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Greencap
Work Package 2
Greening courses

Training

Introduction to the Water Energy Food Nexus

Lionel Lemiale
Université de Nantes

Objectives

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- Individual decision are taken on the basis of product prices. But if prices does not reflect the overall scarcity and conséquences of their consumption, then choices are sub-optimal

- Identifies relationship between water energy and food qualitatively and quantitatively

- Develop a systemic approach

☛ helped to improve people's awareness about the water-energy-food nexus

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Plan

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1. Backgrounds
2. The Water Energy Food question
3. The Water energy Food Nexus definition
4. WEF interdependencies : Description and quantification
5. Benefit of a cross sectoral approach

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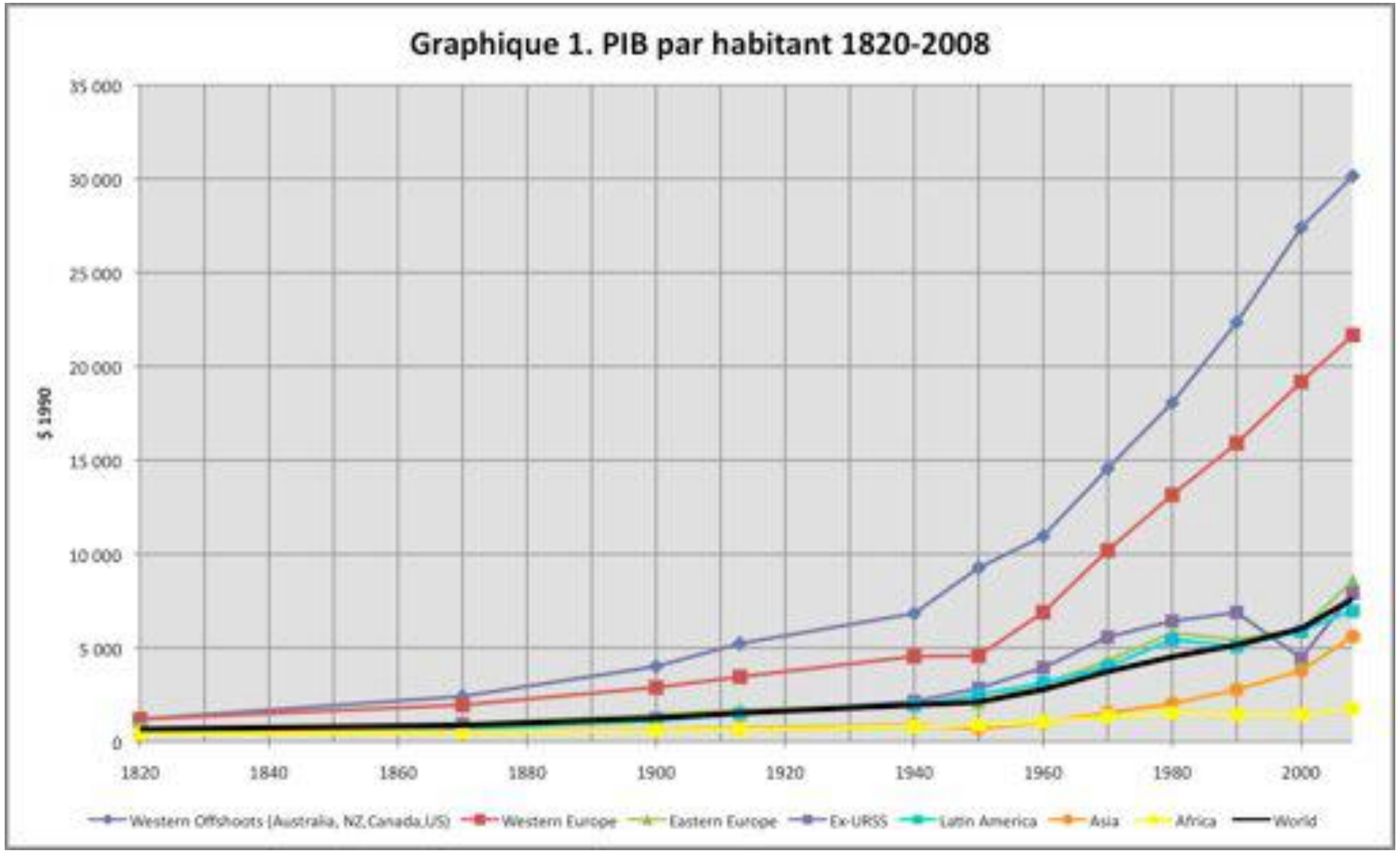
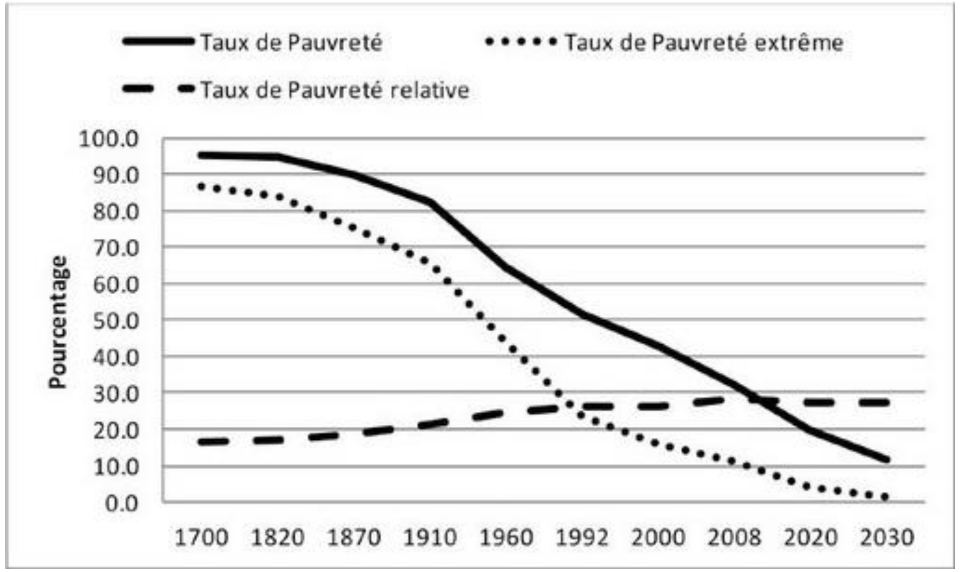
Background

World GDP is multiplied by 14 during the 20th century

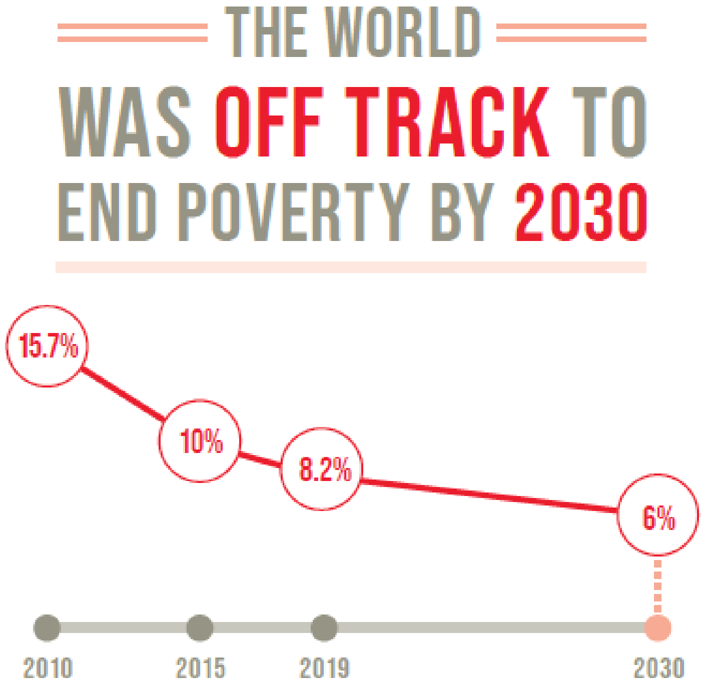


Background

Leading to a decrease in poverty



Source : Christian Morrisson et Fabrice Murtin (2012), Vers un monde plus égal ? Revue d'Economie du Développement, vol. 20.



UN (2020) The Sustainable Development Goals Report

Background

But at the expense of environmental pressures

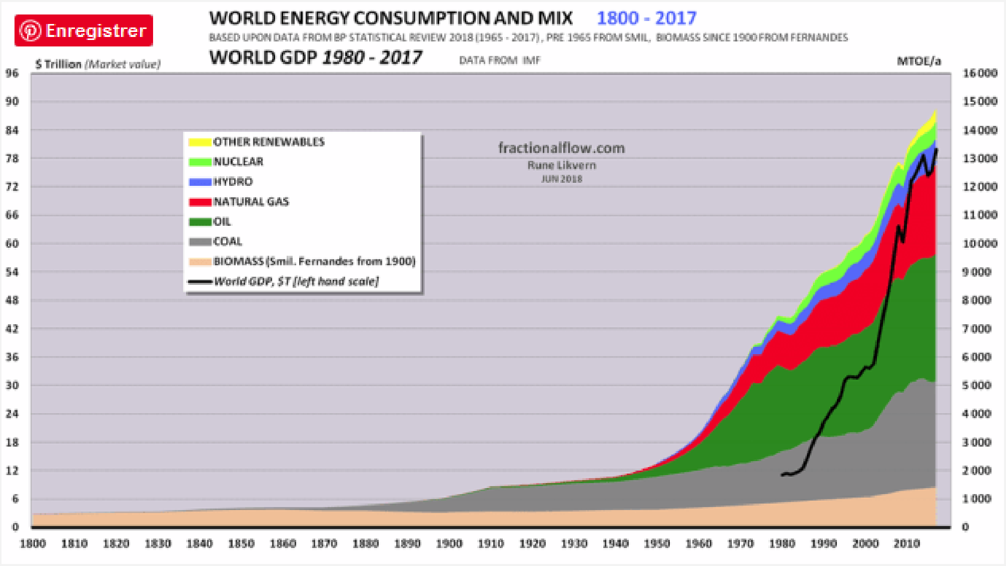
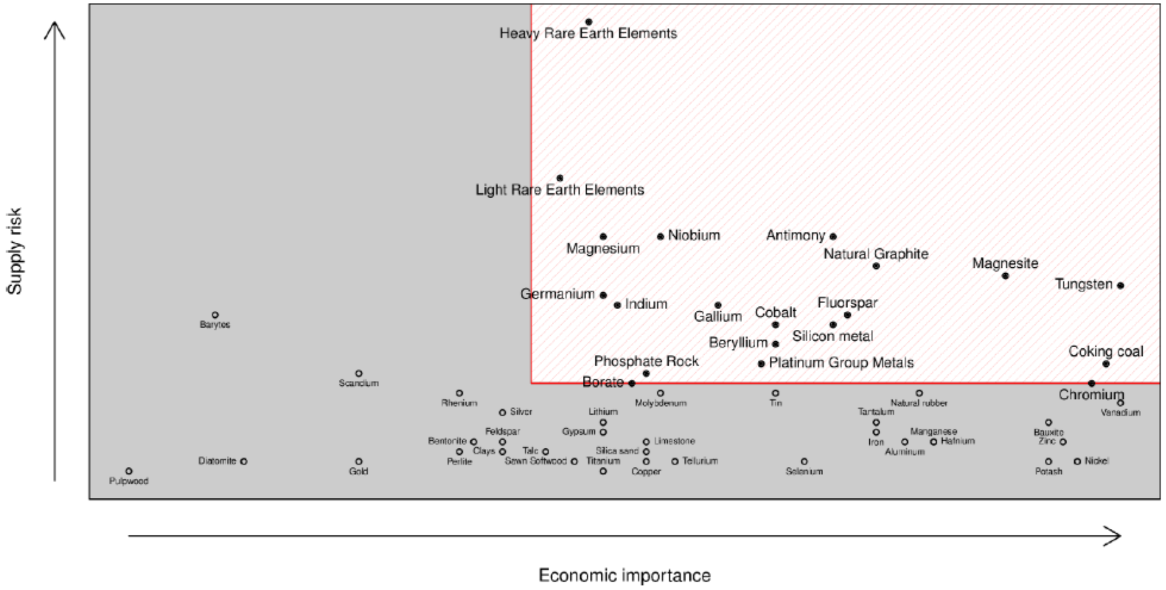


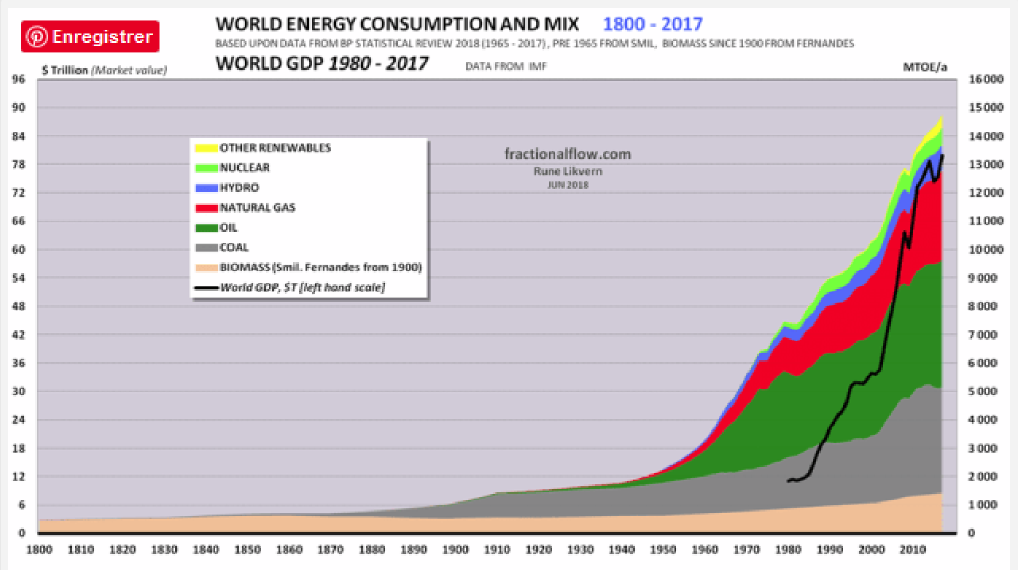
***Figure 1**: The chart shows the developments in total world energy consumption split on sources as of 1800 and per 2017.*



