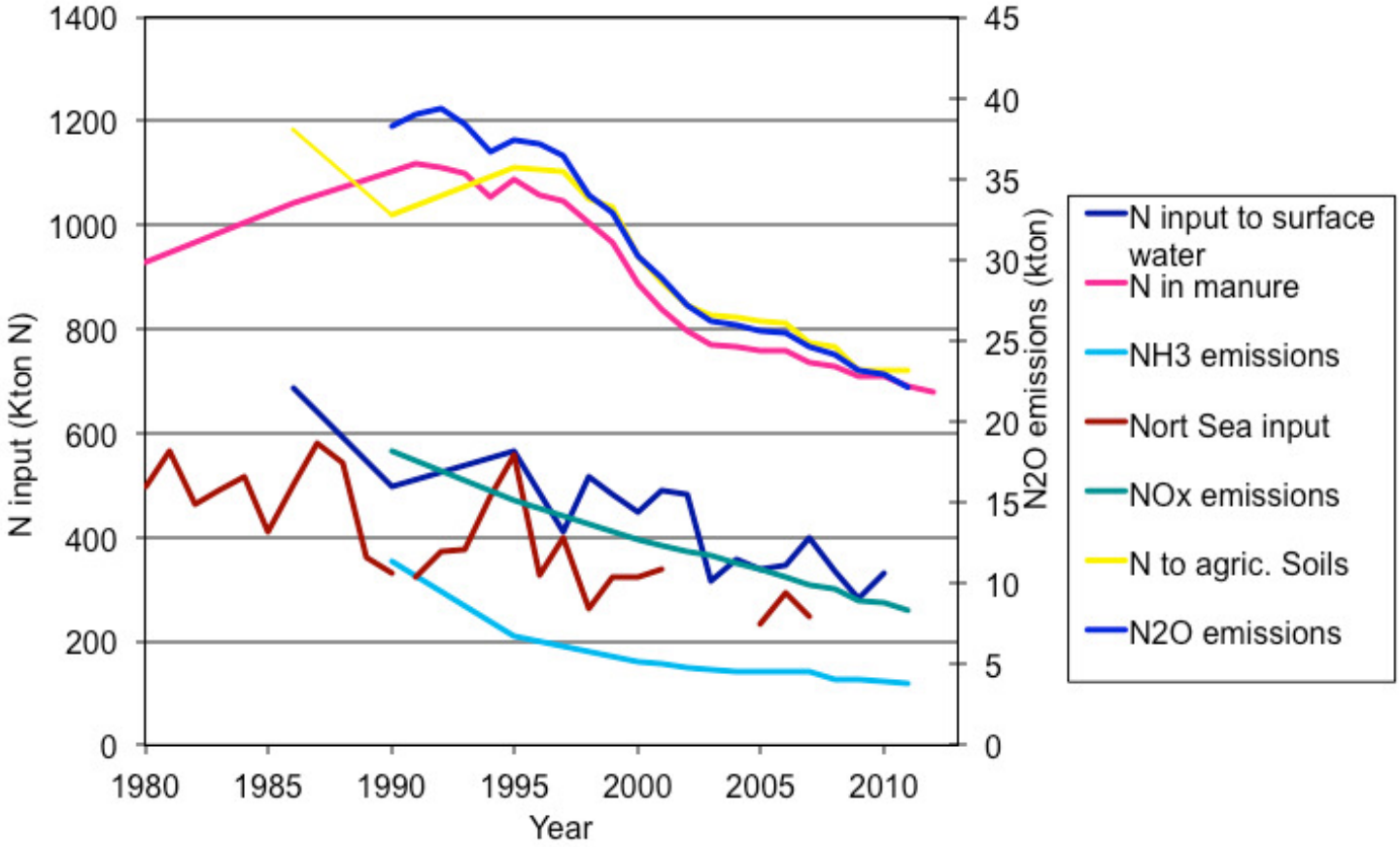


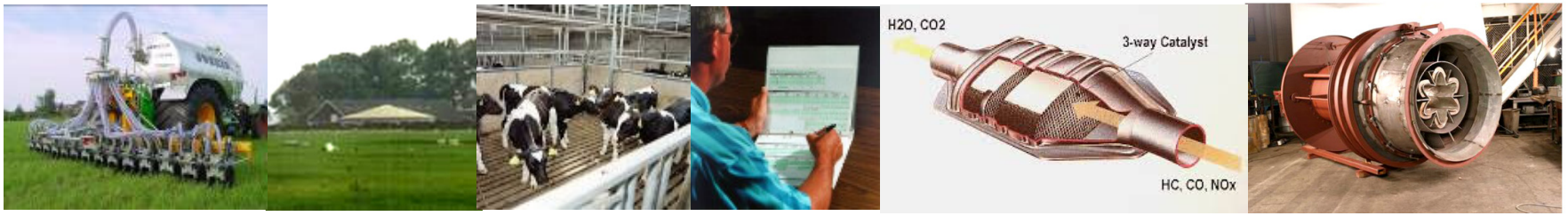
Critical load: "the highest deposition of (…) below which harmful effects in ecosystem structure and function do not occur according to present knowledge"

