Climate Economics for Engineers

ENV-724 (Thalmann/Vielle/Vöhringer), Session 5, 21 Oct. 2020

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Overview

23.09	Economic activity as a source of greenhouse gases, climate scenarios	Frank Vöhringer
30.09	Impacts of climate change: valuation and uncertainty	Philippe Thalmann
07.10	Impacts of climate change: net costs (aggregation, discounting)	Frank Vöhringer
14.10	Adaptation to climate change	Marc Vielle
21.10	Mitigation: abatement measures, cost curves, innovation	Frank Vöhringer
28.10	Cooperation: mitigation as a public good, international climate policy	Frank Vöhringer
04.11	Instruments for climate policy	Philippe Thalmann
11.11	Swiss climate policy	Philippe Thalmann
18.11	Solar radiation management: economics and governance	Frank Vöhringer
02.12	Final exam	all

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Overview for today

- Decisions under risk and uncertainty
  - some experiments
  - bounded rationality
  - prospect theory
  - framing
- mitigation
  - target setting and carbon budgets
  - abatement measures
  - economics of innovation
  - abatement cost
  - mitigation game

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Risk and uncertainty (according to Frank Knight)

- risk:

  future events occur with measurable probability

- uncertainty:

  the likelihood of future events is indefinite or incalculable

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Descriptive vs. prescriptive decision theory

- descriptive:

  how we decide

- prescriptive (or normative):

  how we should decide

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Rational decision-making under risk

- problem needs to be structured and quantified
  - goals
  - alternatives
  - decision tree with defined outcomes
  - (conditional) probabilities
  - continuous alternative: probability distributions
  - …

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Bounded rationality (Herbert Simon)

- limited resources
- cognitive limits
- search for acceptable rather than optimal outcomes
- widespread use of heuristic decision rules

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Behavioral economics

Behavioral economics studies the effects of psychological, cognitive, emotional, cultural and social factors on the decisions of individuals and institutions and how those decisions vary from those implied by classical economic theory.

Behavioral economics is primarily concerned with the bounds of rationality of economic agents. Behavioral models typically integrate insights from psychology, neuroscience and microeconomic theory.

The study of behavioral economics includes how market decisions are made and the mechanisms that drive public choice.

Source: Wikipedia

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Rational decision-making under risk

- expected value: $$EV = \sum_{i=1}^{n} \pi_i \cdot x_i$$

  → probabilities are usually subjective

  → St. Petersburg paradox (Daniel Bernoulli):
  WTP for participating in a game with the expected pay-off

$$E = \frac{1}{2} \cdot 1 + \frac{1}{4} \cdot 2 + \frac{1}{8} \cdot 4 + \cdots = \sum_{k=1}^{\infty} \frac{1}{2^k} \cdot 2^{k-1} = \sum_{k=1}^{\infty} \frac{1}{2} = \infty.?$$

- expected utility: $$EU = \sum_{i=1}^{n} \pi_i \cdot u(x_i)$$
  (von Neumann/Morgenstern)