European commission (2014) REPORT ON CRITICAL RAW MATERIALS FOR THE EU

Background

But at the expense of environmental pressures



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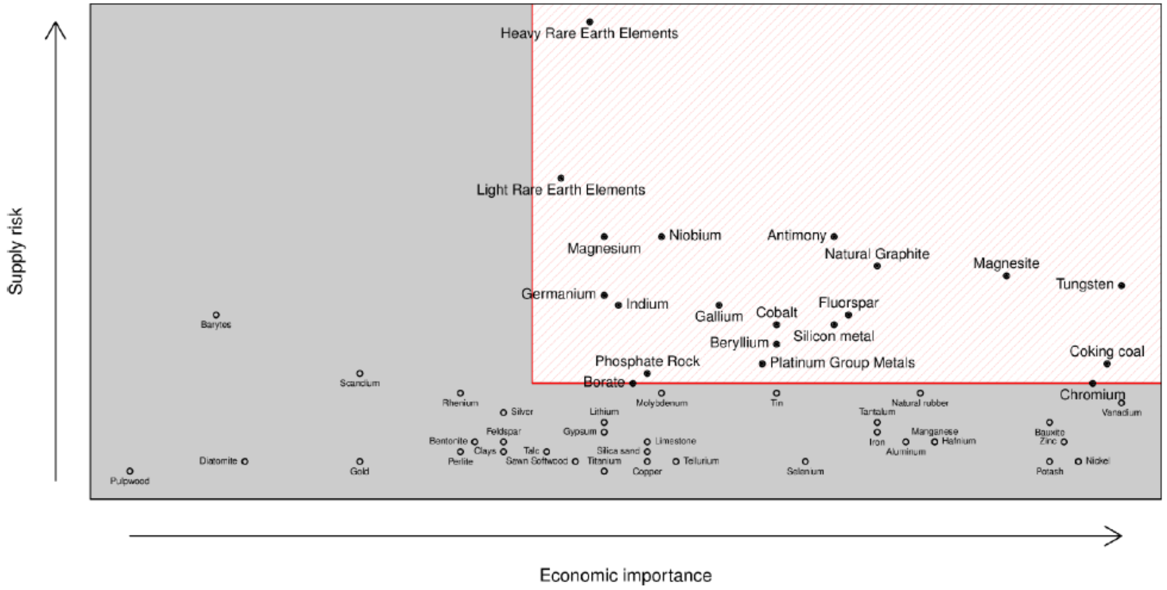


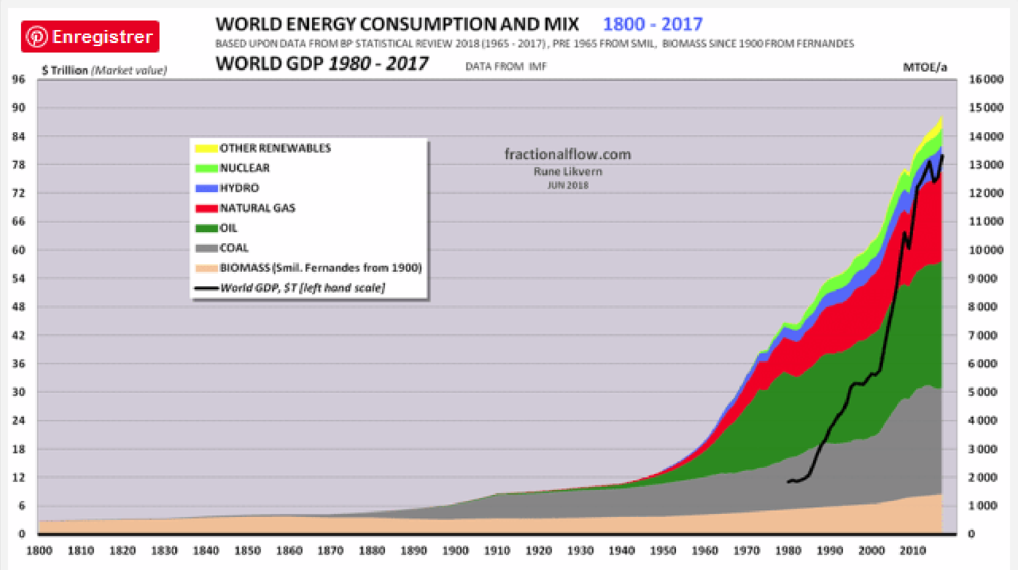
European commission (2014) REPORT ON CRITICAL RAW MATERIALS FOR THE EU

Scientific debates about the role of resources depletion in economic growth is engaged since 1960-1970

Common sense predict that non renewable resource depletion should lead to resource shortage.

Background

But at the expense of environmental pressures



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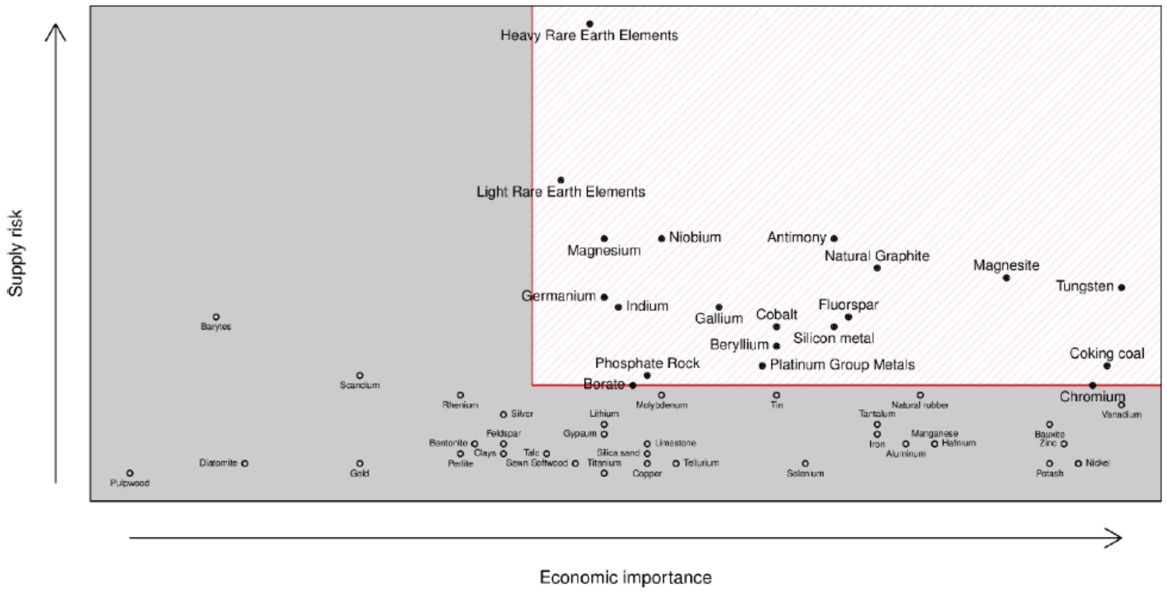

European commission (2014) REPORT ON CRITICAL RAW MATERIALS FOR THE EU

Scientific debates about the role of resources depletion in economic growth is engaged since 1960-1970
Common sense predict that non renewable resource depletion should lead to resource shortage.

During 80’ more optimistic view : technical progress is able to push away resources boundaries due to substitution effect between innovations and natural resources, the so called Kuznet-curve
→ Resources are viewed as economic good and not only physical goods

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Background

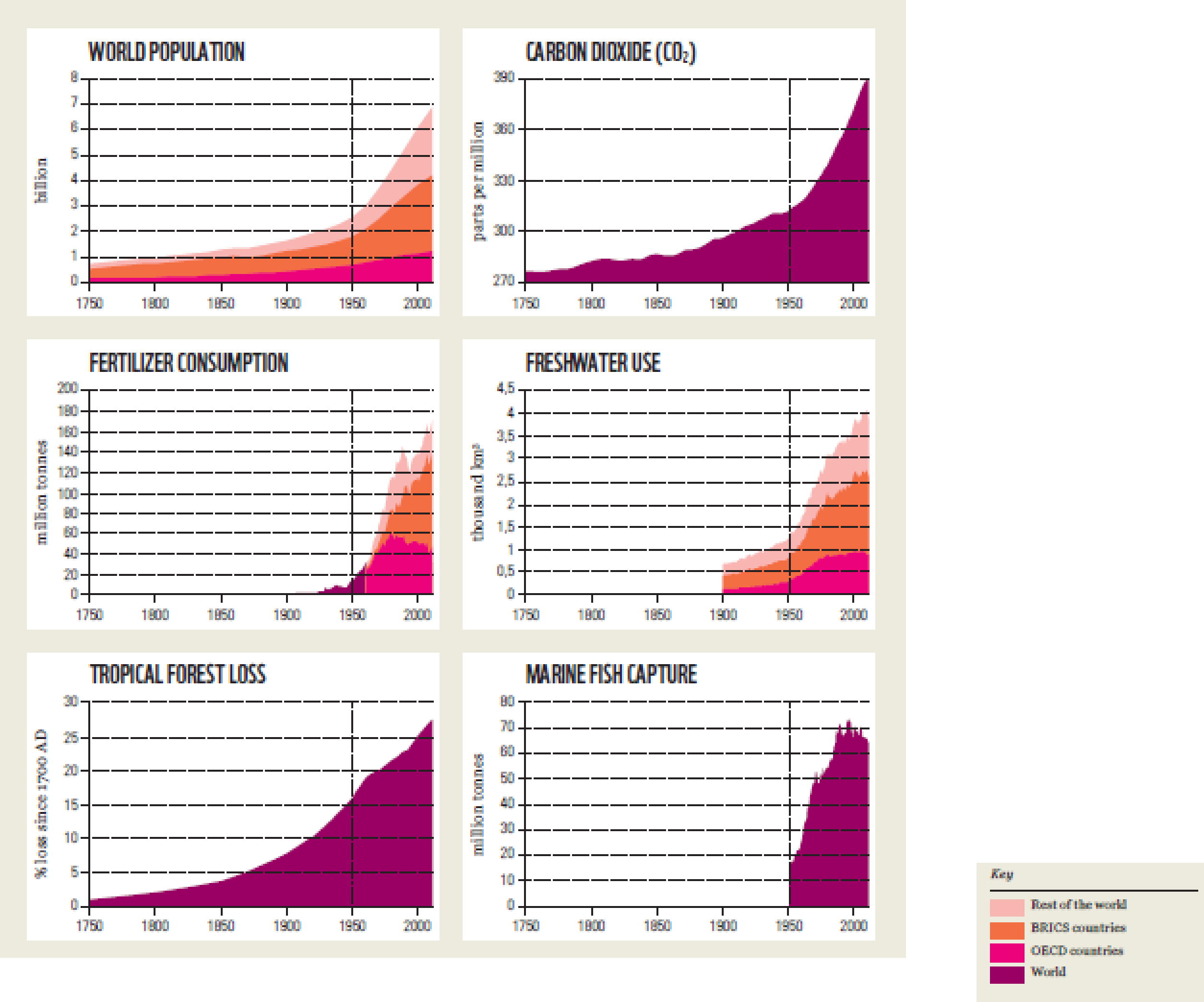
But at the expense of environmental pressures

Since end 80’, resources questions

❑move from local issues to global concern

❑Concern shifted from resources exhaustion to environmental damage in a broad sense (pollution, disease…)

❑Development of earth boundaries not only for economic growth but also for life.



WWF (2016) Living Planet Report

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The Water Food Energy question

WEF questions

Among all resources, water, food and energy are of critical importance because it is essential to livelihood (Bruntland report)

They share comparable characteristics

- All three areas have many billions of people without access (quantity or quality or both).
- All have rapidly growing global demand
- All have resource constraints.
- All are “global goods’’ and involve international trade and have global implications.
- All have different regional availability and variations in supply and demand.
- All require the explicit identification and treatment of risks
- All 3 are vulnerable to climate change and contribute significantly to that change

Bazilian (2011) Considering the energy, water and food nexus: Towards an integrated modelling approach, Energy Policy 39

WEF questions

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Bazilian (2011) Considering the energy, water and food nexus: Towards an integrated modelling approach, Energy Policy 39

So they present deep security issues as they are fundamental to the functioning of the society

WEF questions

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WEF security definition

Food security

"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". (World Food Summit, 1996)

Water security

The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.

Energy security

"The uninterrupted availability of energy sources at an affordable price" (IEA)

Energy security is composed of 3

- reliability
- Affordability
- accessibility to supplies.

