International Environmental Cooperation

Lecture in Spring semester 2024/2025
Tuesday 9:45-11:20
Auditorium A002

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Office hours: Tuesday, 8:45-9:30, Room B310

Introduction

- Artificial borders
- Economic concepts
  - Public goods
  - Externalities
- Lack of enforcement authority
- *The Victim Pays Principle*

Public good

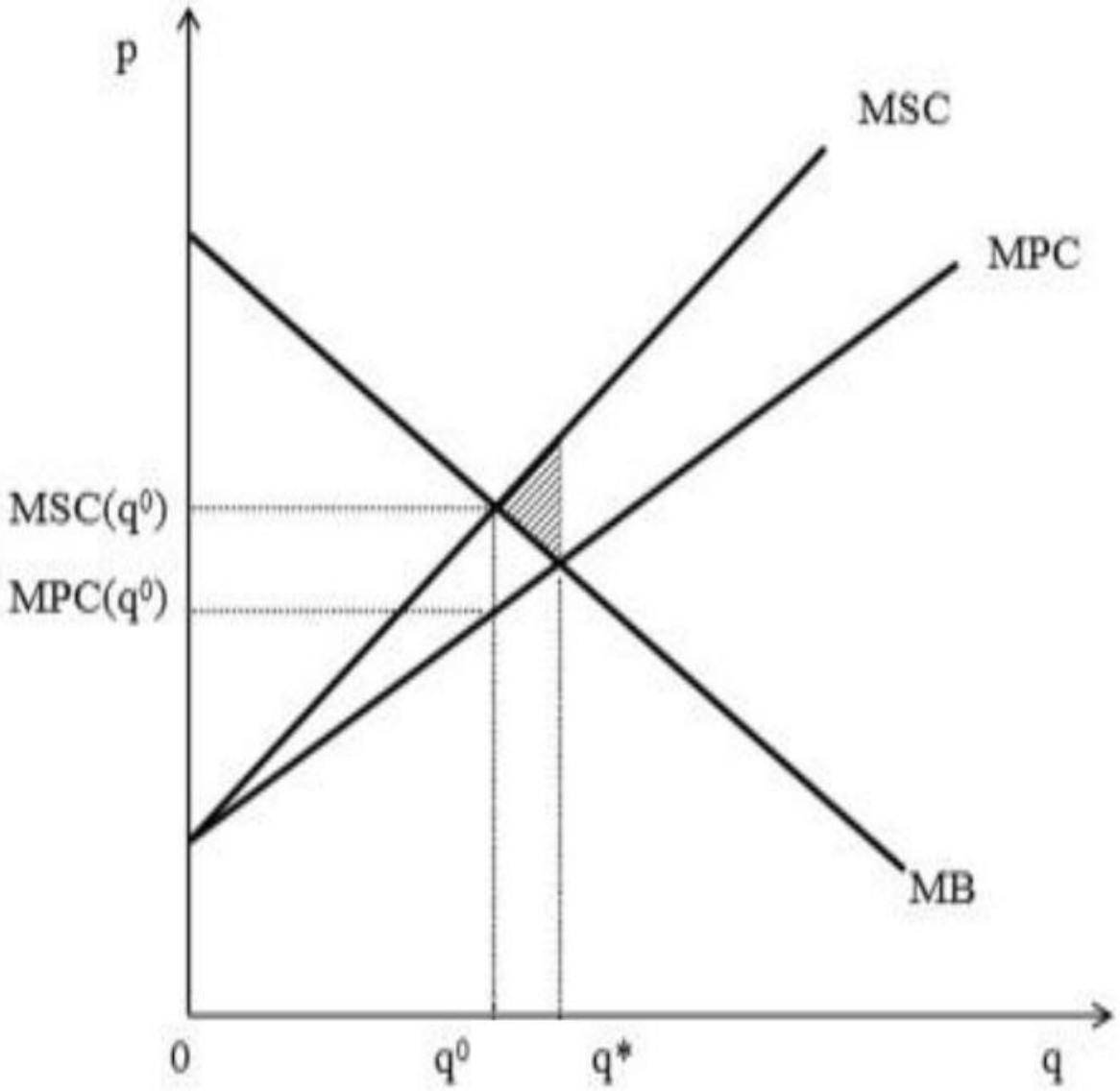
- *Non-rivalry* principle
- *Non-exclusion* principle

Free riding

Externality

- Positive
- Negative

- Direct regulation
- Pigouvian taxes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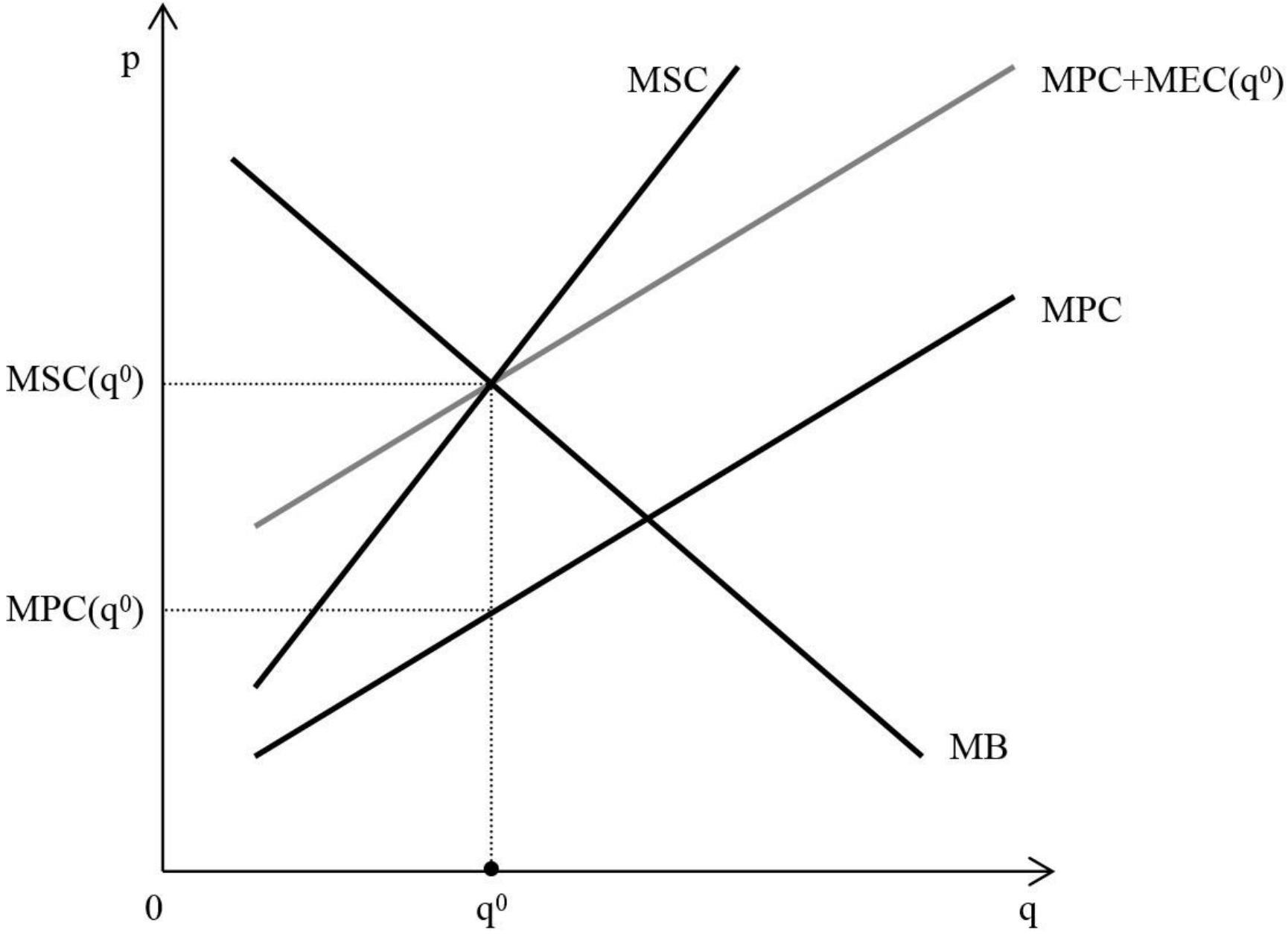
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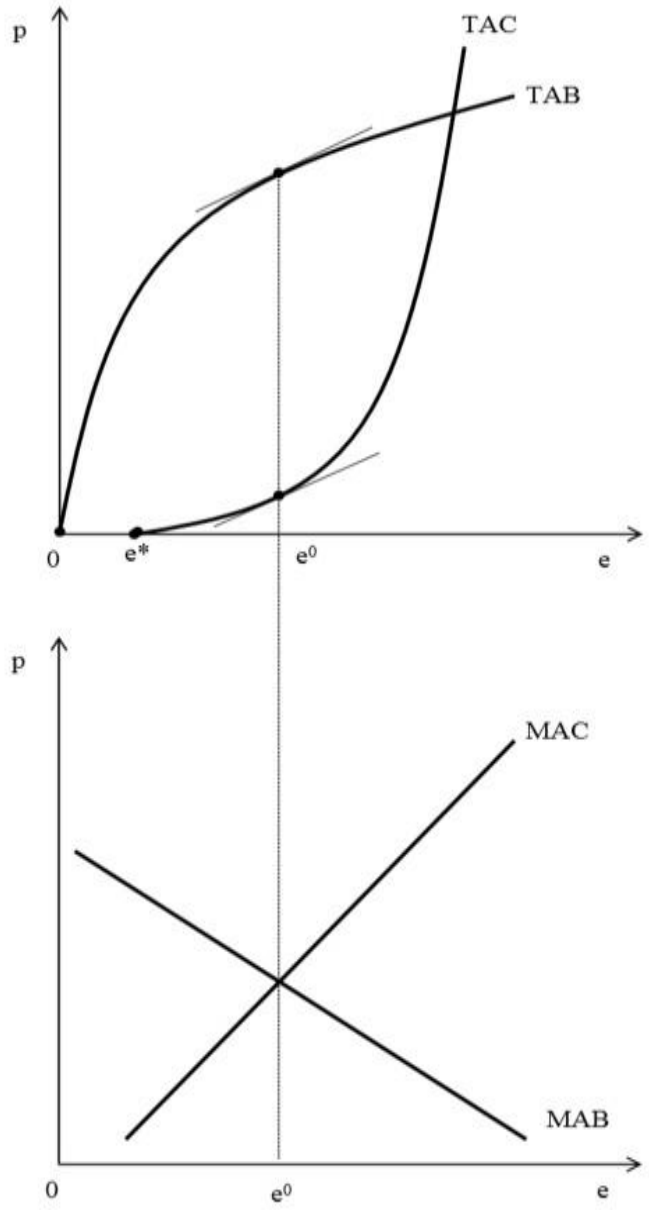
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Enforcement

- Lack of international government
- Self-enforcing agreements

- *Polluter Pays Principle*

  versus

- *Victim Pays Principle*

Questions

Q-0 International Environmental Cooperation

[a] is based on rulings of international institutions

[b] has led to solving major global ecological problems

[c] has to cope with states' sovereignty

[d] applies the *Polluter Pays Principle*

[e] none of the above

Exercises

E-0 It is possible to limit the noise from 60 dB to 40 dB. The cost of an appropriate arrangement is estimated at $c(x)=x^2/10$, and the benefit at $b(x)=6x-x^2/10$ per every dB decreased (i.e. $x \in [0,20]$; $x=0$ corresponds to no reduction, and $x=20$ to the maximum reduction available through this arrangement). Please calculate the economically efficient level of noise reduction.

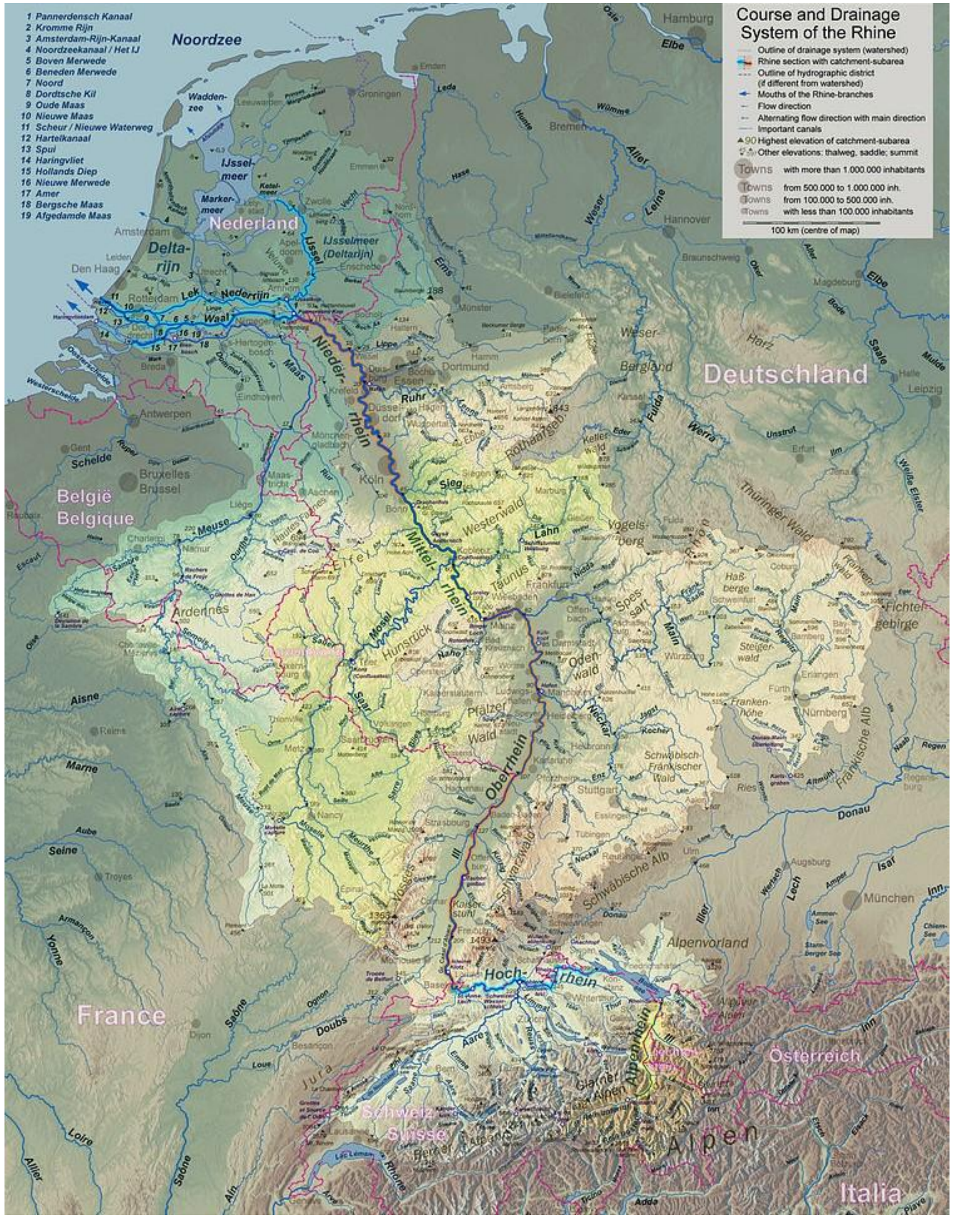
International rivers

1. Rhine
2. Colorado
3. Columbia
4. Danube
5. Nile
6. Mekong
7. La Plata

- Problems
- History
- Agreements

1. The Rhine

- Vienna Congress (1815)
- Bern Convention (1963)
- Chemical pollution (1976)
- Salt pollution (1976)
- Salt Treaty (1991)


Course and Drainage System of the Rhine
Outline of drainage system (watershed)
Rhine section with catchment-subarea
Outline of hydrographic district (if different from watershed)
Mouths of the Rhine-branches
Flow direction
Alternating flow direction with main direction
Important canals
90 Highest elevation of catchment-subarea
Other elevations: thalweg, saddle; summit
Towns with more than 1.000.000 inhabitants
Towns from 500.000 to 1.000.000 inh.
Towns from 100.000 to 500.000 inh.
Towns with less than 100.000 inhabitants
100 km (centre of map)
1 Pannerdensch Kanaal
2 Kromme Rijn
3 Amsterdam-Rijn-Kanaal
4 Noordzeekanaal / Het IJ
5 Boven Merwede
6 Beneden Merwede
7 Noord
8 Dordtsche Kil
9 Oude Maas
10 Nieuwe Maas
11 Scheur / Nieuwe Waterweg
12 Hartelkanaal
13 Spui
14 Haringvliet
15 Hollands Diep
16 Nieuwe Merwede
17 Amer
18 Bergsche Maas
19 Afgedamde Maas
Noordzee
Nederland
Deutschland
België
Belgique
France
Schweiz
Suisse
Österreich
Italia
Alpen
Delta-rijn
Nieder-rhein
Mittel-rhein
Oberrhein
Hoch-rhein
Alpenrhein

2. Colorado river

- USA-Mexico relations
- Rivers commissions for Colorado, Tijuana and Rio Grande, 1884
- Water quantity, 1944
- Water quality, 1974
- Unique water rights (Lake Mead), 2012
- Issue linkage?


WYOMING
Green
Big Sandy
Blacks Fork
Rock Springs
Flaming Gorge Reservoir
Little Snake
UTAH
Yampa
Duchesne
Green
White
Strawberry Reservoir
NEVADA
Grand Junction
San Rafael
Colorado
Gunnison
Dirty Devil
Moab
San Miguel
Blue Mesa Reservoir
Fremont
Dolores
COLORADO
White
Escalante
Animas
St. George
Paria
San Juan
Virgin
Kanab
Lake Powell
Navajo Reservoir
Muddy
Page
Chinle
Farmington
Las Vegas
Chaco
Henderson
Lake Mead
Oraibi Wash
Lake Mohave
Flagstaff
Puerco
Bullhead City
Little Colorado
Lake Havasu City
Verde
Lake Havasu
Prescott
CALIFORNIA
Colorado
Bill Williams
Theodore Roosevelt Lake
NEW MEXICO
Hassayampa
Agua Fria
Salt
Scottsdale
Phoenix
San Carlos Lake
San Francisco
Gila
Painted Rock Reservoir
Yuma
San Luis Rio Colorado
ARIZONA
Santa Cruz
San Pedro
San Simon
Gila
Tucson
BAJA CALIFORNIA
SONORA

3. The Columbia river

- Flood losses concentrated in the USA
- Retention reservoirs in Canada
- US contribution to the Canadian reservoirs
- Hydroelectricity sold to US
- Unclear financial flows
- *Victim Pays* or *Polluter Pays*?


BRITISH COLUMBIA
ALBERTA
MONTANA
WASHINGTON
OREGON
IDAHO
WYOMING
NEVADA
UTAH
Pacific Ocean
Canoe
Kinbasket Lake
Columbia
Golden
Revelstoke
Invermere
Okanagan Lake
Nakusp
Kelowna
Duncan
Elk
Nelson
Cranbrook
Kootenay
Kettle
Castlegar
Trail
Okanogan
Methow
Pend Oreille
Flathead
Flathead Lake
Banks Lake
Spokane
Wenatchee
Crab
Yakima
Snake
Clearwater
Missoula
Clark Fork
Cowlitz
Longview
Yakima
Kennewick
Lewiston
Astoria
Lewis
Richland
St. Helens
Vancouver
Pendleton
Portland
The Dalles
Umatilla
Grande Ronde
Salmon
Salem
Deschutes
John Day
Willamette
Corvallis
Eugene
Bend
Malheur
Payette
Boise
Henrys Fork
Idaho Falls
Boise
Pocatello
Snake
Owyhee
Portneuf
Twin Falls
Bruneau

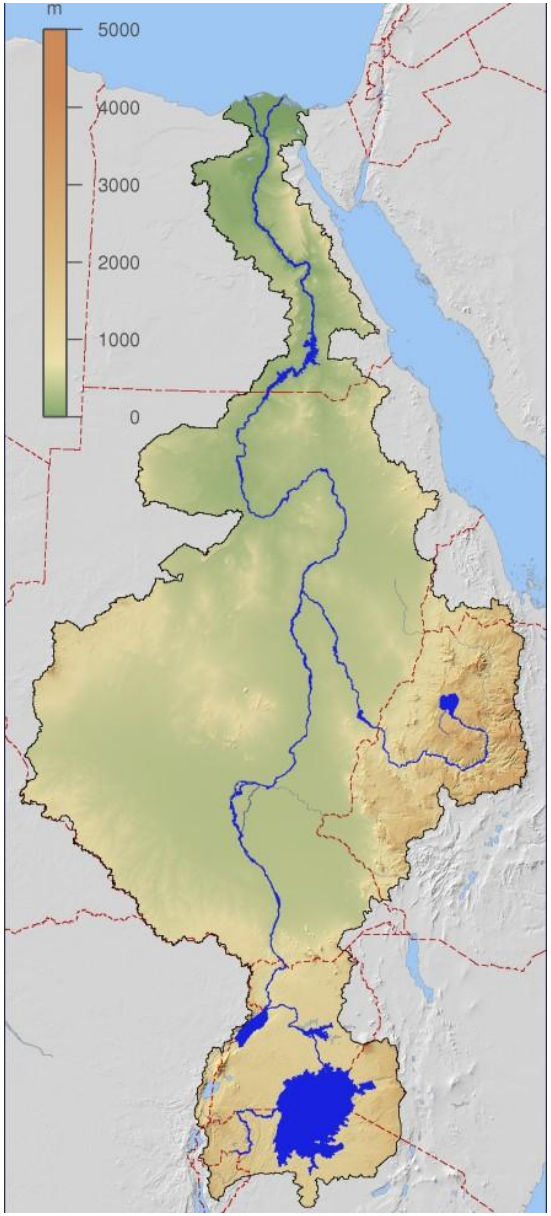
4. The Danube

- Navigation regulated since the 17th century
- Commission Européenne du Danube (CED), 1856
- CED sovereignty granted by Austria-Hungary, Britain, France, Italy, Prussia, and Turkey, 1865
- Russia's withdrawal from CED, 1881
- Hitler's rule, 1941-1945
- Belgrade Convention, 1948
- Danube River Protection Convention (Sofia), 1994


GERMANY
BEL.
Bonn
Frankfurt am Main
Luxembourg
LUX.
Stuttgart
Strasbourg
Rhine
Munich
Prague
CZECH REPUBLIC
Brno
Kraków
L'viv
UKRAINE
Chernivtsi
Mykolayiv
SLOVAKIA
CARPATHIAN MTS.
Chisinau
Bratislava
Danube
Vienna
Budapest
Cluj-Napoca
Iaşi
MOLDOVA
Odesa
LIECH.
AUSTRIA
HUNGARY
ROMANIA
Zürich
Vaduz
Bern
SWITZ.
Geneva
Ljubljana
Zagreb
Bucharest
Constanța
SLOVENIA
Lyon
Milan
Venice
Turin
Po
BOSNIA AND HERZEGOVINA
Belgrade
Danube
Varna
Black Sea
Genoa
CROATIA
SERBIA
SAN MARINO
Sarajevo
BULGARIA
MONACO
Ligurian Sea
Florence
MONTENEGRO
Sofia
Istanbul
ITALY
Adriatic Sea
Podgorica
Skopje
Corsica
Rome
MACEDONIA
Bursa
VATICAN CITY
Tirana
Thessaloniki
ALB.
Naples
TURKEY

5. The Nile

- Three tributaries originating from Ethiopia: Blue Nile, Sobat and Atbara (85% of the water)
- Egypt favoured by international treaties: 1891, 1902, 1906, 1925, 1929
- Egypt lost most of its water rights when the Aswan High Dam was planned and negotiated with Sudan, 1959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3000
2000
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6. The Mekong

- China, Burma (Myanmar), Laos, Thailand, Cambodia and Vietnam involved
- Declaration on preventing of unilateral water appropriations, 1975
- Four downstream countries established the Mekong River Commission (MRC), 1995
- Fear of Chinese agricultural projects


CHINA
瀾沧江 Lancang River
Dali
Kunming
MYANMAR
Mandalay
Mekong River
VIETNAM
Hanoi
Hai Phong
LAOS
Luang Prabang
Chiang Mai
Vientiane
Yangon
Savan-nakhet
Da Nang
THAILAND
Bangkok
CAMBODIA
Siem Riep
Phnom Penh
HCM City
Can Tho

7. La Plata

- Main tributaries – i.e. the Parana and the Uruguay rivers – make up the second largest watershed in South America
- La Plata River Basin Treaty, 1969
- *Hidrovia* – the key issue (conceived in the 19th century, materialised in 1989)
- Conflicts with environmental protection


BOLIVIA
BRAZIL
PARAGUAY
URUGUAY
ARGENTINA
Andes
Cuiabá
Brasília
Goiânia
Santa Cruz
Sucre
Pantanal
Paraguay
Paranaíba
Grand
Uberlândia
Belo Horizonte
Campo Grande
Tietê
Ribeirão Preto
Rio de Janeiro
Paraná
Paranapanema
São Paulo
Pilcomayo
Bermejo
Foz do Iguaçu
Iguazu
Curitiba
Asunción
Salta
Posadas
Resistencia
Corrientes
Canoas
Pelotas
Salado
Paraná
Uruguay
Ibicuí
Porto Alegre
Córdoba
Santa Fe
Negro
Rosario
Buenos Aires
Montevideo
La Plata
Salado
Río de la Plata
Atlantic Ocean

Managing international rivers

- UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992)
- Principles for preventing externalities
- Ruling on Gabcikovo-Nagymaros (inconclusive), 1997


Vienna
Bratislava
PETRŽALKA
Schwechat
Gänserndorf
Klosterneuburg
Lozorno
Stupava
Pezinok
Senec
Trnava
Hlohovec
Sereď
Galanta
Šaľa
Nitra
Lužianky
Zlaté Moravce
Beladice
Vráble
Levice
Nová Baňa
krajinná oblast Štiavnické vrchy
Krupina
Bzovík
Modrý Kameň
Dudince
Podhájska
Šurany
Šahy
Želiezovce
Balassagyarmat
Šamorín
Dunajská Streda
Nové Zámky
Kolárovo
Gabčíkovo
Veľký Meder
Mosonmagyaróvár
Parndorf
Neusiedl am See
Eisenstadt
Nationalpark Neusiedler See Seewinkel
Mattersburg
Sopron
Fertőd
Kapuvár
Csorna
Lébény
Győr
Ács
Bábolna
Komárno
Esztergom
Dorog
Tata
Tatabánya
Pannonhalma
Győrújbarát
Tét
Kisbér
Oroszlány
Bicske
Budapest
Budaörs
Érd
Szentendre
Dunakeszi
Vác
Rétság
Danube
Oberpullendorf
Lutzmannsburg
Beled
Szany
Répcelak
Kőszeg
Bük
Pápa
Ugod
Mór
Bodajk
Szigetszentmiklós
Sárvár
Celldömölk
Bakonybél
Zirc
Eplény
Szombathely
Várpalota
Székesfehérvár
Vélence
Jánosháza
Devecser
Ajka
Veszprém
Kám
Vasvár
Güssing
Körmend
Balatonalmádi
Kunszentmiklós
Sümeg
S1
E58
E77
A21
E59
A4
A6
E75
R7
D4
M15
A3
S4
S31
E65
M19
E60
M85
M3
M1
M5
M0
E71
M86
E66

Questions

Q-1 The Columbia river agreements

[a] serve as a typical example of the *Victim Pays Principle*

[b] make Canada pay for the higher quality of water used by the US citizens

[c] prevented from hydropower developments in Canada

[d] allowed American states – notably Oregon – to enjoy more water available

[e] none of the above

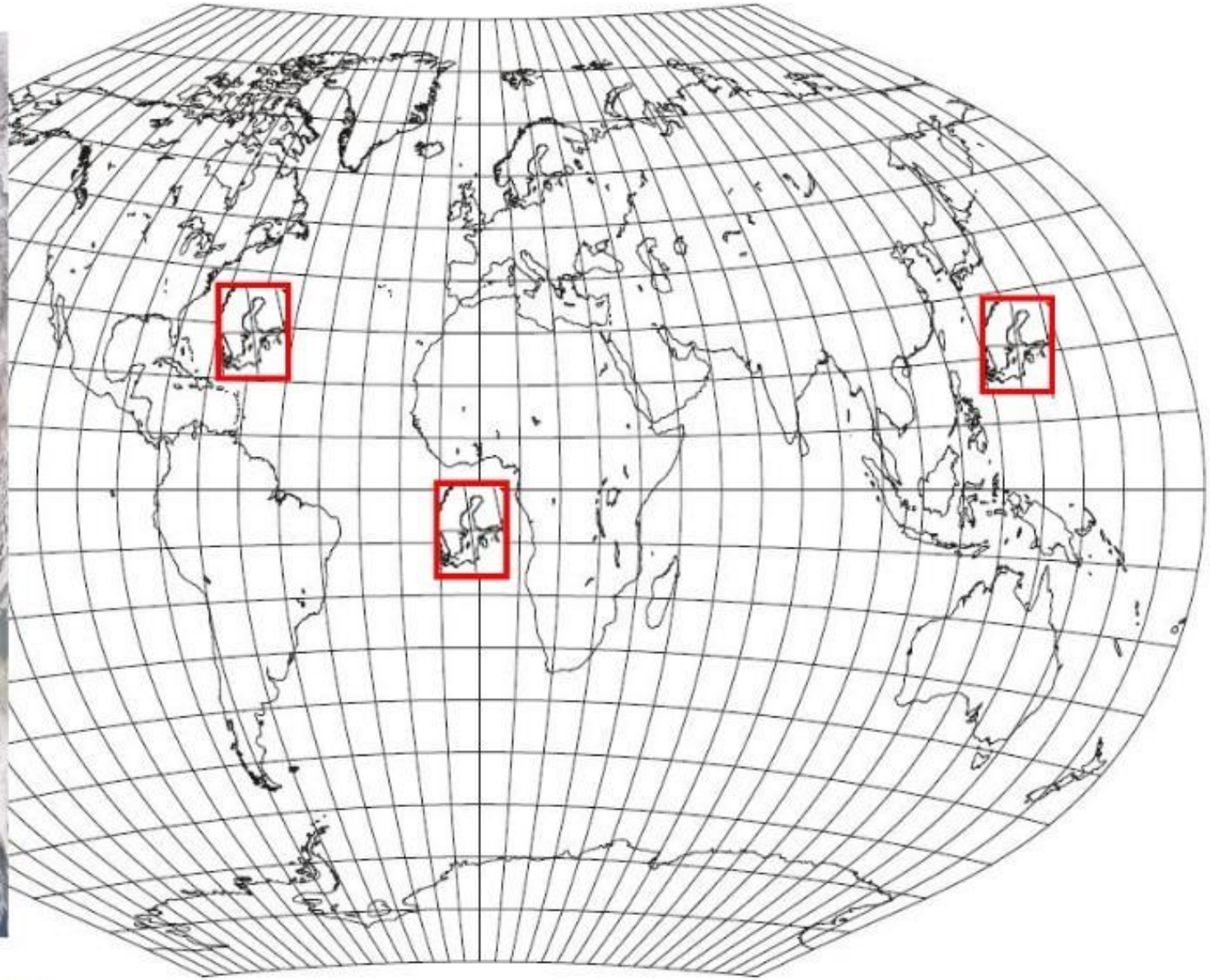
Exercises

E-1 In the Gabcikovo-Nagymaros case, the ruling of the International Court of Justice confirmed the validity of the original Czechoslovakia-Hungary agreement, but observed that the project is controversial. Why is it controversial?