  → usually with diminishing marginal utility of gains

  → resolves the St. Petersburg paradox through risk aversion

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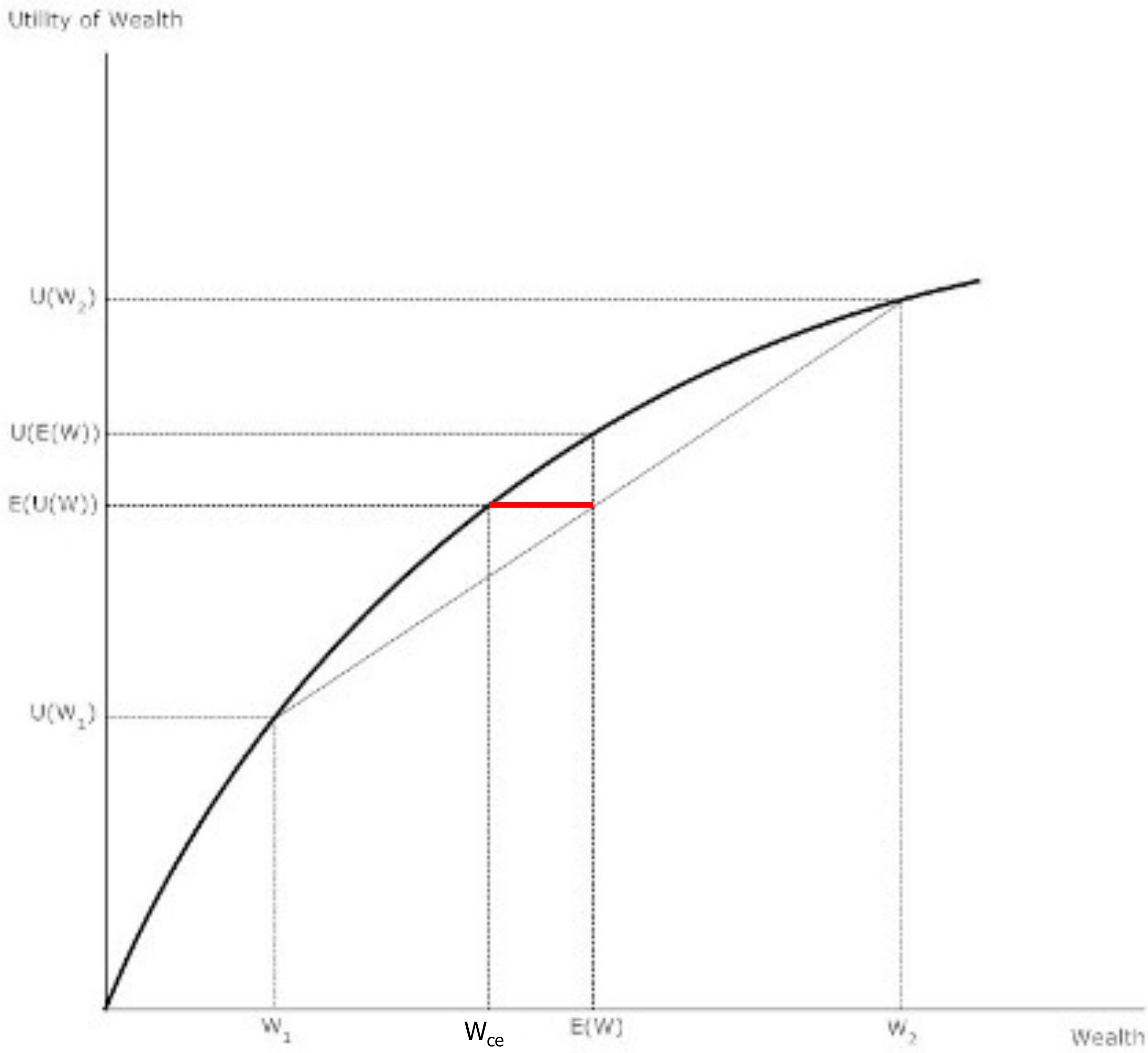
Certainty equivalent and risk premium



Evidence that we don't maximize expected utility

- risk loving behavior over losses
- isolation effect
  - failure to integrate outcomes with current assets
  - reference point matters
  - framing of the problem influences decisions
- Allais paradox (certainty effect)
  - see experiments 3 & 4
  - in experiment 3, substract the utility of an 89% chance to gain 100 million on either side -> it becomes identical to experiment 4
  - most people prefer A in experiment 3, but B in exp. 4 -> whatever we maximize, it is not expected utility

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(Cumulative) prospect theory (Tversky/Kahneman)

$$PT = \sum_{i=-m}^{n} \pi_i \cdot v(x_i)$$

with π_i : probability weighting function

$v(x_i)$: value function

- taking into account:
  - reference dependence
  - loss aversion
  - diminishing sensitivity
  - probability weighting (decision weights)