Physical and economic determinants

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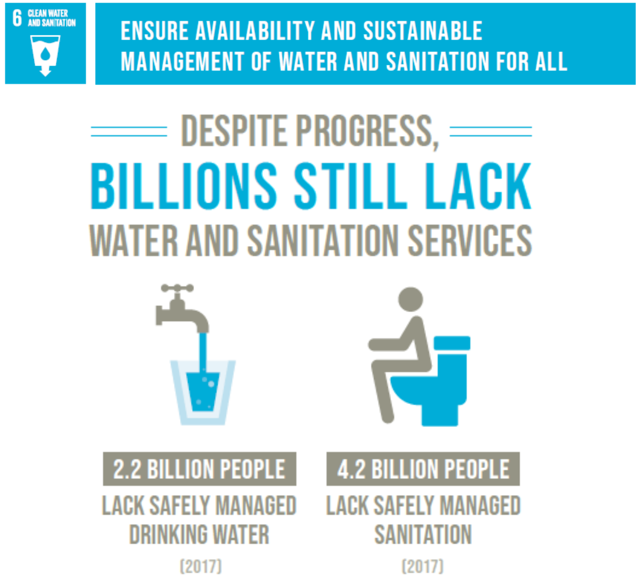
WEF questions



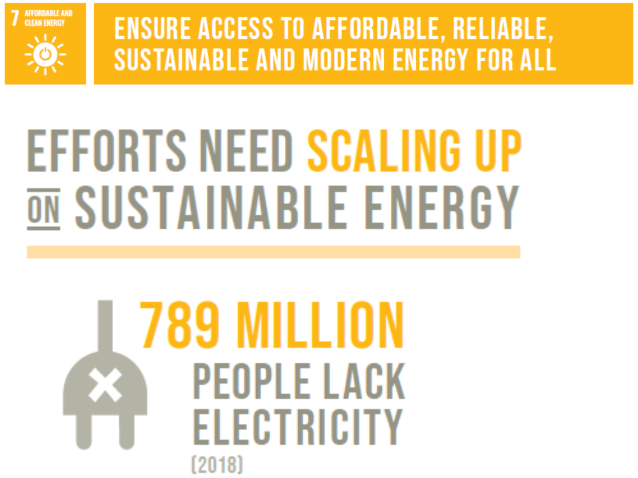
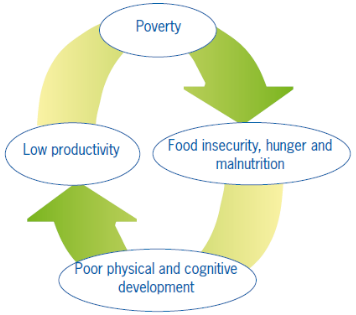


Figure 1: Food insecurity, malnutrition and poverty are deeply interrelated phenomena



FAO (2008) An Introduction to the Basic Concepts of Food Security

Consequences of food and water insecurity : reduce development

Next decades will have to deal with two challenges :

✓Necessity to bring water, energy and food security to these people

✓Increase in world population (10 billions in 2050)

Future trends

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- ❑ Necessity to bring water, energy and food security to these people
- ❑ Increase in world population (10 billions in 2050)

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Future trends

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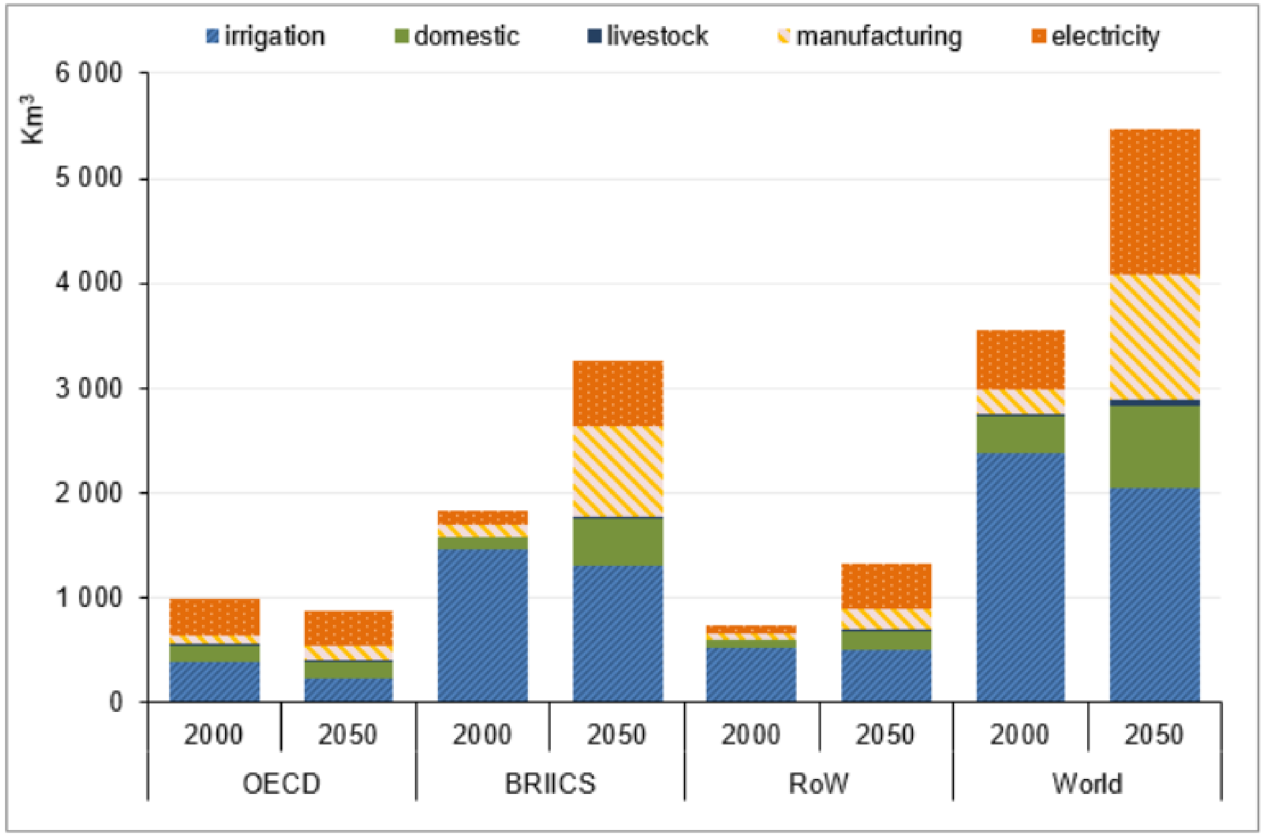
Future trends in water demand

Total global water withdrawals are projected to increase by 50 percent by 2025 in developing countries, and 18 percent in developed countries

OECD (2012) Environmental Outlook to 2050

Agriculture and power sector are the main water consumer

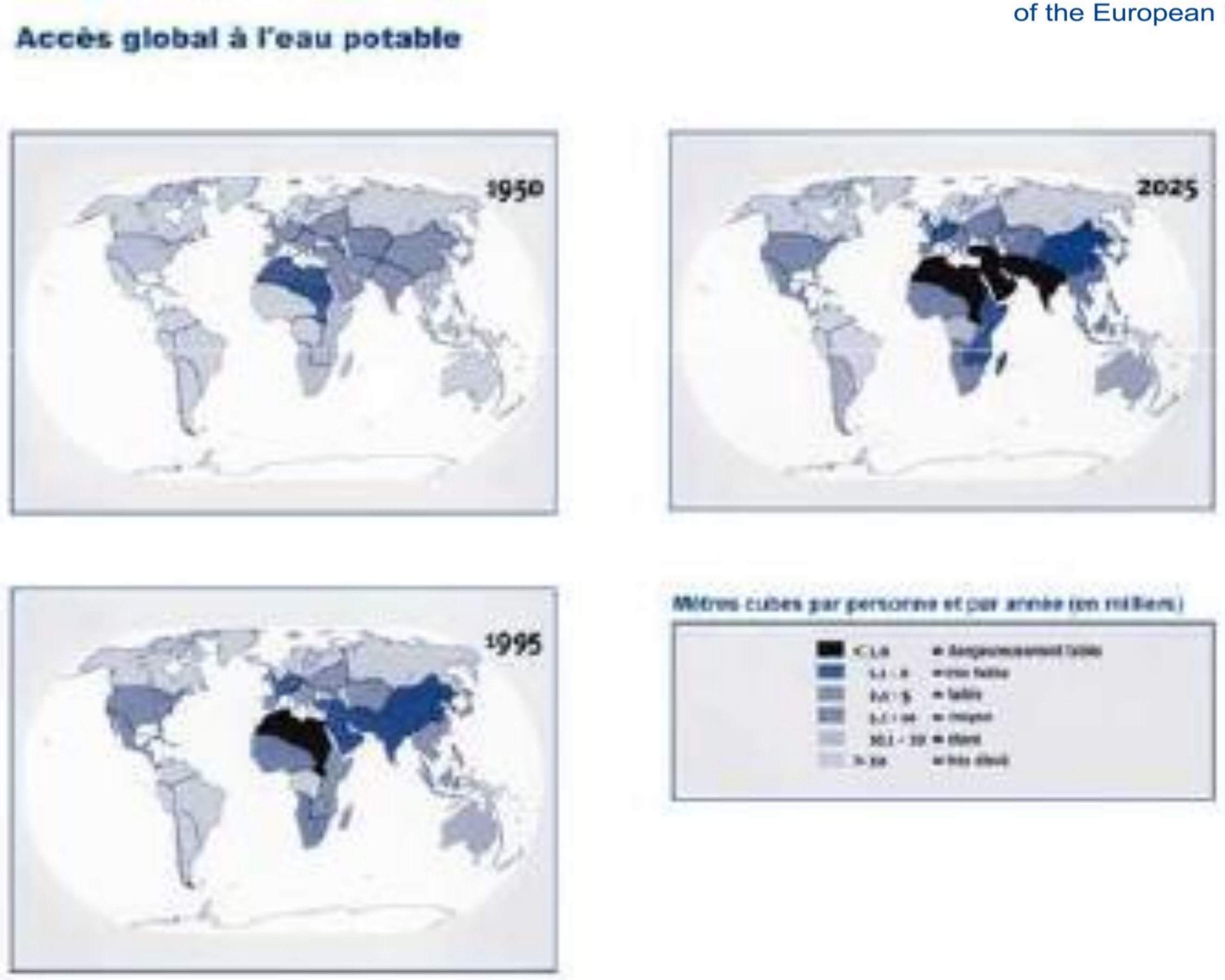
Figure 5.4. Global water demand: *Baseline* scenario, 2000 and 2050



Note: this graph only measures blue water demand (see Box 5.1) and does not consider rainfed agriculture.

Source: The *Environmental Outlook Baseline;* output from IMAGE.

Future trends



<u>Future trends in water demand</u>

Water stress is expected to increase significantly in many regions

Future trends

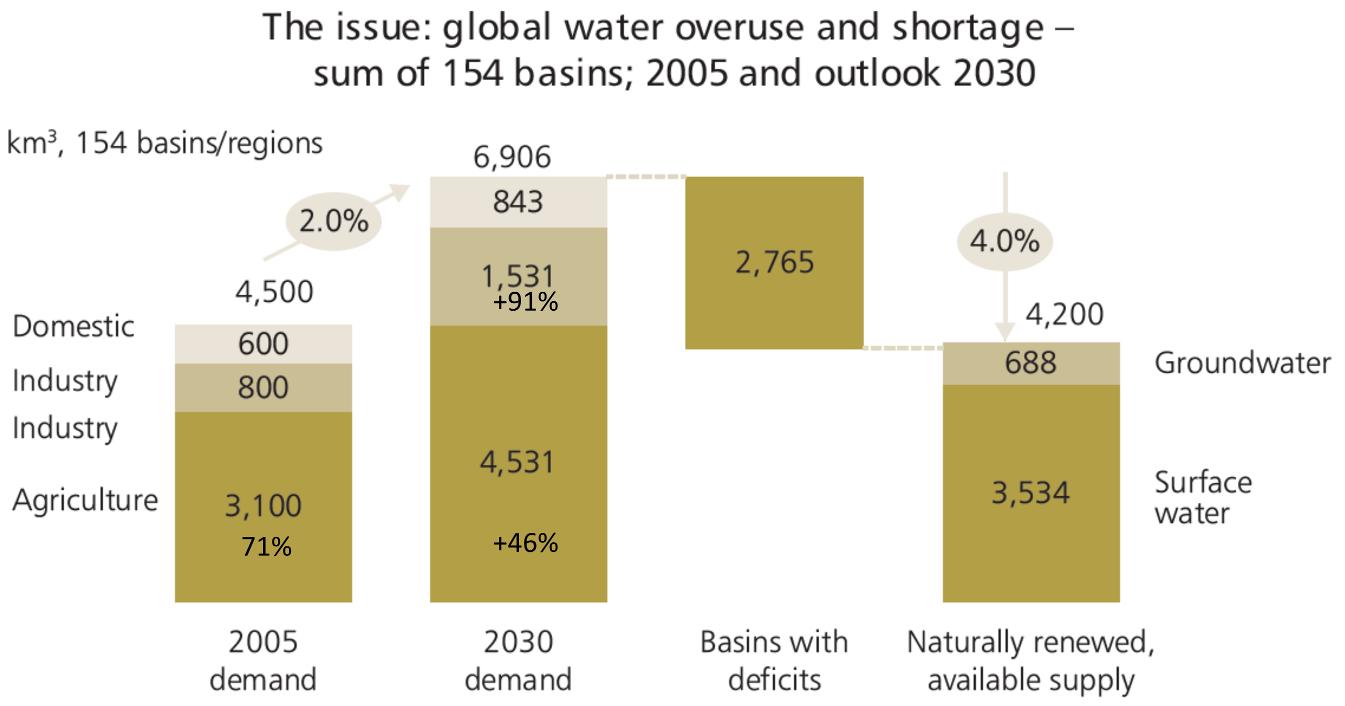
Co-funded by the Erasmus+ Programme of the European Union

Future trends in water demand

Water scarcity projection in Asia

ADB (2014) Thinking about Water Differently

Figure 1: **Gap between Supply and Demand of Water** (forecast for 2030)



km³ = cubic kilometer.

Source: Water 2030 Global Water Supply and Demand model; agricultural production based on IFPRI IMPACT-WATER base case. Cited in World Economic Forum Water Initiative. 2011. *Water Security: The Water–Food–Energy–Climate Nexus*. p. 206. Geneva.