Eutrophication of the Baltic Sea

- Baltic Sea area – 377 thousand km^2
- Drainage basin – 1642 thousand km^2
- Average depth – 55 metres
- Volume – 22 thousand km^3
- Average exchange rate (through the Danish straits) – 25 years
- Many coastal countries


Bothnian Bay
SWEDEN
FINLAND
Bothnia Sea
RUSSIA
NORWAY
Archipelago Sea
Gulf of Finland
ESTONIA
Gulf of Riga
Kattegat
DENMARK
LATVIA
The Sound
Baltic Proper
LITHUANIA
Western Baltic
GERMANY
BELARUS
POLAND
UKRAINE
CZECH
SLOVAKIA



Ginzburg V projection;
(TsNIIGAiK Modified Polyconic);
Neither Conformal or Equal-area;
G. A. Ginzburg; 1950

Eutrophication: excessive inflow of nutrients, such as nitrogen (N) and phosphorus (P)

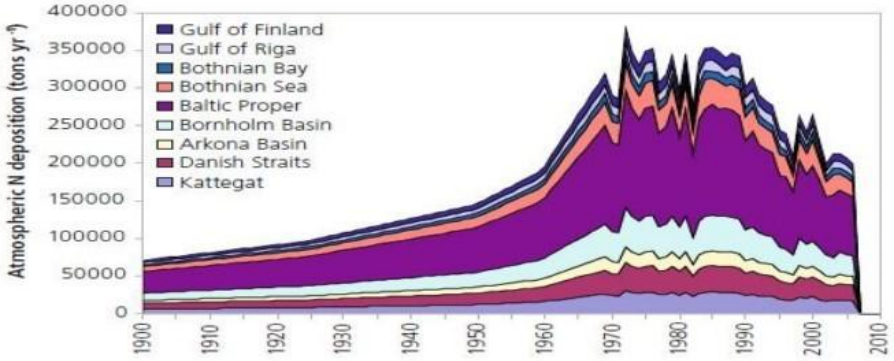
Annual discharges (thousand tonne)

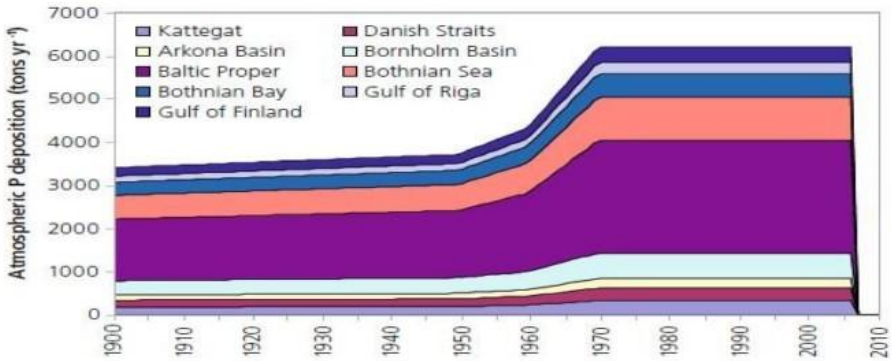
	N	P
1980s	900	40
Now	700	30

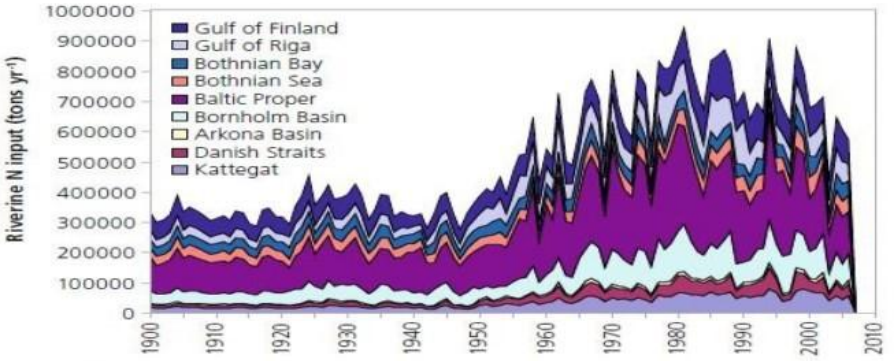
Nitrogen – limiting factor (decisive for algae production) in many locations

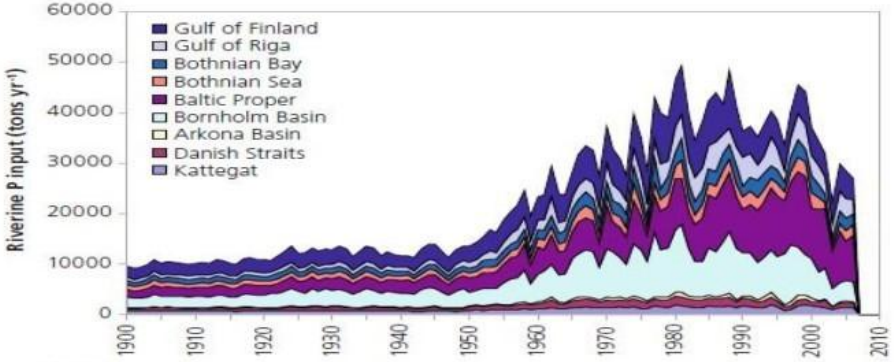
Baltic algae blooms

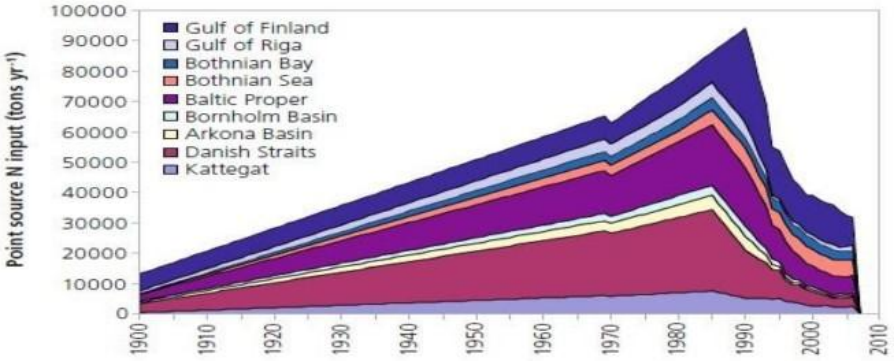
Baltic Sea pollution

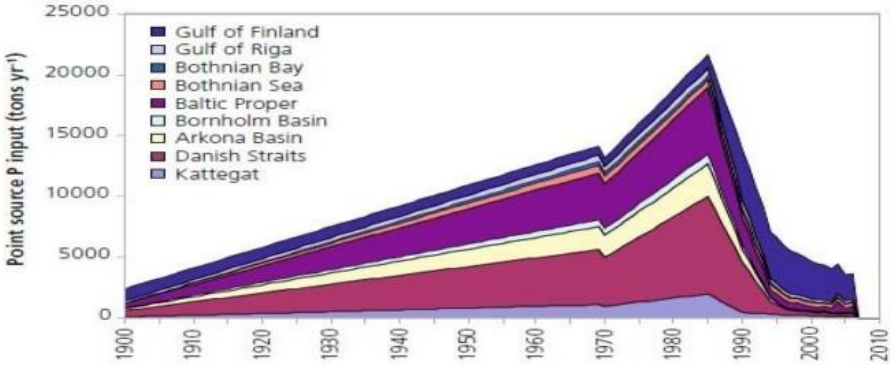




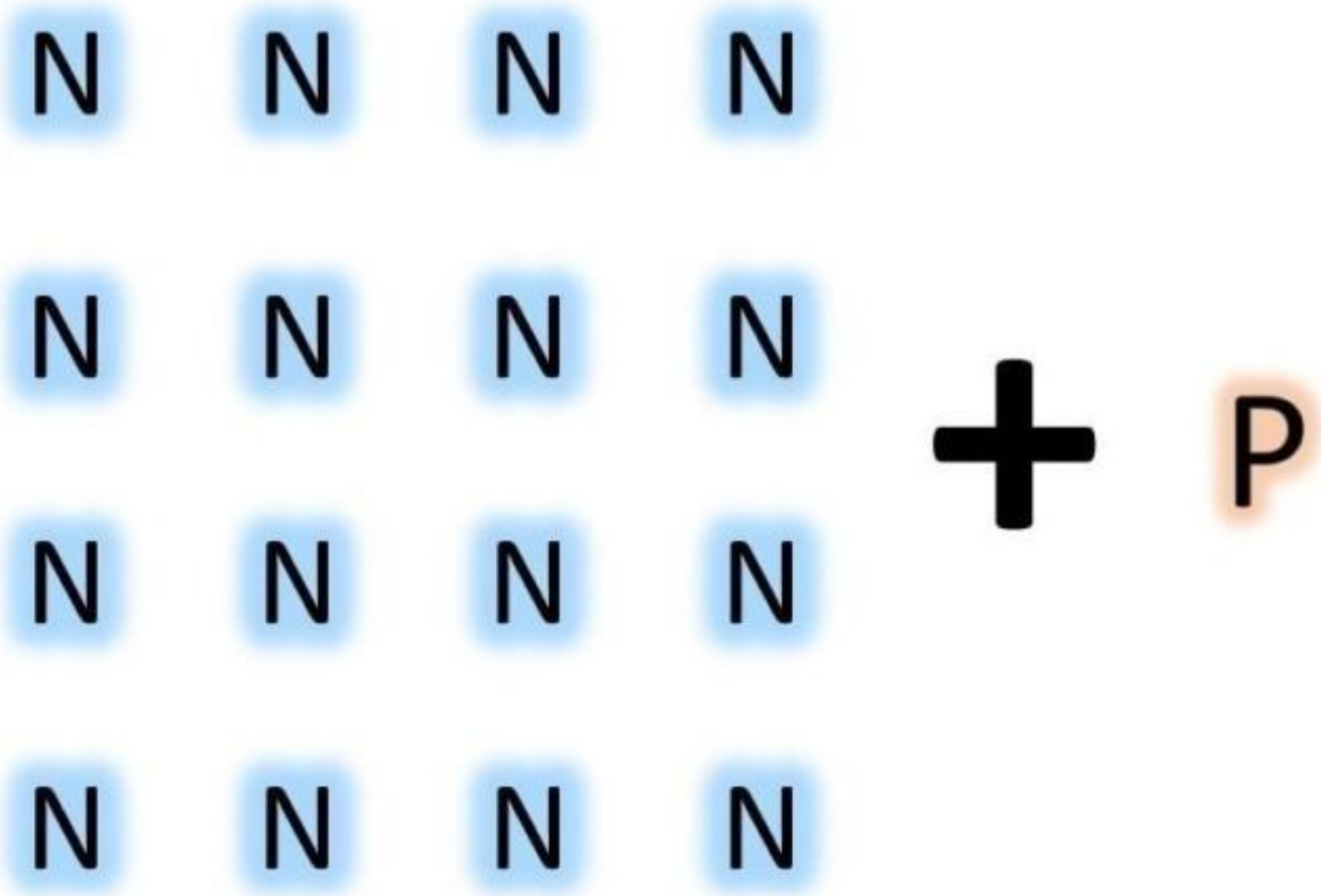








N as a limiting factor



Conventions

- Gdańsk, 1973
  - Protection of marine resources
  - International Baltic Sea Fishery Commission
- Helsinki 1974 and 1992
  - Emphasis on drainage basin activities
  - Helsinki Commission (*Helcom*)

Outcomes of the Helsinki Convention

- Slight decline of inflow of eutrophicating substances (N & P)
- Significant decline for other pollutants

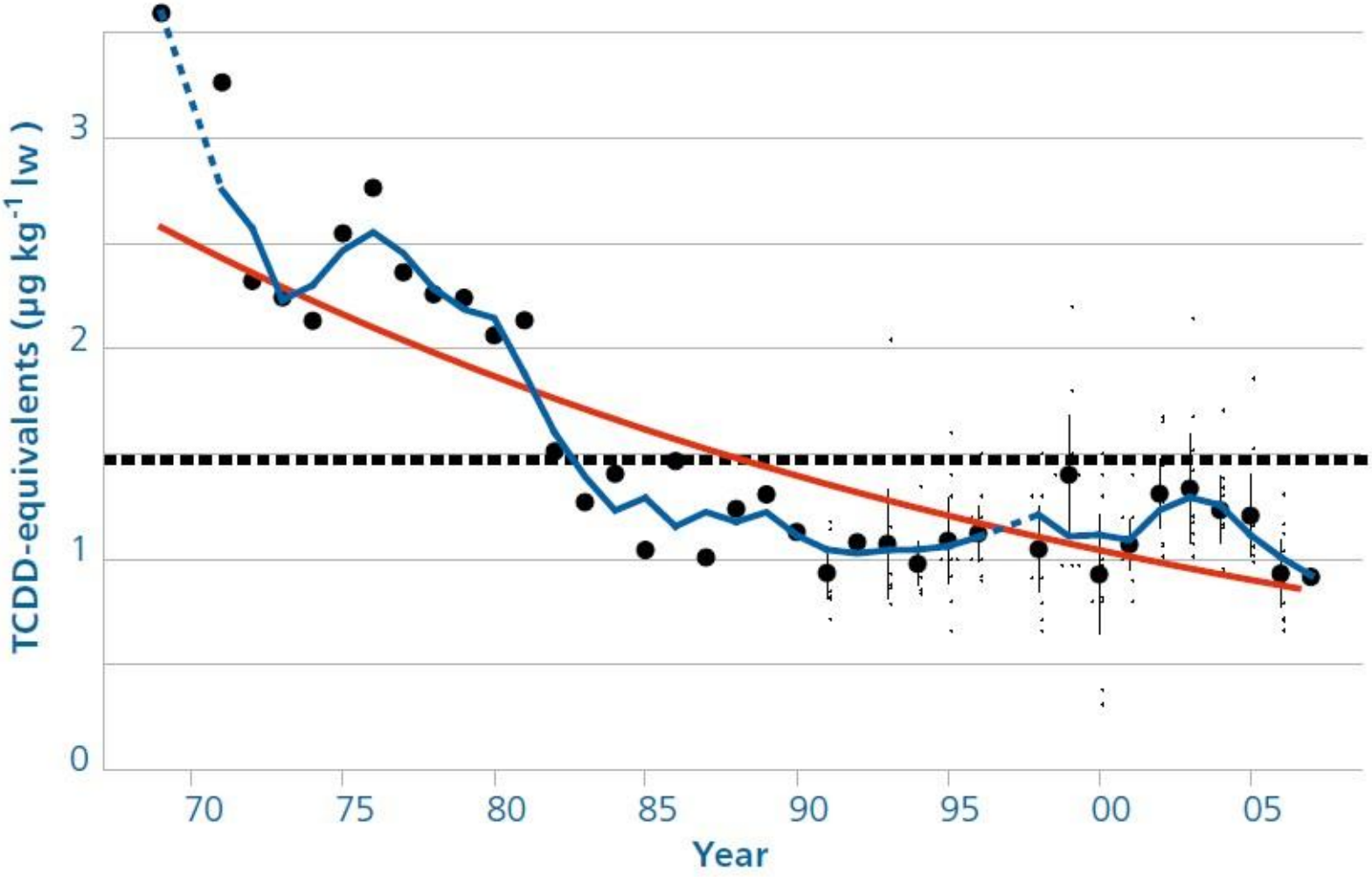


Figure 2.7 Decreasing trends of dioxins (measured as TCDD-equivalents, µg kg^{-1} lipid weight) in common guillemot (*Uria aalge*) eggs from Stora Karlsö in the Western Gotland Basin (HELCOM 2010a).

Forward to the 1950s!

- In the middle of the 20th century the Baltic Sea was in a fairly good shape
- The clean-up requires more than halving the discharges of N and P

Cost-effective abatement in the Baltic drainage basin

Reduction rate (%)	5	10	15	20	25	30	35	40	45	50
Cost (10^9 $/year)	<0.1	0.1	0.1	0.2	0.3	0.5	0.8	1.2	1.9	4.1

Source: Gren *et al*. (1995).

Conclusion:

Abatement costs rise sharply with the ambition level

Questions

Q-2 The Gdansk Convention of 1973

[a] prompted the signatories to adopt environmentally friendly abatement technologies

[b] established International Baltic Sea Fishery Commission

[c] resulted in reduced eutrophication of the Baltic Sea

[d] helped fishermen to apply for harvesting subsidies

[e] none of the above

Exercises

E-2 Provide economic interpretation for abatement expenditures from the table (printed on page IEC-2-9) rising sharply when the ambition level approaches 50%.

Prospects for Baltic cooperation

- Baltic countries abate to the extent they find it domestically beneficial
- "Public good" requires to abate to the extent it is beneficial for the entire region

Public good curse

- Samuelson (cooperative) criterion:

$$MAC_i = \Sigma_i \, MAB_i,$$

- Nash (non-cooperative) criterion:

$$MAC_i = MAB_i.$$

Chander-Tulkens model (CTM)

$T_i = \gamma_i p_i - (\pi_i : \pi_N) \cdot \Sigma_j \gamma_j p_j$,
where:

T_i – money transfer to country i,
γ_i – marginal abatement cost in country i,
p_i – pollution abatement in country i,
π_i – benefits in country i from the region-wide abatement,
π_N – the sum of benefits from the region-wide abatement ($\pi_N = \Sigma_j \pi_j$).

Interpretation of CTM

- Every country gets its abatement cost financed ($\gamma_i p_i$)
- Every country contributes to the total regional abatement cost ($\Sigma_j \gamma_j p_j$)
- In proportion to its share in total benefits ($\pi_i : \pi_N$)
- A negative amount means that a country pays rather than receives money
- The sum of transfers is zero ($\Sigma_j T_j = 0$)

Calibration of CTM (I)

Hypothetical Baltic transfers

Country (*i*)	$\pi_i:\pi_N$ [%]	T_i [10^6 $]
Finland	14.4	-216.9
Sweden	26.7	-395.6
Denmark	16.5	-292.3
Germany	11.2	67.2
Poland	24.1	280.8
Lithuania	1.2	280.0
Latvia	0.8	208.8
Estonia	0.6	177.2
Russia	4.6	-109.2
Total	100.0	0.0

Source: Markowska and Zylicz (1999)

Assumptions for CTM (I)

- Annual flows
- 50% nitrogen abatement
- π_N estimated at \$6 billion
- $\Sigma_j \gamma_j p_j$ estimated at \$4 billion

Conclusion:

- $-\Sigma_{j \in NetPayers} T_j = \Sigma_{j \notin NetPayers} T_j$ = \$1.014 billion

Calculating benefits in CTM (I)

CVM studies results: mean WTP values in 1995 US$ (including zero bidders and excluding protest bidders)

	Lithuania (Pilot, OE)	Poland			Sweden (Mail, DC)
		(Pilot, OE)	(Main, DC)	(Mail, DC)	
WTP	7	14	56	102	458

Source: Markowska and Zylicz (1999)

CVM – Contingent Valuation Method
WTP – Willingness To Pay
OE – Open Ended
DC – Dichotomous Choice

Alternative calibrations

- Different ambition levels
- Different cost estimates
- Different individual benefit estimates
- Different total benefit estimates

Assumptions for CTM (II)

- Annual flows
- HELCOM BSAP (*Baltic Sea Action Plan*)
- π_N estimated at €3.6 billion
- $\Sigma_j \gamma_j p_j$ estimated at €1.5 billion

Calibration of CTM (II)

Alternative hypothetical Baltic transfers

Country (i)	π_i:π_N [%]	T_i [10^6 €]
Finland	4.2	77
Sweden	15.9	19
Denmark	3.5	92
Germany	47.3	-535
Poland	8.3	351
Lithuania	0.6	114
Latvia	0.3	86
Estonia	0.7	64
Russia	19.2	-268
Total	100.0	0

Source: Calculations based on Ahtiainen *et al*. (2014)

Conclusions

- Asymmetry in distribution of costs and benefits
- Germany and Russia are two large Baltic countries whose territories overlap with the drainage basin only partially
- Simplifications:
  - Only drainage basin population is concerned about the Baltic Sea
  - Countries' abatement measures are dedicated to the protection of the Baltic Sea (not for domestic purposes)
- Sweden the single largest beneficiary of the recovery programme (based on CTM(I))

Conclusions (continued)

- Actual transfers between the Baltic drainage basin countries at least by one order of magnitude lower than those derived from CTM (both I and II)
- Efficient level of transfers corresponds to over 20% of the total region-wide costs
- Very modest proposals (corresponding to mere 5% of abatement costs) do not gain political support
- Helsinki Convention signatories not ready to appreciate their public good adequately

Questions

Q-3 Nordic countries provide assistance for the less wealthy South-Eastern Baltic states

[a] in order to let them comply with the Gdansk and Helsinki convention requirements

[b] as mandated by the Gdansk and Helsinki conventions

[c] corresponding to the level estimated in the Chander-Tulkens model (calibrated as CTM-I in the class)

[d] lower than hypothetical transfers estimated in the Chander-Tulkens model (calibrated as CTM-I in the class)

[e] none of the above

Exercises

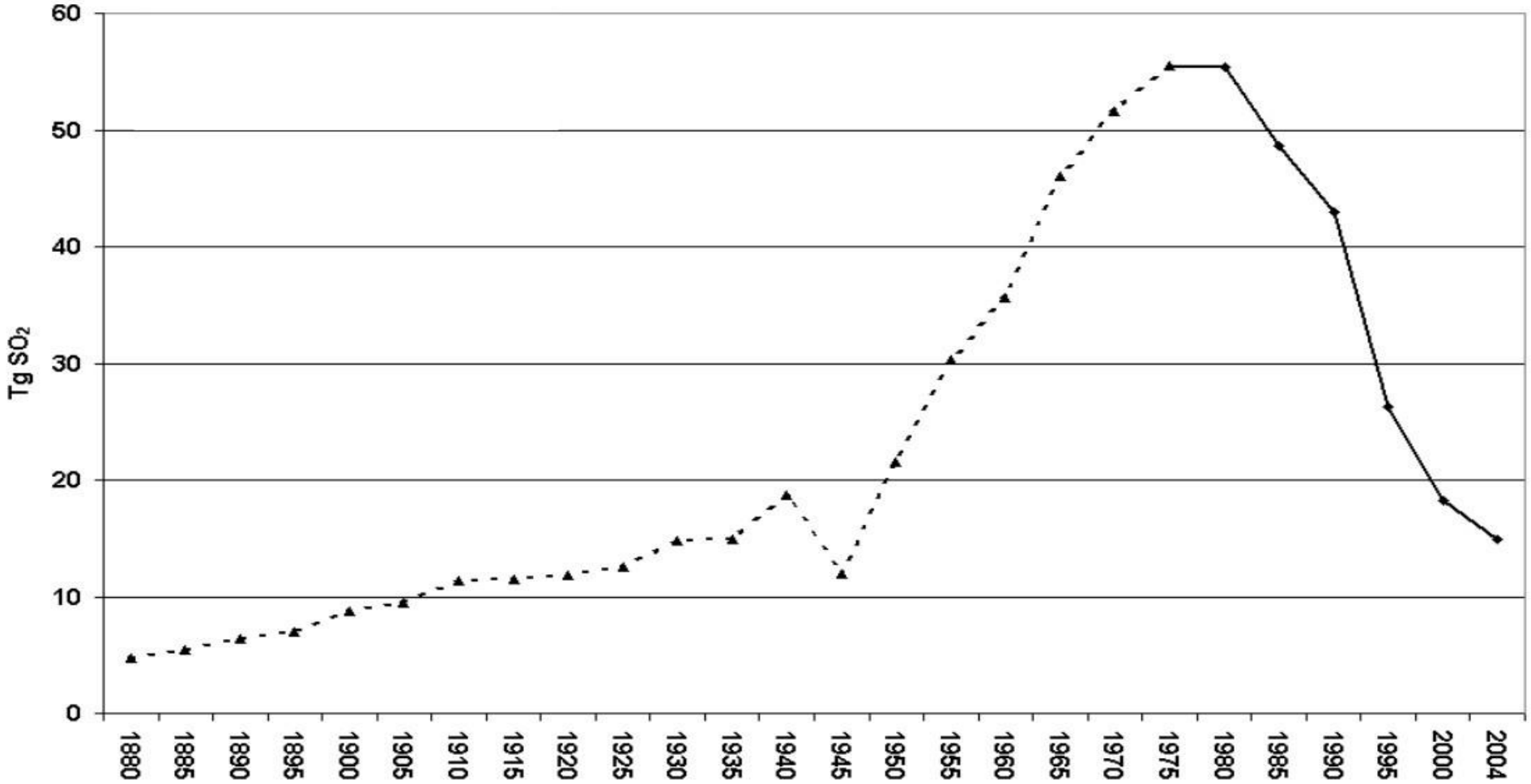
E-3 Prove that if abatement costs ($\gamma_i p_i$) are proportional to countries' abatement benefits (π_j), then the transfers calculated in the Chander-Tulkens model are zero.

Acid Rain

- Rain, snow, fog etc. may have an acidic reaction (measured with pH)
- Carbon dioxide, i.e. the precursor of carbonic acid, adds to the natural acidity of the atmosphere
- Pure water has pH close to 7, half a way between a pure acid (0) and a pure alkaline substance (14)
- Rainwater has pH around 6.5 due to a slight addition of carbon dioxide

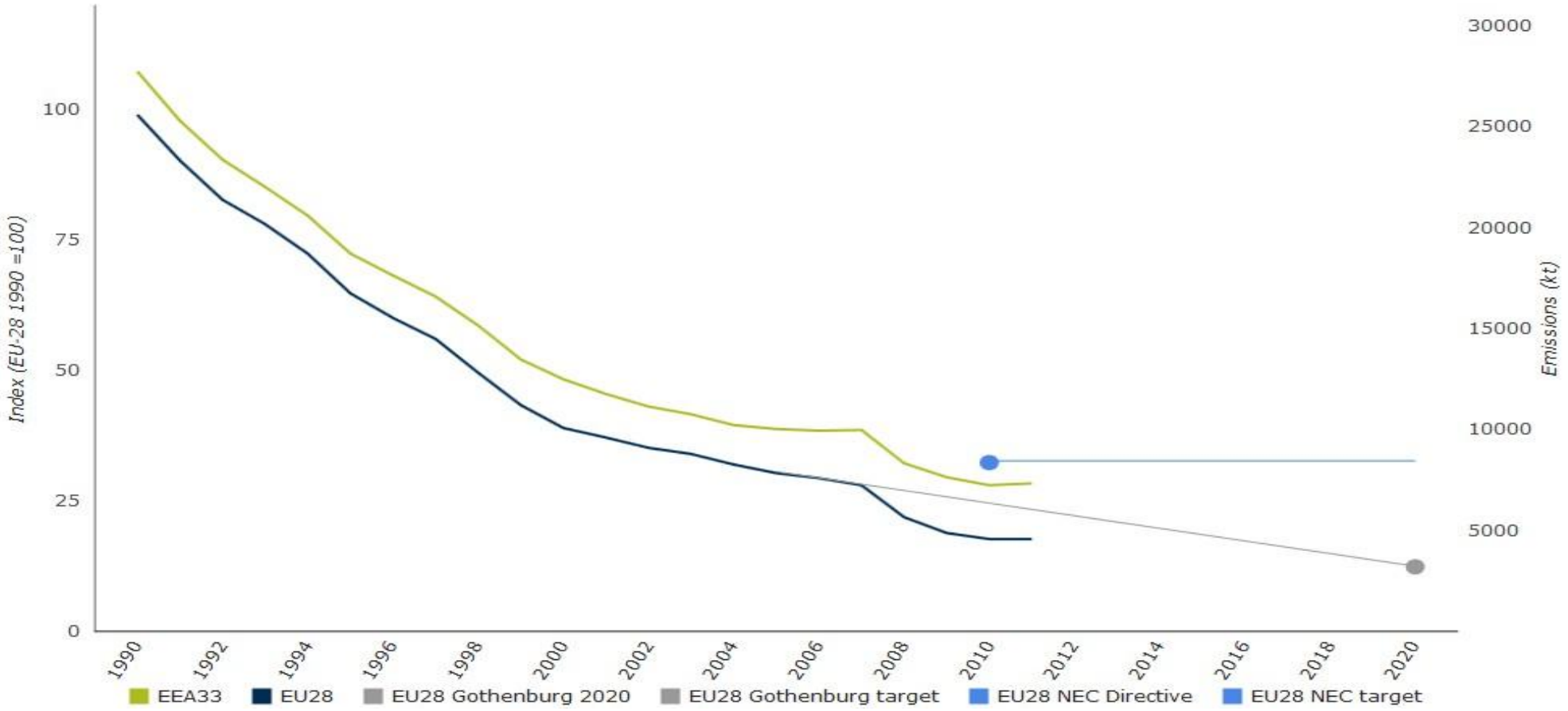
- Problem starts when pH goes below 6.5, for instance due to the addition of sulphur dioxide (the precursor of sulphurous acid) or nitrogen oxides
- Rain in Europe used to have pH of 5 or even less
- The "record-breaking" rain had a pH lower than 3
- The acidity of precipitation has adverse impact on nature, human health and construction materials

European SO_2 emissions



Source: Vestreng et al. (2007)

Chart — Emission trends of sulphur oxides



Source: EEA 2014

European SO_2 migrations in 1985 (tS)

	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	RO	ES	SE	CH	TR	SU	GB	YU	RE	IND	SUM
AL	6	0	0	4	0	0	0	0	0	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	8	29
AT	0	23	1	1	32	0	0	3	23	13	0	17	0	0	19	0	0	0	17	0	0	1	0	1	0	2	3	19	0	27	207
BE	0	0	47	0	2	0	0	15	6	17	0	0	0	0	1	0	4	0	1	0	0	0	0	0	0	0	9	0	0	7	113
BG	0	0	0	159	2	0	0	0	2	0	1	3	0	0	1	0	0	0	4	0	3	0	0	0	2	8	0	5	0	17	212
CS	0	6	1	2	429	1	0	4	110	21	0	50	0	0	5	0	1	0	92	0	1	1	0	0	0	3	5	13	0	30	779
DK	0	0	1	0	2	36	0	2	11	9	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	1	7	0	0	11	88
FI	0	0	0	0	5	1	63	0	13	3	0	0	0	0	0	0	0	0	8	0	0	0	5	0	0	59	4	0	0	69	234
FR	0	2	21	1	23	0	0	313	43	54	0	6	0	1	38	1	5	0	12	1	0	51	0	4	0	1	44	7	0	125	757
DD	0	1	4	0	83	3	0	7	674	57	0	3	0	0	1	0	3	0	30	0	0	1	0	0	0	1	12	2	0	20	905
DE	0	4	20	1	62	4	0	41	148	379	0	8	0	0	14	0	13	0	26	0	0	3	0	3	0	1	43	7	0	62	844
GR	0	0	0	19	1	0	0	0	1	0	47	1	0	0	3	0	0	0	2	0	0	0	0	0	2	3	0	2	0	25	110
HU	0	3	0	4	31	0	0	1	14	3	0	199	0	0	6	0	0	0	22	0	2	0	0	0	0	3	1	34	0	18	345
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	16
IE	0	0	0	0	0	0	0	1	0	1	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	24	57
IT	0	3	0	3	8	0	0	11	7	6	1	6	0	0	401	0	0	0	5	0	0	6	0	3	0	1	3	20	1	69	560
LU	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
NL	0	0	11	0	3	0	0	8	9	36	0	0	0	0	0	0	31	0	2	0	0	0	0	0	0	0	18	0	0	9	131
NO	0	0	1	0	4	4	1	2	11	7	0	1	0	0	0	0	1	10	5	0	0	0	4	0	0	11	18	0	0	102	185
PL	0	2	4	2	151	5	0	6	248	39	0	30	0	0	3	0	2	0	761	0	2	1	2	0	0	18	13	9	0	53	1356
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	19	0	0	0	0	0	0	0	24	82
RO	0	1	0	24	25	0	0	1	16	3	0	42	0	0	5	0	0	0	32	0	37	0	0	0	1	26	1	32	0	46	298
ES	0	0	1	0	2	0	0	16	3	3	0	1	0	0	7	0	0	0	1	8	0	500	0	0	0	0	3	1	2	83	636
SE	0	0	2	0	12	13	9	4	38	17	0	2	0	0	0	0	1	3	23	0	0	0	48	0	0	19	15	1	0	115	330
CH	0	0	0	0	5	0	0	7	6	6	0	1	0	0	17	0	0	0	2	0	0	2	0	12	0	0	1	2	0	13	79
TR	0	0	0	13	1	0	0	0	1	0	3	2	0	0	1	0	0	0	2	0	1	0	0	0	50	16	0	2	0	80	177
SU	0	3	3	14	111	8	26	7	154	36	1	57	0	0	7	0	2	0	285	0	11	1	8	0	22288	19	22	0	436	3508	
GB	0	0	5	0	4	1	0	13	10	12	0	1	0	4	1	0	3	0	4	0	0	2	0	0	0	0	525	0	0	65	654
YU	2	3	0	50	17	0	0	2	10	4	4	37	0	0	32	0	0	0	16	0	3	1	0	0	1	6	2	257	0	74	527
	AL	AT	BE	BG	CS	DK	FI	FR	DD	DE	GR	HU	IS	IE	IT	LU	NL	NO	PL	PT	RO	ES	SE	CH	TR	SU	GB	YU	RE	IND	SUM

Source: EMEP (1989)

European SO_2 migrations in the 1980s

(fragments)

Country	Emission 1000 t	Deposition 1000 t	Density kg/ha	Concentr. μg/m^3	Import %	M.A.N.*	Share of M.A.N. %	Un-ident. %
Austria, AT	480	746	89	27	88	IT	14	10
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
East Germany, DD	4220	1836	170	51	36	DE	10	3
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
Italy, IT	3240	2093	69	21	32	FR	5	11
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
Poland, PL	4000	3539	113	34	54	DD	14	5
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
USRR-Europe, SU-E	19940	16106	30	9	35	PL	7	2
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
Total	**67320**	**.**	**.**	**.**	**.**	**.**	**.**	**.**

* M.A.N. – The Most Annoying Neighbour (the country where the highest share of "imported" depositions comes from)

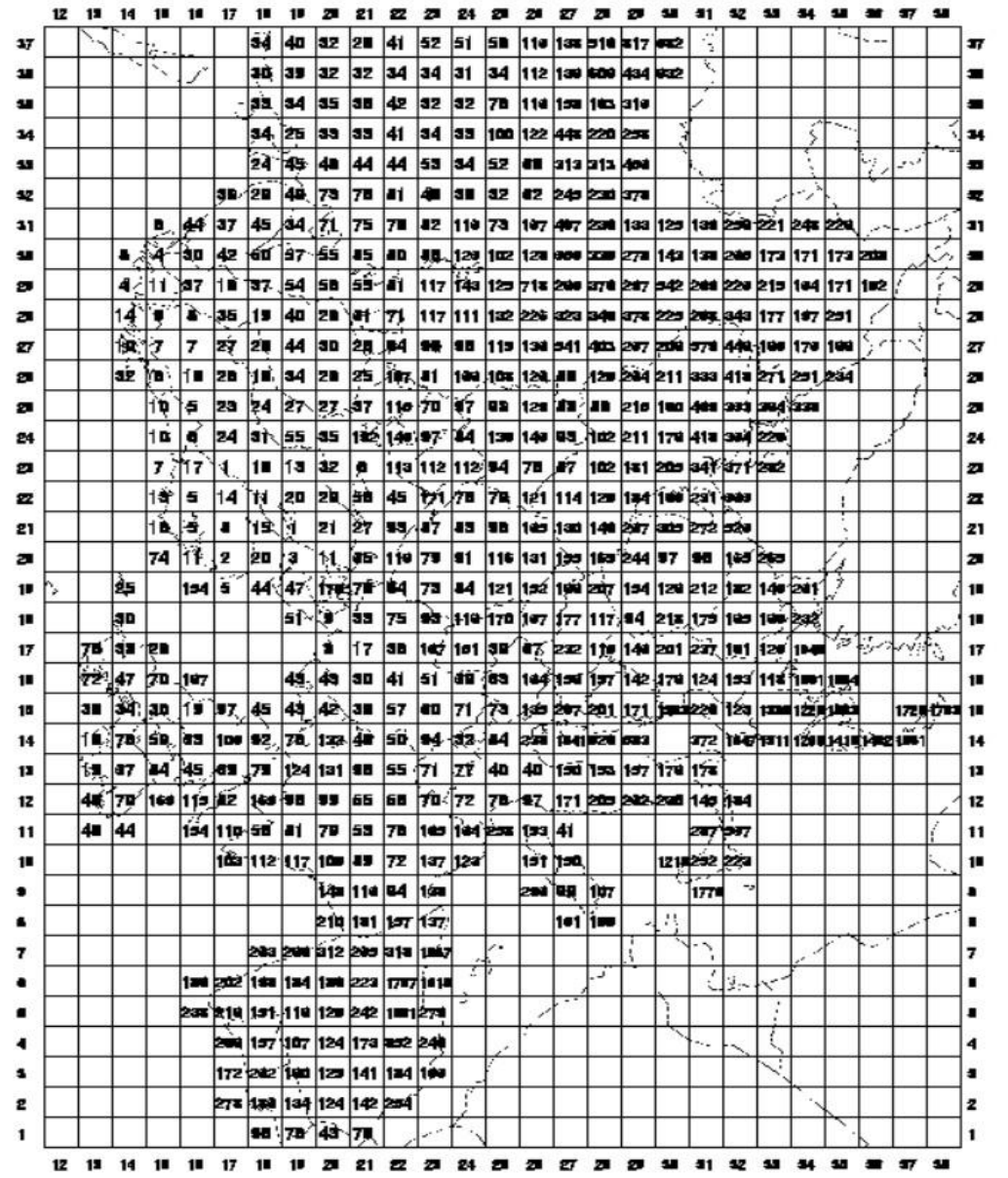
History of European cooperation

- Long Range Transboundary Air Pollution (LRTAP), Geneva 1979

  Protocols:
  - Geneva 1984 (EMEP)
  - Helsinki 1985 (Thirty Percent Club)
  - Sofia 1988 (Nitrogen Oxides, NOX)
  - Geneva 1991 (Volatile Organic Compounds, VOC)
  - Oslo 1994 (The Second Sulphur Protocol)
  - Aarhus 1998 (Heavy metals)
  - Aarhus 1998 (Persistent Organic Pollutants, POP)
  - Gothenburg 1999, (Acidification, eutrophication, and tropospheric ozone)

Critical sulphur deposition

(5-percentile in centigrams of sulphur per square metre per year)



Progress towards meeting NEC targets (I)

Table 1: EU member state progress toward meeting 2010 NEC directive emission ceilings.