Changes in NO_3 in groundwater

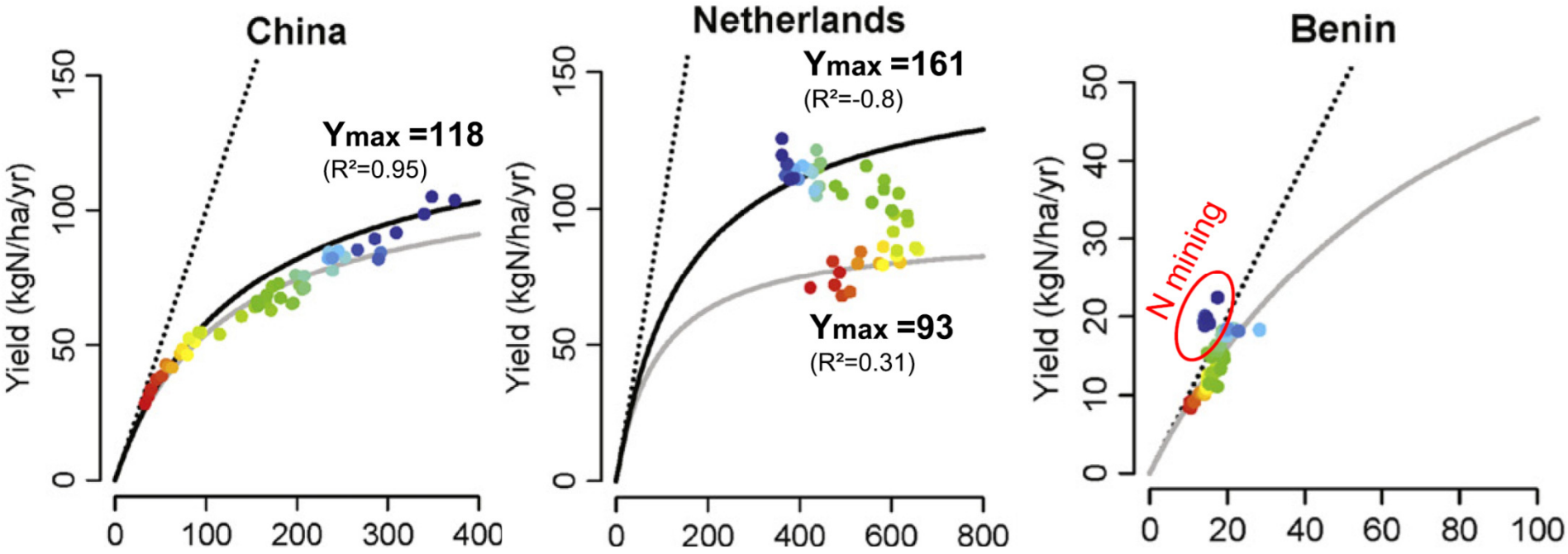


Successful Nitrogen policies in the Netherlands





The Netherlands: Yield increased while N input decreased



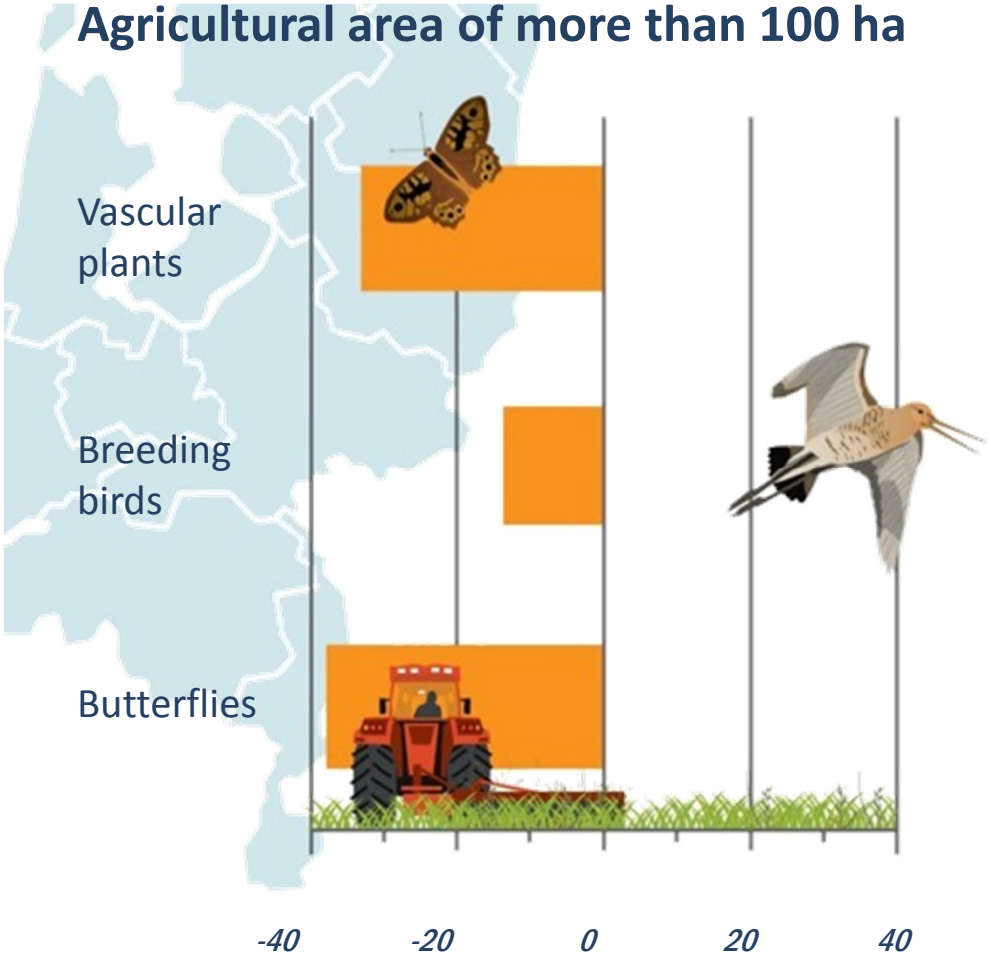
Yield high
Increase slowing
Lowering of NUE