Future trends

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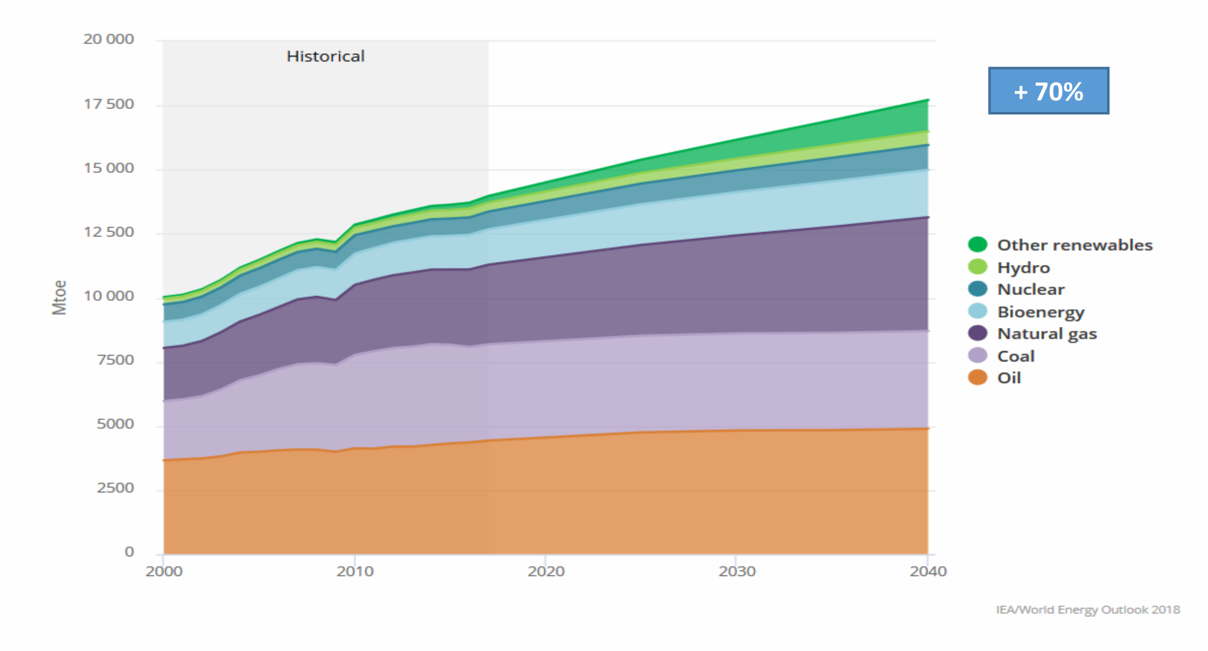
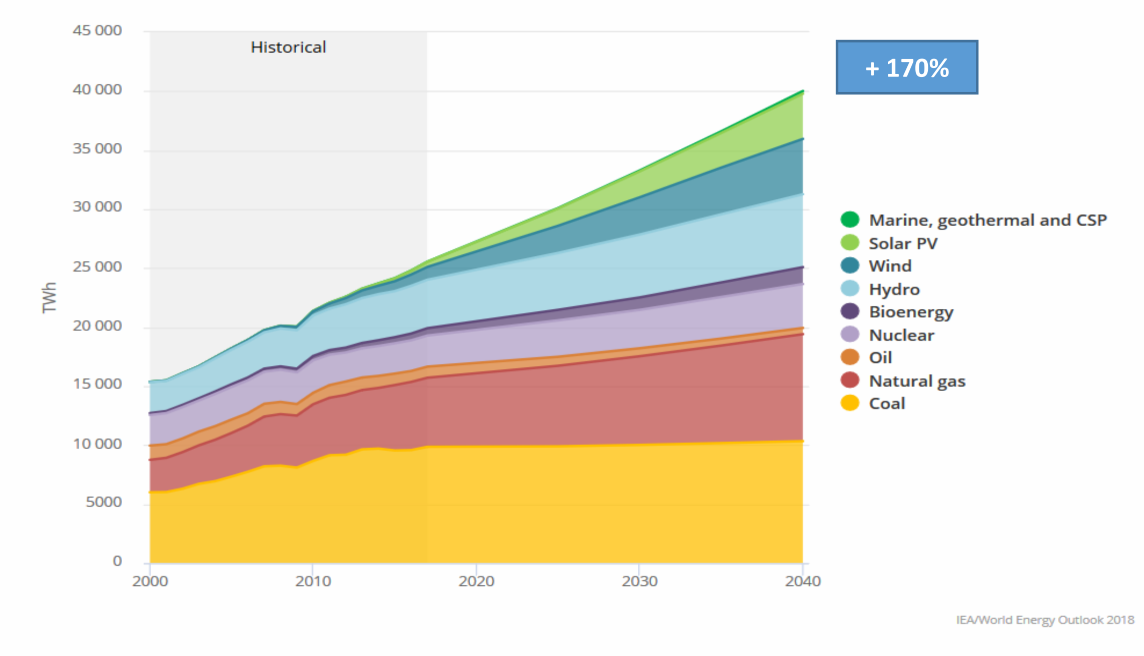
Future trends in energy demand

- Global energy consumption is projected to grow by close to 50 percent by 2035 and 80 percent by 2050 (IEA 2010).



Primary energy demand



Power generation

Energy International Agency

Future trends

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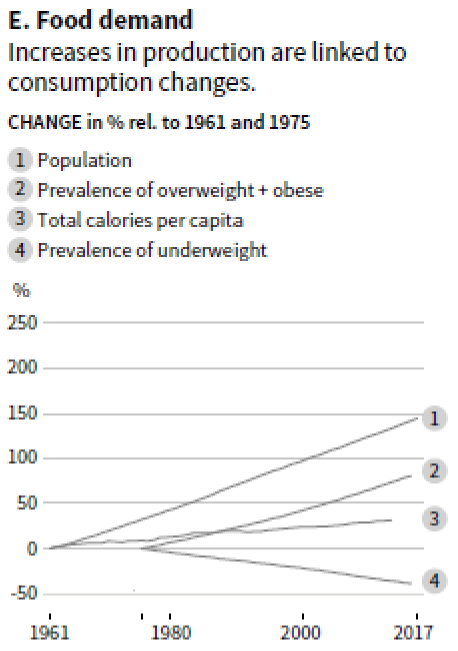
Future trends in food demand

- 60 percent more food will be required to be produced by 2050 in order to meet the demand of more nutritious and better quality food. Diet is supposed to move towards an increasing share of animal product



IPCC (2020) Climate Change and Land

Tableau 1 - Estimations de la demande alimentaire à 2050, toutes calories confondues, végétales et animales

Sources données	FAO 2009	Agri-monde GO	Agri-monde G1	ISV *tendanciel*	ISV *higher meat*	ISV *less fair meat*	ISV *less meat*	IFPRI *progressive policy*	IFPRI *failure*	IFPRI *techno failure*
Évolution population 2005-2050	43 %	43 %	43 %	43 %	43 %	43 %	43 %	26 %	49 %	49 %
Évolution de la demande alimentaire individuelle moyenne	+ 11,4 %	+ 19 %	Stabili-sation	+ 7 %	+ 14 %	Stabili-sation	+ 7,6 %	+ 30 %	+ 5 %	Stabili-sation
Évolution de la demande individuelle de produits d'origine animale	+ 40 % (de 37 à 52 kg/tête/an)	+ 78 % (de 500 à 892 kcal/hab/j)	Stabili-sation (autour de 500 kcal/hab/j)	+ 7 % (de 457 à 489 kcal)	+ 48 % (de 457 à 678 kcal)	− 49 % (de 457 à 233 kcal)	− 21 % (de 457 à 360 kcal)	+ 54 % (de 37 à 57 kg/hab/an)	Stabili-sation	− 14 % (de 37 à 32 kg/hab/an)
Augmentation des besoins alimentaires globaux à 2050 en Kcal	+ 58 %	+ 68 %	+ 40 %	+ 54 %	+ 63 %	+ 44 %	+ 54 %	+ 64 %	+ 58 %	+ 52 %

Source : Extraits des rapports cités et calculs des auteurs.

Ministère de l'Agriculture et de la pêche (2011) La demande alimentaire en 2050 : chiffres, incertitudes et marges de manoeuvre

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Water Food Energy Nexus definition

WEF Nexus definition

Co-funded by the Erasmus+ Programme of the European Union

<u>Consequences</u>

growing demand for energy, food, and water $\Rightarrow$ an intensification of resources use.

<u>Challenges</u>

Achievement of goal in one sector could negatively affect other sector

Competition among resources

Misrepresentation

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Trade off example 1

To feed growing population, countries was engaged in intensive crop production, intensive in water use, energy and chemical product. To reach this goal, water and energy subsidies were promoted.

Consequences

✓Acceleration of deterioration of land soil and water quality

✓groundwater depletion

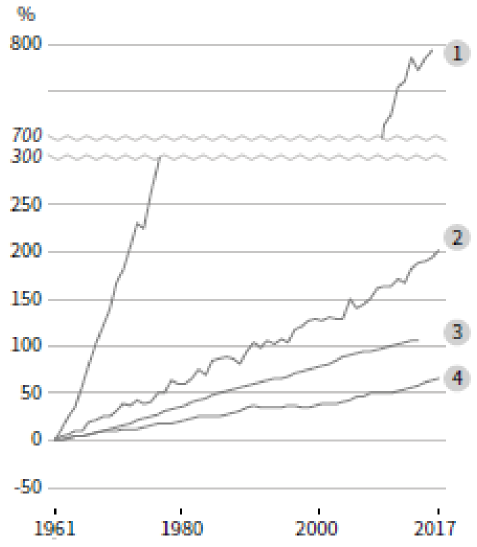
✓Because of intensive use of energy, food production has become vulnerable to price of energy

D. Agricultural production

Land use change and rapid land use intensification have supported the increasing production of food, feed and fibre. Since 1961, the total production of food (cereal crops) has increased by 240% (until 2017) because of land area expansion and increasing yields. Fibre production (cotton) increased by 162% (until 2013).

CHANGE in % rel. to 1961

1 Inorganic N fertiliser use
2 Cereal yields
3 Irrigation water volume
4 Total number of ruminant livestock



IPCC (2020) Climate Change and Land

Misrepresentation

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Trade off example 2

Objective : Enhance energy supply and reduce dependency on fossil fuel

Consequences

diverting cultivable land for biofuels ⇒ threaten food security

lead to social impacts due to higher food prices

For large scale biofuel promoting policy trade-offs have to be made between food security, biodiversity, and climate change

Misrepresentation

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Trade off example 3

30% of the food produced globally goes to waste

⇒ all the land, water, energy, seeds, fertiliser, labour, capital and other resources that went into its production also go to waste.

this translates to wasting at least 6% of total global greenhouse gas emissions

WWF (2016) Living Planet Report

Misrepresentation

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"a system's performance cannot be optimized by optimizing the performance of its subsystems taken in isolation from one another . . .efforts to avoid unwanted policy outcomes and to identify leverage points for effective change must take into account the effect of interactions between sectors."

Smagl *et alii* (2016) from Newel *et alii* (2011)

Smajgl et al. (2016), The water–food–energy Nexus – Realising a new paradigm Journal of Hydrology

WEF Nexus definition

Food, water, and energy are then inextricably linked in a nexus, and actions in one sector influence the others

- ✓ Food production requires water and energy
- ✓ Water extraction, treatment and distribution needs energy
- ✓ Energy generation requires water

Examples of interconnections:

- ✓ Agriculture accounts for 70% of total global freshwater withdrawals
- ✓ 90% of energy produced today is water-intensive
- ✓ Agriculture & food chain account for 33% of global energy demand

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- ✓ Agriculture & food chain account for 33% of global energy demand

- ➢ Needs for understanging linkages
- ➢ Needs for a holistic vision of sustainable development

WEF Nexus definition

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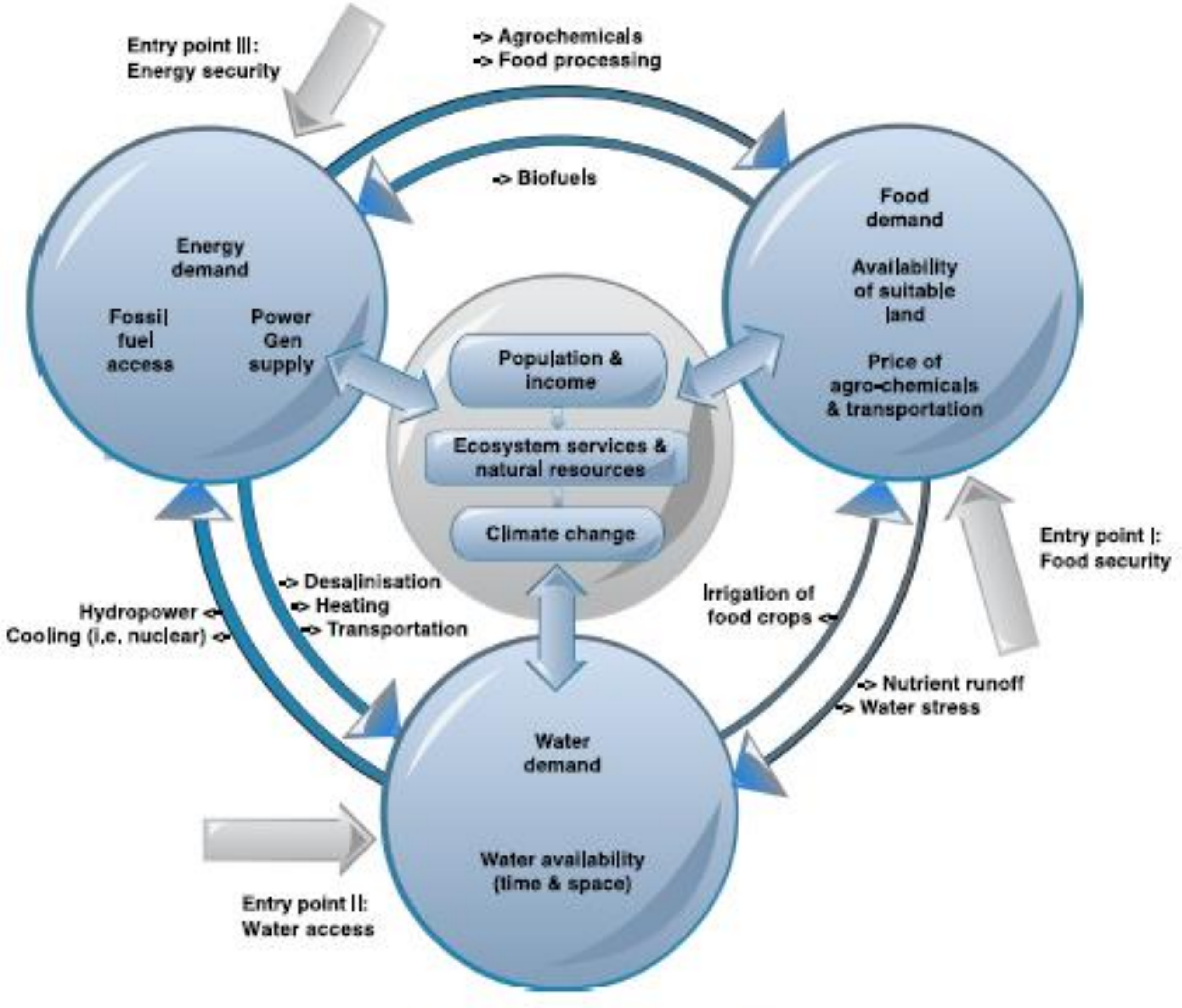

Fig. 1. The energy–water–food Nexus.