Country	NH_3										NMVOCs										NOx										SO_2									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Austria	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Belgium	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bulgaria	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Croatia					✗	✗	✗	✗	✗	✗					✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓
Cyprus	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Czechia	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Denmark	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Estonia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Finland	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
France	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Germany	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Greece	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hungary	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ireland	✓	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Italy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Latvia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lithuania	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Luxembourg	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Malta	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Netherlands	✗	✗	✓	✓	✓	✗	✗	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Poland	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Portugal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Romania	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Slovakia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Slovenia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Spain	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sweden	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EU-27	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes:'✓' indicates that the emission ceiling has been met.'✗' indicates that the emission ceiling has not been met.

Progress towards meeting NEC targets (II)

Table 2: Percentage emission reductions compared with 2019 levels required to meet the national emission reduction commitments for 2020–2029 and 2030 onwards.

Country	2020					2030				
	NH_3	NMVOC	NOx	$PM_{2.5}$	SO_2	NH_3	NMVOC	NOx	$PM_{2.5}$	SO_2
Austria	●	✓	✓	✓	✓	●	✓	●	●	✓
Belgium	✓	✓	✓	✓	✓	✓	✓	●	✓	✓
Bulgaria	✓	●	✓	●	✓	✓	●	●	●	✓
Croatia	✓	✓	✓	✓	✓	●	●	●	●	✓
Cyprus	✓	✓	●	✓	●	✓	●	●	●	●
Czechia	✓	✓	✓	✓	✓	●	●	●	●	●
Denmark	●	✓	✓	✓	✓	●	✓	●	●	✓
Estonia	●	✓	✓	✓	✓	●	✓	✓	✓	✓
Finland	●	✓	✓	✓	✓	●	●	●	✓	✓
France	✓	✓	✓	✓	✓	●	✓	●	●	✓
Germany	●	✓	●	✓	✓	●	✓	●	●	●
Greece	✓	✓	✓	✓	✓	✓	●	●	●	●
Hungary	●	✓	✓	●	✓	●	●	●	●	●
Ireland	●	●	✓	✓	✓	●	●	●	●	✓
Italy	✓	✓	✓	✓	✓	●	●	✓	●	✓
Latvia	●	✓	●	✓	✓	●	●	●	●	✓
Lithuania	●	●	●	✓	✓	●	●	●	✓	●
Luxembourg	●	✓	✓	✓	✓	●	●	●	✓	✓
Malta	✓	●	✓	✓	✓	✓	●	●	●	✓
Netherlands	✓	✓	✓	✓	✓	●	✓	●	✓	✓
Poland	✓	●	●	✓	✓	●	●	●	●	●
Portugal	✓	✓	✓	✓	✓	●	●	●	●	●
Romania	✓	✓	●	●	✓	●	●	●	●	●
Slovakia	●	✓	✓	✓	✓	●	✓	●	✓	●
Slovenia	✓	✓	✓	✓	✓	●	●	●	●	●
Spain	●	✓	✓	●	✓	●	●	●	●	●
Sweden	●	✓	●	✓	✓	●	✓	●	✓	✓
EU-27	✓	✓	✓	✓	✓	●	●	●	●	●

Notes: '✓' indicates current emissions levels below the emissions reductions commitment.
'●' indicates emission reductions needed by less than 10% from current levels.
'●' indicates emission reductions needed by 10% to 30% from current levels.
'●' indicates emission reductions needed by 30% to 50% from current levels.
'●' indicates mission reductions needed by more than 50% from current levels.

Welcome, sulphur dioxide!
Hello, carbon monoxide!
'Hair', 1967

Non-European acid rain

- USA – Canada
- Latin America
- South-East Asia

Questions

Q-4 The Helsinki Protocol to the Long Range Transboundary Air Pollution Convention

[a] called for 30% reduction of acidifying substances such as sulphur dioxide and nitrogen oxides

[b] called for 50% reduction of sulphur dioxide emissions

[c] mandated higher abatement effort of polluters whose emissions imply more acute damages in neighbouring countries

[d] was not signed by several countries, including Poland

[e] none of the above

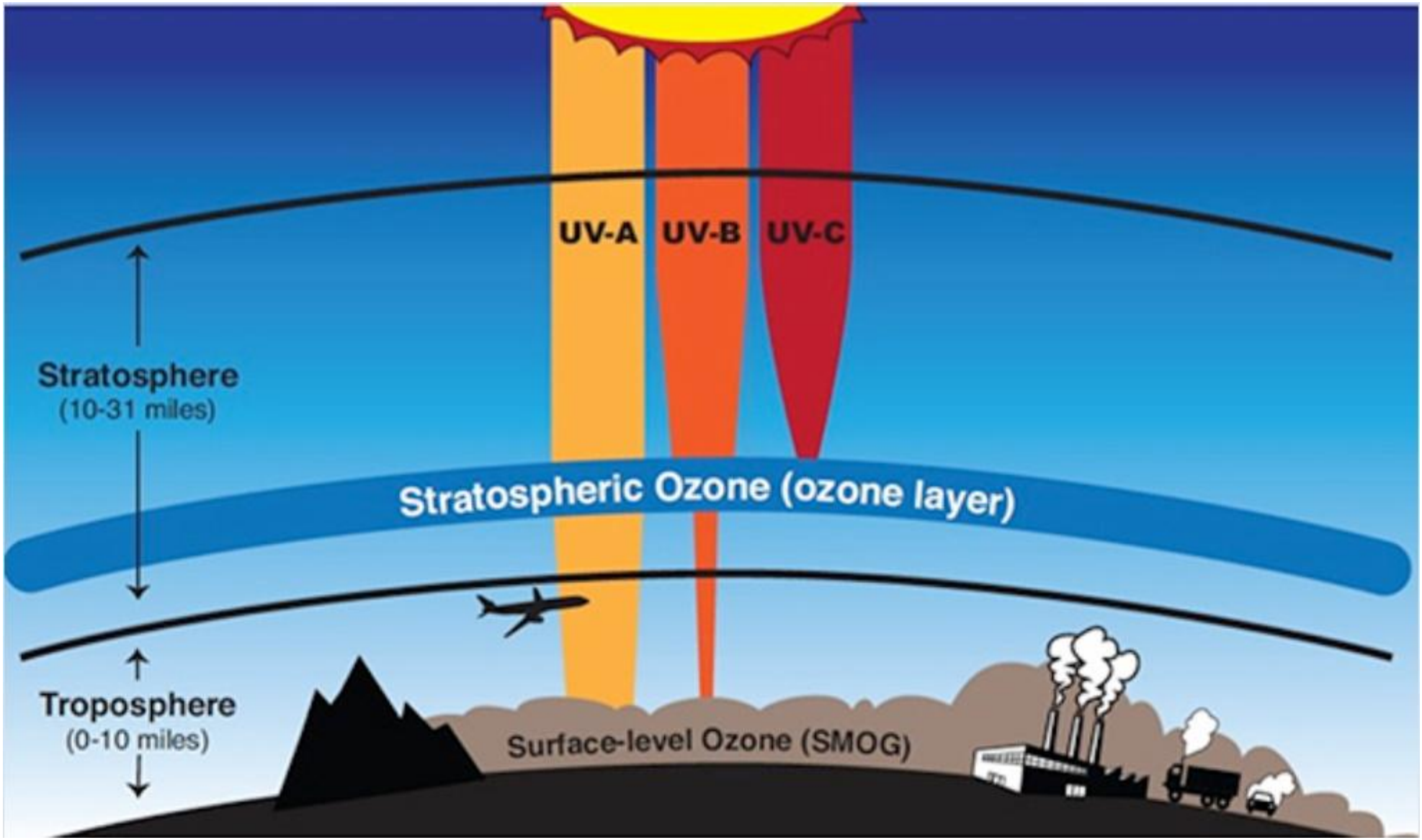
Exercises

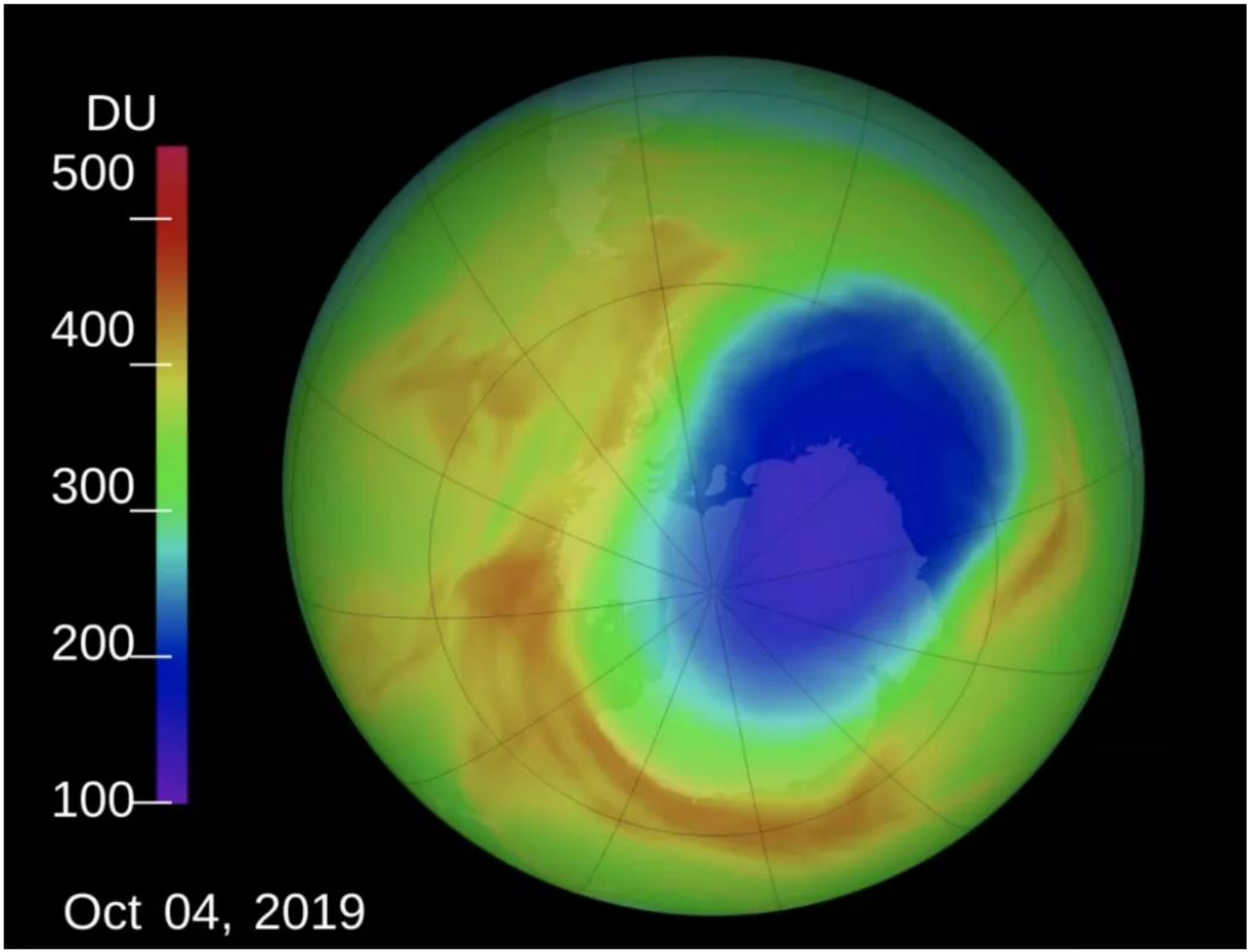
E-4 So-called critical loads are defined statistically (probabilistically). Explain why their deterministic definition would not be practical.

Ozone layer

Ozone layer (stratosphere: 15 km – 50 km)

- Filtering excessive UV radiation
- Discovery of the ozone layer (1913)
- Direct measurements of the ozone layer (1960s)
- Discovery of the ozone hole (late, because of a software failure)


UV-A
UV-B
UV-C
Stratosphere
(10-31 miles)
Stratospheric Ozone (ozone layer)
Troposphere
(0-10 miles)
Surface-level Ozone (SMOG)



The ozone hole (blue) can be seen here over Antarctica on Oct. 4, 2019. (Image credit: NASA Goddard/Katy Mersmann)

Ozone depletion

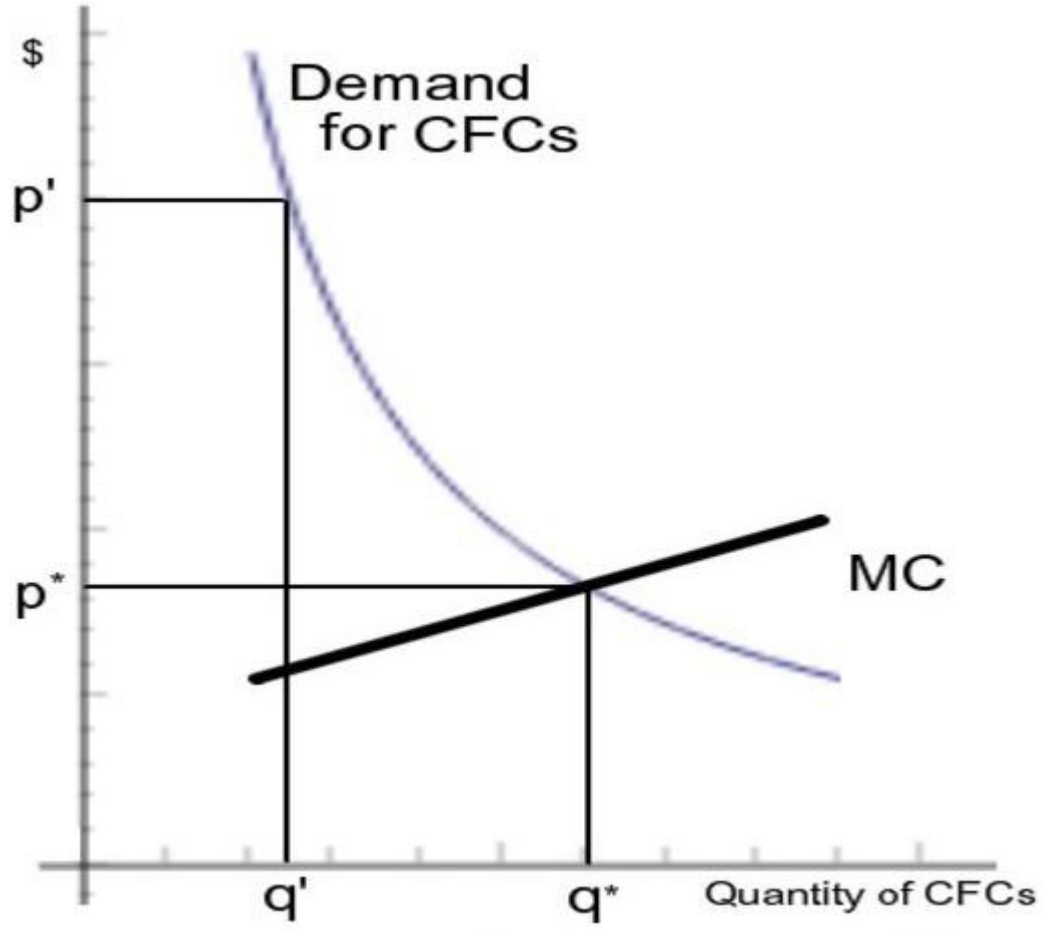
- Physical processes (punctures)
  - Space exploration
  - Supersonic flights
- Chemical processes (destruction of O_3 particles)
  - CFCs (since the 1930s)
  - Other ozone-depleting substances

Ozone hole negotiations

- Partners
  - Scientists
  - Environmentalists
  - DuPont
  - Governments
- Agreements
  - Vienna Convention, 1985
  - Montreal Protocol, 1987

Du Pont strategy		
CFC	HCFC	HFC
Keeping a high CFC price as a result of the immediate ban on its production, and supporting it by requiring CFC recovery and destruction	Stimulating irrevocable commitments of as many producers and users as possible, and thus creating *fait accompli*, as well as political support. Extend the period of using HCFCs	Discouraging expectations of early availability of HFC-based technologies
ICI strategy		
CFC	HCFC	HFC
Keeping a low CFC price as a result of postponing the ban on its production, and supporting it by requiring CFC recovery and reuse	Pressing the European Commission to ban HCFCs, making potential investors afraid of such a ban in the future, and thus reducing their number (which will make the ban perspective more credible). Shorten the period of using HCFCs	Vigorous investing in the new technology and hence creating political support for HFCs

Wind-fall profit tax




no afecta
la capa de ozono


OZONE FRIENDLY
CFC FREE


HARMLESS TO OZONE
CFC FREE


no afecta
la capa de ozono


OZONE FRIENDLY
CFC FREE


HARMLESS TO OZONE
CFC FREE

Montreal Protocol (MP)

- Division of the world into two categories (rich and poor countries)
- Shrinking limits of freon consumption
- Extended compliance periods for poor countries
- Per-head-consumption criteria (300 g per annum)
- Trade sanctions
- Transferability of permits

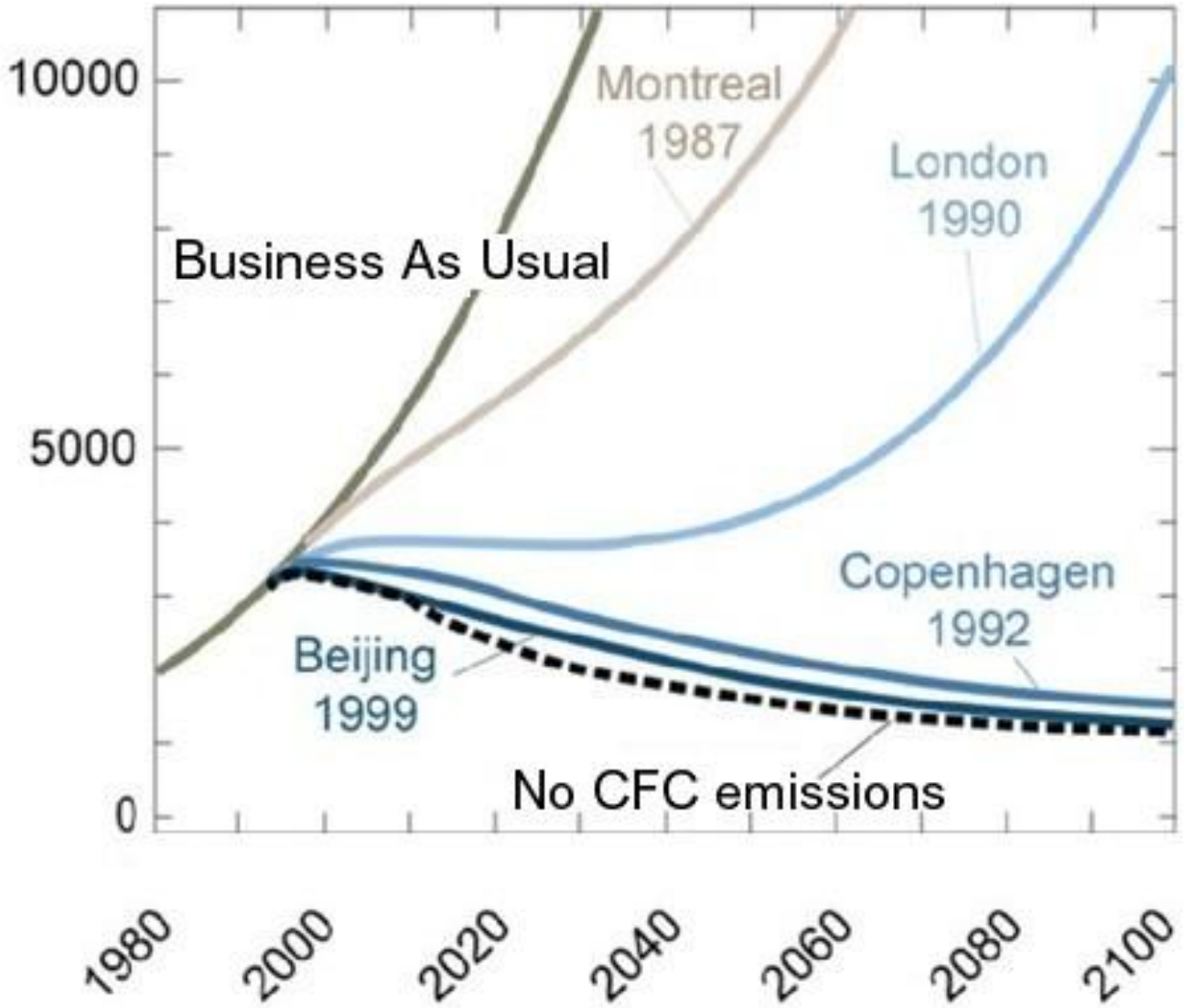
Financial provisions of MP

- Definition of incremental cost
- Poor countries to be subsidized by the rich
- Total incremental cost estimated at $60 M per annum in 1990

Amendments to MP

- London 1990
- Copenhagen 1992
- Montreal 1997
- Beijing 1999

Universal ratification (197 countries)


10000
5000
0
Business As Usual
Montreal
1987
London
1990
Copenhagen
1992
Beijing
1999
No CFC emissions
1980
2000
2020
2040
2060
2080
2100

Precedent-setting provisions of MP

- Division of the world into two categories (European post-communist countries considered "rich")
- "Rich" to finance incremental costs of MP in "poor" countries

Long-term effects of MP

- "Fixing" the ozone hole (the ozone layer is expected to recover by the end of the 21st century)
- "Lock-in" with HCFCs that are potent "greenhouse gases"
- Relatively low compliance costs
  - No challenges for the trade sanctions of MP
  - No opposition to incremental cost reimbursement

Questions

Q-5 The so-called ozone hole refers to

[a] damages done to the stratospheric ozone

[b] insufficient ozone synthesis following weather anomalies

[c] attempts to protect human health by abating tropospheric ozone

[d] the hole in the atmospheric ozone layer created in order to make commercial flights safer

[e] none of the above

Exercises

E-5 Explain why Du Pont advocated for immediate destruction of CFCs removed from used refrigerators rather than recycling the chemicals and reusing them in some other installations.

Climate as a public good

Samuelson criterion:

$$MC_i = \Sigma_i MB_i,$$

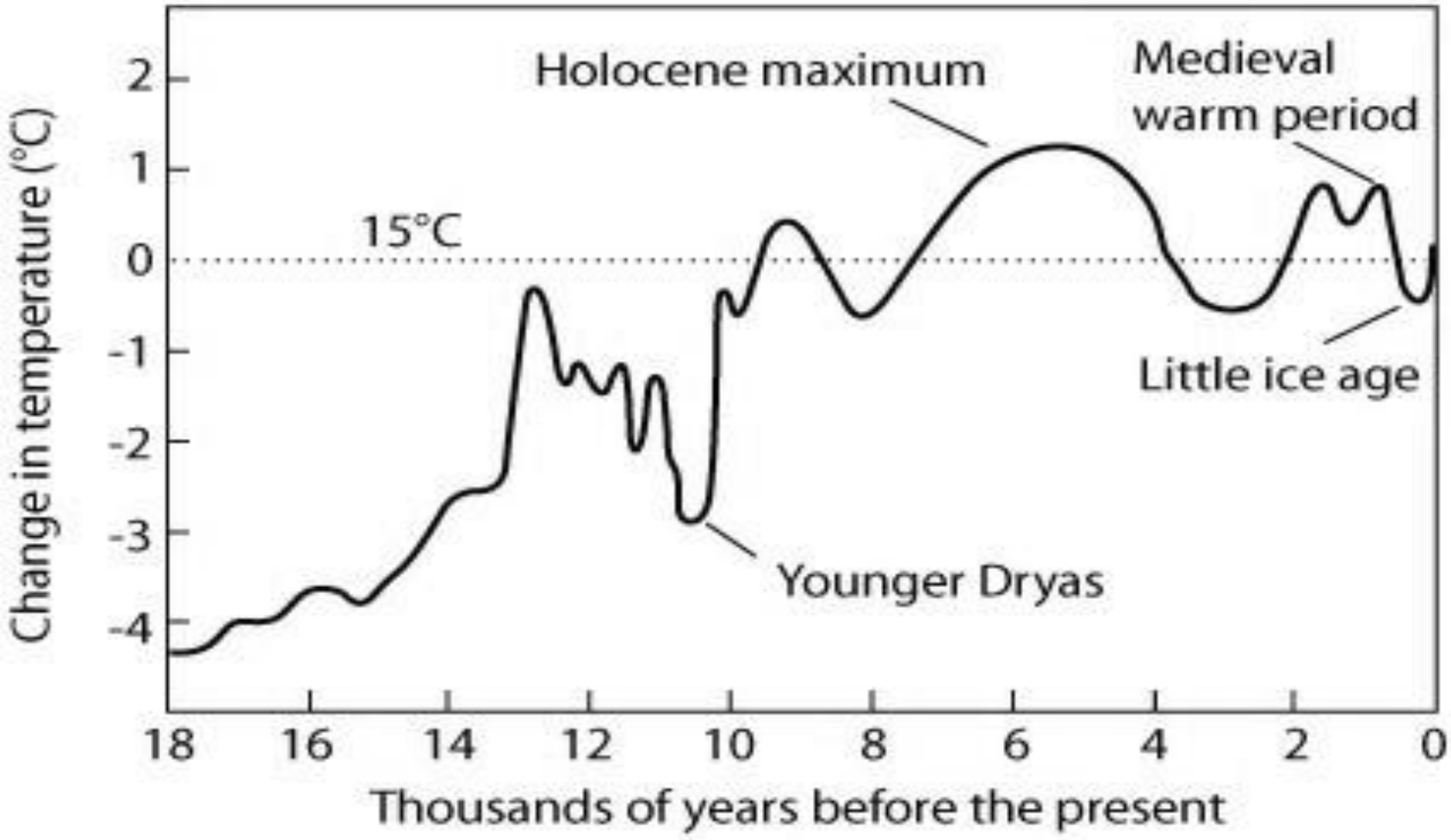
where:

- MC_i – the marginal cost of delivering the good incurred in country *i*,
- MB_i – the marginal benefit from delivering the good for country *i*, and
- summation extends over all the countries (using the good).