Yield increasing
Increase high
Increase of NUE

Yield low
Increase coming
High NUE

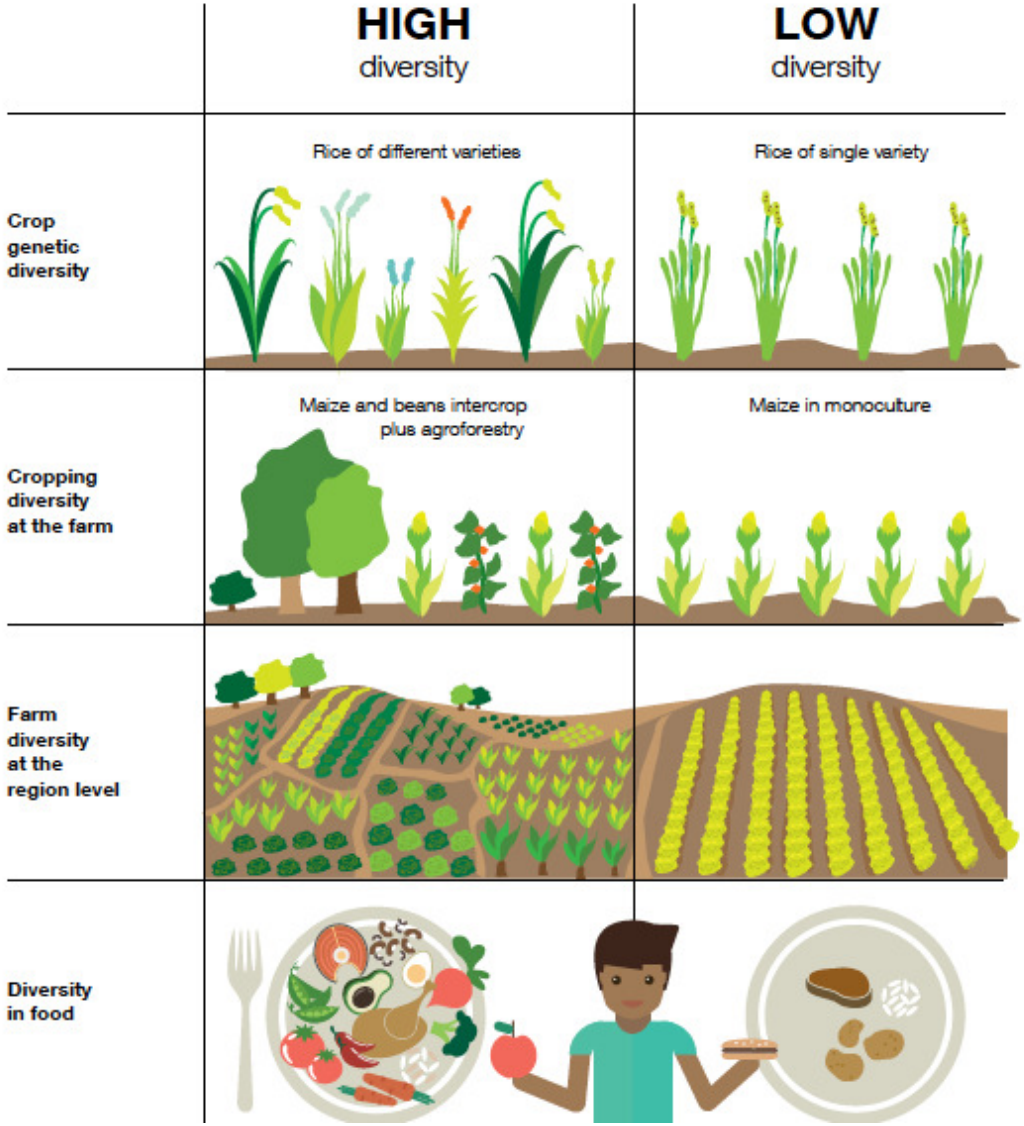
Lassaletta et al., 2014

However, number of species decreased in the period 1980-2005



FLORON, SOVON, Van Swaay 2009

(Bio)diversity for a resilient food system



Four strategies to more sustainability for N cycling

Smarter diets

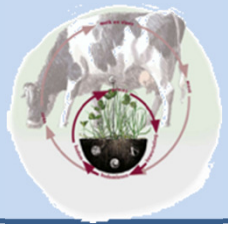
- Healthier diets
- Less animal products
- Less waste

Smart intensification

- Resource (land, feed, nutrient) efficiency
- Closing yield gap, reducing waste

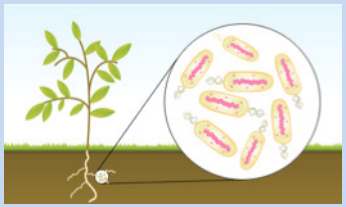
Smart extensification

- Higher margins
- Less impacts: Animal welfare, human health, odour, landscape



Close nutrient cycles

- Start with focussing on healthy soils
- Within their surroundings (losses, emissions, climate)