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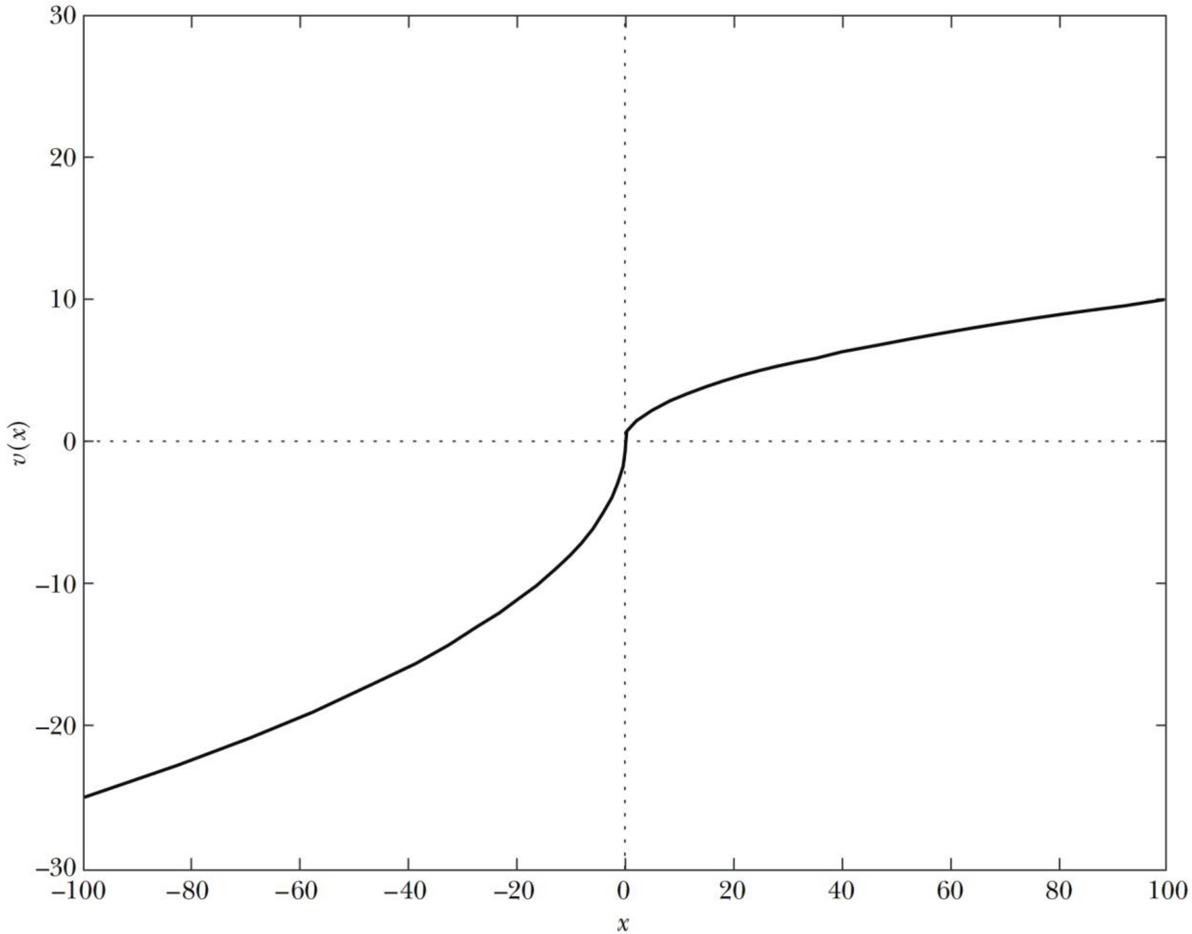
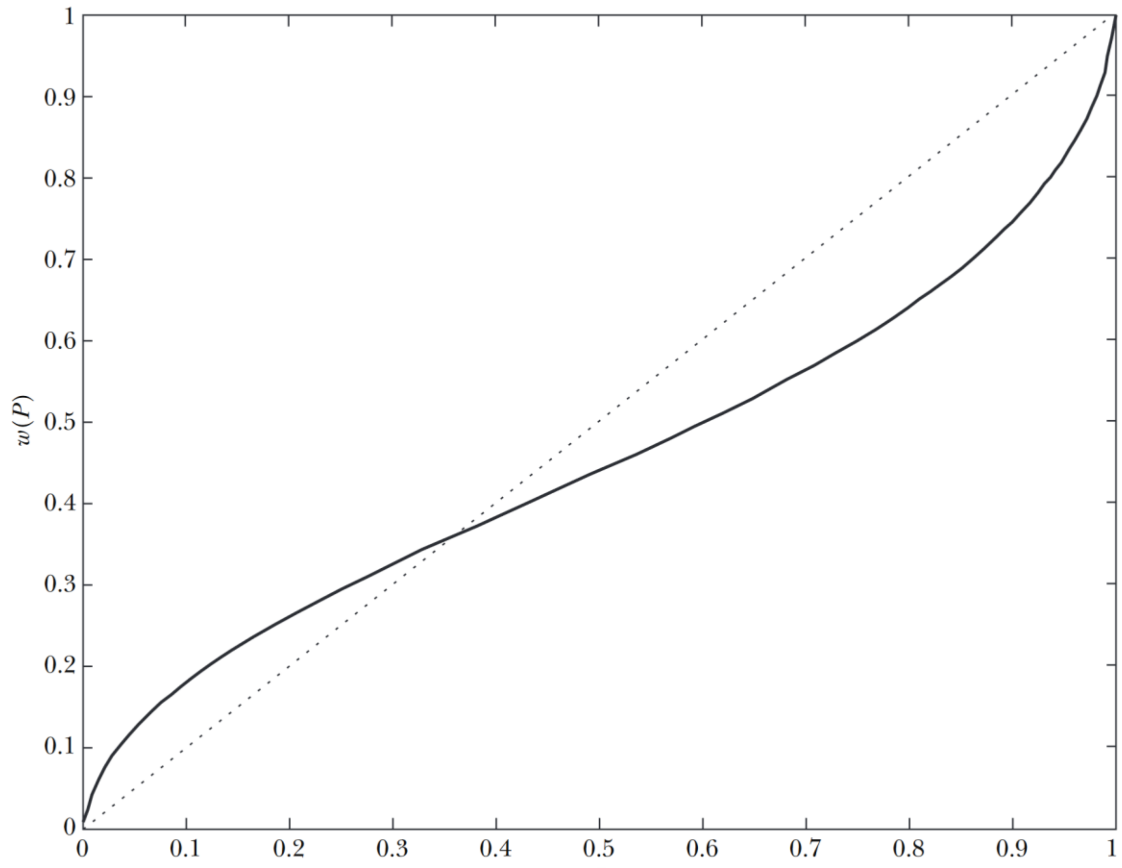
Prospect theory: value function