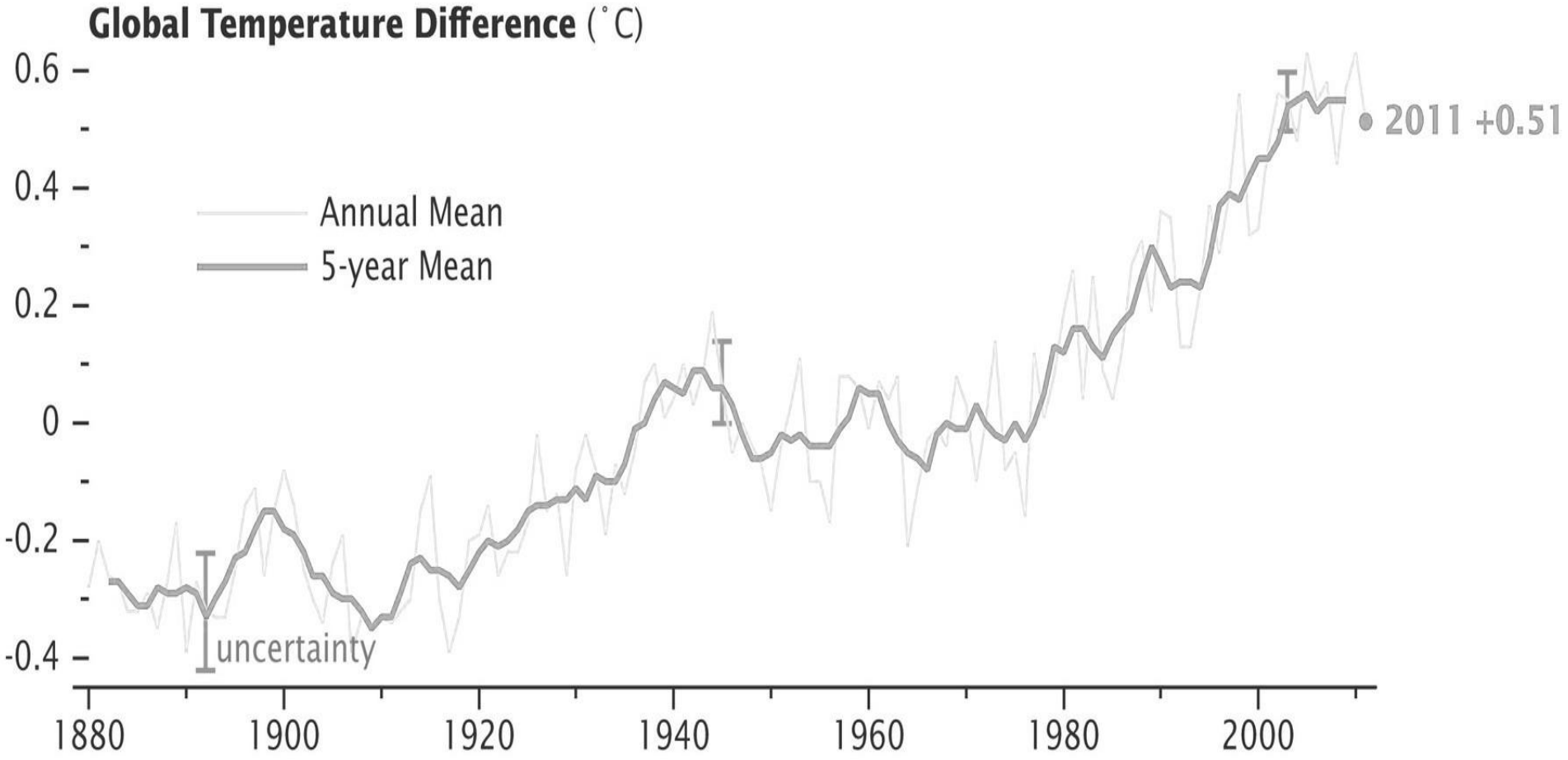
Nash (non-cooperative) criterion:

$$MC_i = MB_i.$$

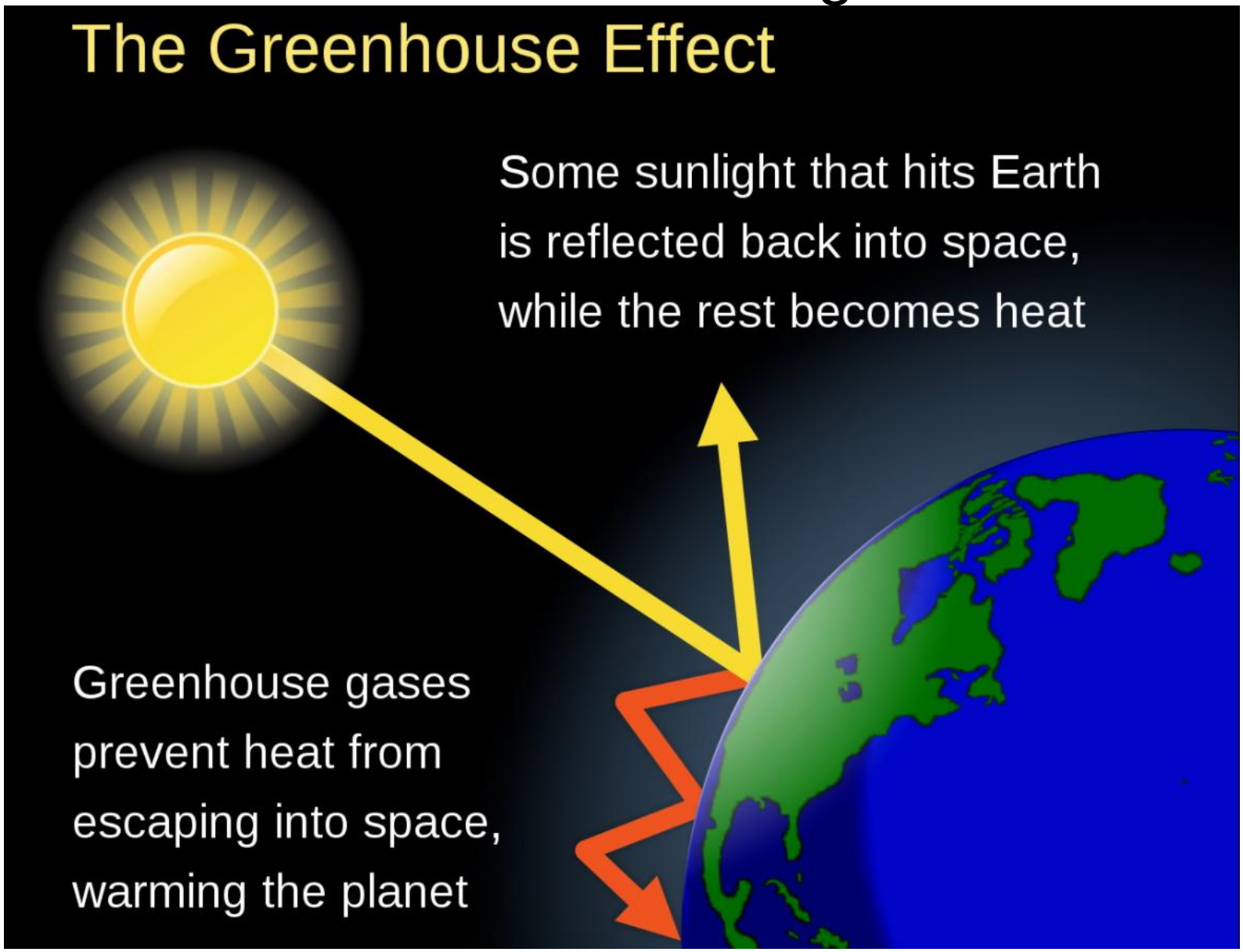
Climate history (long)



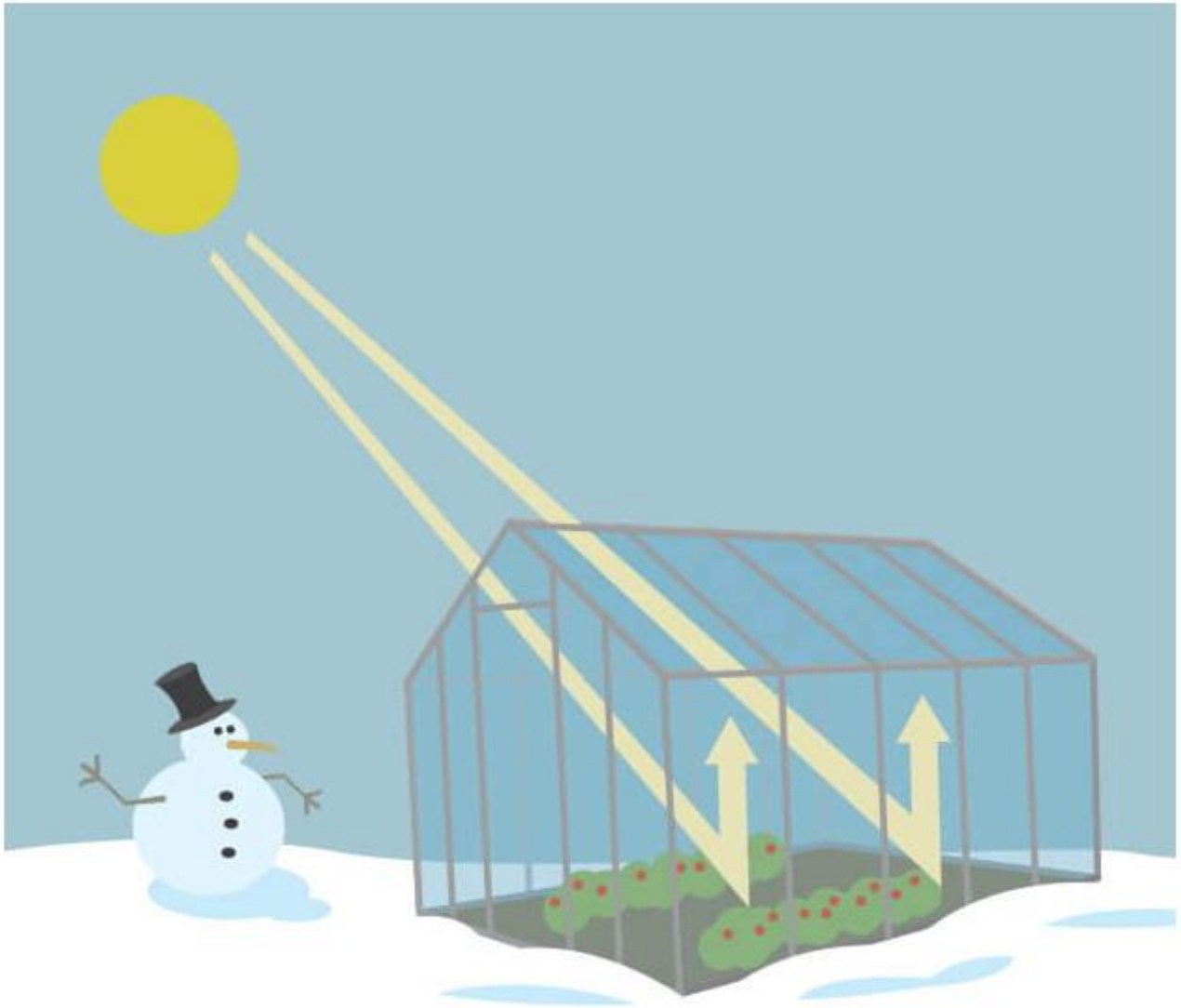
Climate history (recent)

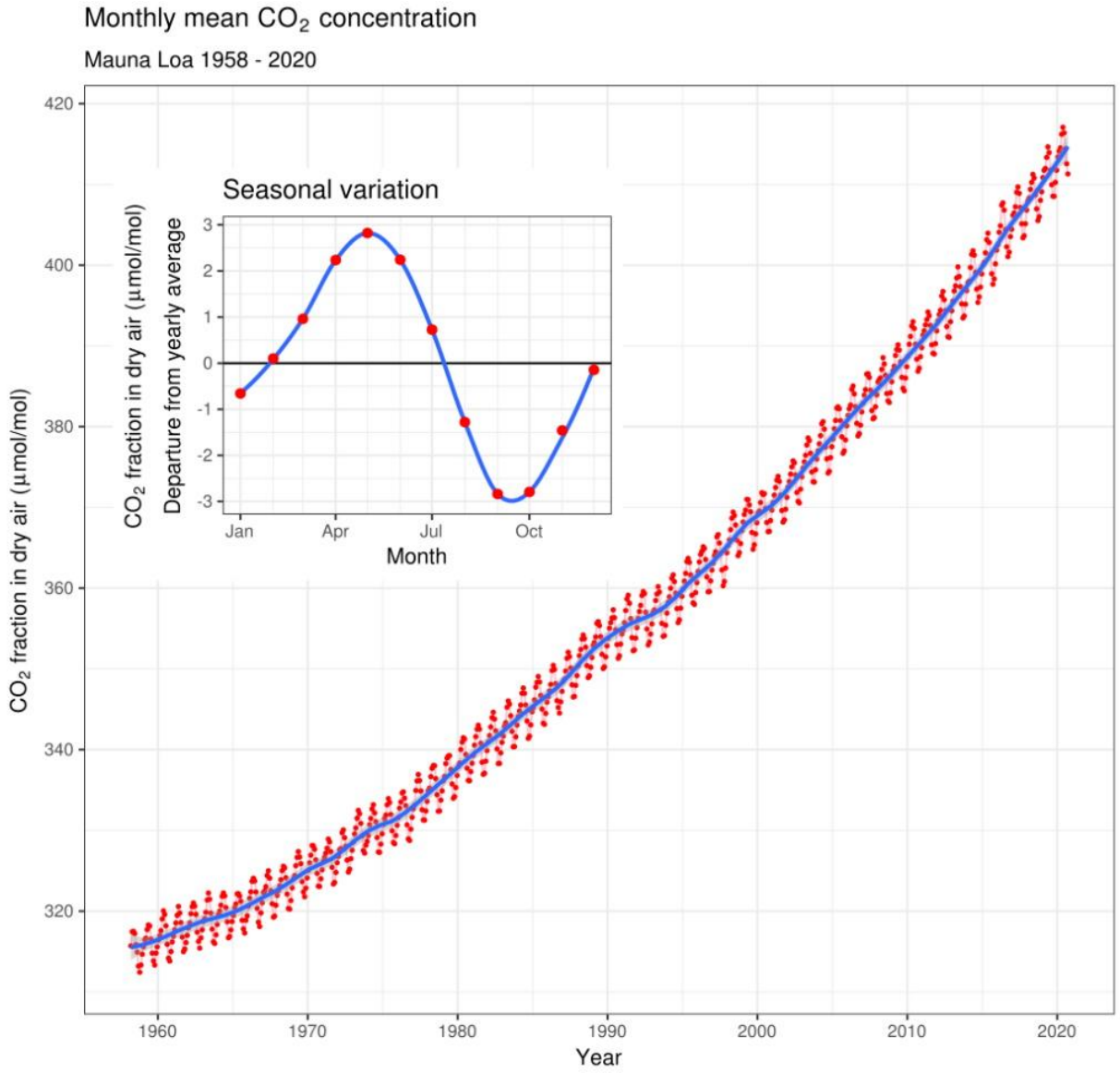


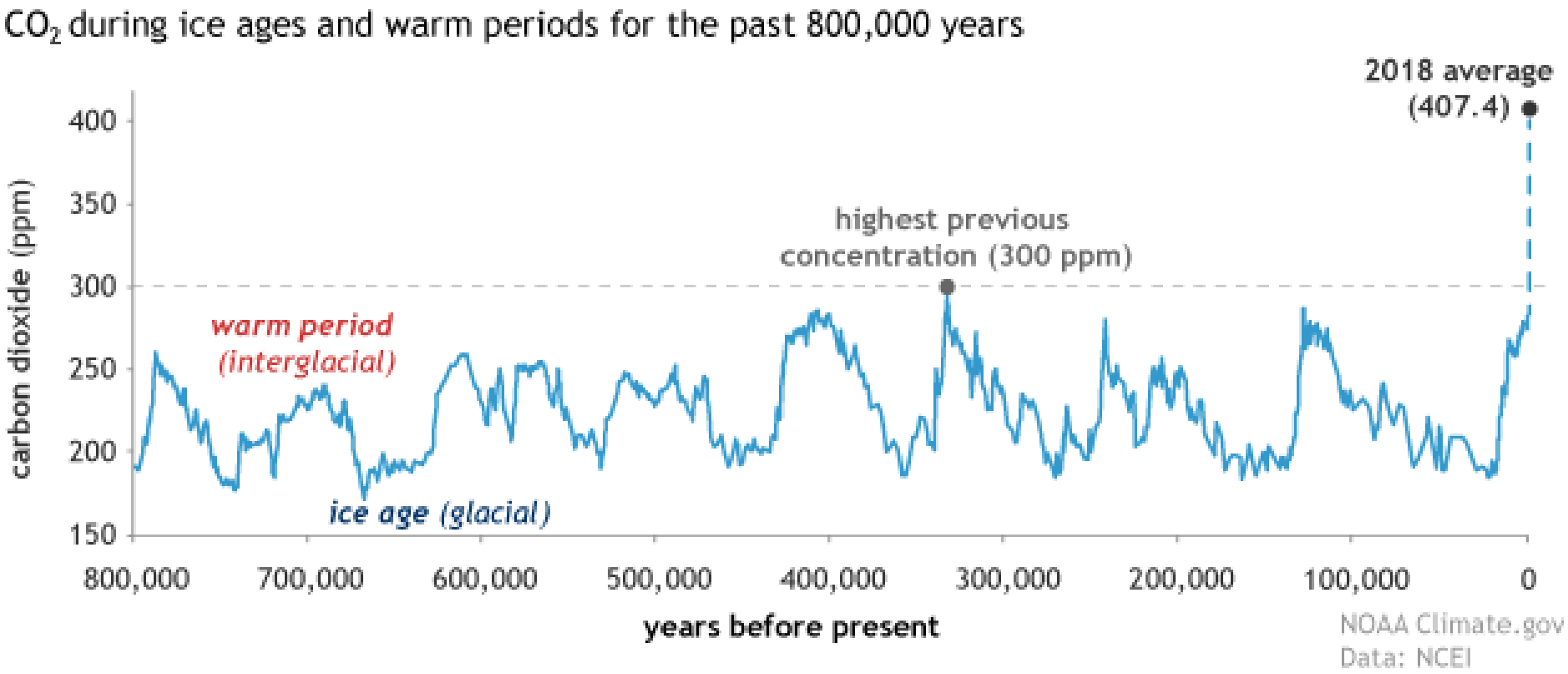
Global warming



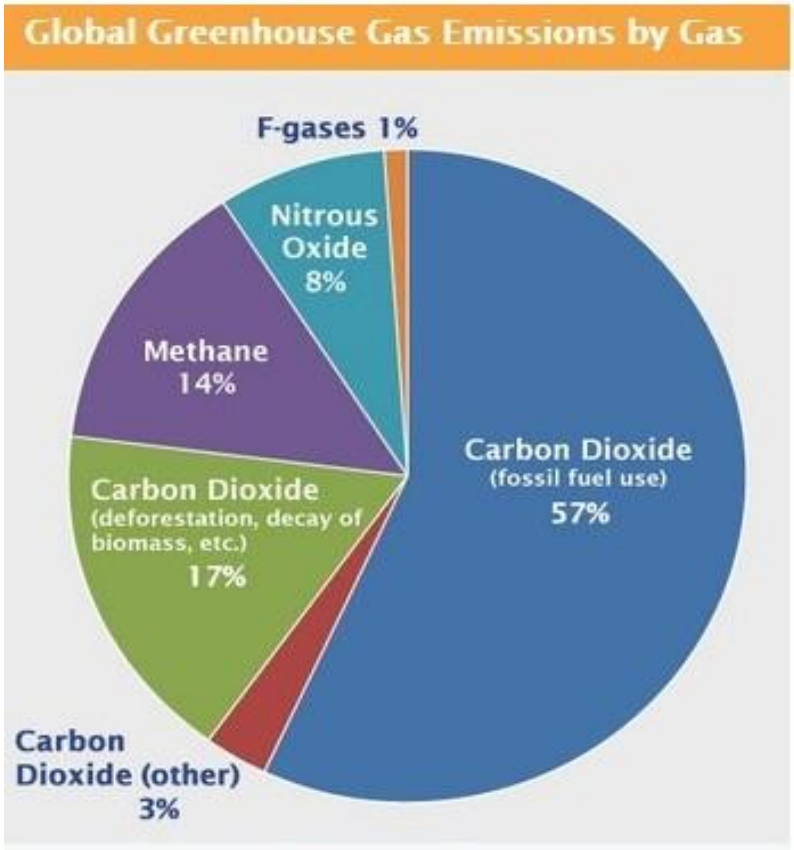
Why "greenhouse effect"?



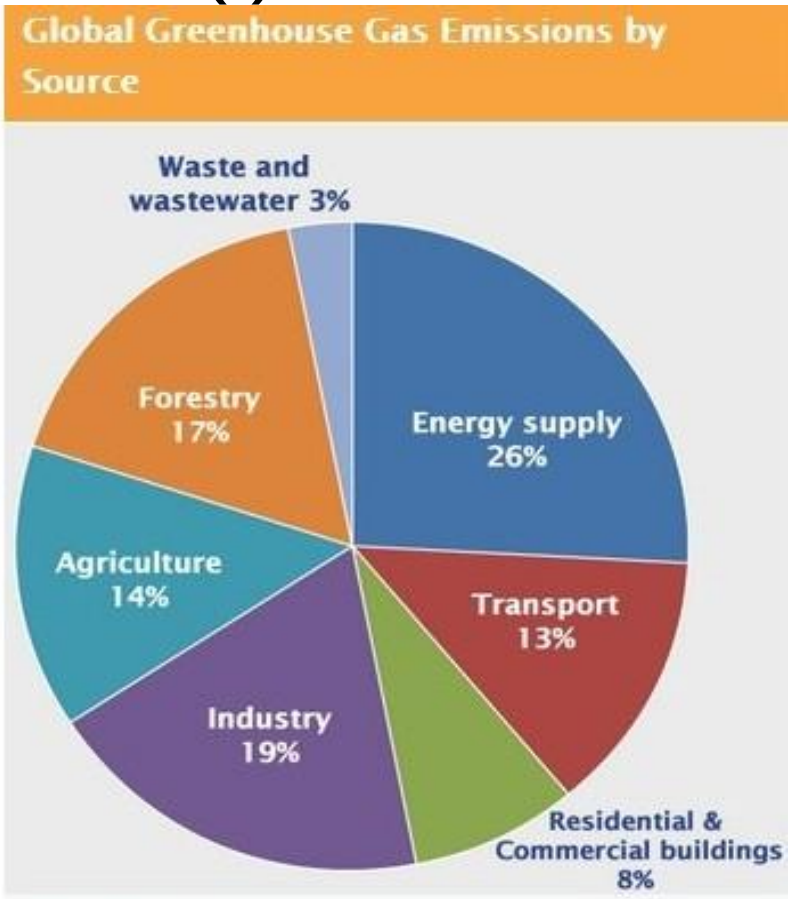

Monthly mean CO_2 concentration
Mauna Loa 1958 - 2020
CO_2 fraction in dry air (µmol/mol)
420
400
380
360
340
320
1960
1970
1980
1990
2000
2010
2020
Year
Seasonal variation
CO_2 fraction in dry air (µmol/mol)
Departure from yearly average
3
2
1
0
-1
-2
-3
Jan
Apr
Jul
Oct
Month


CO_2 during ice ages and warm periods for the past 800,000 years
2018 average
(407.4)
highest previous
concentration (300 ppm)
warm period
(interglacial)
ice age (glacial)
carbon dioxide (ppm)
400
350
300
250
200
150
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
years before present
NOAA Climate.gov
Data: NCEI

Global carbon dioxide emission (I)

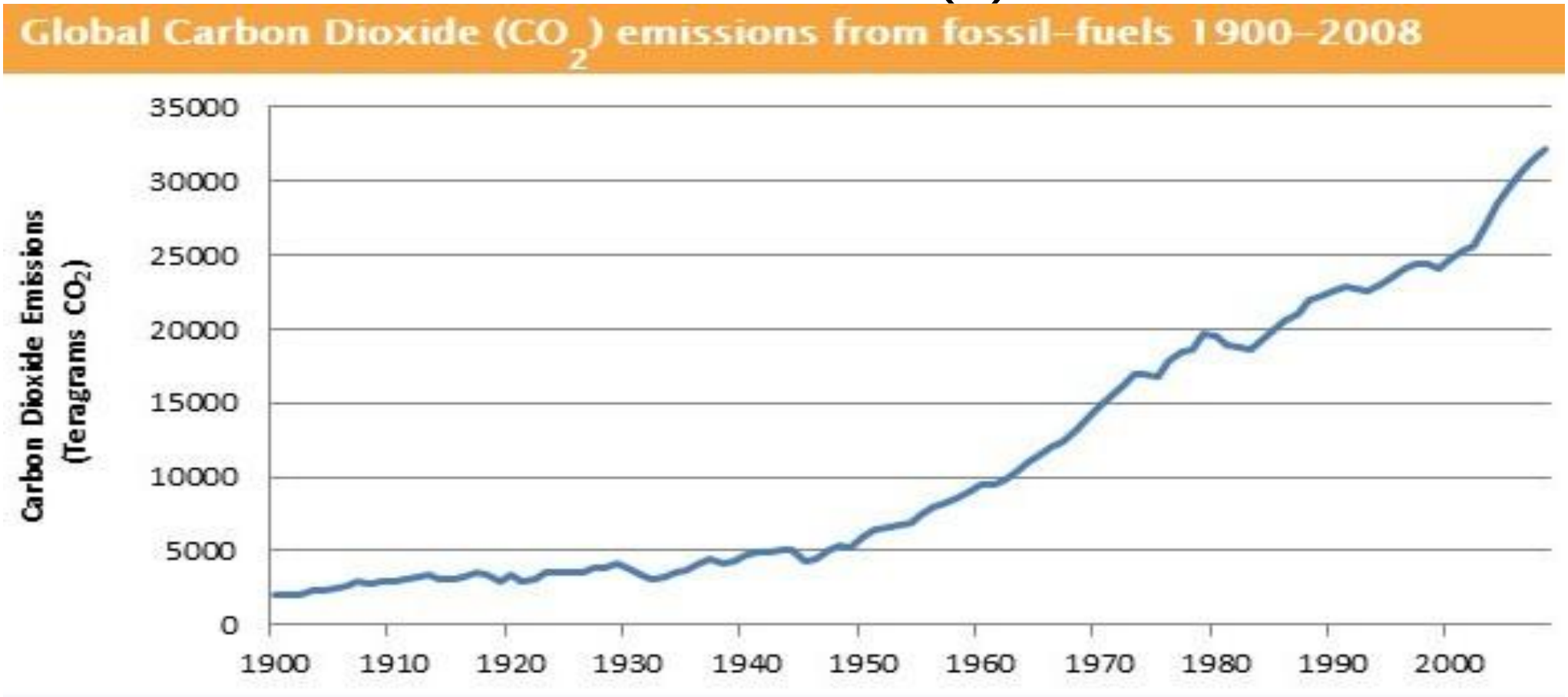


Source: IPCC (2007); EXIT Disclaimer based on global emissions from 2004. Details about the sources included in these estimates can be found in the *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* . EXIT Disclaimer



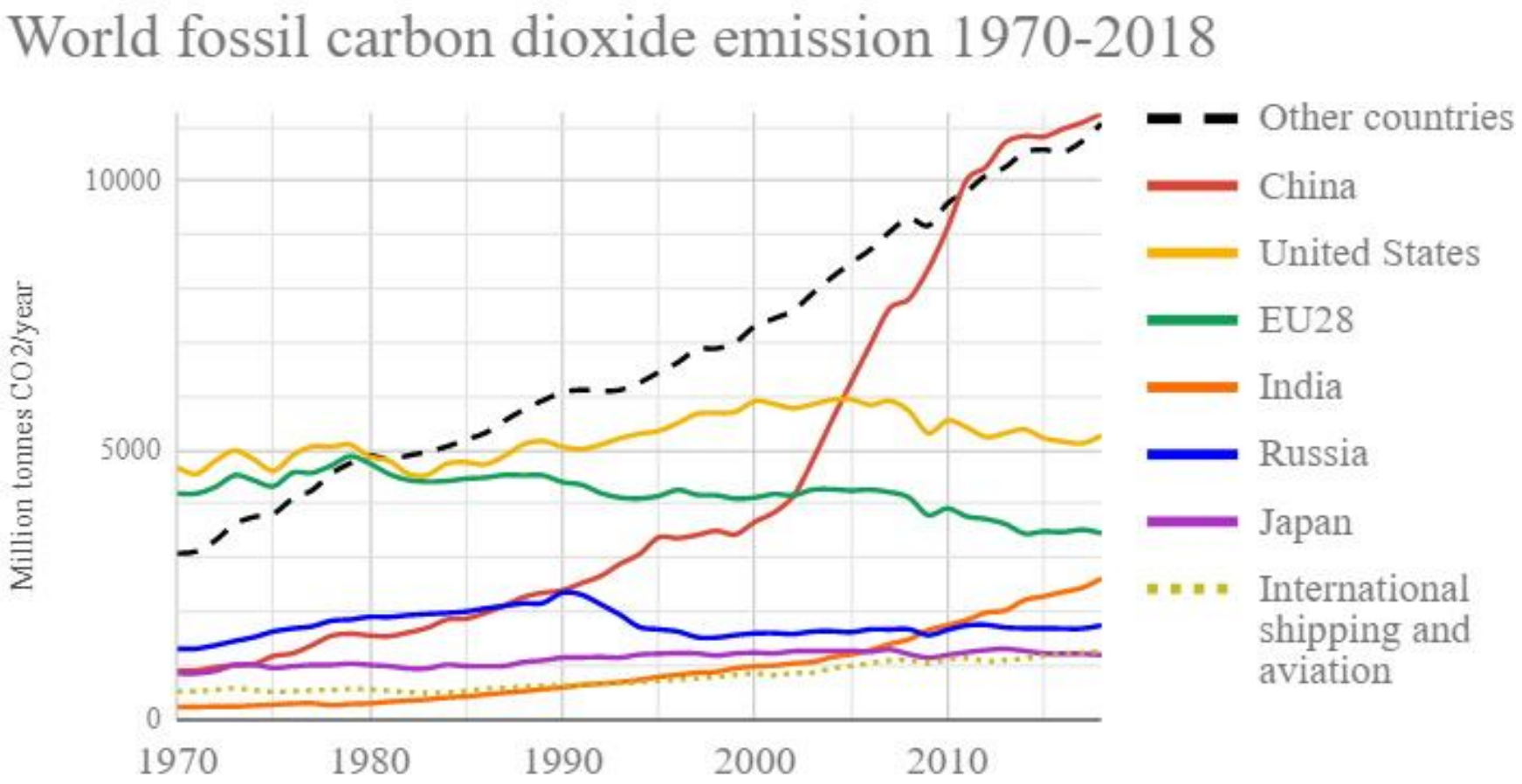
Source: IPCC (2007); EXIT Disclaimer based on global emissions from 2004. Details about the sources included in these estimates can be found in the *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* . EXIT Disclaimer

Global carbon dioxide emission (II)

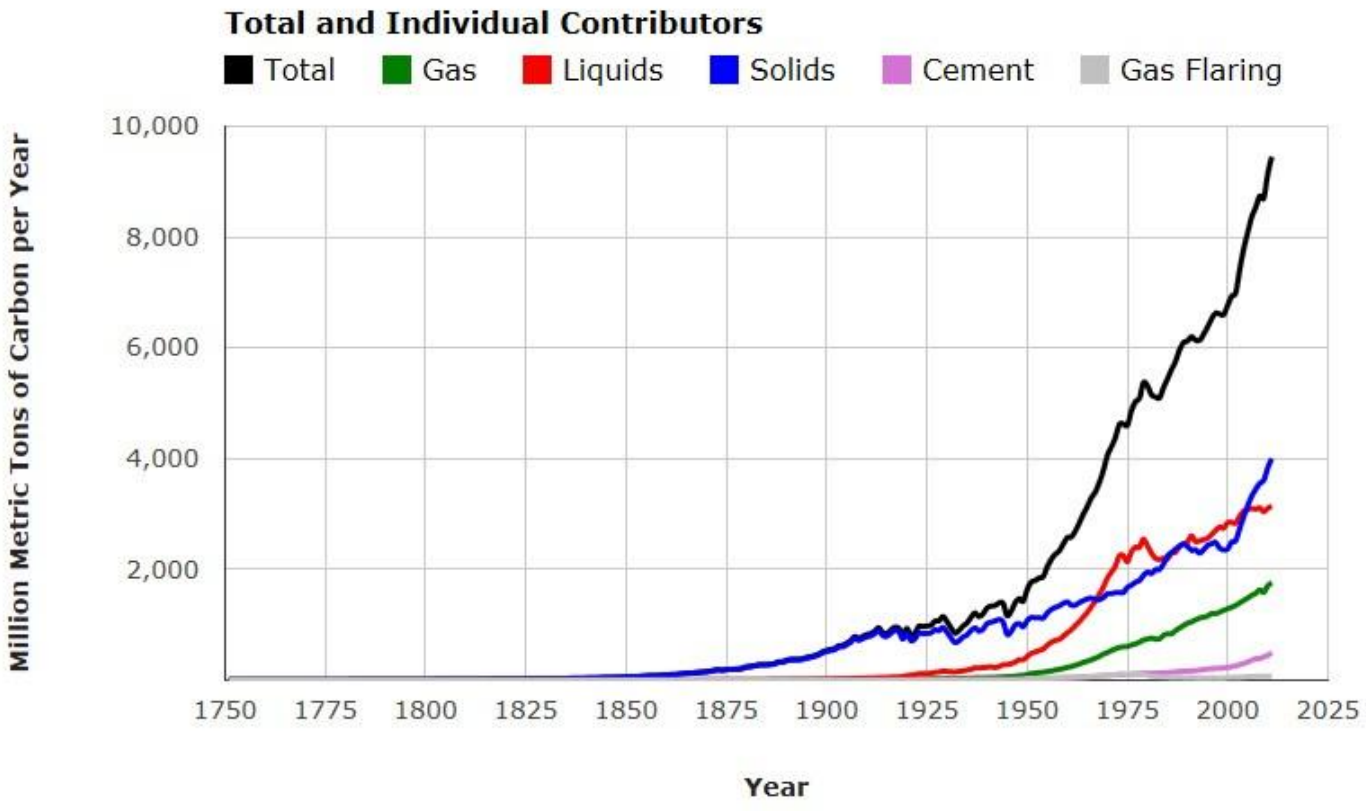


Source of data: Boden, T.A., G. Marland, and R.J. Andres (2010). Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2010.

Global carbon dioxide emission (III)



Global carbon dioxide emission (IV)

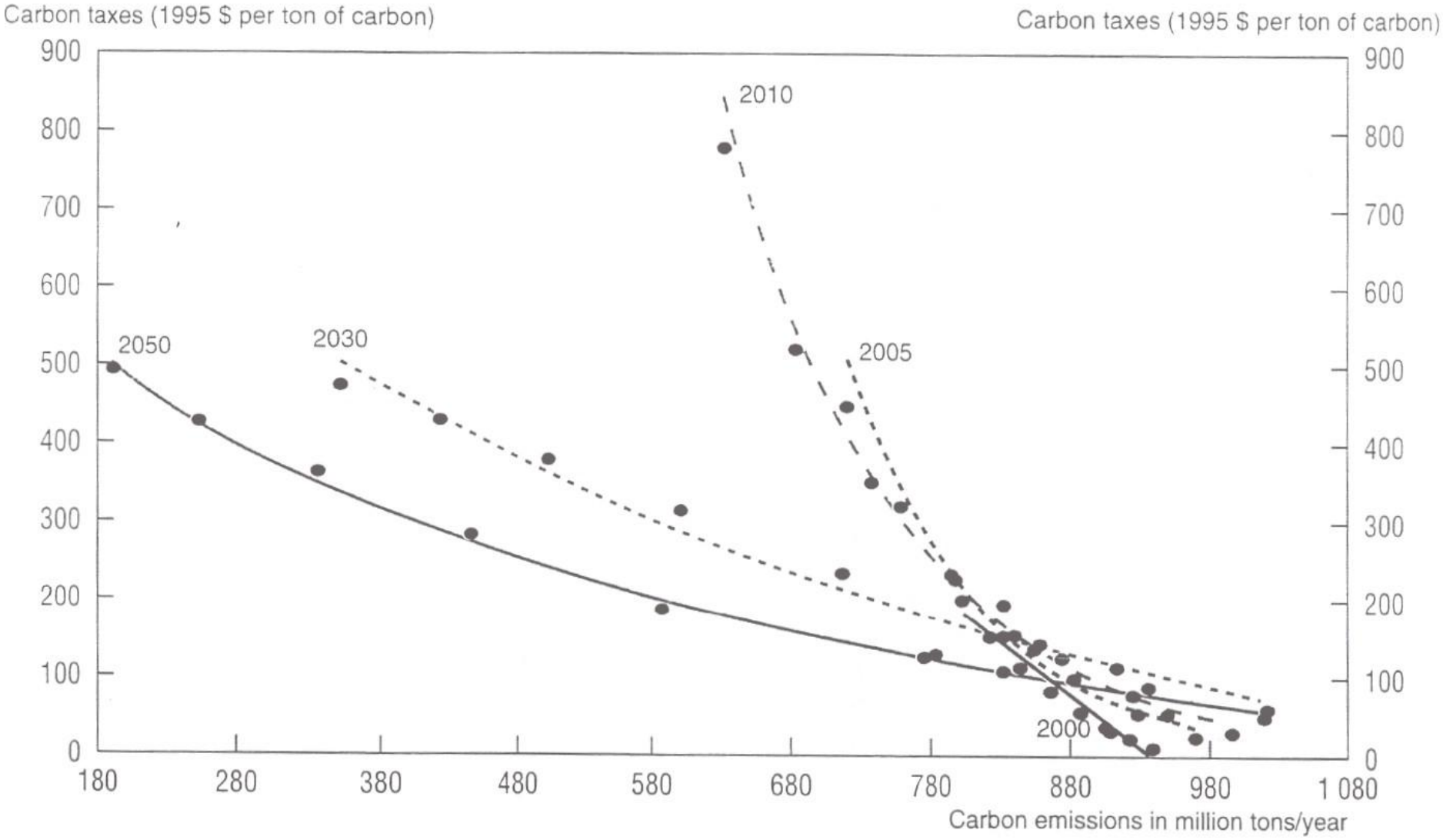


Source: Boden, T.A., G. Marland, and R. J. Andres. 2015. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/00001_V2015.