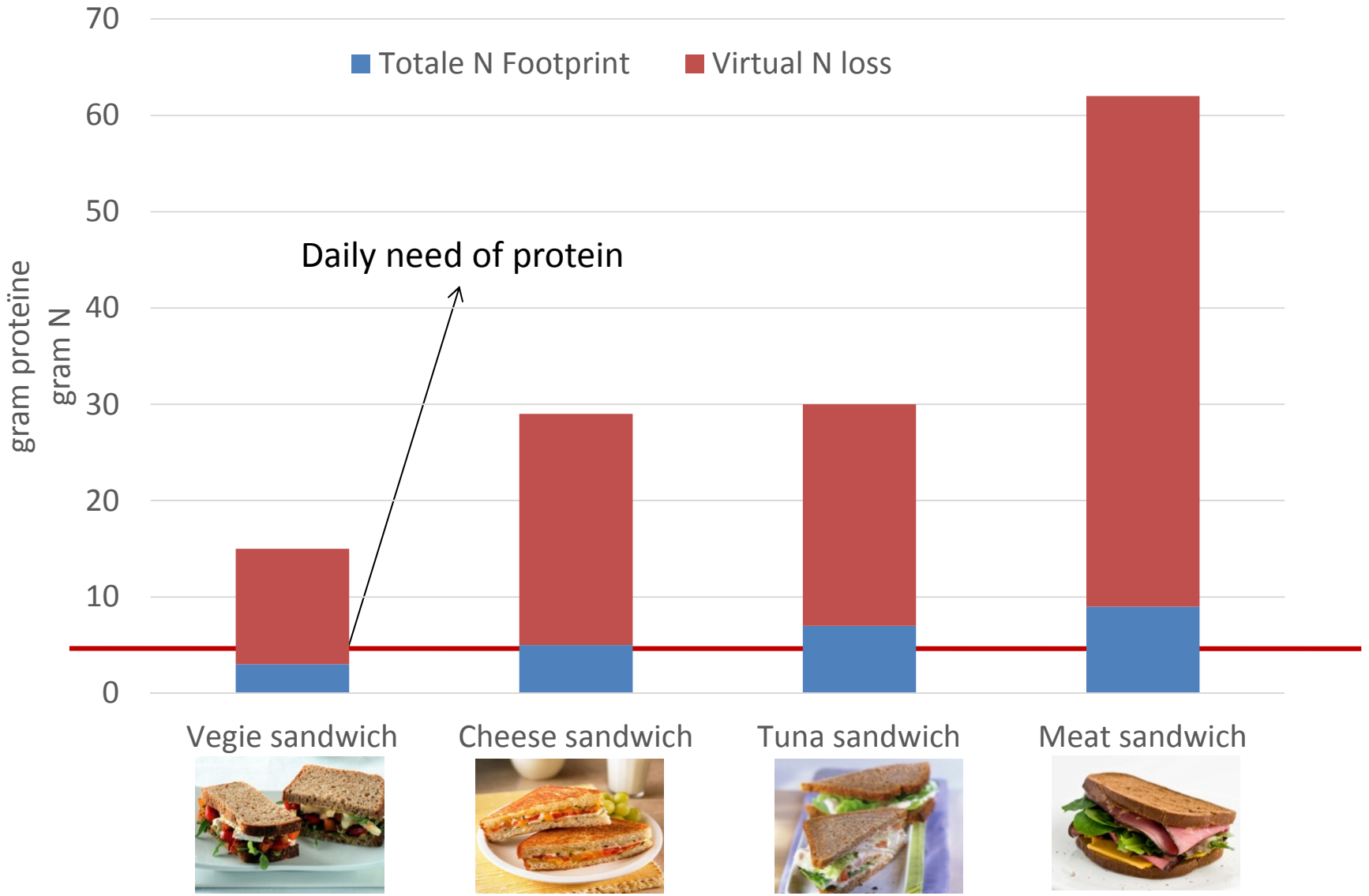


Improve soil and Biological Nitrogen Fixation

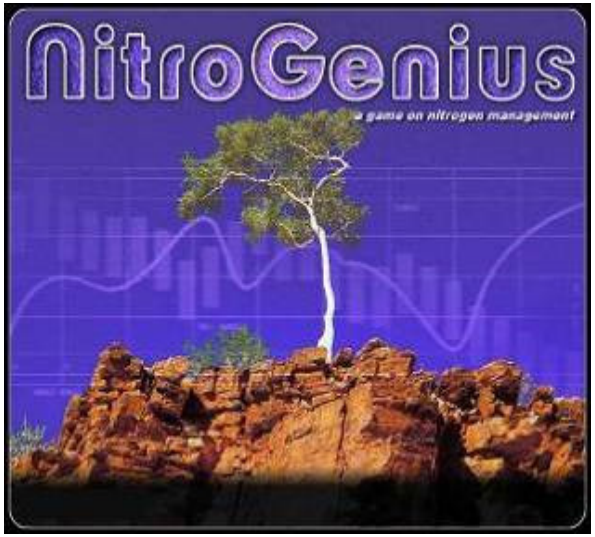
- Improve soil quality and functioning
- Increasing BNF in agriculture
- Crop rotations