Notes: The graph plots the value function proposed by Tversky and Kahneman (1992) as part of cumulative prospect theory, namely $v(x) = x^{\alpha}$ for $x \geq 0$ and $v(x) = -\lambda(-x)^{\alpha}$ for $x < 0$, where x is a dollar gain or loss. The authors estimate $\alpha = 0.88$ and $\lambda = 2.25$ from experimental data. The plot uses $\alpha = 0.5$ and $\lambda = 2.5$ so as to make loss aversion and diminishing sensitivity easier to see.

Source: N.C. Barberis 2013

Prospect theory: probability weighting function



Notes: The graph plots the probability weighting function proposed by Tversky and Kahneman (1992) as part of cumulative prospect theory, namely $w(P) = P^{\delta}/(P^{\delta} + (1 - P)^{\delta})^{1/\delta}$, where P is an objective probability, for two values of δ. The solid line corresponds to $\delta = 0.65$, the value estimated by the authors from experimental data. The dotted line corresponds to $\delta = 1$, in other words, to linear probability weighting.

Framing matters

- What is mitigation of climate change?
  - an insurance against climate damage?
  - a bet on scientific projections?
- What is the reference point?
  - the climate of 1900? today's climate? the 2° target? some expected future climate?
    - similar issues for ecosystems, life expectancy etc.
- Are cost-effectiveness discussions detrimental, because we forget to emphasize the benefits?
- Framing in the design of policy instruments
- "Libertarian paternalism" (e.g. defaults)
- …

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Optimization or precaution?

- optimal emissions trajectories from integrated assessment
  - see e.g. Botzen/van den Bergh 2012
  - economists: framework for thought experiments
  - yet influential in the political debate (e.g. USA 1990s, Stern Review)
- precautionary principle
  - prevent dangerous anthropogenic interference with the climate system (UNFCCC, 1992)
    - “2°C above pre-industrial levels” (EU 1996)
    - “well below 2°C above …” (Paris Agreement 2015)
    - “pursue efforts to limit … to 1.5°C” (Paris Agreement 2015)
  - sustainability concept: critical limits
    - threshold values for natural capital components
    - how arbitrary and how costly is the threshold? -> a bit of CBA?
  - cost-effectiveness analysis rather than cost benefit analysis