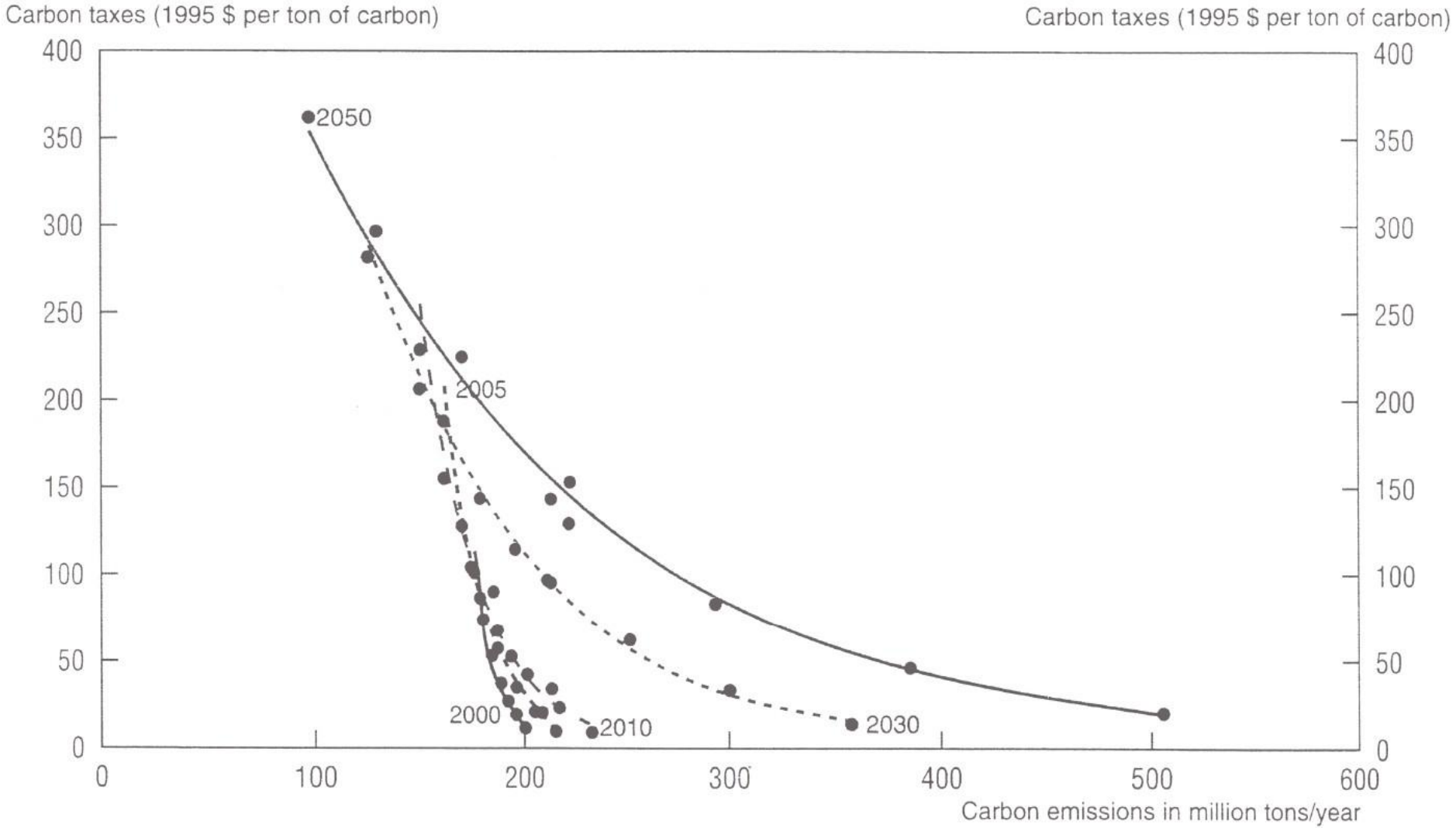
Global carbon dioxide emission (V)

- Like for other "trace gases",CO_2 atmospheric concentration measured in Parts Per Million (PPM)
- Over the last several thousand years it was between 200 and 280
- It grew from 280 in the first half of the 19^{th} century to around 400 in 2014

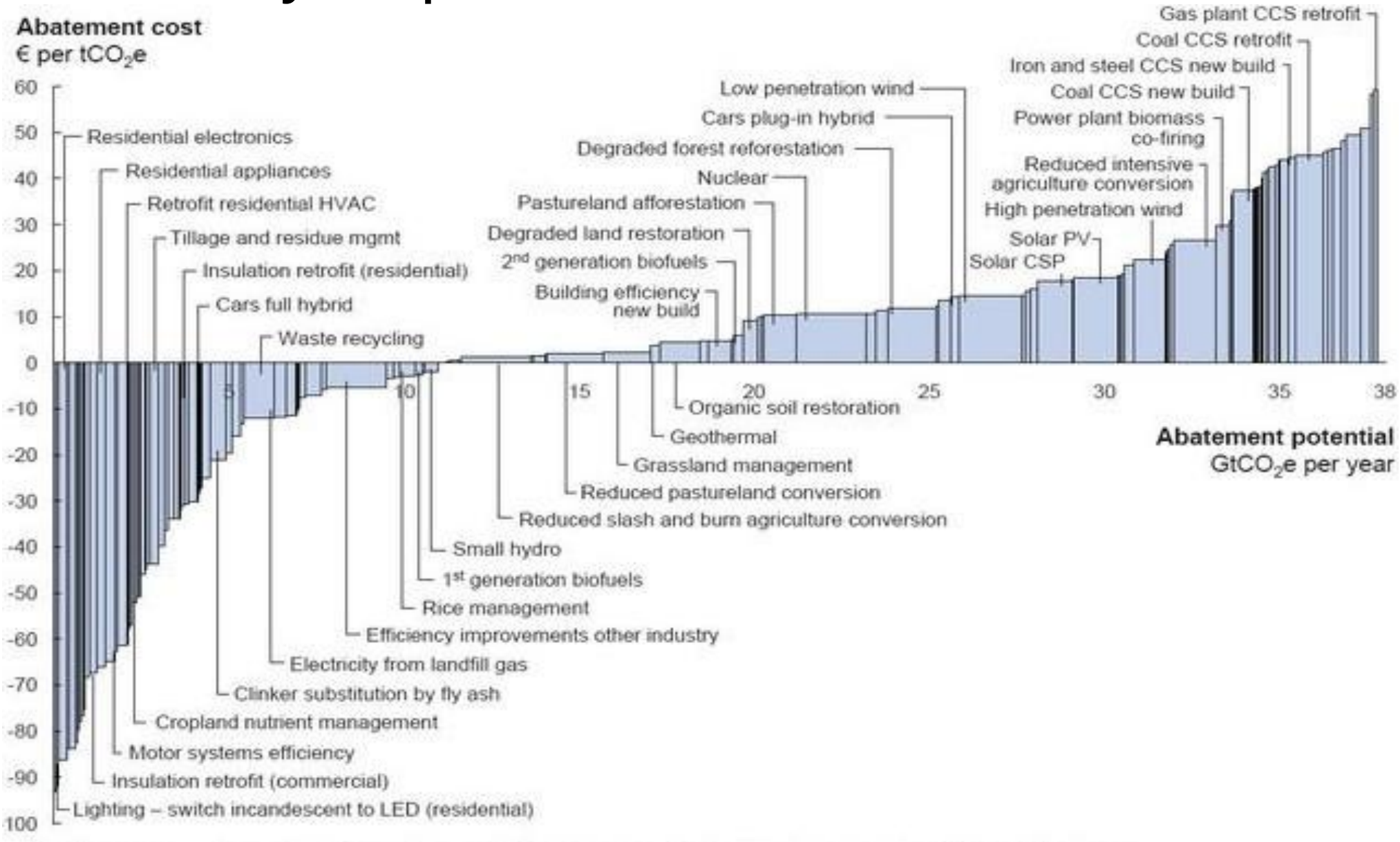
Carbon abatement cost in EU-15



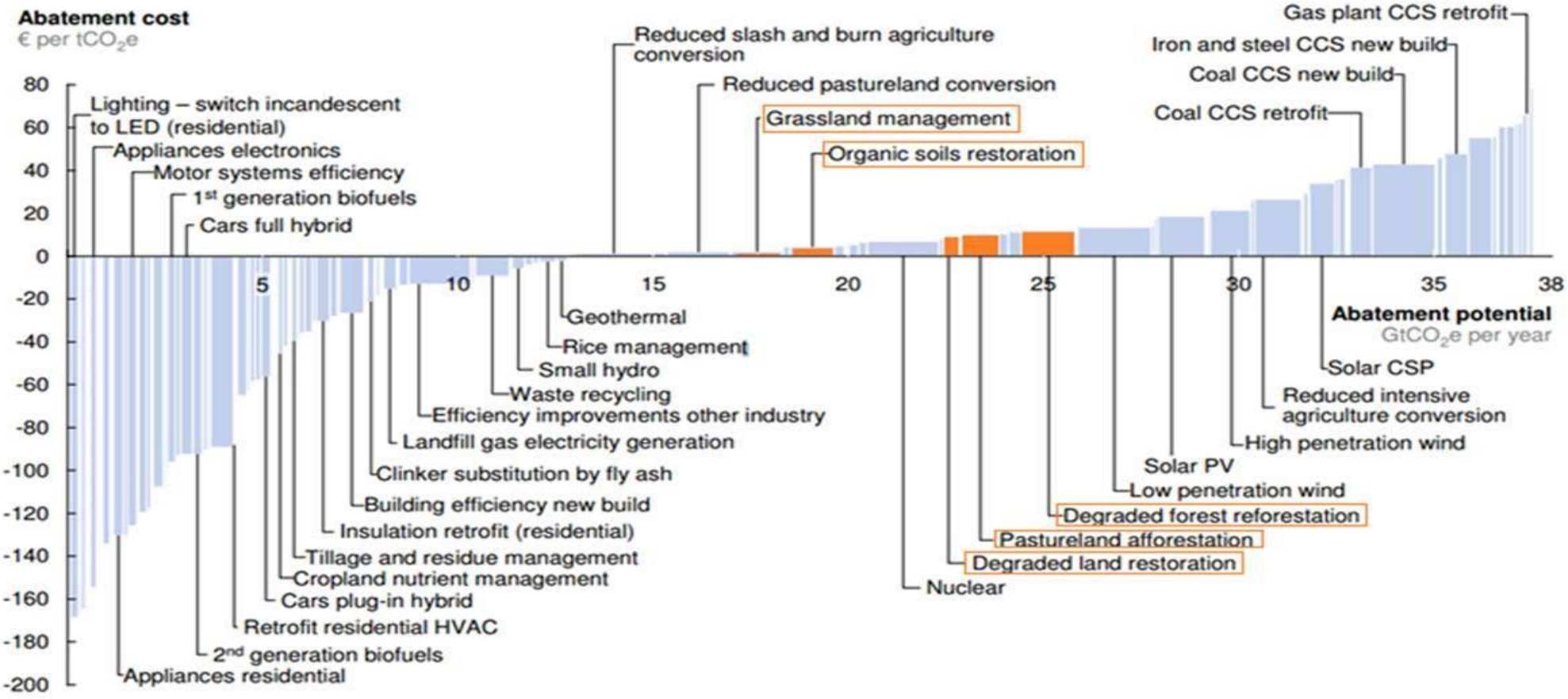
Carbon abatement cost in Eastern Europe



"McKinsey steps"



"McKinsey steps" (corrected)

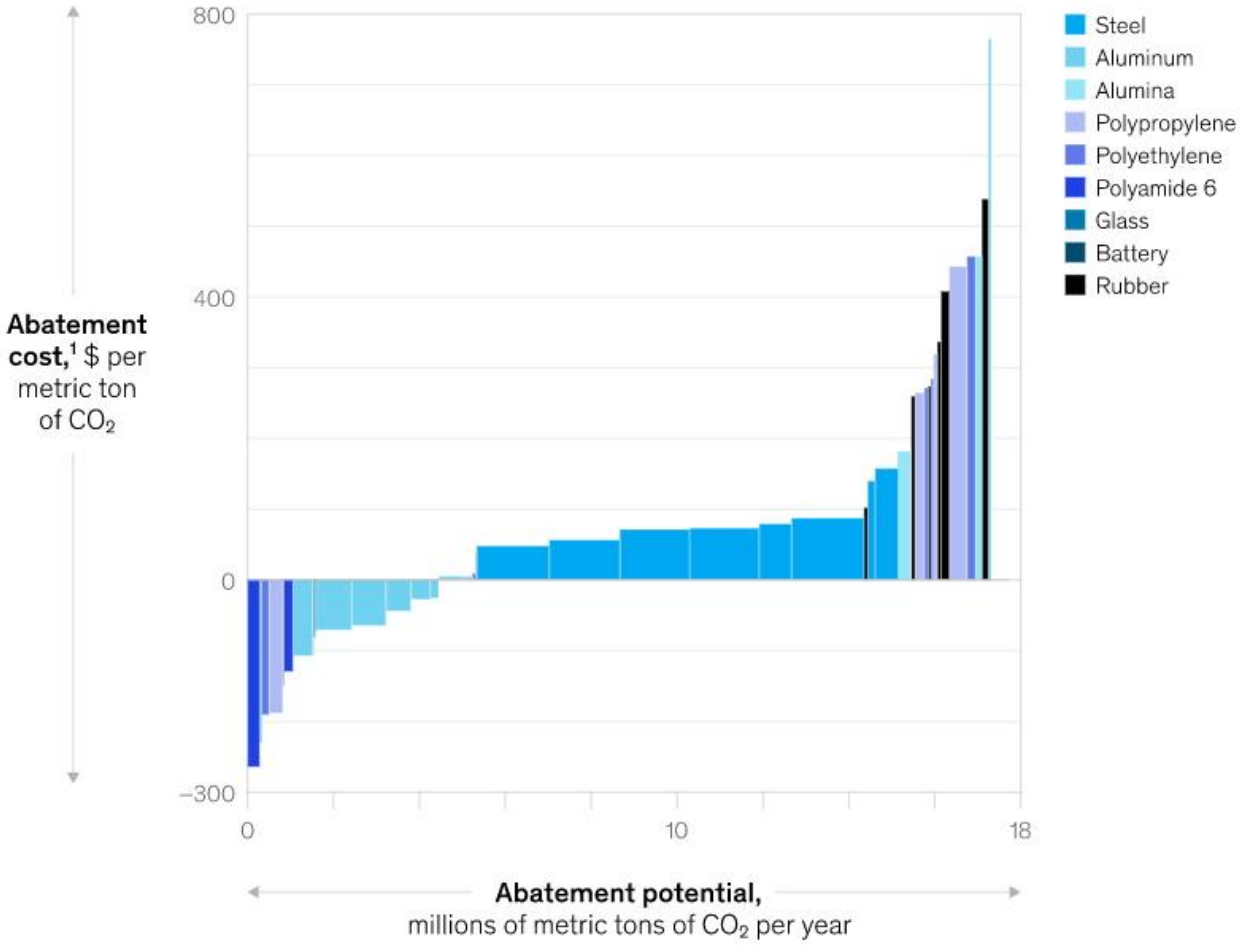


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.1

"McKinsey steps" (recent variant)

In many sectors, the majority of levers available to reduce carbon emissions are value destroying.

For many materials, currently available decarbonization levers are costly



Carbon dioxide abatement – fairness

- Present global sum of carbon dioxide emissions: $x_1+\ldots+x_k = 48$ billion tonnes
- Allocation principle based on population.
  - The number of people in the world is approximately 8 billion
  - This implies an allowance of 6 tonnes per person
  - Allocation principle: $x_i=6L_i$, where L_i is the population of the *i*th country

Consequences of equitable allocation

- European Union and the United States left with allocations much below their current emissions
- China – somewhat less than the level of current emissions
- Other developing countries – much above
- Tradability of permits would then imply a flow of wealth in a direction that is consistent with popular equity convictions

Alternative allocation principles

- Distributing carbon dioxide emissions in proportion to GDP
- This would leave the EU and the US with a much higher allocation than under the previous scheme

Questions

Q-6 Effective climate protection policies

[a] require that environmentally conscious economic agents abate carbon dioxide

[b] require that rich countries reduce carbon dioxide up to the point where their marginal abatement cost meets marginal abatement benefit

[c] require that all countries take binding commitments

[d] require that demographic problems are solved in the first place

[e] none of the above

Exercises

E-6 Discuss welfare implications of carbon dioxide emission limits allocated to countries when GDP per capita criteria are referred to.

Berlin Mandate

United Nations Framework Convention on Climate Change (UNFCCC)

- New York – Rio de Janeiro 1992
- Convention came into force in 1994

Annual Conferences of Parties (COPs)

- COP-1 Berlin (1995)
- COP-2 Geneva (1996)
- COP-3 Kyoto (1997)
- COP-4 Buenos Aires (1998)
- COP-5 Bonn (1999)
- COP-6 Hague (2000) / Bonn (2001)
- COP-7 Marrakesh (2001)
- COP-8 New Delhi (2002)
- COP-9 Milan (2003)
- COP-10 Buenos Aires (2004)

Annual Conferences of Parties (COPs); cont.

- COP-11 / MOP-1 Montreal (2005)
- COP-12 / MOP-2 Nairobi (2006)
- COP-13 / MOP-3 Bali (2007)
- COP-14 / MOP-4 Poznan (2008)
- COP-15 / MOP-5 Copenhagen (2009)
- COP-16 / MOP-6 Cancun (2010)
- COP-17 / MOP-7 Durban (2011)
- COP-18 / MOP-8 Doha (2012)
- COP-19 / MOP-9 Warsaw (2013)
- COP-20 / MOP-10 Lima (2014)

Annual Conferences of Parties (COPs); cont.

- COP-21 / MOP-11 Paris (2015)
- COP-22 / MOP-12 Marrakesh (2016)
- COP-23 / MOP-13 Bonn (2017)
- COP-24 / MOP-14 Katowice (2018)
- COP-25 / MOP-15 Madrid (2019)
- - / - (2020)
- COP-26 / MOP-16 Glasgow (2021)
- COP-27 / MOP-17 Sharm El-Sheikh (2022)
- COP-28 / MOP-18 Dubai (2023)
- COP-29 / MOP-19 Baku (2024)
- COP-30 / MOP-20 Belem (2025)

Kyoto Protocol (KP)

- Signed in 1997 (at COP-3)
- Came into force in 2004
  - 55 ratifications
  - "covering" at least 55% of emission from Annex I
- Since 2005 COPs serve as MOPs (*Meetings of Parties* to the KP)

Berlin Mandate (BM) I

- Signed at COP-1 (1995)
- Adopted principle of "common but differentiated responsibilities" (CBDR)

The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their ***common but differentiated responsibilities*** *and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.*

(Repeated from Article 3.1 of FCCC

Berlin Mandate (BM) II

- "Not [to] introduce any new commitments for Parties not included in Annex I"
- Bulgaria *vs*. South Korea

Failures of BM

- Massive growth of CO_2 emissions
- Annual emissions according to the EBRD:
  - 0.6% before 1992
  - 1.2% after 1992, but before 1997
  - 2.6% after 1997
- Annual emissions (of GHG) according to IPCC:
  - 1.3% in 1970-2000
  - 2.2% in 2000-2010

Implications of BM:

What Annex I countries can do if the non-Annex I countries continue to emit?

- Geoengineering (polluting the atmosphere in order to limit the inflow of solar energy)
- "Negative" emissions (*Carbon Capture and Storage*, CCS)

Paris Agreement (2015)

- First attempt to overcome BM
- Commitments (NDCs, Nationally Determined Contributions) submitted by all signatories
- Some NDCs insincere
- Plans to increase the "ambition level" of NDCs

Intergovernmental Panel on Climate Change (IPCC)

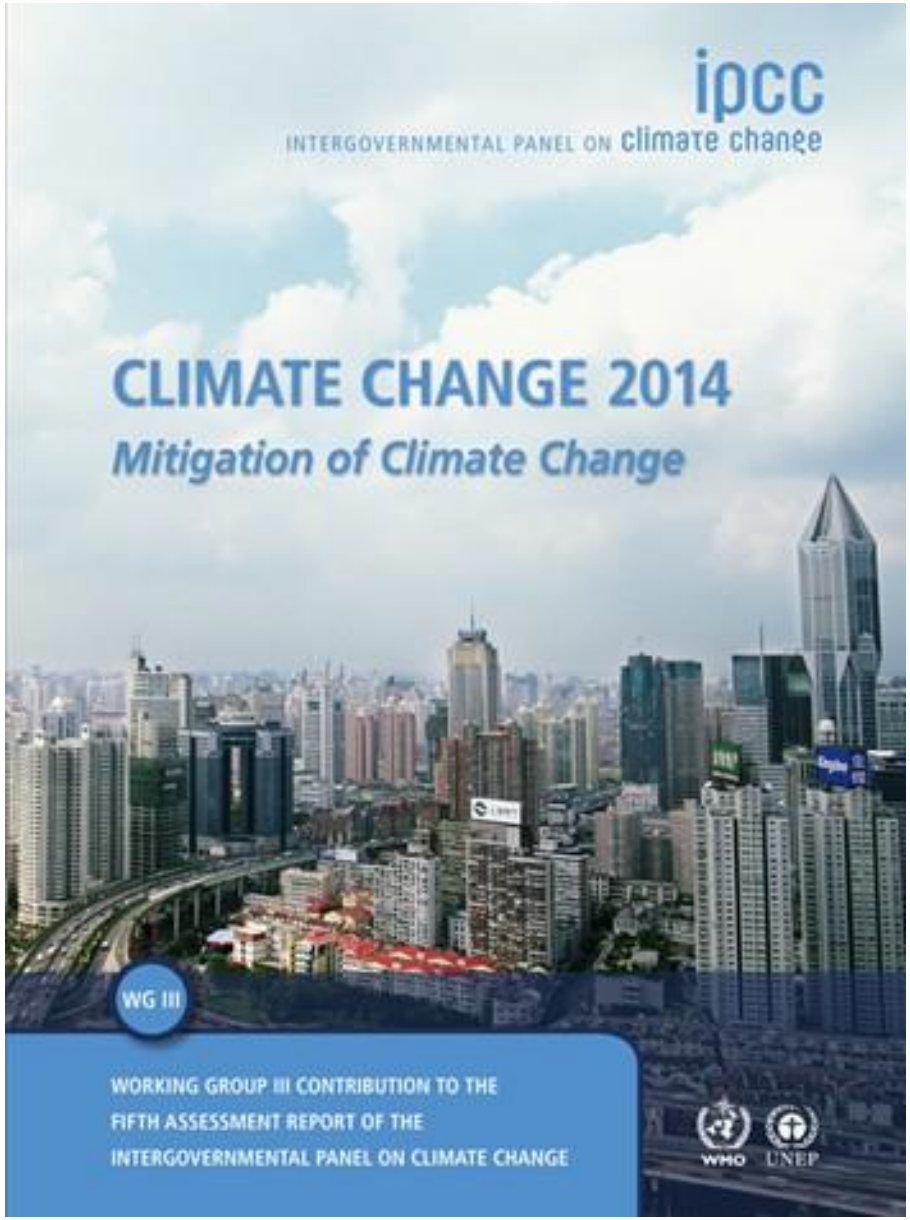
- Established in 1988
- Instrumental in drafting UNFCCC
- 195 governments participate
- Consistent with BM

Assessment Reports by the IPCC

- Working Group I – *Physical Science Basis*
- Working Group II – *Impacts, Adaptation and Vulnerability*
- Working Group III – *Mitigation of Climate Change*

History of *Assessment Reports* by the IPCC

- 1990 1AR
- 1992 Supplementary Reports
- 1995 2AR
- 2001 3AR
- 2007 4AR (Peace Nobel Price)
- 2013-2014 5AR
- 2021-2022 6AR


ipcc
INTERGOVERNMENTAL PANEL ON climate change
CLIMATE CHANGE 2014
Mitigation of Climate Change
WG III
WORKING GROUP III CONTRIBUTION TO THE
FIFTH ASSESSMENT REPORT OF THE
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
WMO
UNEP

Assessment Reports by the IPCC

- Massive intellectual endeavour (financed by the Annex I countries)
- Good synthesis of scientific literature
- Instrumental role of the IPCC Secretariat
- "Summaries for Policy Makers" adopted in a political process

  "[local mitigation] plans and strategies are in their early stages of development and implementation in many countries, making it difficult to assess their aggregate impact on future global emissions"

Uncertainty in *Assessment Reports*

Distinction between

- Evidence
  - Limited
  - Medium
  - Robust

  and
- Agreement (related to the interpretation of the evidence)
  - Low
  - Medium
  - High

Uncertainty in *Assessment Reports* (continued)

Likelihood of the outcome [%]	Expression to be used
99-100	*virtually certain*
95-100	*extremely likely*
90-100	*very likely*
66-100	*likely*
33-66	*about as likely as not*
0-33	*unlikely*
0-10	*very unlikely*
0-5	*extremely unlikely*
0-1	*exceptionally unlikely*

Uncertainty in *Assessment Reports* (example of a careful wording)

> "[i]t is extremely likely that human activities caused more than half of the observed increase in global average surface temperature from 1951 to 2010. This assessment is supported by robust evidence from multiple studies using different methods."

Questions

Q-7 The principle of "common but differentiated responsibility" (CBDR)

[a] was adopted as one of the fundamental principles of UNFCCC

[b] means that developing countries are expected to abate more than the developed ones

[c] allows industrialized countries to exploit natural resources based on their competitive advantage built in the 19th century

[d] is contested by those who were deprived of development opportunities earlier

[e] none of the above

Exercises

E-7 Discuss whether doubts about anthropogenic causes of the "global warming" refer to what the IPCC considers uncertainty related to "evidence" or "interpretation".

Kyoto Protocol (KP)

- Materializes BM
- Limits CO_2 emission from Annex I only
- Baseline of 1990
- To abate 5.2% on average (Annex I countries only)
- Compliance period 2008-2012

Flexibility mechanisms in KP

- Article 6 allows emissions trading
- Article 12 allows *Clean Development Mechanism* (CDM), i.e. claiming an emission reduction credit by an Annex I country created through abatement in a non-Annex I country
- Article 17 allows *Joint Implementation* (JI), i.e. claiming an emission reduction credit by an Annex-I country created through abatement in another Annex I country

CDM – example

Business plan of a refinery in India (non-Annex I country)

- CO_2 emission from a refinery (Soviet technology) 15 Mt
- CO_2 emission from a refinery (Dutch technology) 12 Mt
- Incremental cost: 5 M$
- Global CO_2 emission: +12 Mt or -3Mt ?
- CDM: By financing the incremental cost an Annex I country gets a "credit" for 3Mt of CO_2

Flexibility mechanisms in KP (continued)

- Slight weakening of the dichotomous division of the world into "rich" and "poor" (inherited from the Montreal Protocol) by allowing flexible baselines
- Some economies in transition were allowed to choose alternative baselines and less than 8% reduction (typical for most European countries)
- Poland took advantage of this provision by choosing 1988 and agreeing to 6% reduction

European *Emission Trading System* (ETS)

Anticipating Russian ratification of KP, the European Commission established ETS:

> *This Directive aims to contribute to fulfilling the commitments of the European Community and its Member States more effectively, through an efficient European market in greenhouse gas emission allowances, with the least possible diminution of economic development and employment.*
>
> (2003/87/EC)

Politics of ETS

- European treaties do not allow the European Commission to raise taxes
- ETS auction revenues expected to increase
- High permit prices will
  - Allow the European Commission to finance selected programmes
  - Make carbon-free energy more competitive

Politics of ETS (continued)

Unexpectedly low permit prices (typically less than 10 € / tonneCO_2) motivated the European Commission to manipulate in ETS e.g. by

- Manipulating permit allocations
- "Backloading" (i.e. postponing or confiscating permits)
- Creating "reserves", etc.

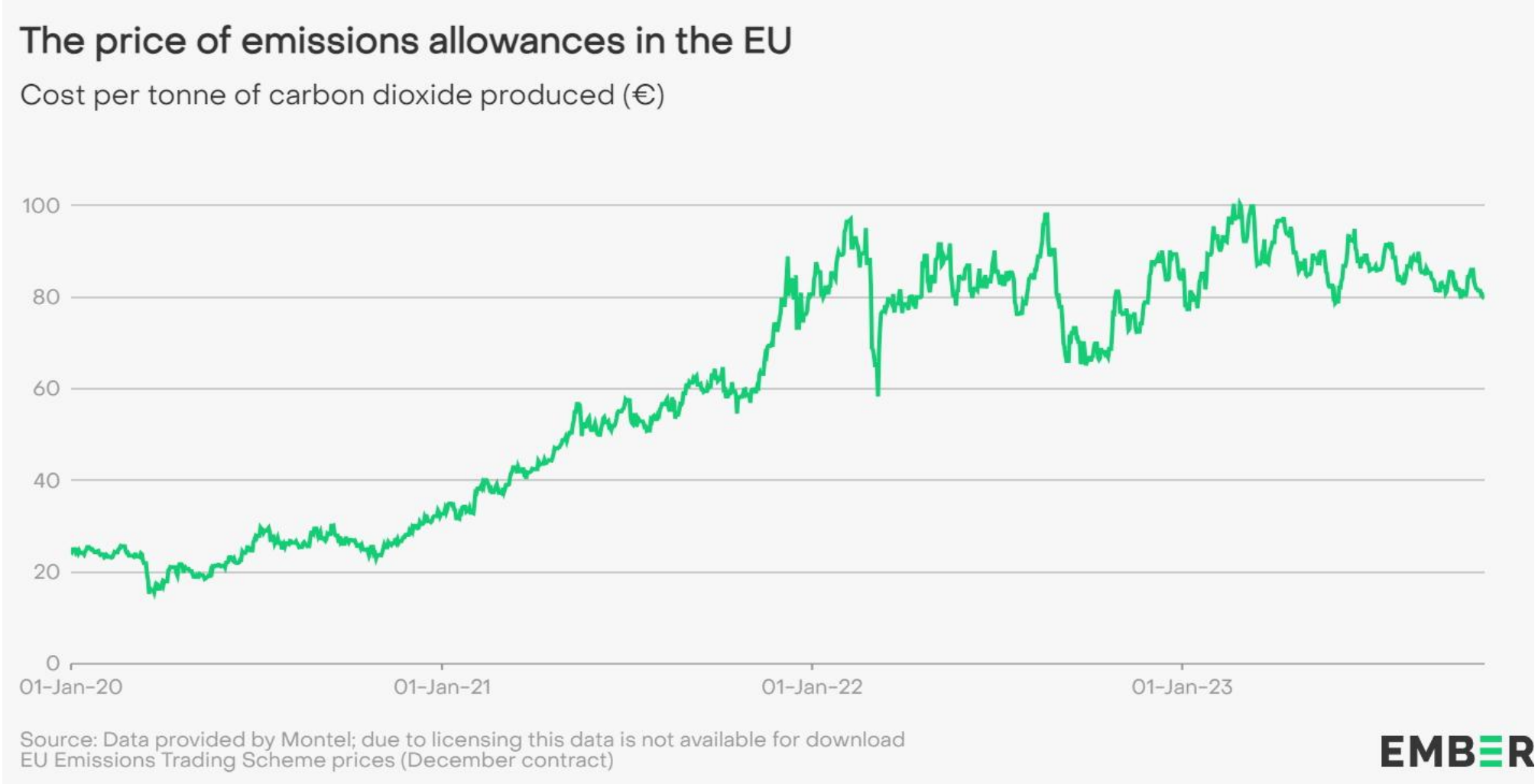
"Backloading" 2014

Total of 900 million tonnes of CO_2:

- 400 million allowances in 2014
- 300 million in 2015
- 200 million in 2016.