Finger and footprint

www.n-print.org



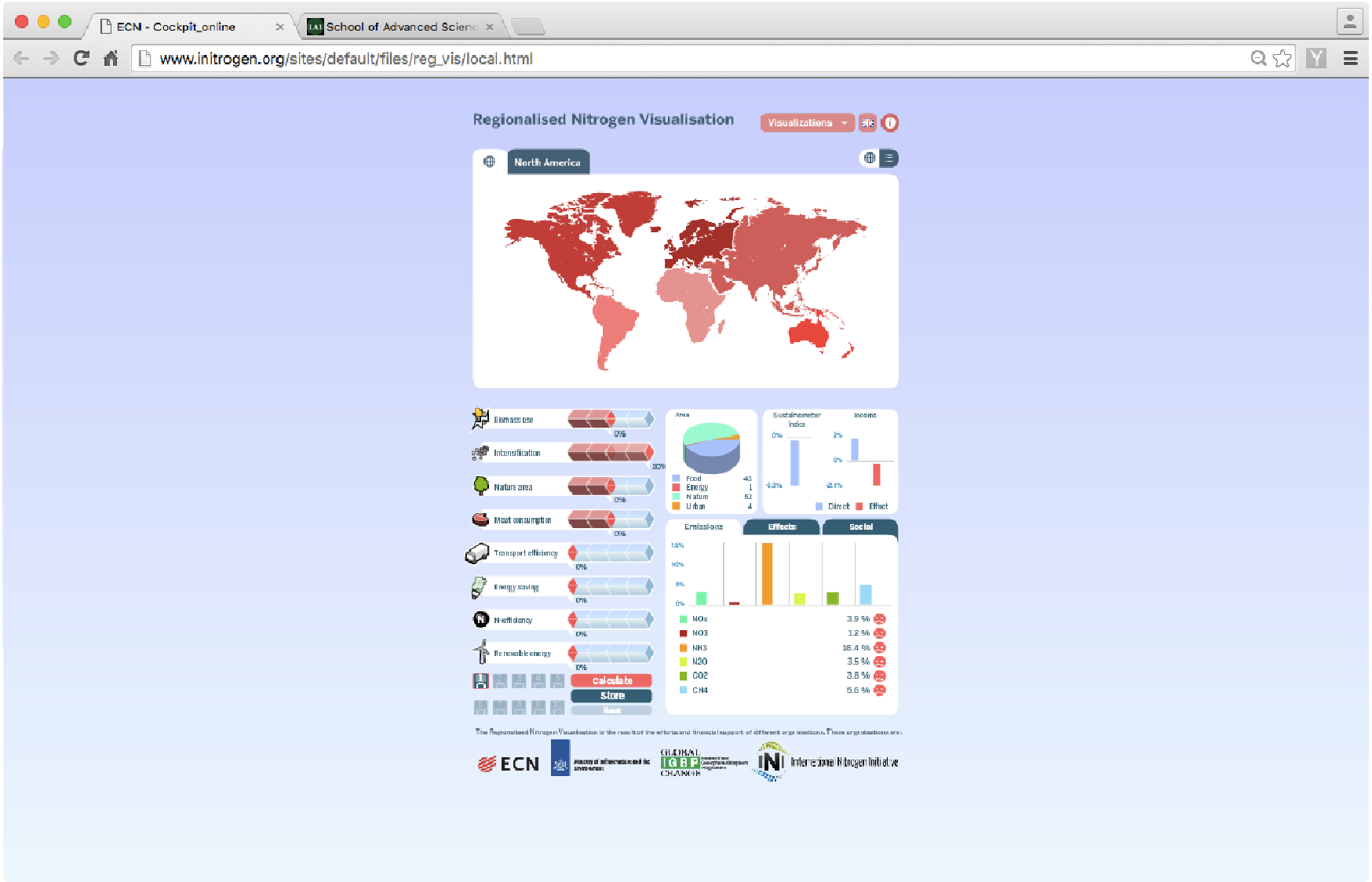
N-tools: Simplification of complex issues