Smajgl et alii (2016) The water–food–energy Nexus – Realising a new paradigm, Journal of Hydrology

WEF Nexus definition

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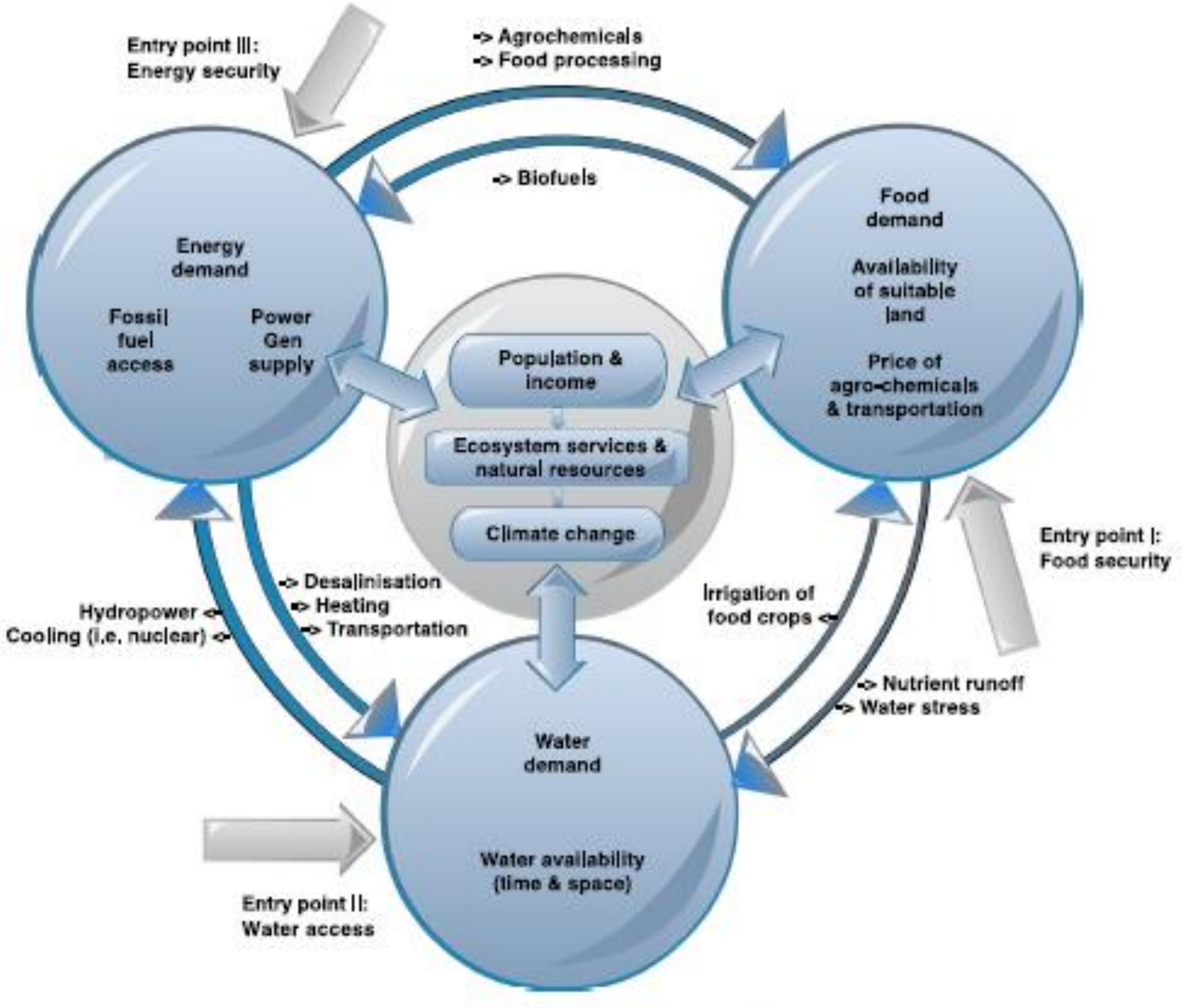

Fig. 1. The energy–water–food Nexus.

What are the drivers of the nexus ?

- ✓ Population
- ✓ Income
- ✓ policy,
- ✓ technology,
- ✓ Governance

- ✓ And also climate change

Smajgl et alii (2016) The water–food–energy Nexus – Realising a new paradigm, Journal of Hydrology

WEF Nexus definition

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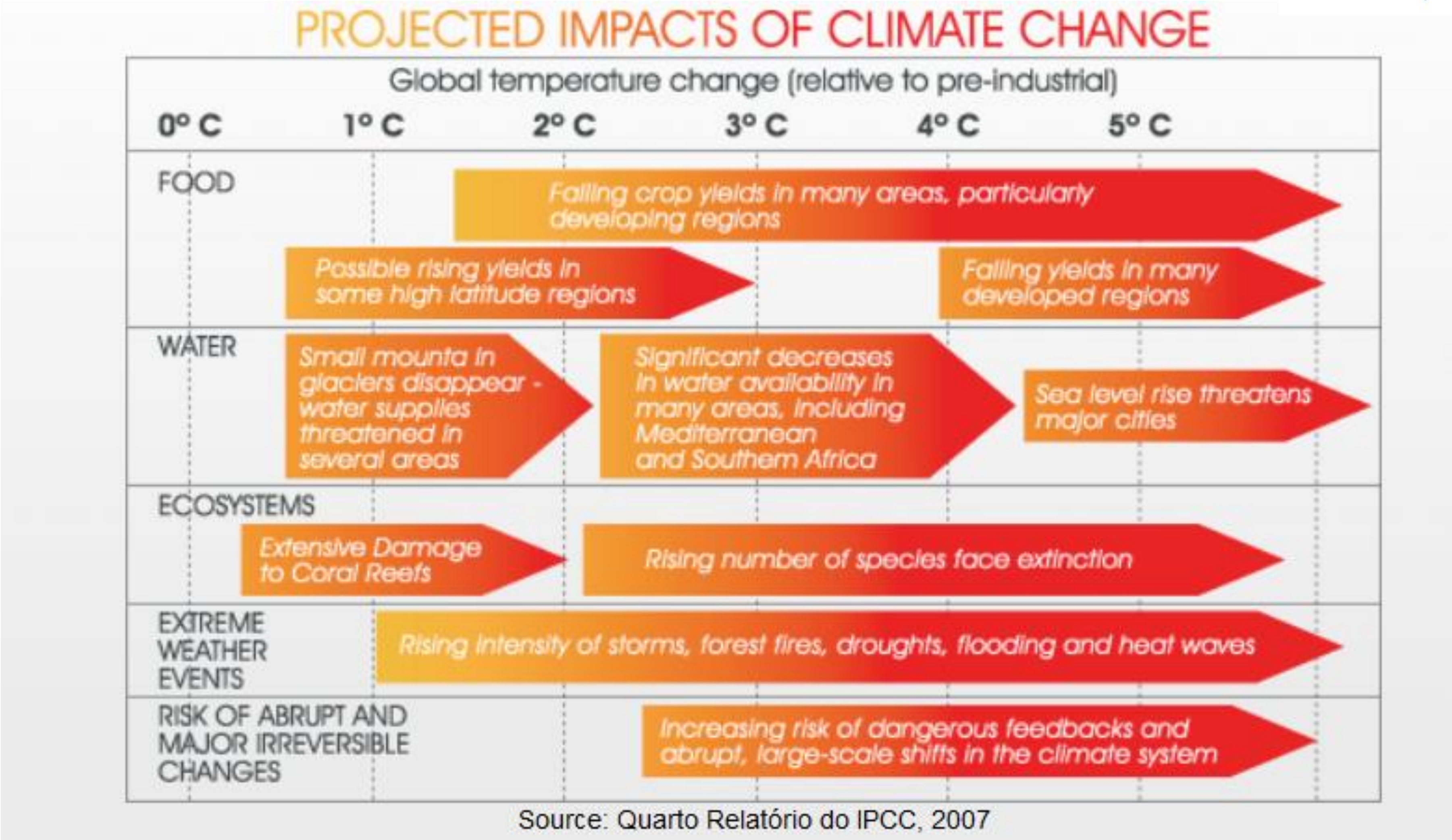
Climate change as a driver of WEF Nexus



WEF Nexus definition

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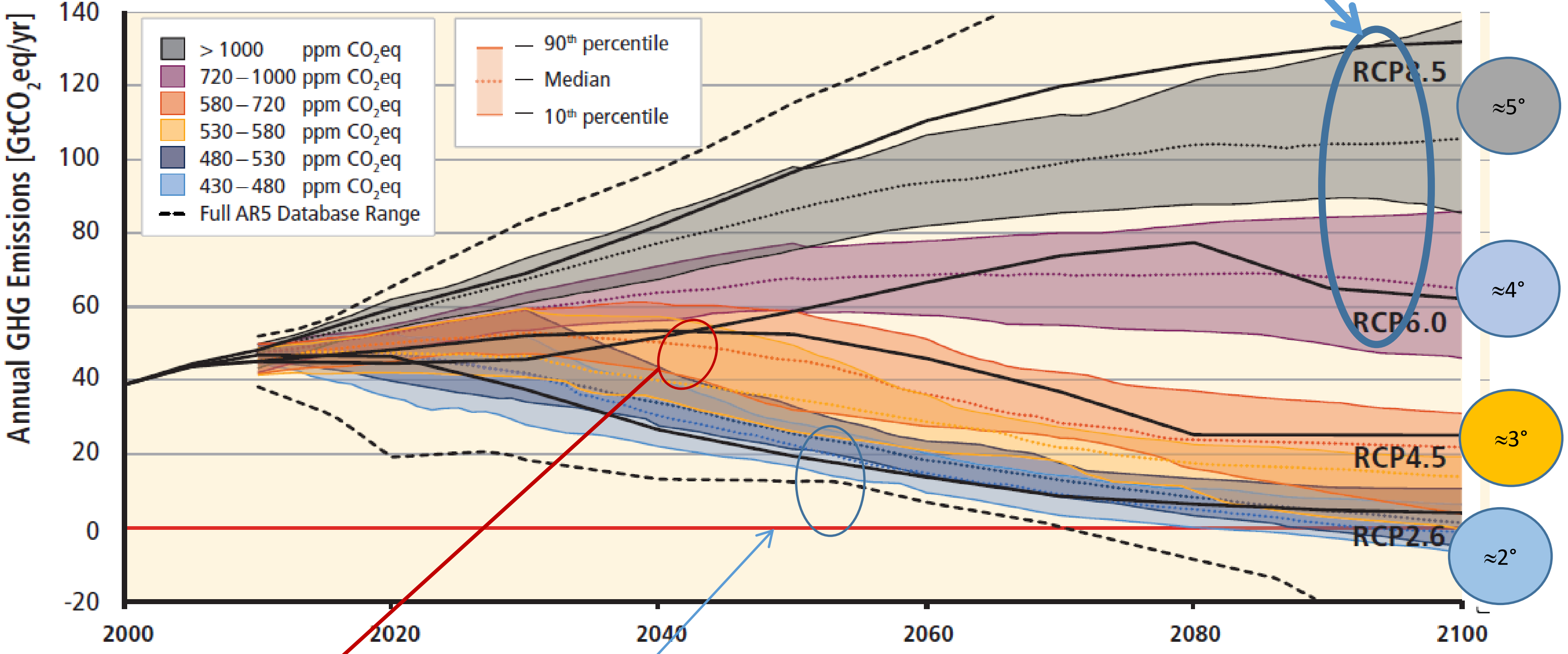
Climate change as a driver of WEF Nexus

Baseline



IPCC (2014)

Trajectory if compliance with Paris agreement

2050 : -25% à -75% with respect to 2010

WEF interdependencies

Description and quantification

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Interlinkage representation

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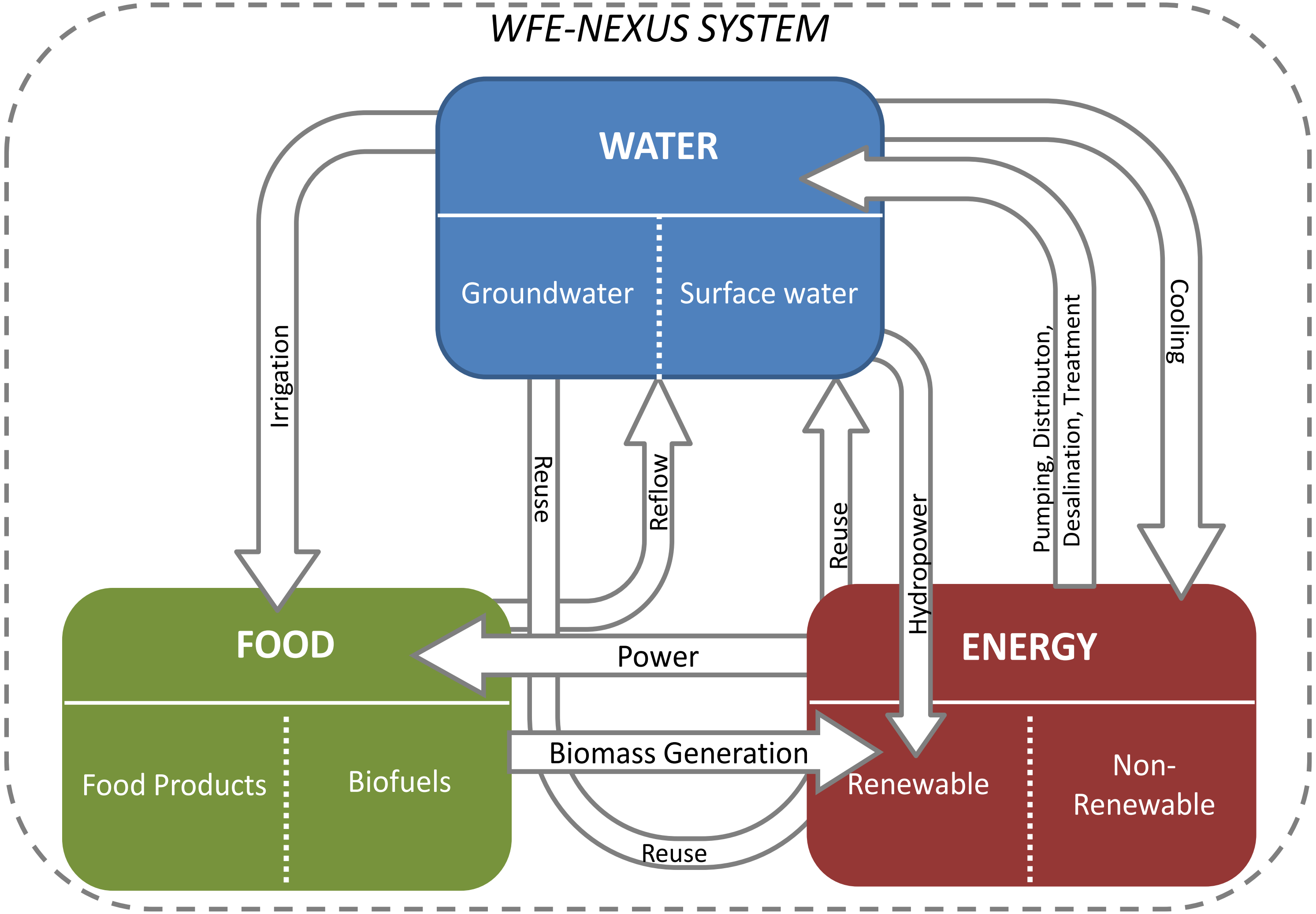