"Market Stability Reserve"

Results of backloading



Carbon leakage (CL)

$$CL(\Delta R) = \left(f_N(GDP_N, P_N, GDP_A(R_0+\Delta R)) - f_N(GDP_N, P_N, GDP_A(R_0))\right) / \Delta R$$

where

- A, N – respectively, abating and non-abating regions
- R_0 is the baseline (standard) reduction target adopted in A
- ΔR is an additional reduction target contemplated in A
- P_N identifies an abatement policy adopted in N
- f_N is an emission function for N
- GDP_A is a function of a reduction target adopted in A

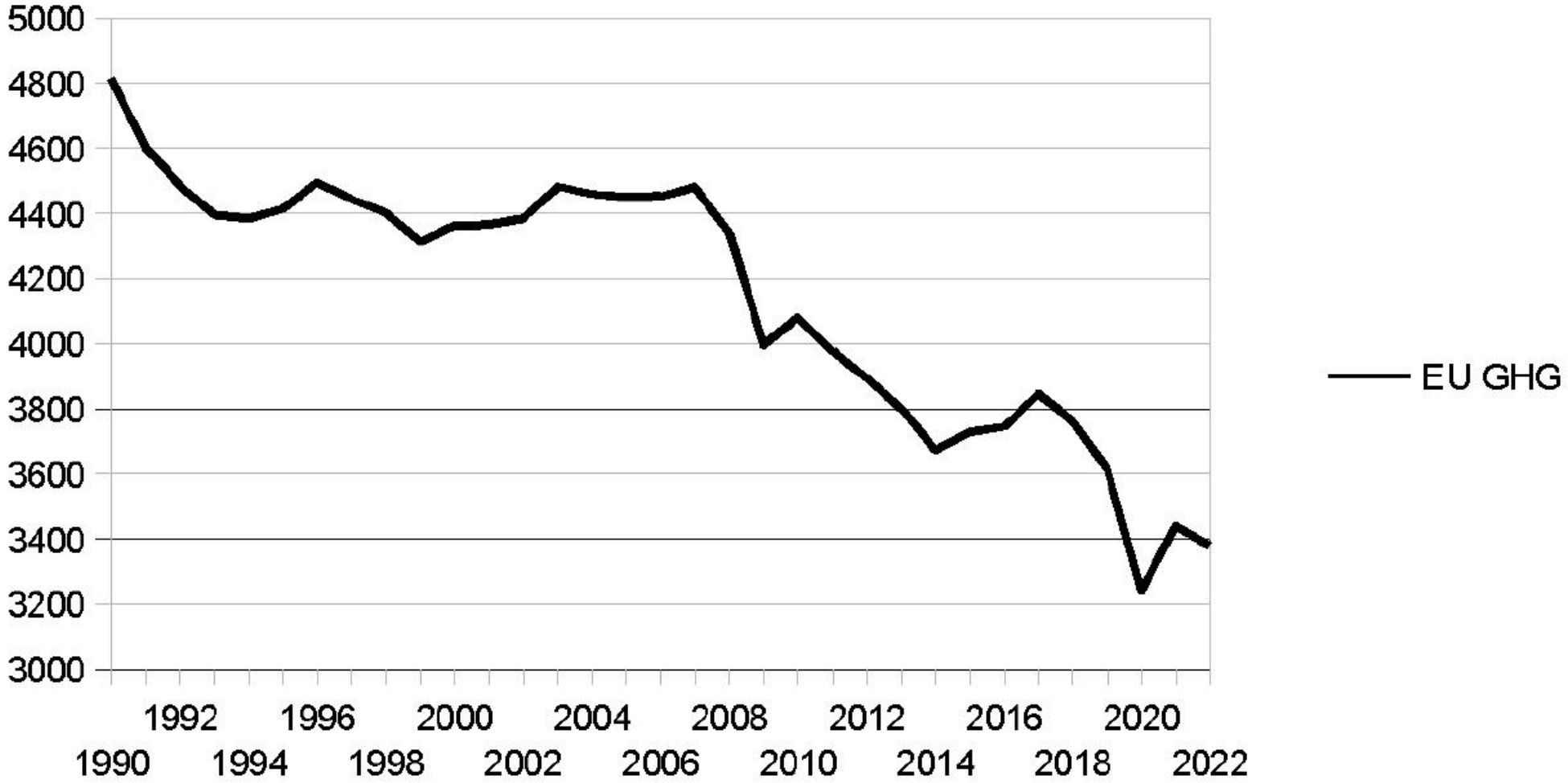
Mechanisms of CL ("green paradox")

- Changes in prices of fossil fuels. An additional abatement effort in A results in lower demand for fossil fuels, which thus leads to their lower price. This, in turn, provides incentives for additional use of fossil fuels in N.
- Changes in prices of final goods. An additional abatement effort in A results in higher prices of carbon-intensive goods there. Their production moves to N, which leads to higher emissions of carbon dioxide in N.
- Changes in production factor prices. An additional abatement effort in A reduces the remuneration of capital there. The capital moves to N, which leads to higher emissions of carbon dioxide in N.

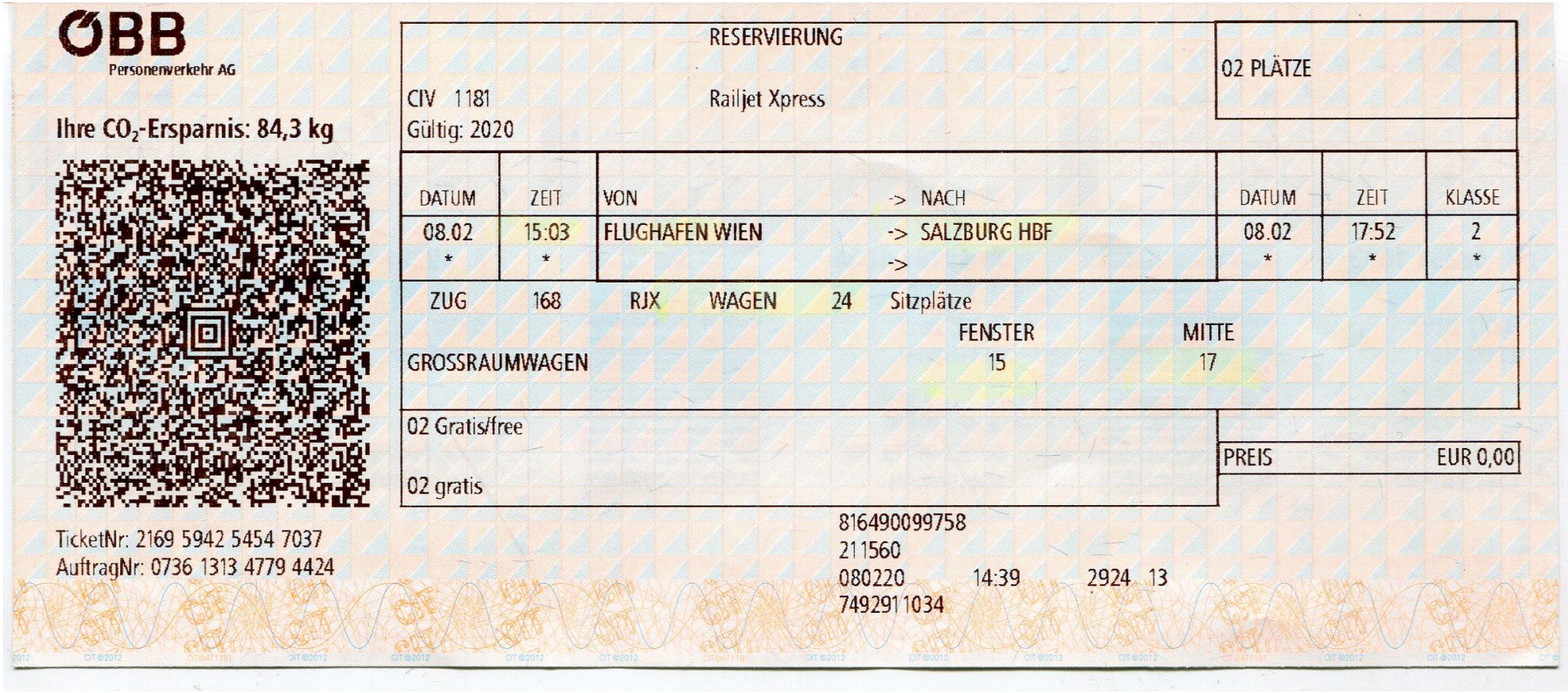
Implications of CL

- Ineffectiveness of "climate protection" policies when a global limit on carbon dioxide emission does not exist
- Abatement commitments of Annex I countries result in higher emissions in non-Annex I countries
- Anti-leakage measures (such as e.g. *Border Tax Adjustments*, BTA; or protection of *Energy Intensive Trade Exposed*, EITE, sectors) can be
  - Contradicting WTO rules
  - Welfare decreasing

European CO_2 emissions



Popularity of "Carbon Footprints"



ÖBB
Personenverkehr AG

Ihre CO_2-Ersparnis: 84,3 kg

RESERVIERUNG

02 PLÄTZE

CIV 1181
Railjet Xpress
Gültig: 2020

DATUM	ZEIT	VON		NACH	DATUM	ZEIT	KLASSE
08.02 *	15:03 *	FLUGHAFEN WIEN	->	SALZBURG HBF ->	08.02 *	17:52 *	2 *

ZUG 168 RJX WAGEN 24 Sitzplätze

GROSSRAUMWAGEN

FENSTER 15

MITTE 17

02 Gratis/free

02 gratis

PREIS EUR 0,00

TicketNr: 2169 5942 5454 7037
AuftragNr: 0736 1313 4779 4424

816490099758
211560
080220 14:39 2924 13
7492911034

Questions

Q-8 Kyoto Protocol failed to protect the global climate
[a] because it was not ratified by the US
[b] because it did not establish binding commitments for most countries
[c] because CDM projects did not attract sufficient funding
[d] despite undertaking effective anti-leakage measures
[e] none of the above

Exercises

E-8 Explain the "green paradox" by analysing what may happen if some agents undertake conservation measures.

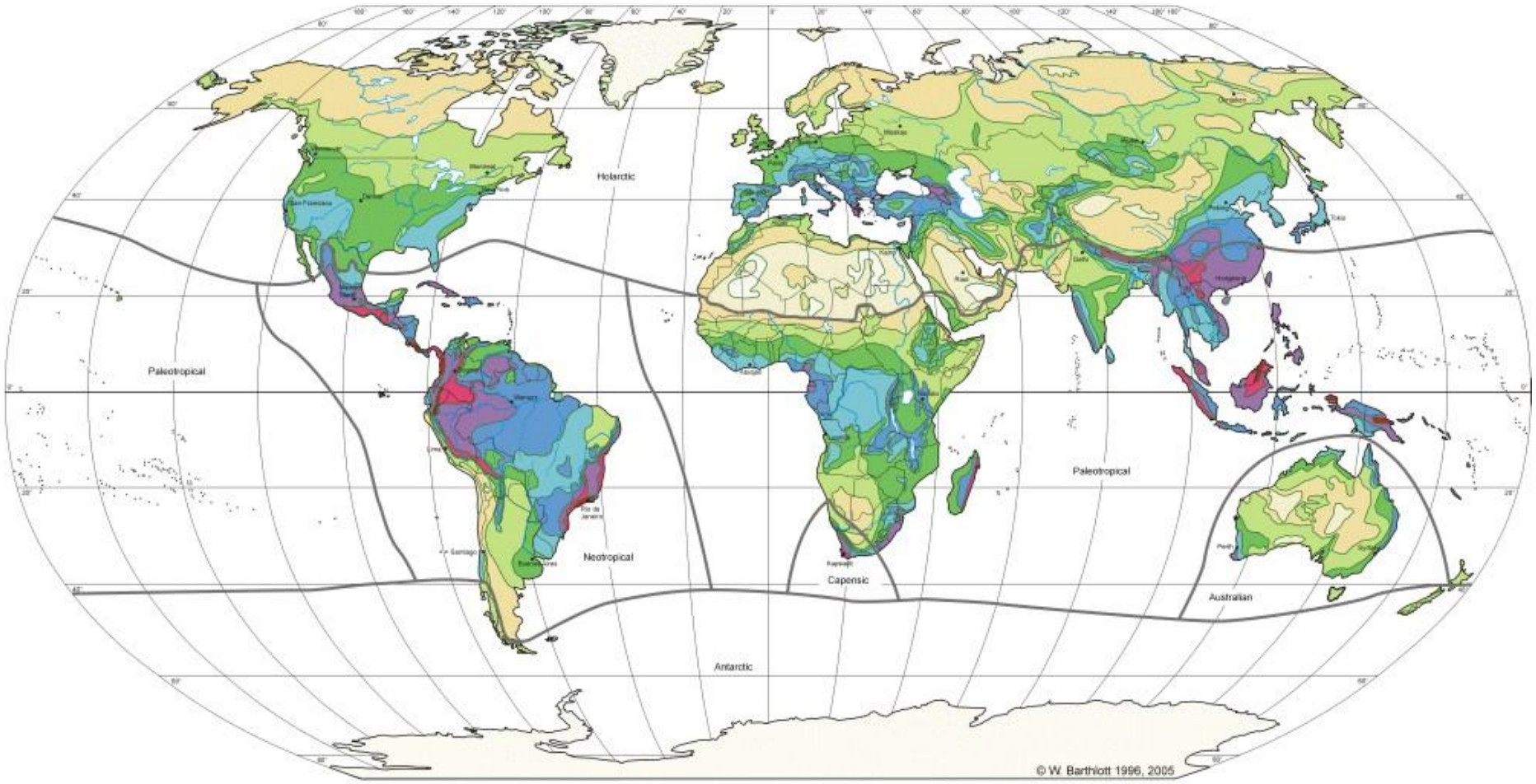
Biodiversity

Biodiversity – a descendant of "nature protection"

Three layers of biodiversity

- Species diversity
- Genetic or population diversity
- Landscape diversity

GLOBAL BIODIVERSITY: NUMBERS OF VASCULAR PLANT SPECIES



Robinson Projektion
Standard-Parallelen 38°N und 38°S

Diversity zones (DZ): Vascular plant species per 10.000 km²

- DZ 1 (<100)
- DZ 2 (100 - 200)
- DZ 3 (200 - 500)
- DZ 4 (500 - 1000)
- DZ 5 (1000 - 1500)
- DZ 6 (1500 - 2000)
- DZ 7 (2000 - 3000)
- DZ 8 (3000 - 4000)
- DZ 9 (4000 - 5000)
- DZ 10 (> 5000)

Capensic: Floral Kingdoms

W. Barthlott, G. Kier, H. Kreft, W. Küper,
D. Rafiqpoor & J. Mutke 2005
verändert nach
W. Barthlott, W. Lauer & A. Placke 1996
Nees-Institut für Biodiversität der Pflanzen
Universität Bonn

Traditional nature conservation measures insufficient to allow future generations to benefit from the Earth's living resources

The preamble to the Convention on Biological Diversity (CBD):

- There is a *general lack of information and knowledge regarding biological diversity*
- There is an *urgent need to develop scientific, technical and institutional capacities to provide the basic understanding upon which to plan and implement appropriate measures*

Biodiversity – public good

- Non-rivalry principle (many simultaneous users can benefit from the same information)
- Non-exclusion principle (those who do not contribute to biodiversity preservation can benefit from the information preserved)

Conclusion:

- Free-riding
- Under-supply of the good
- International convention needed

Convention on Biological Diversity (CBD)

- Prepared by United Nations Environmental Programme (UNEP) in Nairobi
- Signed in Rio de Janeiro in 1992
- Came into force in 1993
- Almost universal acceptance (193 ratifications)
- "Toothless" convention

Aichi biodiversity targets (adopted at the 10th Conference of Parties to the CBD in Nagoya in 2010):

- Five strategic goals
- Almost no quantified targets

Nagoya – capital of Aichi prefecture

Aichi targets

<u>Strategic Goal A</u>: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society

Items 1 through 4, such as:

> *1. By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.*

Aichi targets (continued)

<u>Strategic Goal B</u>: Reduce the direct pressures on biodiversity and promote sustainable use

Items 5 through 10, such as:

> *5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.*

Aichi targets (continued)

<u>Strategic Goal C</u>: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity

Items 11 through 13:

> *11. By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.*

Aichi targets (continued)

<u>Strategic Goal D</u>: Enhance the benefits to all from biodiversity and ecosystem services

Items 14 through 16:

> *14. By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.*

Aichi targets (continued)

<u>Strategic Goal E</u>: Enhance implementation through participatory planning, knowledge management and capacity building

Items 17 through 20:

> *17. By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.*

Access and benefit sharing (ABS)

- Present in CBD (art. 15.7)
- Formalized in Nagoya meeting
- Anecdotic evidence (no regular reporting)
- Merck's arrangement in Costa Rica
  - Donation to In-Bio (1.13 M$)
  - 10,000 samples to be collected
  - 113 $ per sample

Nagoya Protocol

List of benefits from biodiversity exploration

1. Monetary benefits may include, but not be limited to:

(a) Access fees/fee per sample collected or otherwise acquired;

and other items (b) through (j)

2. Non-monetary benefits may include, but not be limited to:

(a) Sharing of research and development results;

and other items (b) through (q)

Division of the world in CBD

- Distinction between the "rich" and the "poor" inherited from Montreal Protocol (and adopted in UNFCCC)
- The convention (and subsequent protocols) introduces the category of "economies in transition" (art.20.2)

Intergovernmental Platform on Biodiversity and Ecosystem Services(**IPBES**) – less influential politically than IPCC

- 2020: Common report of IPCC and IPBES
- Climate protection policies may affect biodiversity protection adversely
- Increase carbon sequestration in natural ecosystems (both marine and terrestrial)

Questions

Q-9 An important reason why the Convention on Biological Diversity (CBD) did not adopt specific quantified targets

[a] is that developed countries did not join the Convention

[b] is that developing countries did not join the Convention

[c] is that biodiversity loss is likely to continue despite efforts undertaken

[d] is the lack of scientific analysis to support any potential targets

[e] none of the above

Exercises

E-9 Discuss whether the Nagoya Protocol ABS payments can be avoided by those who benefit from "bioprospecting".

Rio de Janeiro 1992

"Earth summits"

- Stockholm 1972
- Nairobi 1982
- Rio de Janeiro 1992
- Johannesburg ("Rio+10") 2002
- Rio de Janeiro ("Rio+20") 2012
- Stockholm ("Stockholm+50") 2022


ons Conference
BRASIL
Antonio de Aguiar Patriota
Minister of External Relations
Fernando Collor de Mello
Senator
Former President of Brasil
Maurice Strong

History of "sustainable development" concept

Brundtland Commission (World Commission on Environment and Development) 1983
Brundtland Report (*Our Common Future*) 1987

> *To meet the needs of the present without compromising the ability of future generations to meet their own needs*


UNDP
Empowered lives.
Resilient nations.
United Nations
Development Progra
www.undp.org

Rio achievements (documents)

- UNFCCC
- CBD
- Convention to Combat Desertification
- *Agenda 21*
- Rio Declaration on Environment and Development
- Forest Principles

Agenda 21

Chapter 24: the role of women

Agenda 21

Chapter 24: the role of women

Weak vs. *strong* sustainability

- Types of capital:
  - man-made,
  - human,
  - natural
- Weak sustainability: all capital types are substitutable
- Strong sustainability: all capital types are complementary

What development is sustainable?

- Strong sustainability:
  - no natural capital (especially no exhaustible resources) can be depleted
- Weak sustainability:
  - depletion of exhaustible resources should be offset by investing in renewables (*Hartwick rule*)

Issues in weak sustainability

- Irreversibility of environmental damages
- Societal preferences
- Economic valuation of non-market goods

Herman Daly principles (1990)

(1) With respect to the physical volume of inputs into the economy and its outputs: by consciously limiting the overall scale of resource use, shift technological progress from the current pattern of maximizing throughput to maximizing efficiency understood as the ratio of economic effects achievable from a given throughput.

throughput = input + output

H. D. principles (1990) (cont.)

(2) With respect to renewable resources: by exploiting these on a profit maximizing sustained yield basis prevent them from driving to extinction. More specifically this means that:

(a) with respect to resources serving as inputs such as plants and animals, harvesting rates should not exceed regeneration rates;

(b) with respect to resources serving as "sinks" such as the atmosphere of Earth, waste emissions should not exceed the renewable assimilative capacity.

H. D. principles (1990) (cont.)

(3) With respect to exhaustible resources: maintain the total stock of natural capital by depleting non-renewable natural components (such as mineral deposits) at a rate corresponding to the creation of renewable substitutes.

Misconceptions of *sustainability*

- Synonym for "environmental protection"
- "Sustainability" at local scales
- Sustainable development *versus*
  - Balanced development (growth)
  - Eco-development

Questions

Q-10 The difference between strong and weak sustainability
[a] is that the former imposes stricter constraints on rich countries
[b] is that the latter imposes stricter constraints on rich countries
[c] is that the former does not allow for substitution of natural capital with man-made one
[d] is that the latter does not allow for substitution of natural capital with man-made one
[e] none of the above

Exercises

E-10 Discuss the Herman Daly's emphasis on throughput rather than inputs to production (such as resource extraction) and outputs (such as emission of waste).

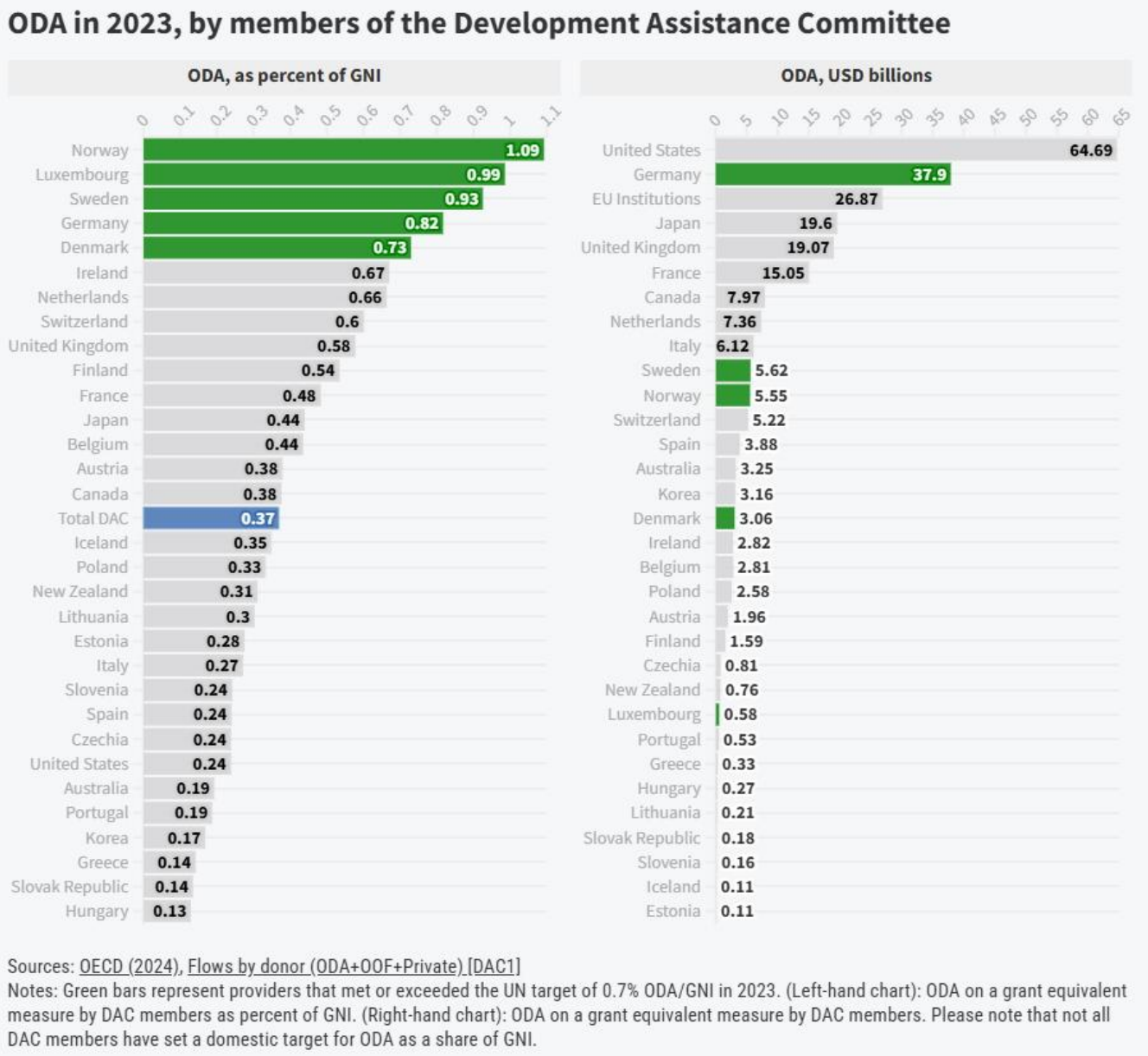
International environmental assistance

Development Assistance Committee (DAC)

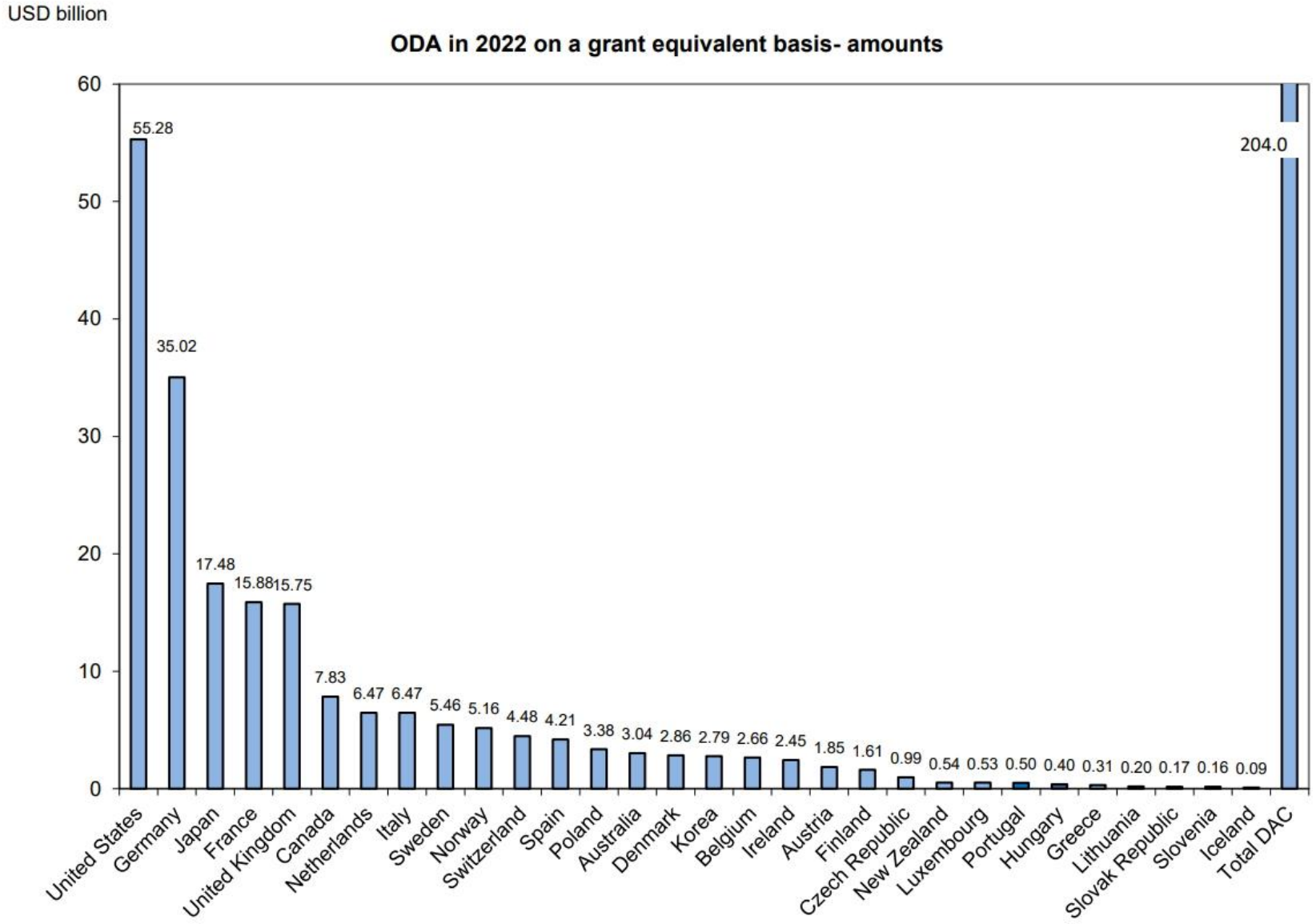
- Club of 29 countries and the European Union
- DAC statistics crucial for development aid analyses
- DAC numbers outweigh anything else

DAC definition of development assistance:

- Undertaken by the official sector (rather than private entities)
- With promotion of economic development and welfare as the main objective (even though they may serve other purposes as well)
- At concessional financial terms (in the case of a loan, the pay-back terms should be more favourable than the standard 10% interest, and no grace period; a grant element of these terms should be equivalent to at least 25%)
- grants, loans and credits are not for military purposes

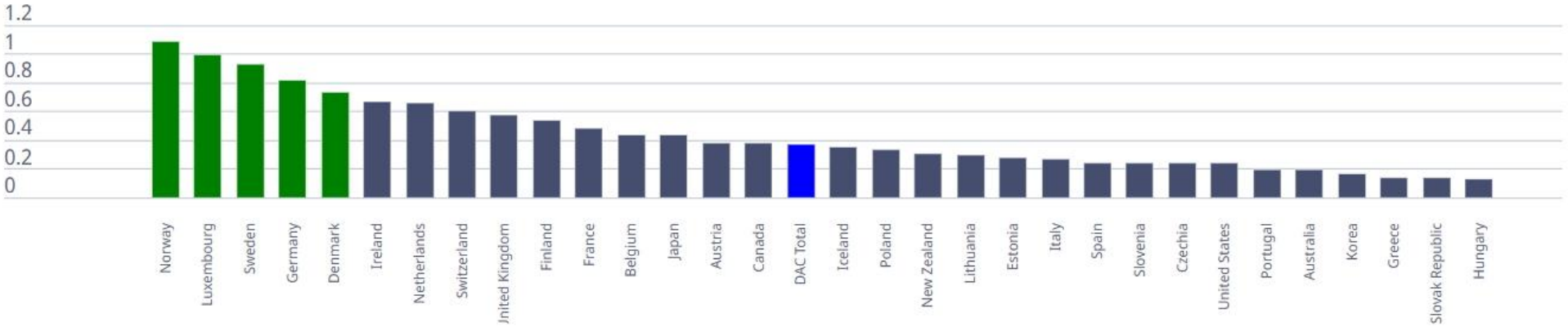


Sources: OECD (2024), Flows by donor (ODA+OOF+Private) [DAC1]
Notes: Green bars represent providers that met or exceeded the UN target of 0.7% ODA/GNI in 2023. (Left-hand chart): ODA on a grant equivalent measure by DAC members as percent of GNI. (Right-hand chart): ODA on a grant equivalent measure by DAC members. Please note that not all DAC members have set a domestic target for ODA as a share of GNI.