www.initrogen.org
www.nine-esf.org
www.n-print.org

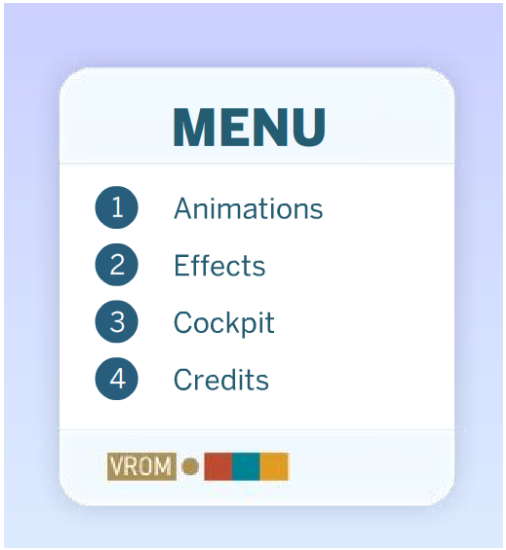
NITROGEN VISUALISATION

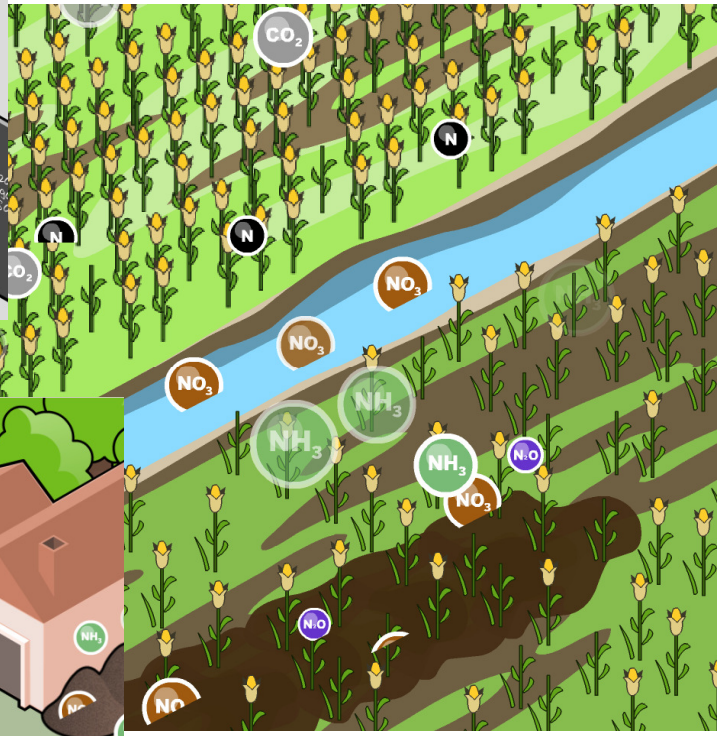
www.initrogen.org



VISUALISATION: ANIMATIONS

4: Artificial Fertiliser





VISUALISATION: ACTION IN DE COCKPIT

8 Questions for 2030

Check the effects

Last 10 sets stored

THE QUESTIONS ….

- Use of Biofuel
- Intensification of agriculture ?
- More room for nature ?
- Meat consumption decrease/Increase ?
- Optimize transport ?
- Energy technology a solution ?
- N use efficiency ?
- Renewable wind/water/solar