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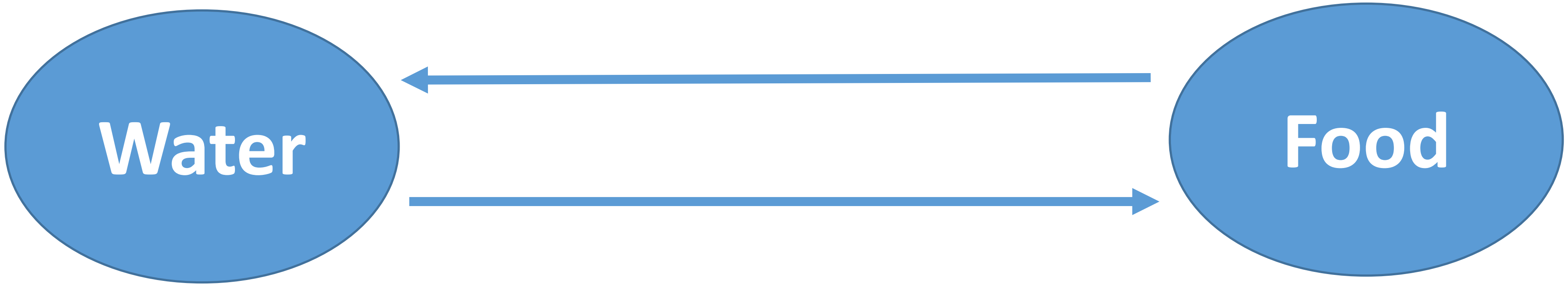
Water – Food Nexus



<u>Water is used for food</u>
Irrigation
livestock

<u>From food to water</u>
pollution
(Point and non point source)

GREENCAP

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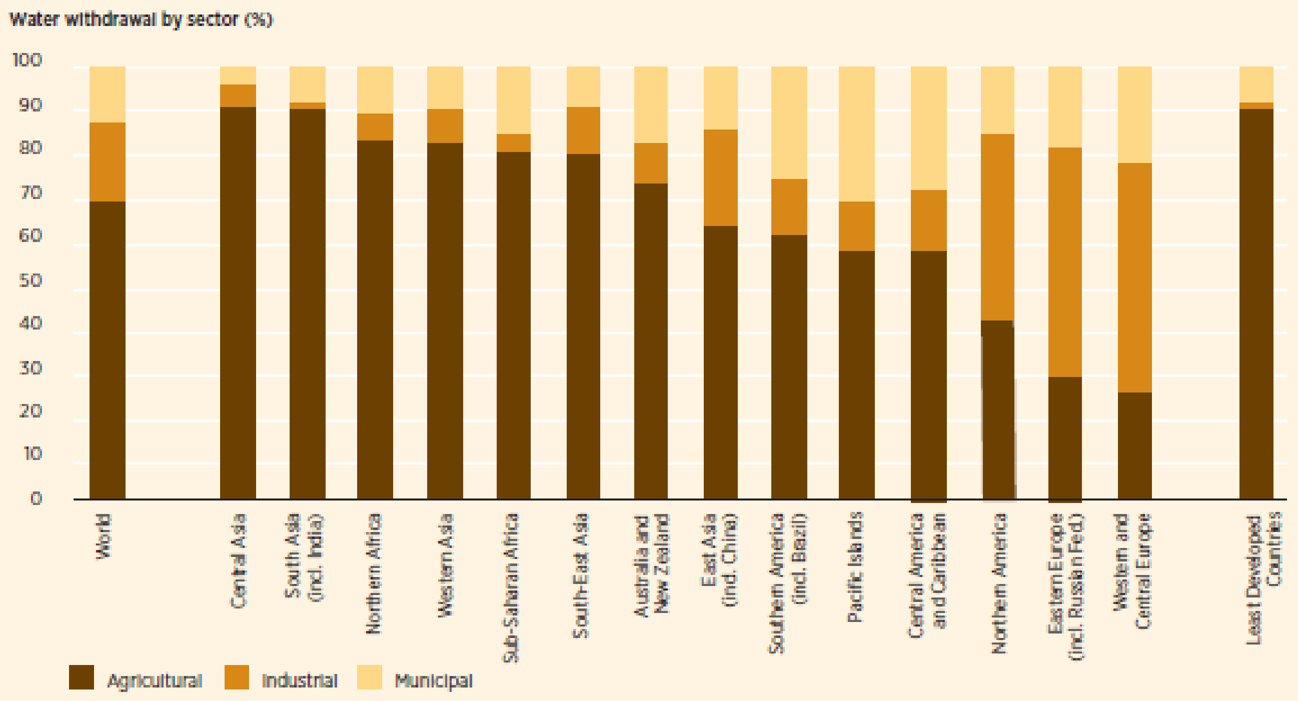
Water – Food Nexus

FIGURE 2.1

Water withdrawal by sector by region (2005)



Source: FAO AQUASTAT (http://www.fao.org/nr/water/aquastat/main/index.stm, accessed in 2011).

UN (2012) Managing Water under Uncertainty and Risk

Water for food

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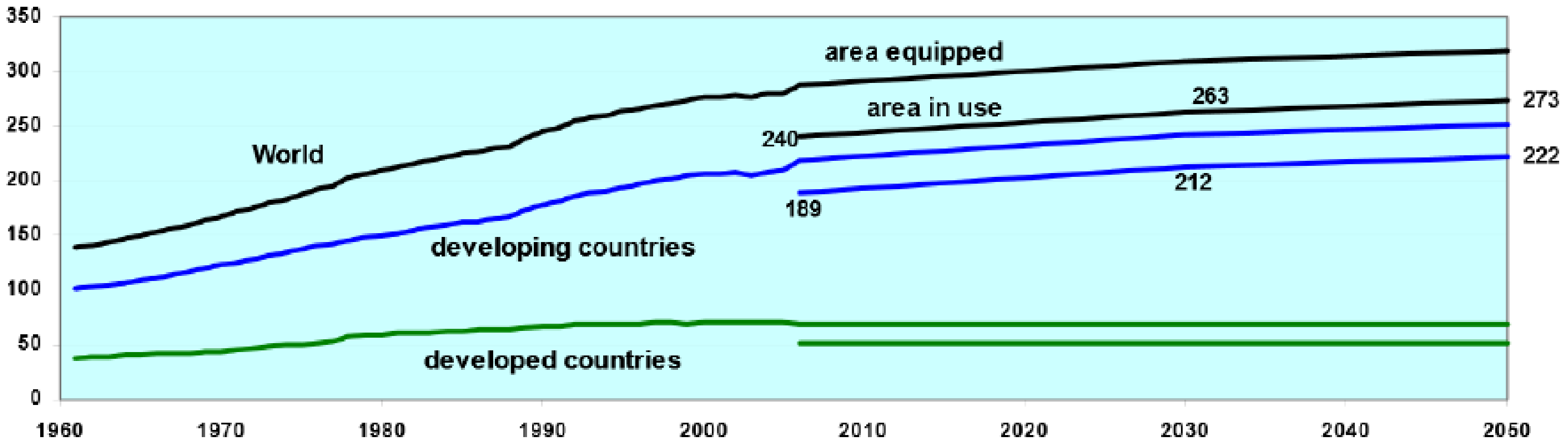
Area equipped for irrigation: historical and projected (Mha).



Source: Bruinsma (2009)

Hertel, T. W. and J. Liu (2016), “Implications of water scarcity for economic growth”, *OECD Environment Working Papers*, No. 109, OECD Paris.

Water for food

Co-funded by the Erasmus+ Programme of the European Union

Table 1. Global water footprint of production (1996–2005)

	Agricultural production					
	Crop production	Pasture	Water supply in animal raising	Industrial production	Domestic water supply	Total
Global water footprint of production, Gm^3/y						
Green	5,771*	913†	—	—	—	6,684
Blue	899*	—	46†	38	42	1,025
Gray	733*	—	—	362	282	1,378
Total	7,404	913	46	400	324	9,087
Water footprint for export, Gm^3/y	——	1,597	——	165	0	1,762
Water footprint for export compared to total, %	——	19	——	41	0	19

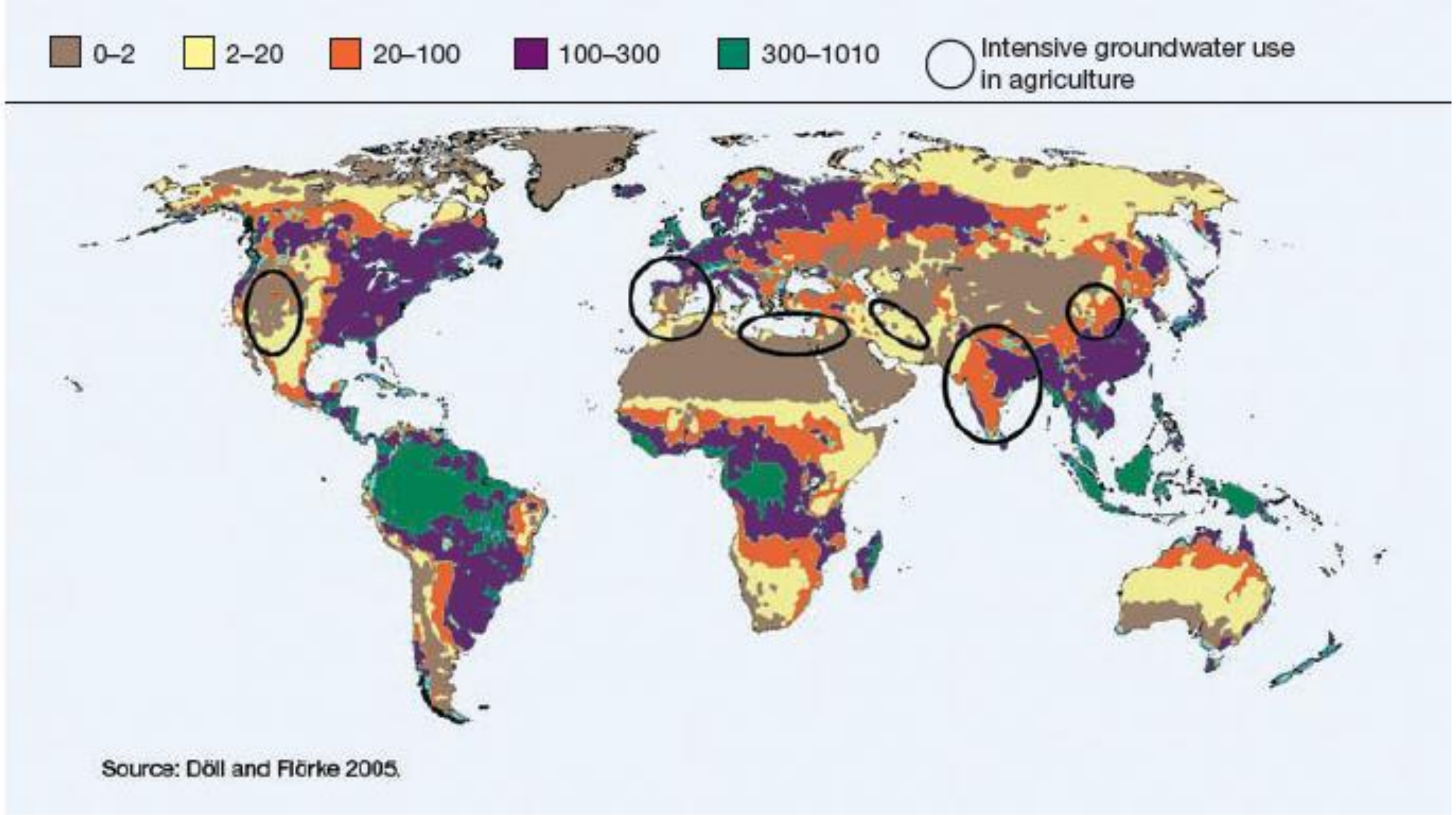
*Mekonnen and Hoekstra (21, 22).
†Mekonnen and Hoekstra (23).

Hoekstra and Mekonnen (2012) The water footprint of humanity, PNAS

Irrigation uses mainly surface water…

Water for food

Long term average groundwater recharge rates (mm/year)



Hertel, T. W. and J. Liu (2016), "Implications of water scarcity for economic growth", *OECD Environment Working Papers*, No. 109, OECD Paris.