USD billion
ODA in 2022 on a grant equivalent basis- amounts
60
50
40
30
20
10
0
55.28
35.02
17.48
15.88
15.75
7.83
6.47
6.47
5.46
5.16
4.48
4.21
3.38
3.04
2.86
2.79
2.66
2.45
1.85
1.61
0.99
0.54
0.53
0.50
0.40
0.31
0.20
0.17
0.16
0.09
204.0
United States
Germany
Japan
France
United Kingdom
Canada
Netherlands
Italy
Sweden
Norway
Switzerland
Spain
Poland
Australia
Denmark
Korea
Belgium
Ireland
Austria
Finland
Czech Republic
New Zealand
Luxembourg
Portugal
Hungary
Greece
Lithuania
Slovak Republic
Slovenia
Iceland
Total DAC

ODA as percent of GNI (grant equivalent) in 2023, by Development Assistance Committee (DAC) members

Percent of GNI



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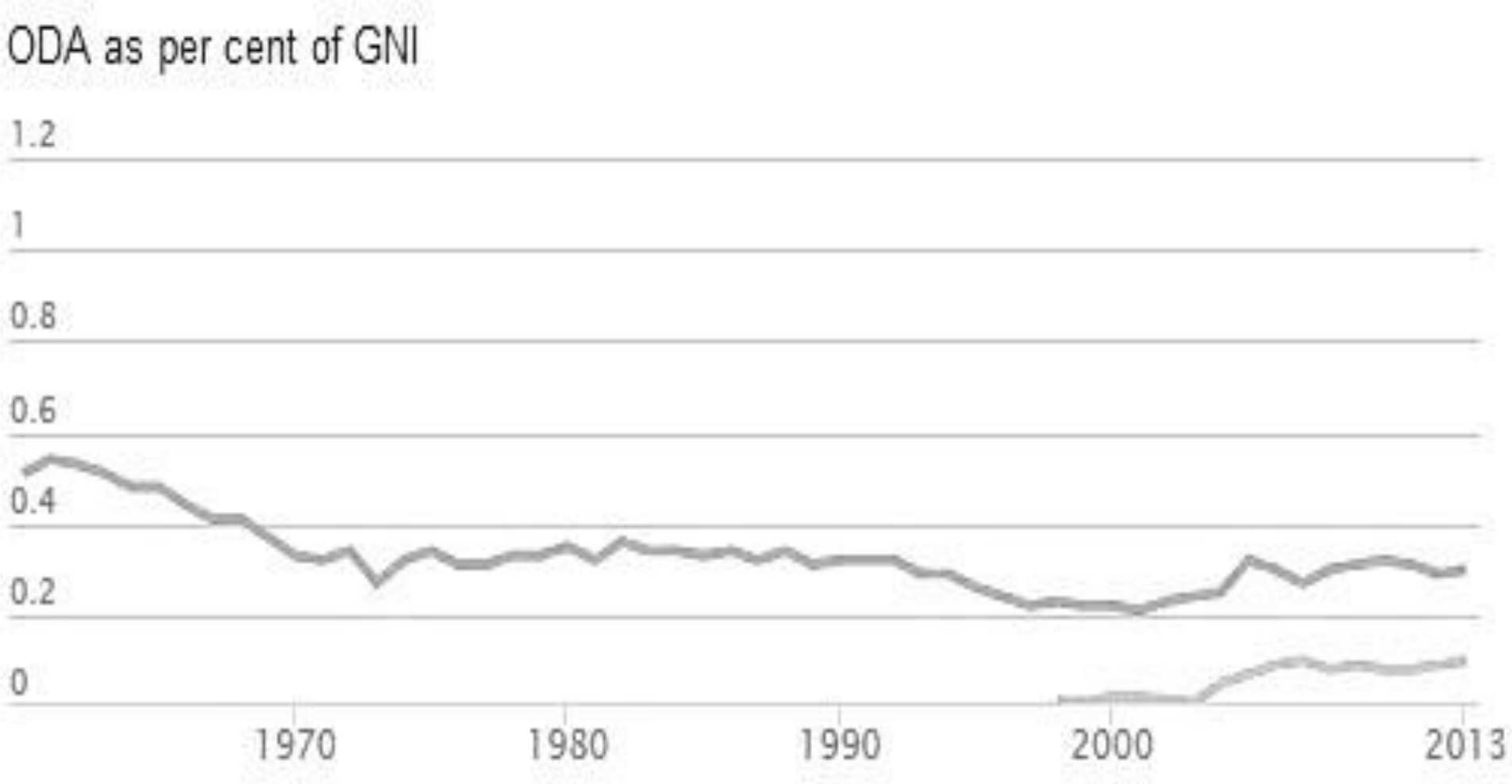
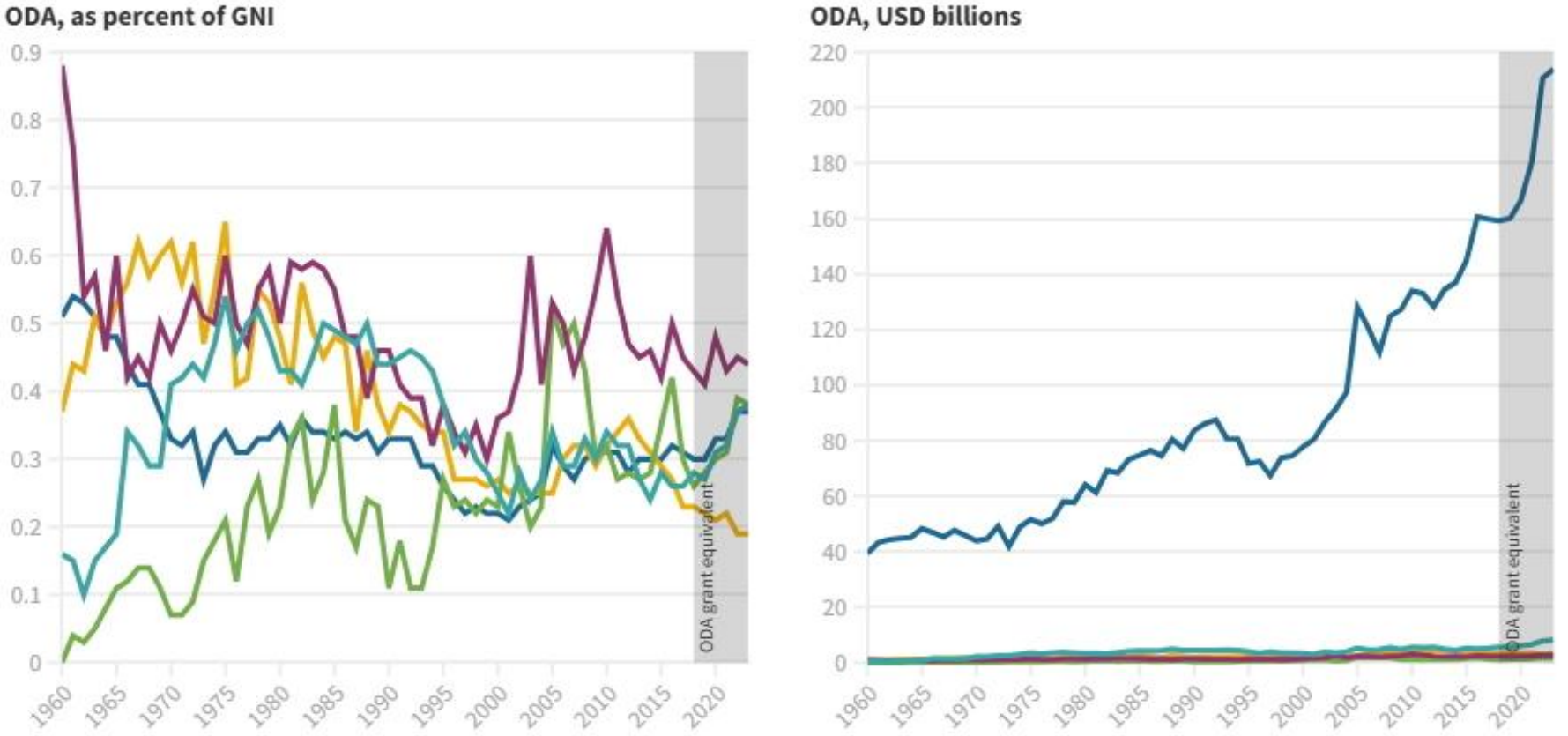


Poland is represented by the lower curve

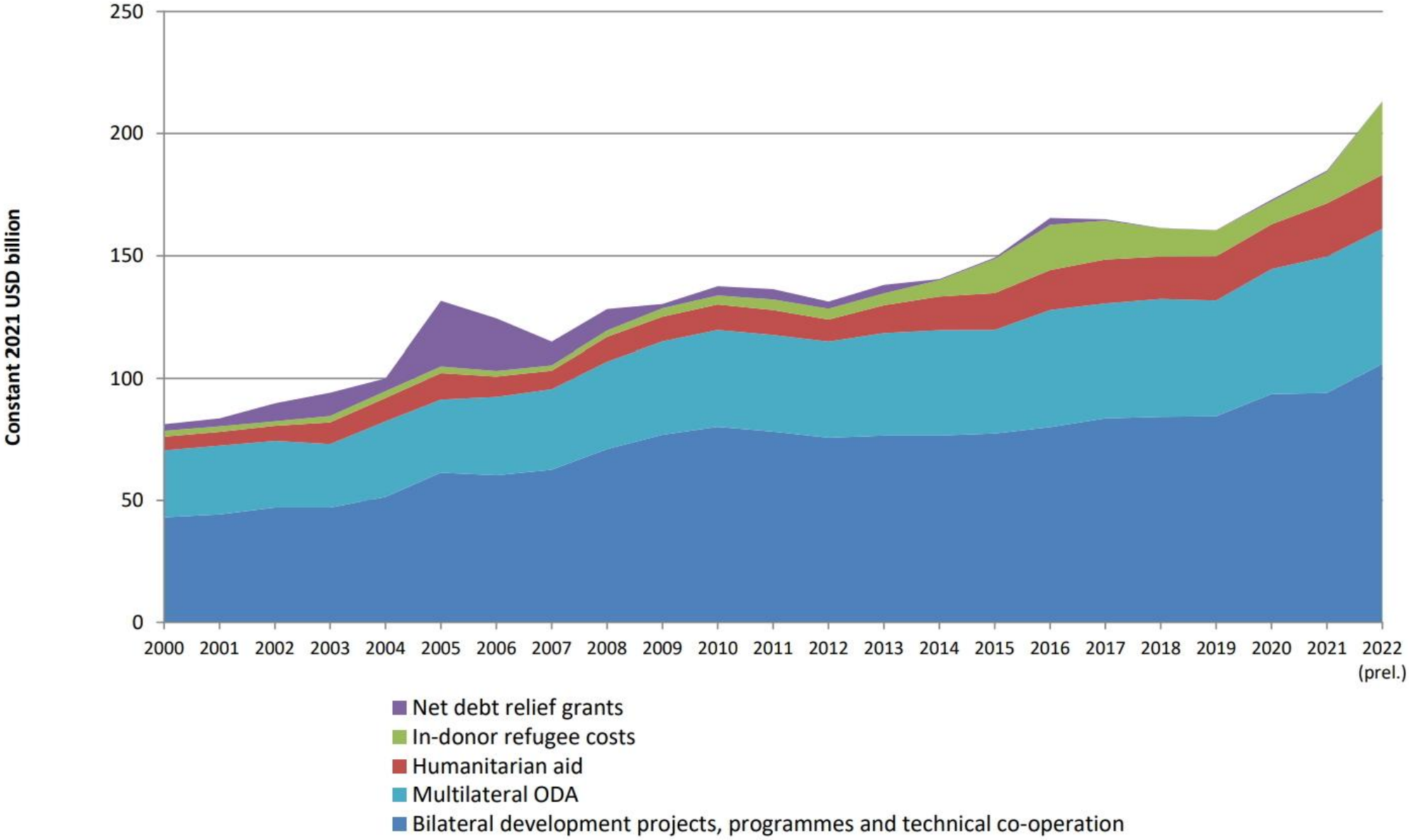
ODA in historical perspective: 1960-2023

Please note: from 2018 onwards, ODA is measured based on grant equivalents.



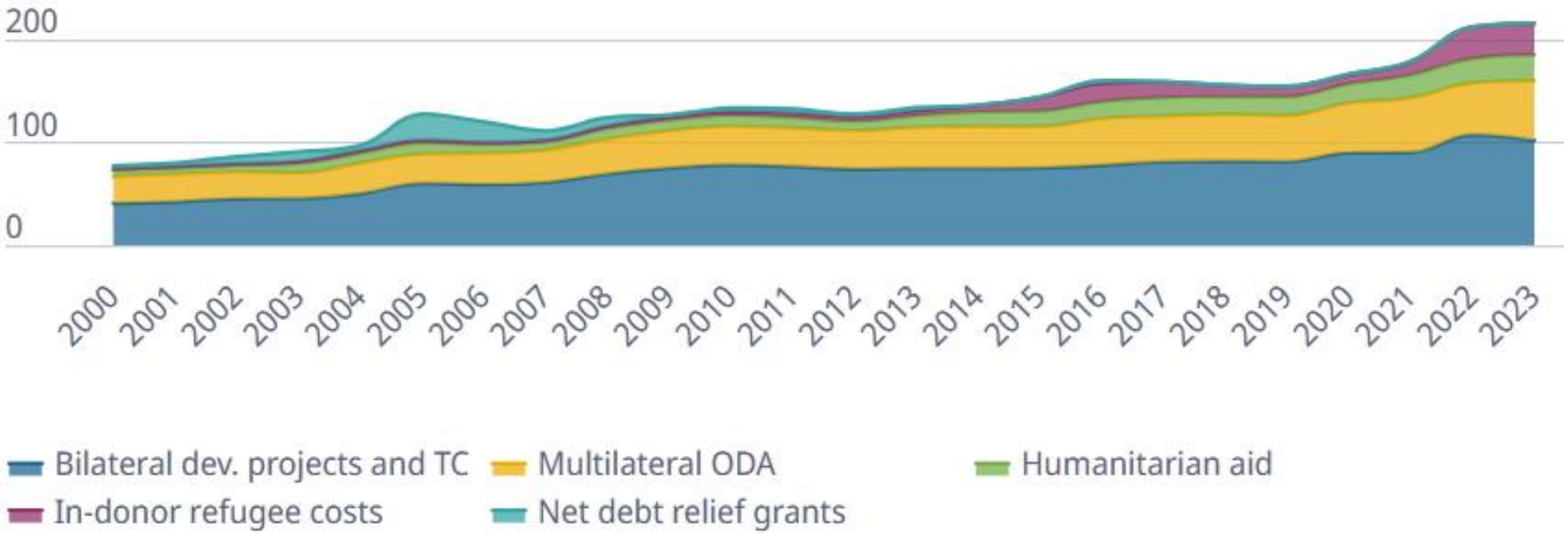
Sources: OECD (2024), Flows by donor (ODA+OOF+Private) [DAC1]
Notes: (Left-hand chart): ODA on flows and grant equivalent measure by all official ODA providers as percent of gross national income (GNI). (Right-hand chart): ODA on flows and grant equivalent measure by all official ODA providers.

Forms of ODA


Constant 2021 USD billion
250
200
150
100
50
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022 (prel.)
Net debt relief grants
In-donor refugee costs
Humanitarian aid
Multilateral ODA
Bilateral development projects, programmes and technical co-operation

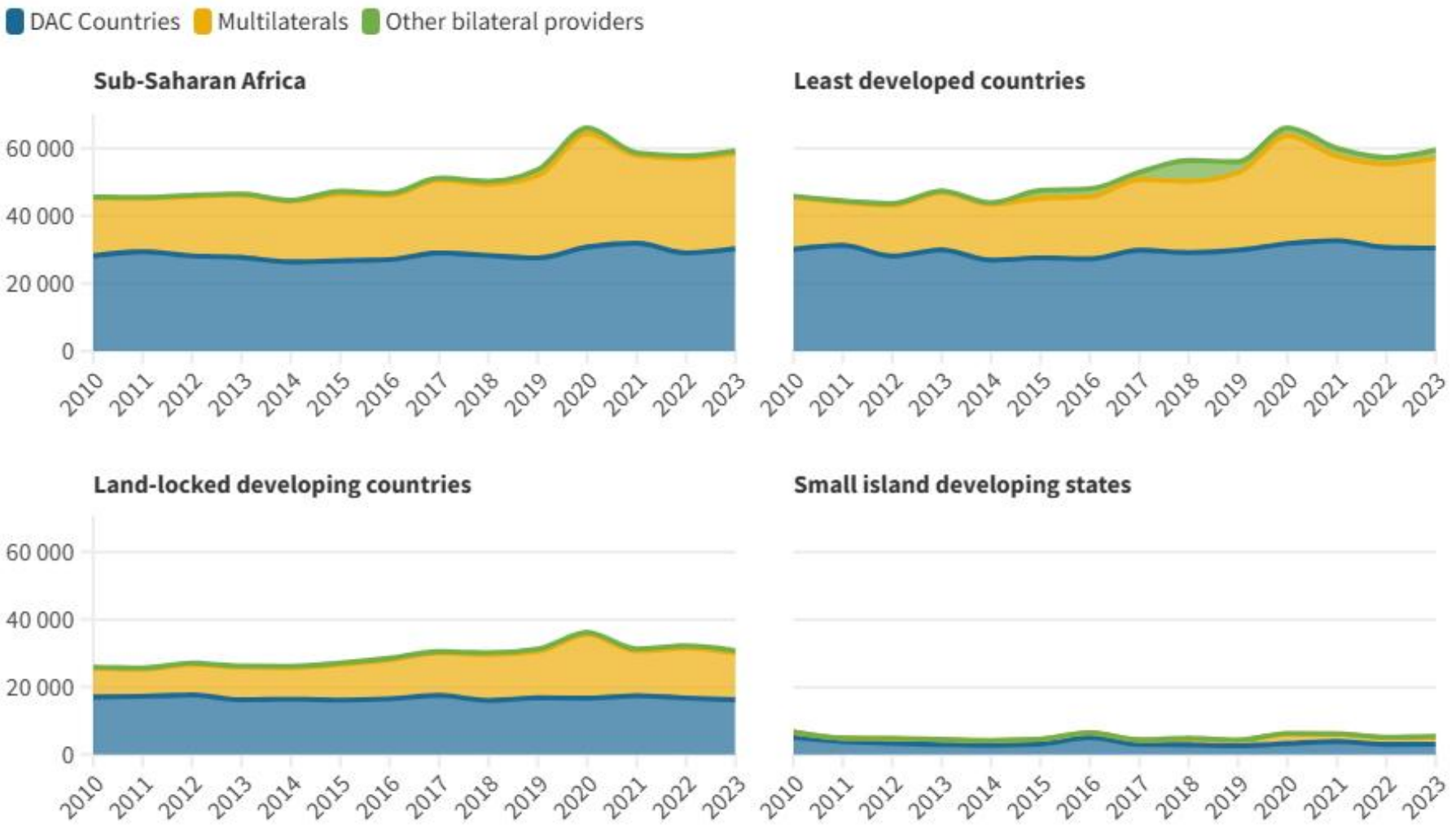
DAC countries - Components of net official development assistance (ODA), 2000-23

USD billions (constant 2022 prices)

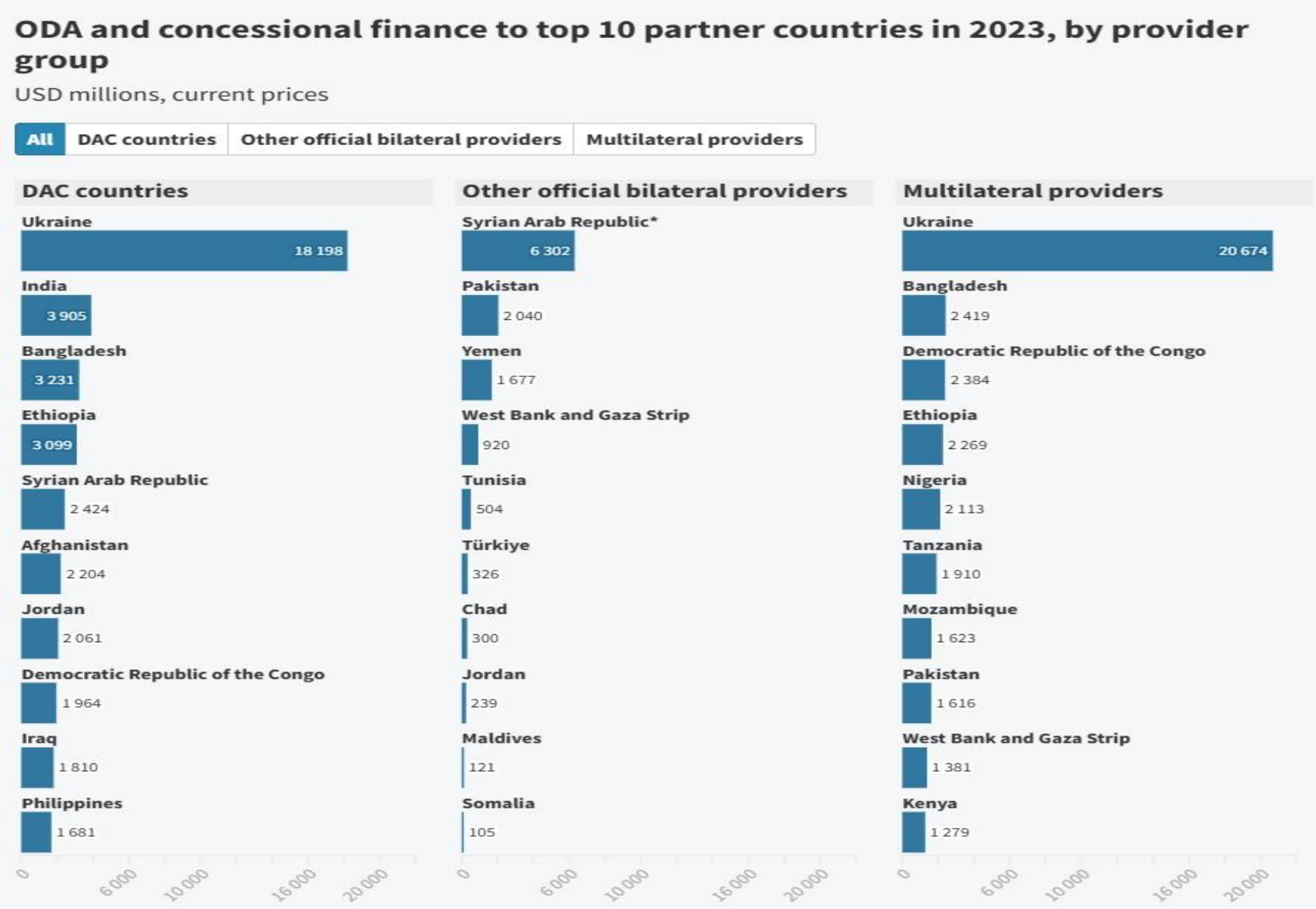


ODA and concessional flows to countries in need, 2010-23

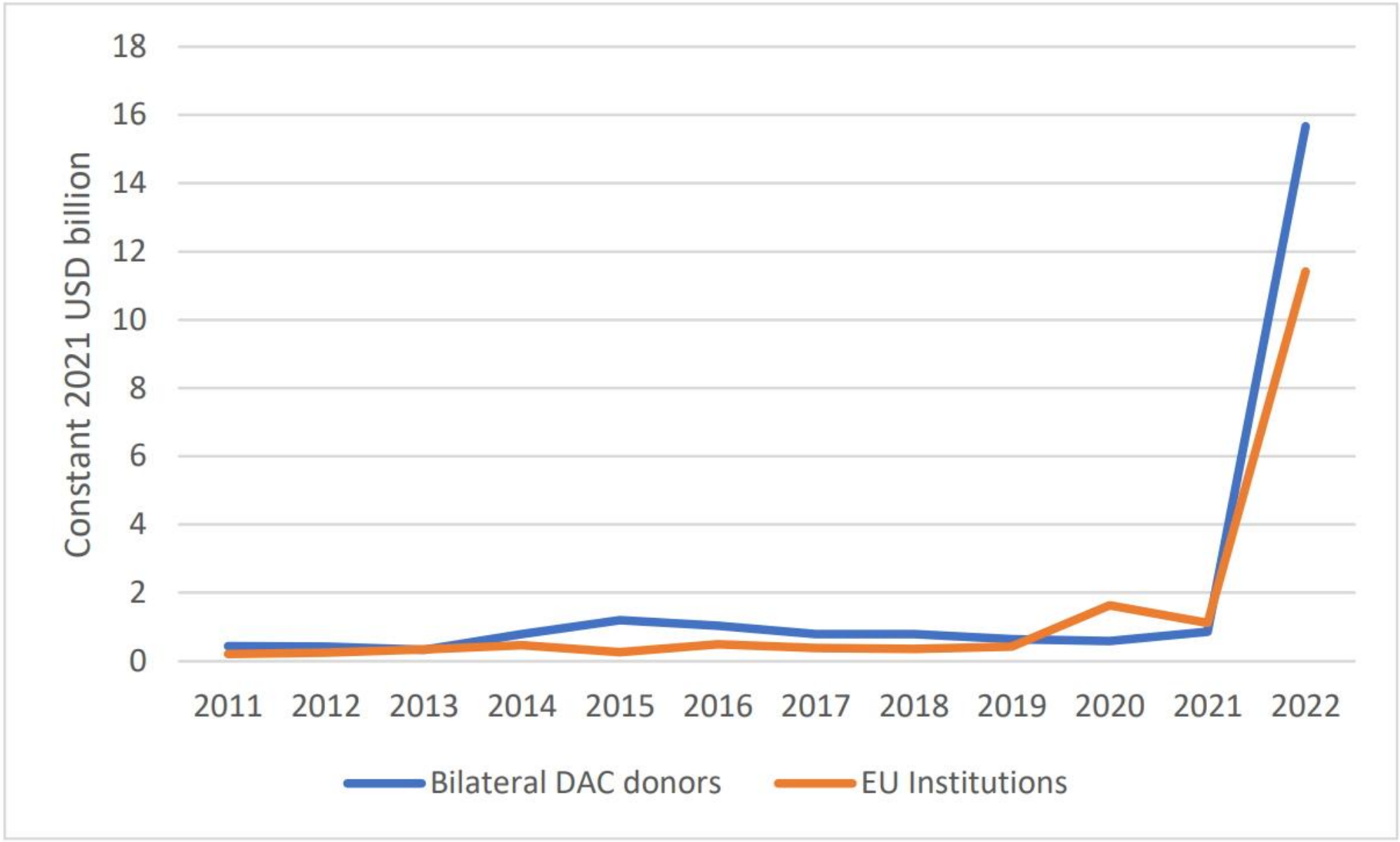
USD millions, constant 2022 prices

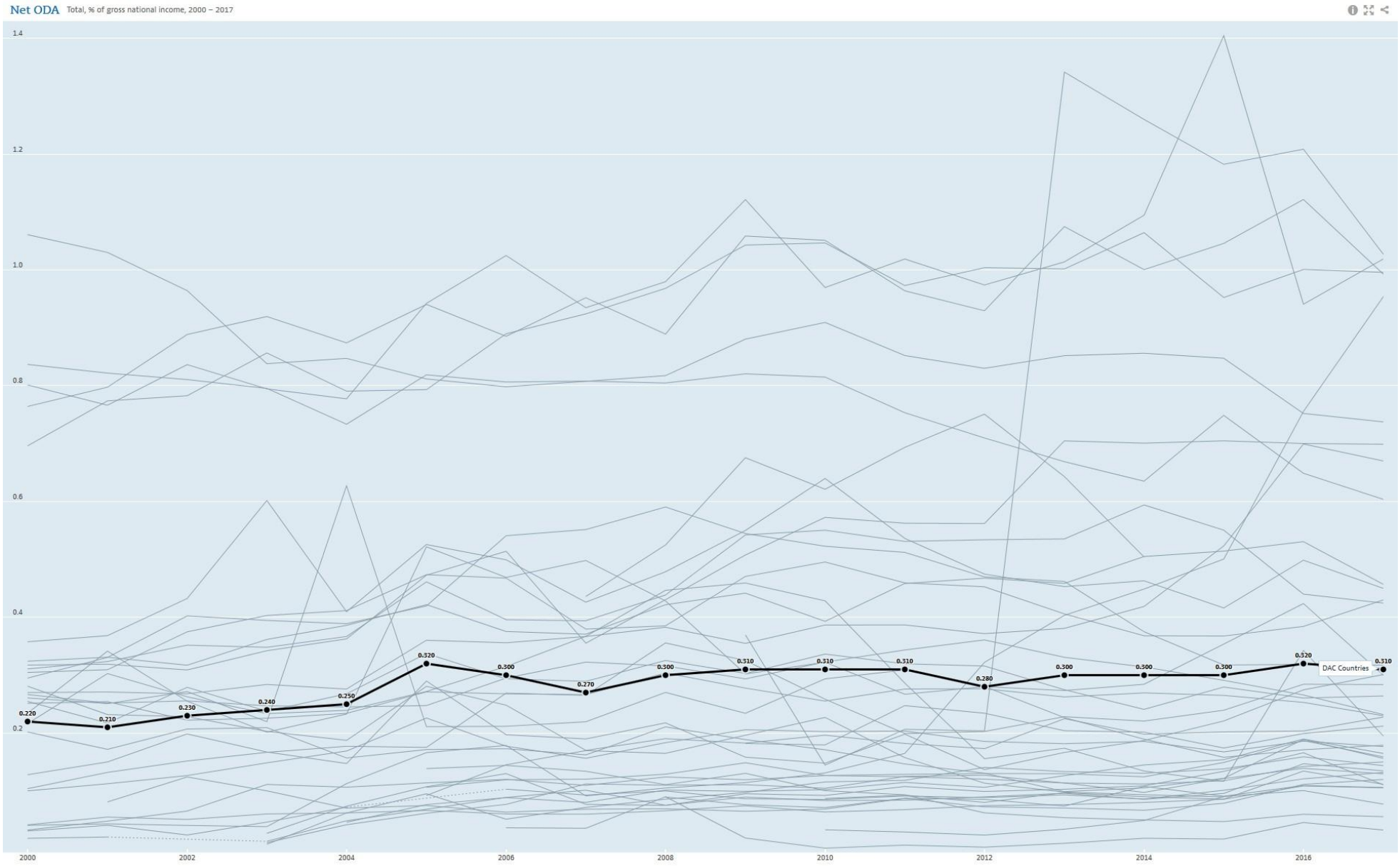


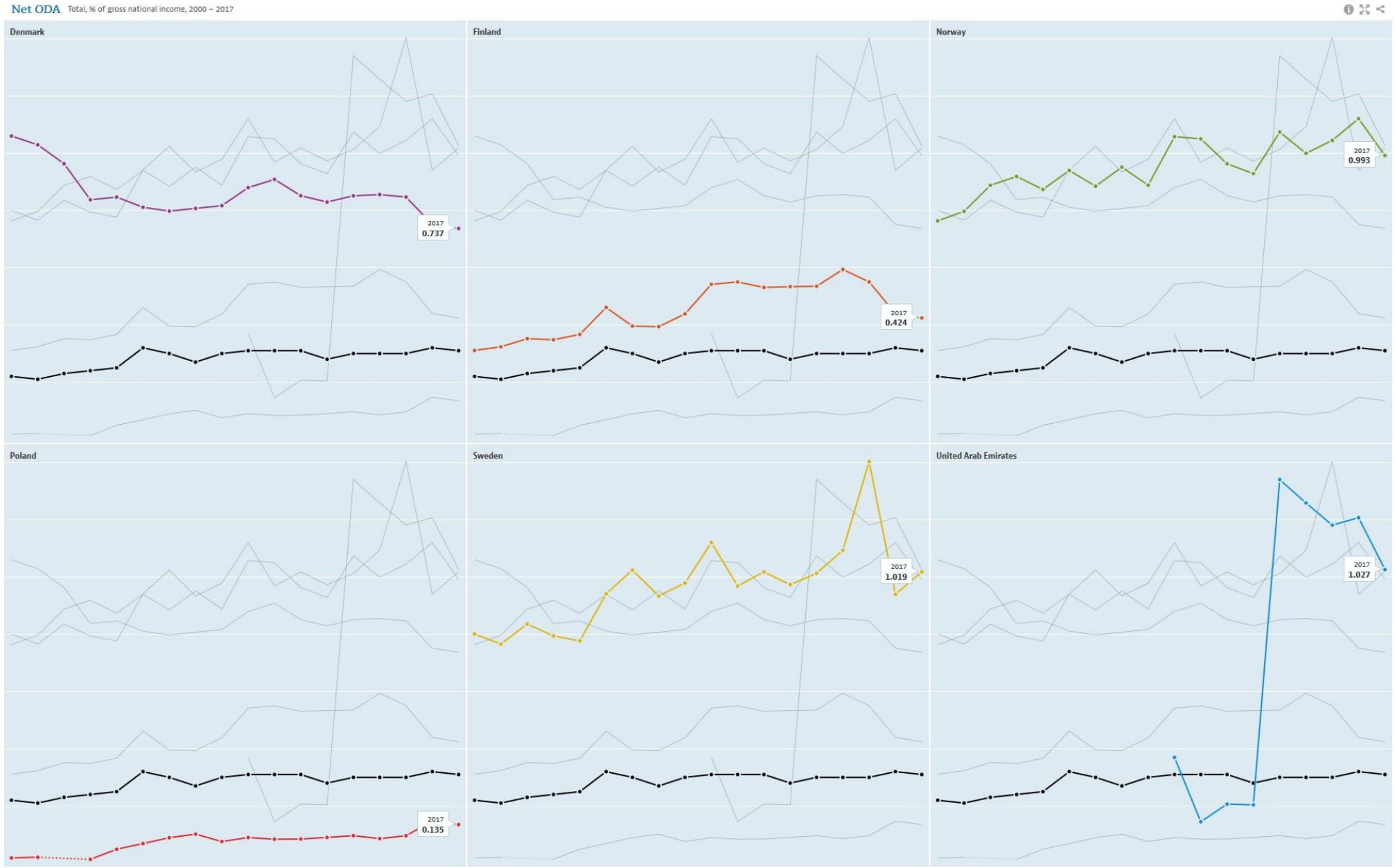
Sources: OECD (2024), ODA disbursements to countries and regions [DAC2a]


ODA and concessional finance to top 10 partner countries in 2023, by provider group
USD millions, current prices
All
DAC countries
Other official bilateral providers
Multilateral providers
DAC countries
Ukraine
18 198
India
3 905
Bangladesh
3 231
Ethiopia
3 099
Syrian Arab Republic
2 424
Afghanistan
2 204
Jordan
2 061
Democratic Republic of the Congo
1 964
Iraq
1 810
Philippines
1 681
Other official bilateral providers
Syrian Arab Republic*
6 302
Pakistan
2 040
Yemen
1 677
West Bank and Gaza Strip
920
Tunisia
504
Türkiye
326
Chad
300
Jordan
239
Maldives
121
Somalia
105
Multilateral providers
Ukraine
20 674
Bangladesh
2 419
Democratic Republic of the Congo
2 384
Ethiopia
2 269
Nigeria
2 113
Tanzania
1 910
Mozambique
1 623
Pakistan
1 616
West Bank and Gaza Strip
1 381
Kenya
1 279
0
6 000
10 000
16 000
20 000

Political circumstances (assistance to Ukraine)




Net ODA
Total, % of gross national income, 2000 – 2017
1.4
1.2
1.0
0.8
0.6
0.4
0.2
2000
2002
2004
2006
2008
2010
2012
2014
2016
0.220
0.210
0.230
0.240
0.250
0.320
0.300
0.270
0.300
0.310
0.310
0.310
0.280
0.300
0.300
0.300
0.320
0.310
DAC Countries


Net ODA
Total, % of gross national income, 2000 – 2017
Denmark
2017
0.737
Finland
2017
0.424
Norway
2017
0.993
Poland
2017
0.135
Sweden
2017
1.019
United Arab Emirates
2017
1.027

Quantitative assessments

- Total ODA was almost $180 billion in 2012 (grants and loans)
- In current prices, it has grown by 3%-4% annually
- Growth has been slower in real terms
- The total corresponds to
  - $180 per head in donor countries
  - $30 per head for an average recipient of ODA

Quantitative assessments (continued)

- Large geographical and time variations
- Iraq received over $20 billion in 2005, but between 2009 and 2012 it got less than $2 billion per annum
- In contrast, between 2009 and 2012, Afghanistan received more than $5 billion each year, while between 2003 and 2008 it was less than $2.5 billion

Environmental components in ODA

According to OECD statistics:

- Water and sanitation
- Energy
- Agriculture, Forestry, Fishing

Broader than environmental protection – may serve as its upper estimate

- This total grew from $15.5 billion in 2006 to $35.7 billion in 2012, i.e. from 12% to 20%
- Environmental protection has absorbed roughly 15% of ODA.