EXAMPLE

Example

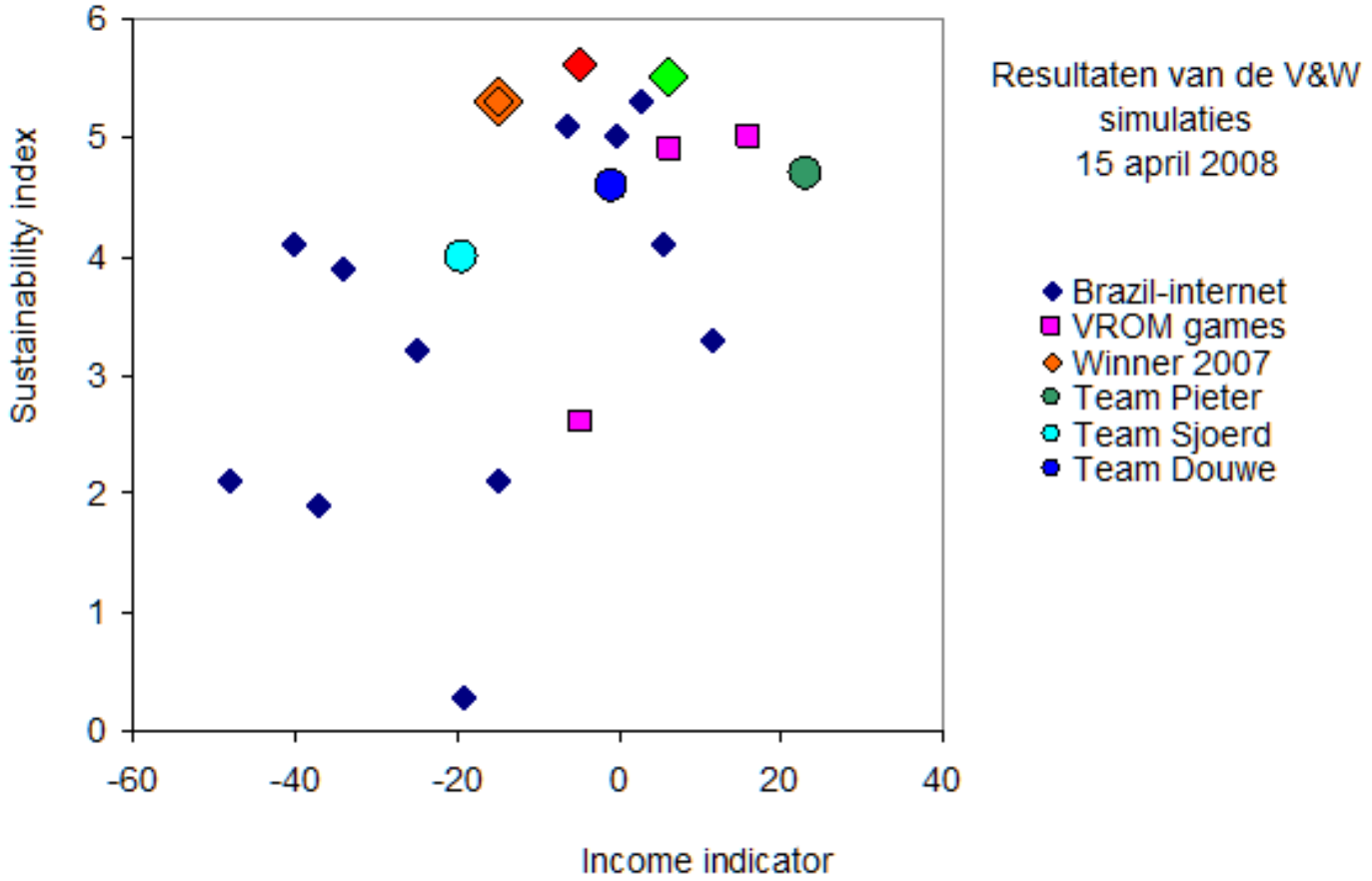
Transport efficiency

EXAMPLE

Example

Intensive agriculture

COMPARISON OF SOLUTIONS



Summary and conclusions

Nitrogen challenge:
We must optimize nitrogen's benefits while minimizing its negative consequences

Consumers

Personal N footprint model can help and educate consumers

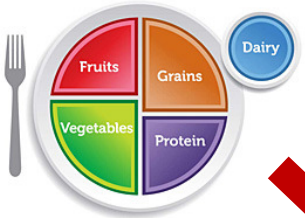
N-Print

www.N-Print.org

Policies

Aimed at reducing Nr creation and NUE increase

Reductions



Thank you!

www.N-Print.org

Assignment for today

- Fill in the N-footprint Beta-version at: www.N-Print.org
- N issue: Optimizing N uses while minimising environmental impacts
- Aim is to provide regional cost-effective solutions for the N impacts while feeding the growing world population in 2015
- Population about 9.2 billion; Agricultural area not expanded; improvement in N issue

Product

- Same groups as Tuesday
- Top 3 measures/policies
- Presentation with 3 slides (one per measure):
  - Proposed measure
  - How much N reduced/increased (within the set boundaries)
  - Cost-effectiveness: costs versus revenues
  - Argumentation/references/quantification: how can thiswork?

Example

- 3-way catalyst for cars
- 90% reduction of car NOx (in Europe: 30% relative to 1990 emissions); increase of NH3 emission of 320% since 1990).
- Cost: x Kg x y €