…in some area agriculture uses intensively groundwater

Water for food

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Water for aquaculture also !

Table 2. Water footprint (WF) of main food products.

Food Items		WF per Food Product (m³/kg)	WF per Food Energy Provision (L/kcal)
Cereal	Rice	1.7	0.5
	Wheat	1.8	0.7
	Maize	1.2	0.4
Animal products	Beef	3.8–23.8	1.9–11.8
	Pork	4.4–12.1	1.3–3.5
	Chicken meat	1.7–6.7	0.9–3.7
	Sheep meat	5.8–11.3	2.9–5.6
	Goat meat	1.6–8.5	0.8–4.2
	Eggs	1.3–6.0	0.9–4.1
	Milk	0.5–1.3	0.7–1.9
Vegetables		0.2–0.3	1.1–1.6
Fruits		0.5–1	1.2–2.4
Groundnuts		3.1	1.0
Beverage products	Wine	1	1.4
	Tea	0.12	-
	Soft drinks	0.3–0.6	0.7–1.4

Note: Data resources include [45–49]. The WF consists of green, blue, and gray water consumption. Single estimates are global average values. The energy content of tea is almost zero. The soft drink estimate derives from a case study [50].

Y. Chang, G Li, Y Yao, L Zhang and C Yu (2016), Quantifying the Water-Energy-Food Nexus: Current Status and Trends. *Energies, 9, 65*.

Water for food

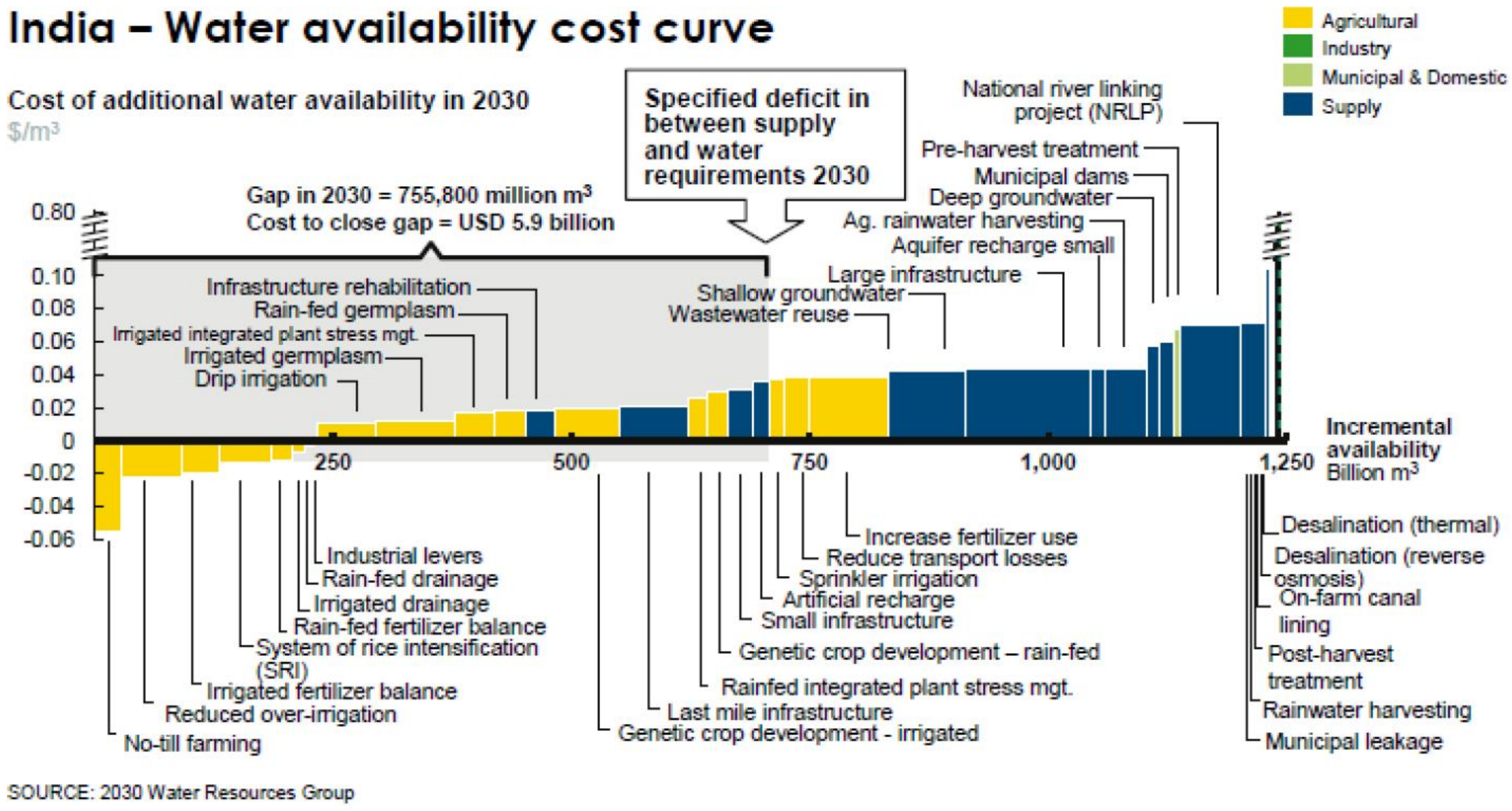
Hoekstra (2009) *A Comprehensive Introduction to Water Footprints*

Water cost curve

Co-funded by the Erasmus+ Programme of the European Union

What are the cost of water savings

Figure 16. Cost of increasing water availability in India in 2030 through conservation and supply considerations



Source: Reproduced from McKinsey & Co. (2009)

Hertel, T. W. and J. Liu (2016), "Implications of water scarcity for economic growth", *OECD Environment Working Papers*, No. 109, OECD Publishing,

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From food to water

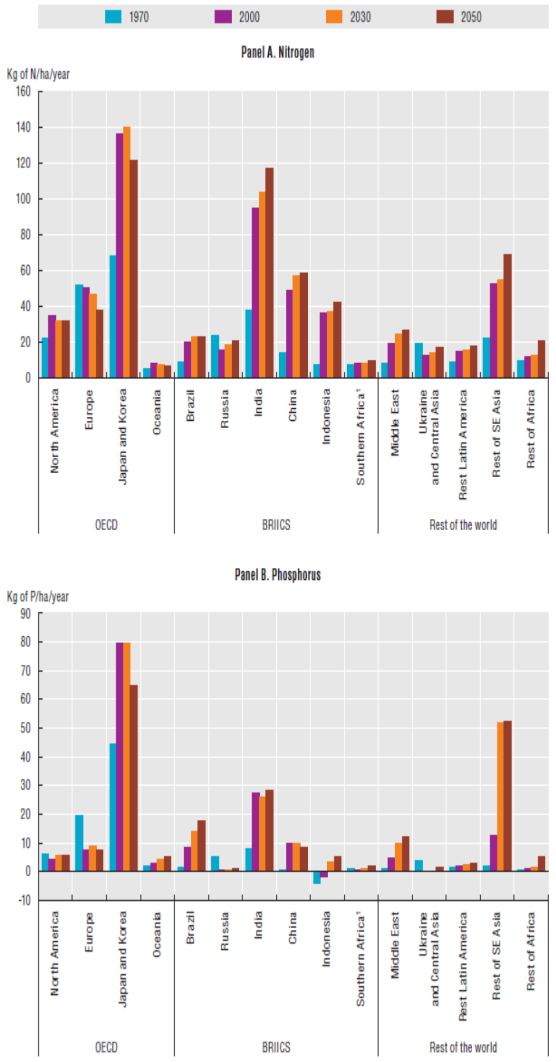
Nitrogen comes from fertiliers use

Phosphorus comes from animal manure

Excess nutrient causes eutrophication of surface and coastal water (stimulation plant growth leading to oxygen depletion)

OECD (2012) Environmental Outlook to 2050 : the consequences of inaction

Figure 5.8. **Nutrient surpluses per hectare from agriculture: Baseline, 1970-2050**



1. In the IMAGE model the *Southern Africa* region includes ten other countries in this geographical area including the Republic of South Africa, when dealing with land use, biodiversity, water and health. For energy-related modelling the region has been split into the Republic of South Africa and "Rest of Southern Africa".

Source: OECD *Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571247

Energy – water Nexus

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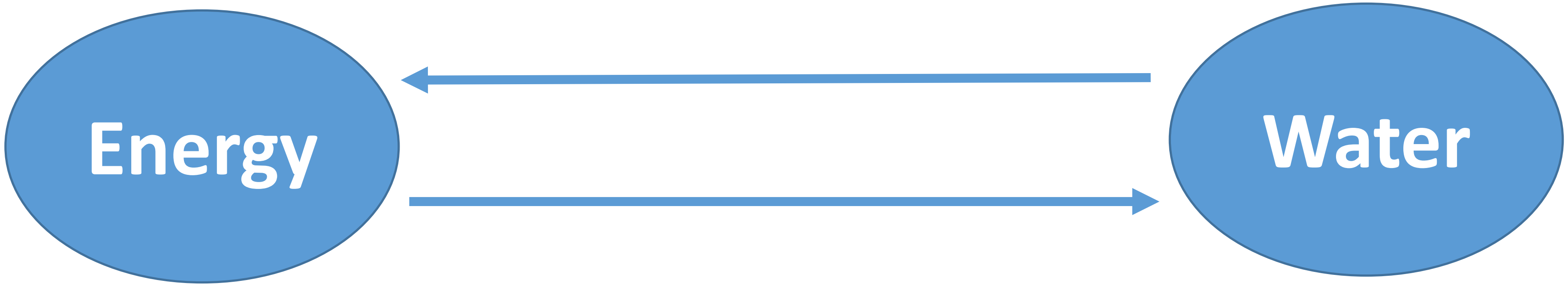

Water for energy

- Hydropower
- Extraction
- Electric power generation

Energy for water

- Desalinisation
- pumpage

Water for energy

Co-funded by the Erasmus+ Programme of the European Union

Energy Element	Connection to Water Quantity	Connection to Water Quality
Energy Extraction and Production		
Oil and Gas Exploration	Water for drilling, completion, and fracturing	Impact on shallow groundwater quality
Oil and Gas Production	Large volume of produced, impaired water*	Produced water can impact surface and groundwater
Coal and Uranium Mining	Mining operations can generate large quantities of water	Tailings and drainage can impact surface water and ground-water
Electric Power Generation		
Thermo-electric (fossil, biomass, nuclear)	Surface water and groundwater for cooling** and scrubbing	Thermal and air emissions impact surface waters and ecology
Hydro-electric	Reservoirs lose large quantities to evaporation	Can impact water temperatures, quality, ecology
Solar PV and Wind	None during operation; minimal water use for panel and blade washing	

*Impaired water may be saline or contain contaminants

Energy Element	Connection to Water Quantity	Connection to Water Quality
Refining and Processing		
Traditional Oil and Gas Refining	Water needed to refine oil and gas	End use can impact water quality
Biofuels and Ethanol	Water for growing and refining	Refinery waste-water treatment
Synfuels and Hydrogen	Water for synthesis or steam reforming	Wastewater treatment
Energy Transportation and Storage		
Energy Pipelines	Water for hydrostatic testing	Wastewater requires treatment
Coal Slurry Pipelines	Water for slurry transport; water not returned	Final water is poor quality; requires treatment
Barge Transport of Energy	River flows and stages impact fuel delivery	Spills or accidents can impact water quality
Oil and Gas Storage Caverns	Slurry mining of caverns requires large quantities of water	Slurry disposal impacts water quality and ecology

**Includes solar and geothermal steam-electric plants

Figure 3 Connections between the energy sectors and water availability and quality (US DOE 2006)

Water for energy

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Table 2. Water consumption for raw materials

	Raw material	Water for energy (L/MWh)	Transformation	Water for energy (L/MWh)
Oil	Traditional oil	11–25	Oil refining	89–232
	Enhanced oil Recovery	176–32,143		
	Oil sands	250–6,429		
Biofuels	Corn	32,413–357,143	Ethanol	168–179
	Soy	178,571–964,286	Biodiesel	50
	Sugar	N/A		
Coal	Coal	18–250	Coal-to-liquids	500–786
Gas	Traditional gas	Minimal	Natural gas processing	25
	Shale gas	129–193		

Source: US Department of Energy (2006).

Yoon (2017), A Review on Water-Energy Nexus and Directions for Future Studies: From Supply to Demand End, Documents d'Anàlisi Geogràfica 2018, vol. 64/2 365-395

Water for energy

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Yoon (2017), A Review on Water-Energy Nexus and Directions for Future Studies: From Supply to Demand End,
Documents d'Anàlisi Geogràfica 2018, vol. 64/2 365-395

Table 3. Water intensity for thermoelectric power plants

Plant type Steam	Process	Steam condensing: Withdrawal (L/MWh)	Steam condensing: Consumption (L/MWh)
Fossil/biomass/waste	OL	75,708–189,271	~1,136
	CL tower	1,136–2,271	1,136–1,817
	CL pond	1,893–2,271	~1,817
Nuclear	OL	94,635–227,124	~1,514
	CL tower	1,893–4,164	1,514–2,726
	CL pond	3,028–4,164	~2,726
Geothermal steam	CL tower	~7,571	~5,300
Solar trough	CL tower	2,877–3,483	2,877–3,483
Solar tower	CL tower	~2,839	~2,839
Other			
Natural gas CC	OL	28,390–75,708	379
	CL tower	~871	~681
Coal IGCC*	CL tower	~946	~757

OL= Open loop cooling, CL= Closed loop cooling, CC= Combined cycle, IGCC= Integrated gasification combined cycle

Water for other cooling loads such as gas turbine, equipment washing, emission treatment, restroom, etc. which range from 26 to 530 depending on the plant type. Dry cooling systems require 0 withdrawal & consumption.

*Includes gasification process water

**Reference did not specify whether values are for withdrawal or consumption

Source: Adapted from US Department of Energy (2006). Data based on EPRI (2002), CEC (2002, 2006), Leitner (2002) and Cohen et al. (1999).