Poland as a recipient of environmental assistance

- Taxpayers in many developed countries were inspired by news about environmental disruption in the former Soviet bloc
- Poland offered a fairly stable administrative infrastructure, promising much less corruption than in alternative destinations
- As a result, Poland received quite sizable environmental assistance
- The amount pledged for 1991-1996 was $230.1 million, i.e. $46 million per annum – slightly over $1 per head
- It accounted for 1%-2% in the early 1990s

Poland (continued)

Out of assistance money in 1991-1996:

- Areas of expenditure
  - 39% spent on air protection
  - 26% spent on water protection
- Types of expenditures
  - Investment expenditures – 57%
  - Pre-investment expenditures (e.g. technical projects, analyses, etc.) – 22%
  - Other (such as training) – 21%

"Tied" procurement

- Money to be spent on purchases from the donor country
- Increases the cost of purchases by 15%-30%
- *Recommendation on Untying ODA* (OECD 2001)
- Share of untied assistance grew from 46% to 82% by 2008

Questions

Q-11 Adopted by the Development Assistance Committee (DAC) definition of assistance
[a] excludes any loans
[b] excludes measures aimed at increasing material standards
[c] includes military expenditures if the beneficiary needs to defend its territory
[d] includes only those subsidies that are not "tied"
[e] none of the above

Exercises

E-11 Does the share of Official Development Assistance (ODA) in a country's Gross National Income (GNI) inform about the generosity of its citizens?

Debt for environment (DFE) swaps

- The predicament of developing countries
  - Indebtedness
  - Natural capital disruption

- 1984-1990: Early optimism
  - Lovejoy, 1984: debt-for-nature swap
  - Bolivian "debt-for-environment swap", 1987
    ($ 100,000 ? $ 100,000 + $150,000 ? $ 650,000 ?)

DFE experience

- 1990-1996: Second thoughts
  - Do creditors have environmental interests?
  - Direct payments more efficient
  - Social / financial mechanisms ambiguous
    - Serving First World banks' bottom lines
    - Ignoring Third World people preferences
  - Creditors' preference for debt-for-equity swaps (99% of swapped funds)
- 1997-1998: Revived interest

The USA-Bolivia swap

Money flows

USA

CityCorp → Conservation International
$ 100,000

US-Taxpayers → CityCorp
$ 100,000

Bolivia

Government → Beni
$ 250,000

B-Taxpayers → Budget
$ 250,000

Environmental interests

Country *A* can be said to have an environmental interest in country *B* when

(1) *B* is an "upstream" (or "upwind") polluter affecting *A*
(2) *B* is a provider of a public good whose supply is of interest to *A*
(3) *A* and *B* exploit the same common resource stock
(4) *A* and *B* consume services provided by the same common environment, but the value attached to these by *A* is higher than that attached by *B*
(5) *A* appreciates the option, vicarious, or existence value of a resource owned by *B*

Environmental interests (continued)

To the extent that the indebtedness problem affects first of all those:

- who control biodiversity (type 2)
- who can offer inexpensive carbon sinks (type 3)
- whose production and development plans do not undergo the same domestic checks (type 4)
- whose survival very much depends on saving their resource base (type 5)

Correlation with environmental interests is, in fact, implied.

DFE as a game: economic literature

- Conflicting preferences: debtor-creditors
- Earlier game theoretic approaches
  - Free riding / public good aspect
    - Pollution abatement game (e.g. Mäler 1989)
    - Self-enforcing agreements (e.g. Barrett 1994)
  - Issue-linkage (e.g. Folmer *et al*. 1993)
  - Second best solution to imperfect enforcement: Debt-for-nature game (Chambers *et al*. 1996)

Game I: Environment *vs*. Equity (1)

- Game I played by a debtor with creditors separately – main options available:
  - No swap (NS);
  - Debt-for-equity swap (EQ); and
  - Debt-for-environment swap (EN)

Game I: Environment *vs*. Equity (2)

Hypothetical payoffs in a creditor-debtor game

		Creditor		
		NS	EQ	EN
Debtor	NS	0,0	0,0	0,0
	EQ	0,0	*a*,*b*	*c*,*d*
	EN	0,0	0,0	*e*,*f*

- The payoffs understood as incremental to the no-swap option
- Trivial non-cooperative outcome

Game I: Environment *vs*. Equity (3)

- Nash equilibrium (EN-EN) if $e \geq c$, and $e, f \geq 0$;
  - If, in addition a<0, then (EN-EN) is the only non-trivial equilibrium
- If $a, b \geq 0$, and $b \geq d$ then (EQ-EQ) is another Nash equilibrium
- For a solvent debtor
  - $a < 0$
  - $e \geq c$, and $e > 0$
  - creditor's "environmental bias" implies $c > 0$
- Creditor's general preference $b \geq d \geq f$; substantial environmental benefits of the creditor imply $f \geq 0$

Game I: Environment *vs*. Equity (4)

The model

- Predicts a debt-for-environment swap as a Nash Equilibrium between a solvent and environmentally conscious debtor and a creditor without a strong established presence in the debtor's market
- Anticipates that no swap will take place if the creditor is successful in debtor's market anyway
- Explains why the debtor may be better off without a swap rather than with a precedent-setting debt-for-equity arrangement which makes other creditors expect a departure from the debt-for-environment preference

Game II: Membership in DFE (1)

- Recognition of the debtor's firm preference for debt-for-environment swaps
- Non-environmental (mainly financial) benefits perceived as crucial by creditors
  - Contracts
  - "Leverage" through co-financing requirement
- Benefits from non-participation include free-riding on the debtor's spending available for non-members

Game II: Membership in DFE (2)

- How many members can the DFE accommodate?
  - Payoff functions:
    - $R_p(\mathbf{s}) = g - h\mathbf{s}$ (for participants)
    - $R_n(\mathbf{s}) = j + k\mathbf{s}$ (for non-participants)
    - **s** is the number of participants in the swap,
    - $g, h, j, k > 0$ are constants
  - Participation pays if:
    - $R_p(\mathbf{s}) > R_n(\mathbf{s}-1)$, i.e.
    - $\mathbf{s} < (g-j-k)/(k+h)$
- $\mathbf{s}^* = [(g-j-k)/(k+h)]$ is the largest number of countries that the DFE can sustain

Game II: Membership in DFE (3)

- More realistic analyses:
  - Creditors perceived as non-identical
  - **s** defined as the amount of money contributed to the DFE rather than the number of countries
  - The equilibrium condition for $\mathbf{s}^*$ reinterpreted as a condition for increasing a creditor's contribution to the DFE (e.g. between zero and some percent of the debt)

Game II: Membership in DFE (4)

- Observations
  - Downwind or downstream countries enjoy higher benefits from participation
  - Countries having strong established presence in the debtor's country market perceive higher benefits from non-participation

Questions

Q-12 Debt-for-environment (DFE) swaps

[a] emerged as a frequent mechanism to solve indebtedness and nature disruption problems simultaneously

[b] became more popular than debt-for-equity swaps

[c] globally account for less than 2% of debt rescheduling agreements

[d] have provided a stable source of environmental expenditures in many European countries

[e] none of the above

Exercises

E-12 Explain why in Game I analysed in the class, a mismatch between debtor's and creditor's preferences such that the former insists on debt-for-equity swap while the latter insists on debt-for-environment swap results in payoffs (c,d) rather than (0,0) i.e. no swap at all.

Polish EcoFund

- Polish debt rescheduling negotiations in 1990-1991
  - Over $ 33 billion at stake
  - Polish targeted level: 80% reduction
  - International consensus: 50% reduction
- March 5, 1991: Memorandum of the Minister of Environment, *Redirecting debt service for environmental protection purposes*; 4 international priority issues:
  - Long range transboundary air pollution
  - Eutrophication of the Baltic Sea
  - Climate change
  - Biodiversity

The Paris Club decision of 1991

- April 4, 1991: Prime Minister appoints *Interim Interministerial Committee* in charge of the debt-for-environment swap
- April 21, 1991: Paris Club decisions
  - 50% debt forgiveness
  - Additional 10% can be swapped in voluntary bilateral agreements (potentially up to $ 3.3 billion)
  - No environmental preference

Designing the Polish EcoFund (1)

- Eruption of "debt-for-something swap" proposals
- The environmental proposal wins as the most comprehensive and convincing one

Designing the Polish EcoFund (2)

- July 1, 1991 (Oslo): Creditors meet to discuss the Polish EcoFund proposal
  - 4 priority areas based on the March 5 Memorandum
  - Located in Poland, multilateral facility to coordinate all bilateral swaps
  - Collective minority representation of creditors on the supervisory board (but: 2/3 majority voting rule)
  - Project selection according to cost-effectiveness criteria

Designing the Polish EcoFund (3)

- Purchases (co-)financed on a "club basis"; no *ex ante* tied procurement
- Periodic analyses of the geographical distribution of contracts in order to *ex post* approximate the distribution of commitments
- Additionality of expenditures

"Games" played by the Polish government

- Game I – to convince about DFE (no Debt-for-Equity swaps)
- Game II – to maximize membership of the EcoFund

Poland's debt owed to Paris Club countries

Rank		Debt (as of April 1, 1991)		Debt-for-Environment Swap	
		Million USD	%	Year	Million USD
3.	Austria	3719	11	-	-
13.	Belgium	336	1	-	-
5.	Brazil	3403	10	-	-
6.	Canada	2899	9	-	-
15.	Denmark	243	<1	-	-
16.	Finland	143	<1	-	-
2.	France	5171	15	1992	51.7
1.	Germany	6000	18	-	-
7.	Great Britain	2762	8	-	-
8.	Italy	1647	5	1998	32.6
9.	Japan	1276	4	-	-
11.	Netherlands	662	2	-	-
14.	Norway*	322	1	1997	0.1
17.	Spain	96	<1	-	-
10.	Sweden	613	2	1997	6.6
12.	Switzerland	528	2	1993	52.8
4.	United States	3538	11	1991	367.0
	Total	**33358**	**100**	**x**	**510.8**

* Having been satisfied with the EcoFund's operations, Norway increased its contribution to 10% of debt due after 1998.

EcoFund's experience (1)

- Multilateralism, elimination of tied procurement, and emphasis on cost-effectiveness have proved to be successful design characteristics of the EcoFund
- Outstanding performance of the EcoFund (confirmed by the OECD and KPMG in 1997) has led to renewed interest in debt-for-environment swaps
- A "creditor" is a heterogeneous entity with some interest groups advocating for debt-for-environment swaps and others insisting on debt-for-equity swaps

EcoFund's experience (2)

- Strong international pressures for bilateralism and tied procurement
- Participation in the Polish swap initiative reflects financial rather than environmental considerations (interests) of the creditor countries
- Participation is more likely for creditors without a strong established presence in the Polish market
- Confining procurement strictly to the EcoFund "club" – justified by the "club's" diversity – could have weakened *free-rider* motivation not to join the "club"

EcoFund's experience (3)

- Financial contribution to Poland's environmental protection modest (in quantitative terms)
- Lasting contributions:
  - Establishing a domestic institution to address international priorities
  - Promoting the concept of cost-effectiveness, later taken over by other Polish financial institutions

EcoFund's experience (4)

- Weak prospects for replicating the Polish EcoFund pattern in other heavily indebted countries
- The (limited) success of the Polish DFE swap required a strong commitment from the debtor and a fair degree of trust on behalf of participating creditors

EcoFund's experience (5)

- Neither of these factors is easily replicable
- Encouraged by the Polish example, the Swiss government established a similar DFE swap facility in Bulgaria, but no other creditors were willing to participate
  - Lack of strong pressure from the Bulgarian government
  - *Free-riding* of other creditors – another factor that prevented this initiative from developing into a larger-scale arrangement

Questions

Q-13 Polish EcoFund

[a] was established by the Paris Club in order to harmonize all the bilateral debt rescheduling agreements

[b] was established by the Polish government following the Paris Club decision on partial debt forgiveness

[c] proved to be an effective instrument of using pollution charges

[d] disbursed almost 1 billion USD in the course of its 18 year operation

[e] none of the above

Exercises

E-13 Explain why the Norwegian government – despite its initial support for the Polish initiative – hesitated to join the EcoFund with the maximum contribution allowed by the Paris Club.

Trade and Environment

- Fashionable topic in the early 1990s
- *The economic logic behind dumping a load of toxic waste in the lowest wage country is impeccable and we should face up to that* (Larry Summers, World Bank, 1991)
- Report of the Swedish government, 1993
- Special Issue of *Ecological Economics*, 1994

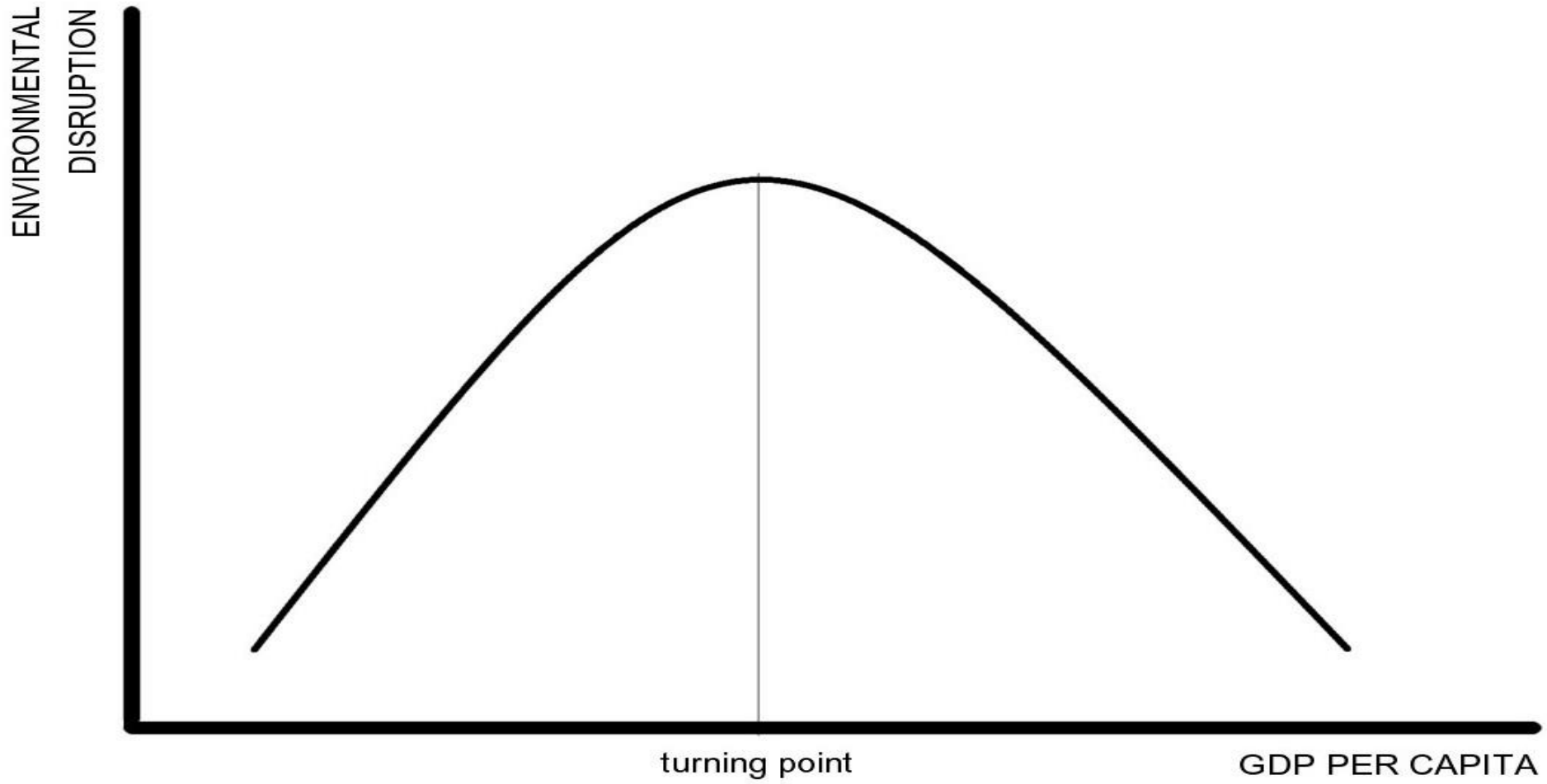
Conclusions of the Swedish government report

- Trade is neither good nor bad for the environment
- As any instrument, it is neutral (if applied skilfully, it improves things, but if applied inadequately, it can worsen the predicament)

Causality in trade *versus* environment debate

- Why are dirty industries found in countries with lax environmental regulation?
- One may argue that dirty industries go where environmental regulation is not strict
- But it can be also argued that strict environmental regulations are not adopted in countries where dirty industries exist, since politicians would hesitate to struggle with their lobbyists
- Hence the trade-environment nexus is far from obvious

Environmental Kuznets Curve (EKC)



Conclusions from EKC analyses

TRADE ⇒ ECONOMIC SURPLUS ⇒ ENVIRONMENTAL PROTECTION

- Neither of these implications is indispensable
- Specialization trap
  - Growing affluence is environmentally harmful before the "turning point"
  - Growing affluence may not translate into higher demand for, and supply of, environmental protection

Non-income-based negative arguments

- Export specialization favours monoculture
- "Race to the bottom" argument

Typical criticism of liberalization

- *Pollution Haven Hypothesis*
- *Ecological dumping*

Inconclusive empirical evidence

Conclusions based on Frankel (2008), referring mainly to 1990-2004 data

- Is the trade-to-GDP ratio (a measure of the role international trade plays in a given economy) correlated with environmental protection?
  - Sometimes it is – in the case of protection against local pollutants (such as e.g. sulphur dioxide abatement; sulphur dioxide is an international pollutant, but it has a domestic role too); more trade implies less pollution
  - Sometimes it is not – in the case of protection against global pollutants (such as e.g. carbon dioxide abatement; its abatement is not correlated with domestic losses); more trade implies more pollution

Conclusions based on Frankel (2008), referring mainly to 1990-2004 data (continued)

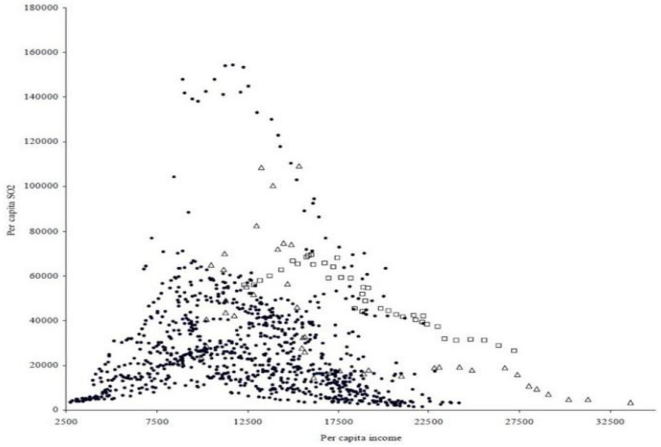
- Based on empirical observations, it turns out that detecting a relationship between trade and abatement is very difficult and subject to technical econometric assumptions
- If at all, these relationships are very weak, i.e. at the border of statistical significance
- Sometimes they seem to be slightly negative for global pollutants, such as carbon dioxide emission (as a result of *carbon leakage*), and slightly positive for domestic pollutants, such as sulphur dioxide emission

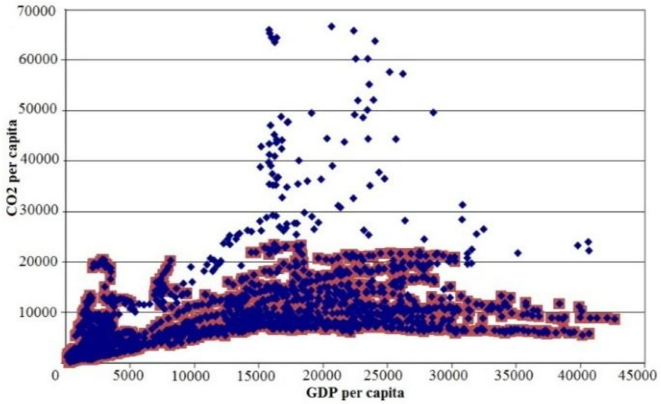
Questions

Q-14 Many analysts consider international trade detrimental for the environment, because
[a] the trade makes the people more materialistic
[b] opening up an economy leads to adopting "dirty technologies"
[c] exporters may have stricter environmental requirements
[d] countries may fall into a "specialization trap"
[e] none of the above

Exercises

E-14 The following two graphs portray typical relationships captured by the Environmental Kuznets Curve (EKC) idea. Explain why the idea is more convincing in the SO_2 (left picture) than in the CO_2 case (right picture).





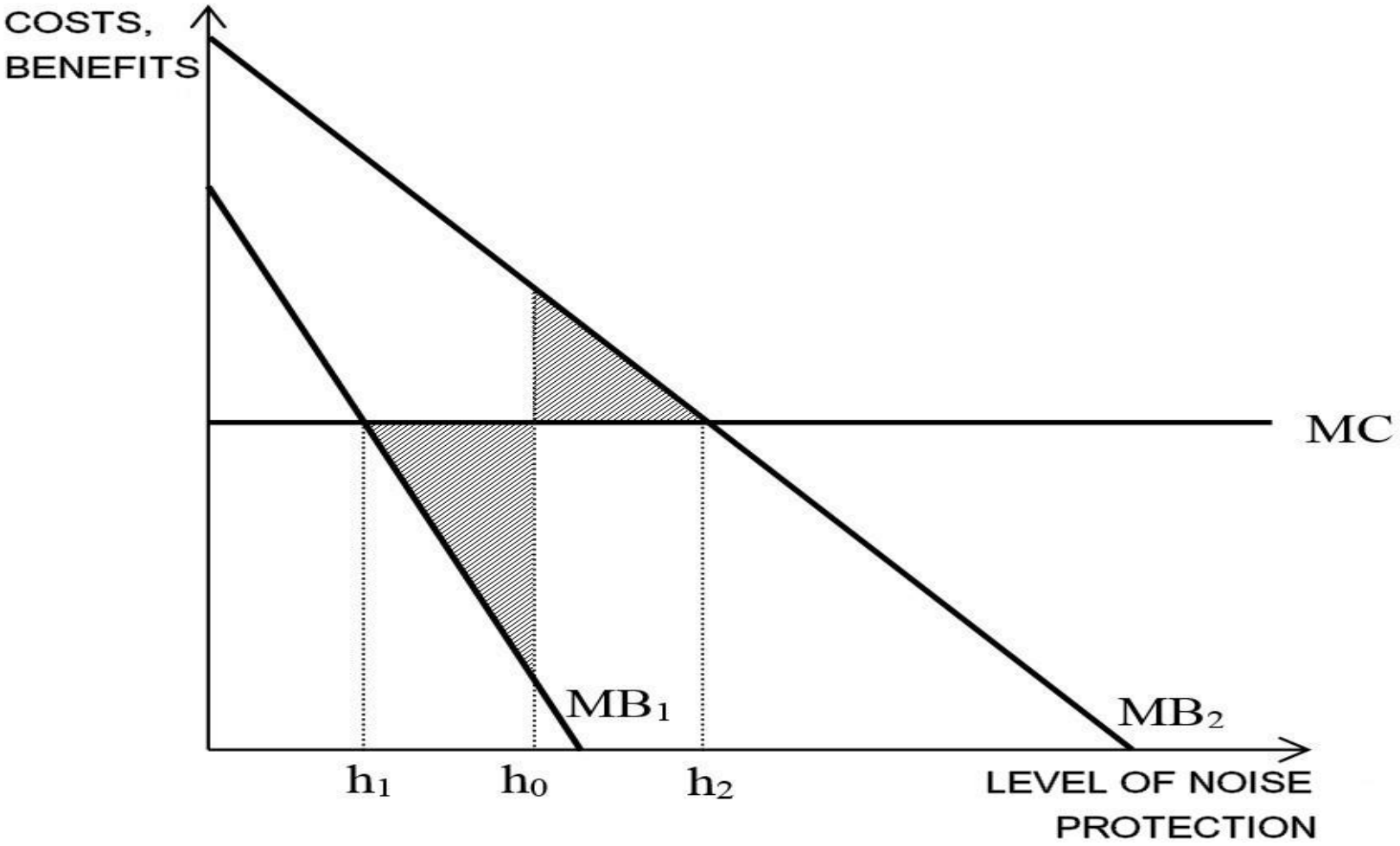
Environmental policy in the EU

- Environmental policy results from hundreds of "environmental" directives
- Environmental outcomes of non-environmental policies

Rationale for common standards

- There are five directives on noise emitted by lawn mowers:
  - 84/538/EEC
  - 85/409/EEC
  - 87/252/EEC
  - 88/180/EEC
  - 88/181/EEC

Rationale for common standards (continued)



Rationale for common standards (continued)

- Country no. 1: the people are not very upset by the noise
- Country no. 2: the people are willing to pay more in order to reduce the noise
- The lower number h_1 is the level of noise protection justified in the first country
- The higher number h_2 is the level of noise protection justified in the second country
- Seeking a "compromise", an average h_0 of the two numbers, can be suggested as a uniform standard

Rationale for common standards (continued)

- This uniform standard lowers the welfare in either country, as illustrated by the shaded area
  - The first country has to pay a cost which is higher than its benefit (confined to the first country)
  - The second one loses benefits (confined to the second country) which are higher than the cost saved

Cohesion policies

- Non-environmental benefits from having a uniform standard may justify its introduction
- Cohesion = making regions similar to each other (providing people with equal opportunities to support their aspirations)
- Cohesion policies are aimed at increasing employment and innovativeness in depressed regions

Effectiveness of European cohesion policies

- "Beta" convergence = faster change rate observed for units below the average than for those that are above
- "Sigma" convergence = lowering dispersion between the units
- $\sigma \Rightarrow \beta$, but not *vice versa*

"Beta" does not imply "sigma" (example)

GDP *per capita* in two countries: A (poor) & B (rich)

Growth rate in A: 4%; growth rate in B: 3%

- In 2020: 8,000 € & 15,000 € (7,000 € apart)
- In 2021: 8,320 € & 15,450 € (7,130 € apart)

Distance between A & B increased

Effectiveness of European cohesion policies (continued)

- "Sigma" convergence is observed at the national level (i.e. among countries)
- At sub-national levels GDP per capita "sigma" diverged (i.e. among regions)
- "Beta" convergence was observed internally in few countries only
- In most EU countries GDP per capita "beta" diverged (among regions)

Lisbon Strategy

- Seeking synergies between various policies
- Adopted in 2000 as a strategy to "make Europe the most competitive and the most dynamic knowledge-based economic region of the world by the year 2010"
- Amended in 2001 by adding that competitiveness and dynamism should be consistent with sustainability

Lisbon Strategy (continued)

Strong "environmental pillar"

- Climate protection by slowing down fossil fuel consumption
- Conservation of natural resources
- Mitigating transport pressure
- Improving public health

Lisbon Strategy (continued)

- Kok Committee (2004) reviewed the Lisbon Strategy and recommended its revision for the second half of its period, i.e. for 2005-2010
- The revised Lisbon Strategy was "freed" from most of its environmental ambitions
- The entire environmental pillar was reduced to Guideline no. 14 (out of the total of 23):
  - *To encourage the sustainable use of resources and strengthen the synergies between environmental protection and growth*

Lisbon Strategy (continued)

- More specifically, Guideline no. 14 recommended:
  - Internalising external costs;
  - Increasing energy efficiency; and
  - Support for environmentally-friendly technologies (ETAP)

Lisbon Strategy (continued)

- Mid-term assessment: *European Union and its Member States have clearly themselves contributed to slow progress by failing to act on much of the Lisbon strategy with sufficient urgency. This disappointing delivery is due to an overloaded agenda, poor coordination and conflicting priorities*
- The report anticipated that, once freed from an "environmental ballast", the strategy would achieve its purely economic objectives

Lisbon Strategy (continued)

- In 2010, upon its completion, it was anyway declared a failure by many European political leaders
- It has not failed because of "overloading" with environmental objectives
- Hence, as environmentalists believe, it may be possible to combine environmental ambition with economic performance

Questions

Q-15 Despite massive efforts of the European Commission, EU regions still reveal significant differences in GDP per capita.

[a] Cohesion policies were more effective at national than at sub-national scales.

[b] "Sigma" convergence was not observed at the national level.

[c] "Beta" convergence was observed in most countries

[d] In most European countries the gap between rich and poor regions closed.

[e] None of the above.

Exercises

E-15 Why is the Environmental Technology Action Plan (ETAP) questioned by environmental economists as an instrument of environmental improvement?

Outline solutions to exercises

E-0 According to the notation adopted, $TAB(x)=6x-x^2/10$, and $TAC(x)=x^2/10$. First of all we need to calculate $MAB(x)=dTAB(x)/dx=10-x/5$, and $MAC(x)=dTAC(x)/dx=x/5$. Solving the equation $6-x/5=x/5$ yields $x=15$. The economically justified level of noise is thus 45 dB.

E-1 The Gabcikovo-Nagymaros project aims at developing a segment of the Danube river found to be a particularly valuable natural habitat and an important source of underground water resources. Both countries – Hungary and Slovakia (as a successor of Czechoslovakia) – breached the original Treaty (of 1977), but benefits of the project are hardly justified by its costs i.e. investment outlays and environmental damages.

E-2 Hint: less expensive measures are applied before one reaches for more expensive ones.

E-3 If $\gamma_i p_j = \alpha\pi_i$, then $T_i = \alpha\pi_i - (\pi_i:\pi_N)\cdot\Sigma_j\, \alpha\pi_j = \alpha\pi_i\,(1 - \Sigma_j\, \pi_j:\pi_N) = \alpha\pi_i\,(1 - 1) = 0$.

E-4 As applied in the Second Sulphur Protocol, the definition of a critical load refers to the 5th percentile of areas adversely affected by sulphur deposition. In other words, 95% of a given area (each square on the map included in Annex I to the Protocol) is not affected adversely. Requiring that 100% of the area is not affected (the deterministic approach) would not be appropriate, because there might be some very sensitive places (with very small area);

protecting such minor places would require drastic abatement efforts even many kilometres away.

E-5 Recycling and reuse of CFCs would have resulted in preventing their price to sky-rocket. Yet, as the owner of patents, Du Pont was interested in maximizing their price.

E-6 Take the population-based allocation principle analysed in the class ($x_i=6L_i$) as a starting point. There are two basic ways GDP per capita can modify this formula: either by increasing x_i for countries with high GDP per capita, or by increasing x_i for countries with low GDP per capita. The former is likely to be favoured by rich countries while the latter – by poor countries. The former implies lower wealth transfers from the rich to the poor (if any) while the latter – the other way around.

E-7 There is little doubt about the rising temperature of the Earth surface. Thus in the IPCC language, the evidence of the rising temperature is "virtually certain". However, the causal link is not so universally accepted. Even though most scientists agree that this increase has been caused by human activities (such as burning fossil fuels), some argue that it could have been caused by natural processes (such as solar radiation changes). Thus the interpretation is, perhaps, only "very likely" (less than 99% sure).

E-8 If a country improves its environmental performance by e.g. reducing the consumption of coal, the price of the coal goes down. This may result in higher demand for coal in another country. If this other country uses the coal less efficiently than the first one, then the "transfer" of the coal may result in even more environmental disruption.

E-9 If a pharmaceutical company successfully developed a new product thanks to a chemical compound found in a wild plant, then – according to the Nagoya Protocol – the profit should be shared with those who preserved this wild plant. However the Protocol does not specify a detailed "price list" of preservation services. Therefore the pharmaceutical company may claim that most of the profit is attributable to its own laboratory exploration rather than inspiration provided by the plant.

E-10 Unlike many analysts, Herman Daly stresses that – based on materials balance approach – every input results in an output. For instance, extraction of phosphate rock resulting in environmental disruption (e.g. in Morocco), leads to phosphorus discharges resulting in eutrophication (e.g. in the Baltic Sea). Thus, instead of looking at inputs and outputs separately, one should look at "throughput", i.e. the flow of materials which is responsible for the lack of sustainability in economies. Achieving sustainability requires putting constraints on the throughput; this will lead to limiting both inputs and outputs.

E-11 No, it does not. The ODA numbers exclude assistance provided by citizens not through the public budget. In order to assess the "generosity" one should add ODA to the flows created by non-government organizations from a given donor country.

E-12 Debt-for-equity swap gives the creditor a possibility to enjoy monetary revenues. The revenues can then be spent on anything, including environmental protection. Therefore if the debtor insists on debt-for-equity and creditor insists on debt-for-environment (strange, but theoretically possible), the swap can be carried out and the creditor may spend the revenues on environmental protection (in the debtor country) rather than simply enjoying the money.

E-13 The Norwegian government was strongly supportive of the Polish initiative, as it hosted an international conference in 1991 devoted to the EcoFund. Soon, however, Poland was affected by a series of political crises resulting in frequent government changes. Thus some creditors could have had doubts whether the environmental preference (revealed in 1991) was a stable one. Consequently the Norwegian government joined the EcoFund with a very low share in 1997 and increased its contribution up to the maximum allowed by the Paris Club (i.e. 10%) after one year of its "trial" membership.

E-14 The EKC hypothesis implies a conclusion that there is a "turning point" such that when a country increases its GDP per capita sufficiently, it exerts less pressure on the environment. In the case of SO_2 this "turning point" seems to be around $10,000, i.e. a moderate wealth (a number of countries are already above this level). In the case of CO_2 such a "turning point" is much less evident, and – if at all – it corresponds to something like $30,000, i.e. a fairly high wealth (not many countries have passed this level yet). Consequently, arguments that "a problem will be solved once an economy becomes rich" are less convincing in this case.

E-15 ETAP is a programme of selecting and supporting technologies that are identified by the European Commission as "environmentally friendly". The "environmental friendliness" of a technology is difficult to establish, and often it results from lobbying rather than from scientifically established facts. More importantly, promoting a selected technology rather than identifying an environmental objective results in providing less incentives for further technological improvements. Hence in the long run ETAP may be less environmentally effective than a spontaneous technological progress triggered by strict environmental constraints.