- Revenues: x less years life lost; crop reduction; etc. x € benefit
- Reference: EEA, 2014

Resources

- Costs of environmental impacts: Van Grinsven et al (2013), Table 1
- Regional N fluxes, diet, etc: Lassaletta et al 2016
- N-footprint: www.N-Print.org
- Regional visualisation tool:
- http://www.initrogen.org/sites/default/files/reg_vis/local.html

Table 1. Marginal Costs and Benefits Between 1995 and 2005 of Different N_r-Threats in EU (See SI Table S1 for Description of N_r-Threats)

effect	emitted nitrogen form	emission/loss to	estimated cost € per kg N_r emitted, used or produced[a]
human health (particulate matter, NO_2 and O_3)	NO_x	air	10–30 (18)
crop damage (ozone)	NO_x	air	1–2
ecosystems (eutrophication, biodiversity)	N_r (nitrate) N_r deposition	surface water	5 to 20 (12)
human health (particulate matter)	NH_3	air	2–20 (12)
climate (greenhouse gas balance)	N_2O	air	4–17 (10)
climate[**]	NOx	air	−9 to 2 (−3)
climate[**]	NH_3	air	−3 to 0 (−1)
ecosystems (eutrophication, biodiversity)	NH_3 and NO_x	air	2–10 (2)
human health (drinking water)	N_r (nitrate)	groundwater	0–4 (1)
human health (increased ultraviolet radiation from ozone depletion)	N_2O	air	1–3 (2)
climate (N-fertilizer production)	N_2O, CO_2	air	0.03–0.3
crop yield increase (benefit): 1st year	N-fertilizer	soil	0.5–3 (1.7)
long term			1.5–5 (3.7)

- Van Grinsven et al. 2013