Water for energy

Water impact of hydropower

- Costs
  - ✓ Water consumption is reduced to evaporation (≠ from run-of-river ?)
  - ✓ downstream impacts associated with altered flow (sources of conflicts)
- Benefit
  - ✓ Power generation
  - ✓ Water storage for irrigation upstream

See Shokhrukh-Mirzo Jalilov, Olli Varis and Marko Keskinen (2015) Sharing Benefits in Transboundary Rivers: An Experimental Case Study of Central Asian Water-Energy-Agriculture Nexus, Water, 7

Water for energy

3.3 TABLE

Economically feasible hydropower potential, installed capacity and power generation by region

	Economically feasible hydropower potential (GWh/year)	Installed hydrocapacity (MW)	Hydro generation in 2011 or average/most recent (GWh/year)
Africa	842 077	25 908	112 163
Asia	4 688 747	444 194	1 390 800
Australasia/Oceania	88 700	13 327	39 394
Europe	842 805	181 266	531 152
North America	1 055 889	140 339	681 496
South America	1 676 794	140 495	712 436
World	**9 195 041**	**975 528**	**3 467 440**

Source: WWAP, with data from Aqua-Media International Ltd (2012).

UN (2014): Water and Energy

Energy for water

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Energy to produce water

- ✓ Groundwater pumping : energy is necessary to pump water for sanitation and irrigation. for example, energy use for moving and treating water and wastewater represents over 12% of total U.S. primary energy consumption
- ✓ Energy for clean drinking water : energy is used to boil and sterilize water
- ✓ Water desalination : energy can be used to desalinize salt water to provide fresh water in dry coastal country. Need a large amount of electricity
- ✓ Waste water treatment

Energy for water

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Table 6. **Domestic Water Industry Value Chain—Energy Consumption (kilowatt-hour per 1,000 cubic meters)**

Source	Raw Materials	Transformation	Delivery
Surface water	0–2,400	Treatment: varies with raw water quality	Depends on distance and elevation: 290
Groundwater	40 meters: 150 120 meters: 520	High-quality groundwater: 26 Brackish water: 300–1,400 Seawater desalinization: 3,600–4,500	
Municipal wastewater		660	

Source: World Economic Forum with Cambridge Energy Research Associates. 2008. *Energy Vision Update 2009. Thirsty Energy: Water and Energy in the 21st Century*. Geneva.

ADB (2014) Thinking about Water Differently

Energy – Food Nexus

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<u>Energy for food</u>

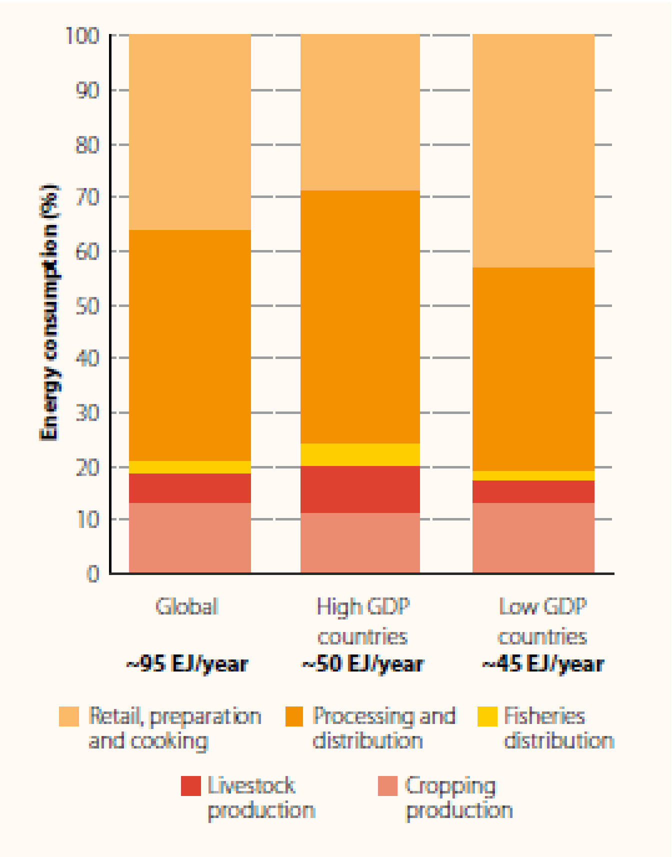
- Pumping for Irrigation
- Modern technologies
- Food transportation
- Cooking

<u>Agriculture for Energy</u>

- biofuels

Energy for Food

Indicative shares of final energy consumption for the food sector globally and for high and low GDP countries



Source: FAO (2011b, fig. 6, p. 11, based on sources cited therein).

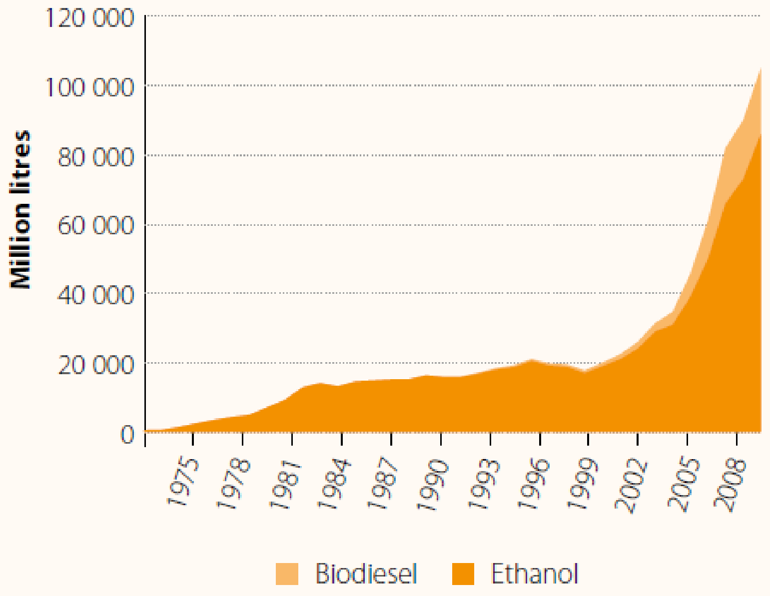
UN (2014) : Water and Energy

Agriculture to energy

Bioenergy represent 14% of global energy consumption

FIGURE 3.3

World ethanol and biodiesel production, 1975–2010



Source: Shrank and Farahmand (2011, fig. 1, from source cited therein).

UN (2014) : Water and Energy

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Conclusion

Benefits of nexus approach

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The benefits of a nexus approach can be summarized as follows:

- Help to better understand interrelationship between WEF
- Identify integrated policy solutions to minimize trade-offs and maximize synergies across sectors
- Ensure policy coherence and coordination across sectors and stakeholders to build synergies and generate co-benefits.
- Provide opportunity to increase resources use efficiency (at international, national, community or individual scale)

Usefulness

- Environmental pressure inventory at different scale level (world, national, city, communauty or firm)

  Marko Keskinen et alii (2015) Water-Energy-Food Nexus in a Transboundary River Basin: The Case of Tonle Sap Lake, Mekong River Basin, Water
  Welsch et alii (2014), Adding value with CLEWS – Modelling the energy system and its interdependencies for Mauritius, Applied Energy 113, pp 1434–1445

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- Benchmarking resources consumption for producers (example in agriculture)

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  ADB (2009) The Economics of Climate Change in Southeast Asia: A Regional Review

  Shokhrukh-Mirzo, Varis and Keskinen (2015), Sharing Benefits in Transboundary Rivers: An Experimental Case Study of Central Asian Water-Energy-Agriculture Nexus, Water

- Define sustainable development pathways taking into account resources interlationship (national, city, communauty scale)

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Thank you for your attention

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Annex

Water availability is affected by CC

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Table 3.8. Summary of Observed Impact of Climate Change on Water Resources Sector in Southeast Asia	
Climate Change	Observed Impact
Increasing temperature	– Increased evapotranspiration in rivers, dams, and other water reservoirs leading to decreased water availability for human consumption, agricultural irrigation, and hydropower generation
Variability in precipitation (including El Niño Southern Oscillation)	– Decreased river flows and water level in many dams and water reservoirs, particularly during El Niño years, leading to decreased water availability; increased populations under water stress – Increased stream flow particularly during La Niña years leading to increased water availability in some parts of the region – Increased runoff, soil erosion, and flooding, which affected the quality of surface water and groundwater
Sea level rise	– Advancing saltwater intrusion into aquifer and groundwater resources leading to decreased freshwater availability
Sources: Boer and Dewi (2008), Cuong (2008), Ho (2008), Jesdapipat (2008), Perez (2008).	

ADB (2009) The Economics of Climate Change in Southeast Asia: A Regional Review

Agriculture is affected by CC

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Table 3.9. Summary of Observed Impacts of Climate Change on Agriculture Sector in Southeast Asia

Climate change	Observed impacts
Increasing temperature	— Decreased crop yields due to heat stress — Increased livestock deaths due to heat stress — Increased outbreak of insect pests and diseases
Variability in precipitation (including El Niño Southern Oscillation)	— Increased frequency of drought, floods, and tropical cyclones (associated with strong winds), causing damage to crops — Change in precipitation pattern affected current cropping pattern; crop growing season and sowing period changed — Increased runoff and soil erosion caused decline in soil fertility and consequently crop yields
Sea level rise	— Loss of arable lands due to advancing sea level — Salinization of irrigation water affected crop growth and yield

Sources: Boer and Dewi (2008), Cuong (2008), Ho (2008), Jesdapipat (2008), Perez (2008).

Asian Development Bank (2009) , The Economics of Climate Change in Southeast Asia: A Regional Review

Agriculture is affected by CC

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TABLE 14 TOTAL IMPACT OF CLIMATE CHANGE ON PRODUCTION BY SCENARIO IN 2050 (MMT)

Climate scenario Impact	Paddy rice			Maize Yields	Cassava Yields	Sugar cane Yields	Coffee Yields	Vegetables Yields
	Yields	Sea level	Total					
Dry	-6.7	-2.4	-9.1	-1.1	-1.9	-3.7	-0.4	-1.7
Wet	-5.8	-2.5	-8.4	-1.0	-2.6	-2.9	-0.4	-3.1
MoNRE	-3.4	-2.4	-5.8	-0.3	-0.6	-1.4	-0.1	-0.9

World Bank (2010) Economics of Adaptation to Climate Change : Vietnam

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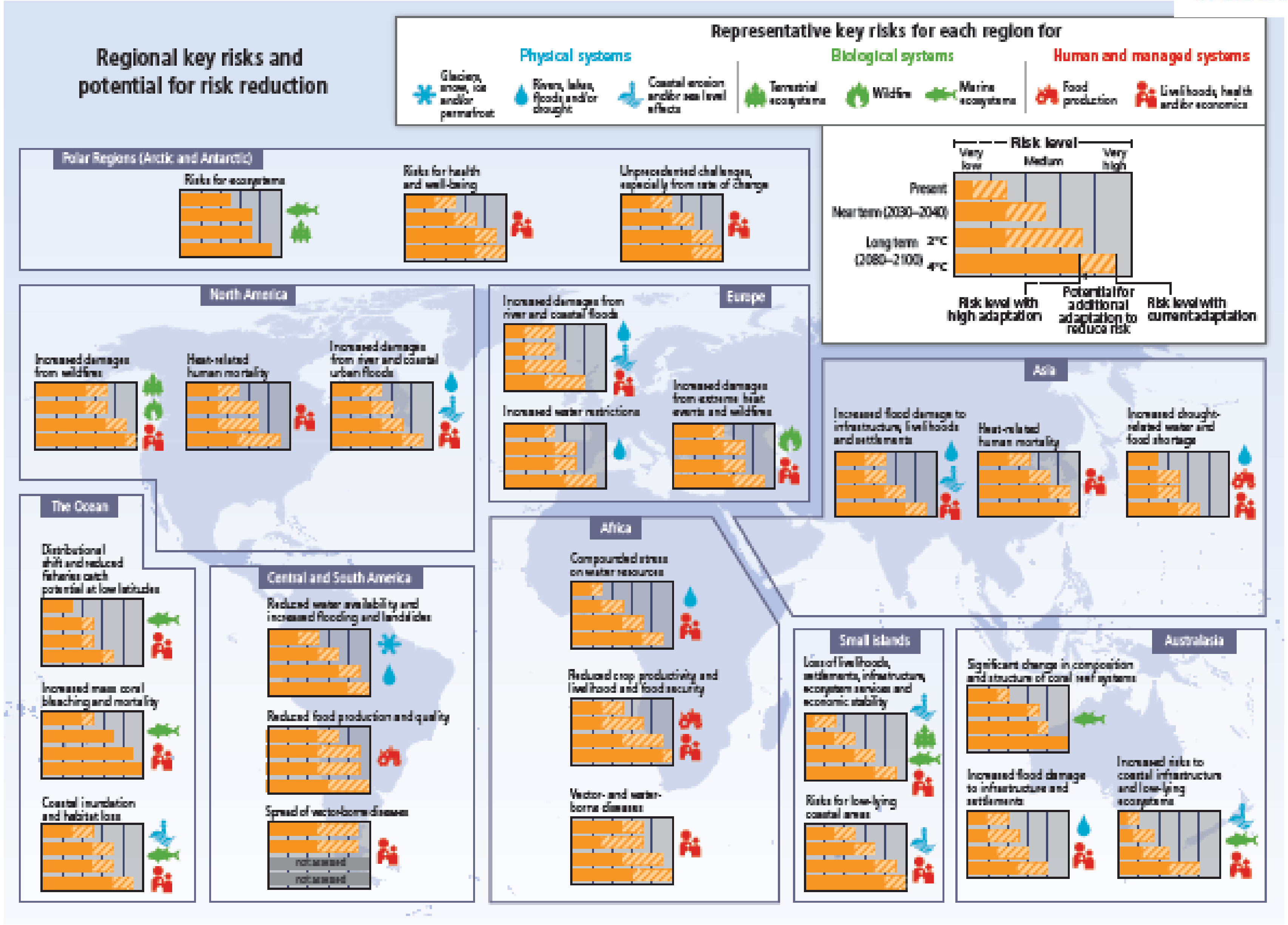

IPCC (2014)