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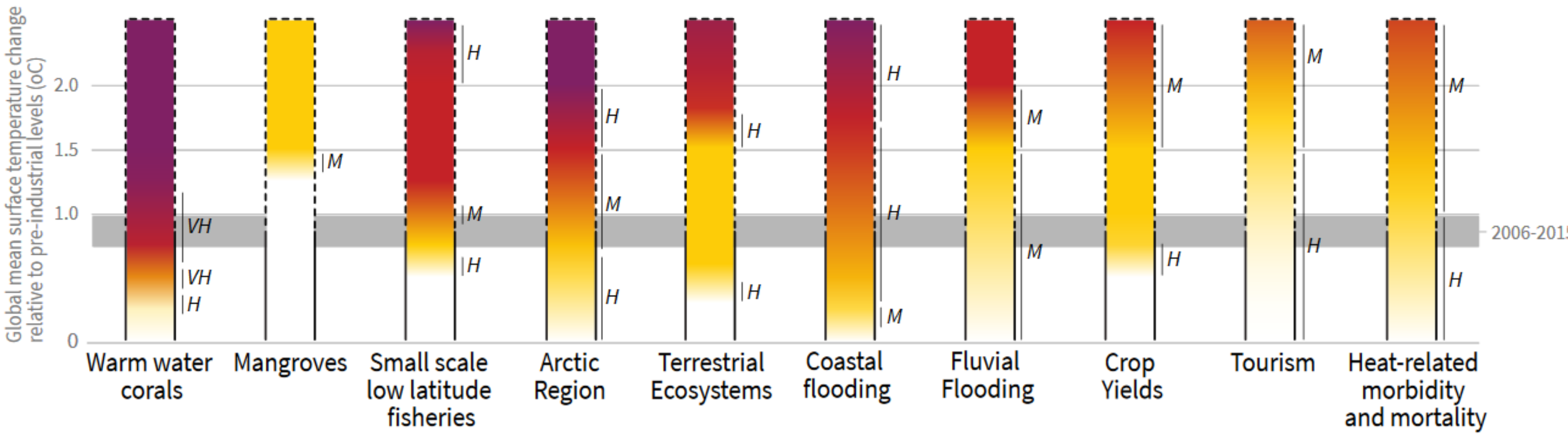
Special Report 1.5°C: impacts & risks

Impacts and risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.

Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Source: IPCC SR1.5

Carbon budgets

IPCC 5AR

<table>
<tr><th rowspan="3">CO_2eq Concentrations in 2100 [ppm CO_2eq] Category label (concentration range)[9]</th><th rowspan="3">Subcategories</th><th rowspan="3">Relative position of the RCPs[5]</th><th colspan="2">Cumulative CO_2 emissions[3] [$GtCO_2$]</th><th colspan="2">Change in CO_2eq emissions compared to 2010 in [%][4]</th><th colspan="5">Temperature change (relative to 1850–1900)[5, 6]</th></tr>
<tr><th rowspan="2">2011–2050</th><th rowspan="2">2011–2100</th><th rowspan="2">2050</th><th rowspan="2">2100</th><th rowspan="2">2100 Temperature change [°C][7]</th><th colspan="4">Likelihood of staying below temperature level over the 21st century[8]</th></tr>
<tr><th>1.5 °C</th><th>2.0 °C</th><th>3.0 °C</th><th>4.0 °C</th></tr>
<tr><td>< 430</td><td colspan="11">Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq</td></tr>
<tr><td>450 (430–480)</td><td>Total range[1, 10]</td><td>RCP2.6</td><td>550–1300</td><td>630–1180</td><td>−72 to −41</td><td>−118 to −78</td><td>1.5–1.7 (1.0–2.8)</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500 (480–530)</td><td>No overshoot of 530 ppm CO_2eq</td><td></td><td>860–1180</td><td>960–1430</td><td>−57 to −42</td><td>−107 to −73</td><td>1.7–1.9 (1.2–2.9)</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2eq</td><td></td><td>1130–1530</td><td>990–1550</td><td>−55 to −25</td><td>−114 to −90</td><td>1.8–2.0 (1.2–3.3)</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550 (530–580)</td><td>No overshoot of 580 ppm CO_2eq</td><td></td><td>1070–1460</td><td>1240–2240</td><td>−47 to −19</td><td>−81 to −59</td><td>2.0–2.2 (1.4–3.6)</td><td rowspan="3">More unlikely than likely[12]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2eq</td><td></td><td>1420–1750</td><td>1170–2100</td><td>−16 to 7</td><td>−183 to −86</td><td>2.1–2.3 (1.4–3.6)</td></tr>
<tr><td>(580–650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>1260–1640</td><td>1870–2440</td><td>−38 to 24</td><td>−134 to −50</td><td>2.3–2.6 (1.5–4.2)</td></tr>
<tr><td>(650–720)</td><td>Total range</td><td>1310–1750</td><td>2570–3340</td><td>−11 to 17</td><td>−54 to −21</td><td>2.6–2.9 (1.8–4.5)</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720–1000)[2]</td><td>Total range</td><td>RCP6.0</td><td>1570–1940</td><td>3620–4990</td><td>18 to 54</td><td>−7 to 72</td><td>3.1–3.7 (2.1–5.8)</td><td rowspan="2">Unlikely[11]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000[2]</td><td>Total range</td><td>RCP8.5</td><td>1840–2310</td><td>5350–7010</td><td>52 to 95</td><td>74 to 178</td><td>4.1–4.8 (2.8–7.8)</td><td>Unlikely[11]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

Source: IPCC 5AR TS WG3

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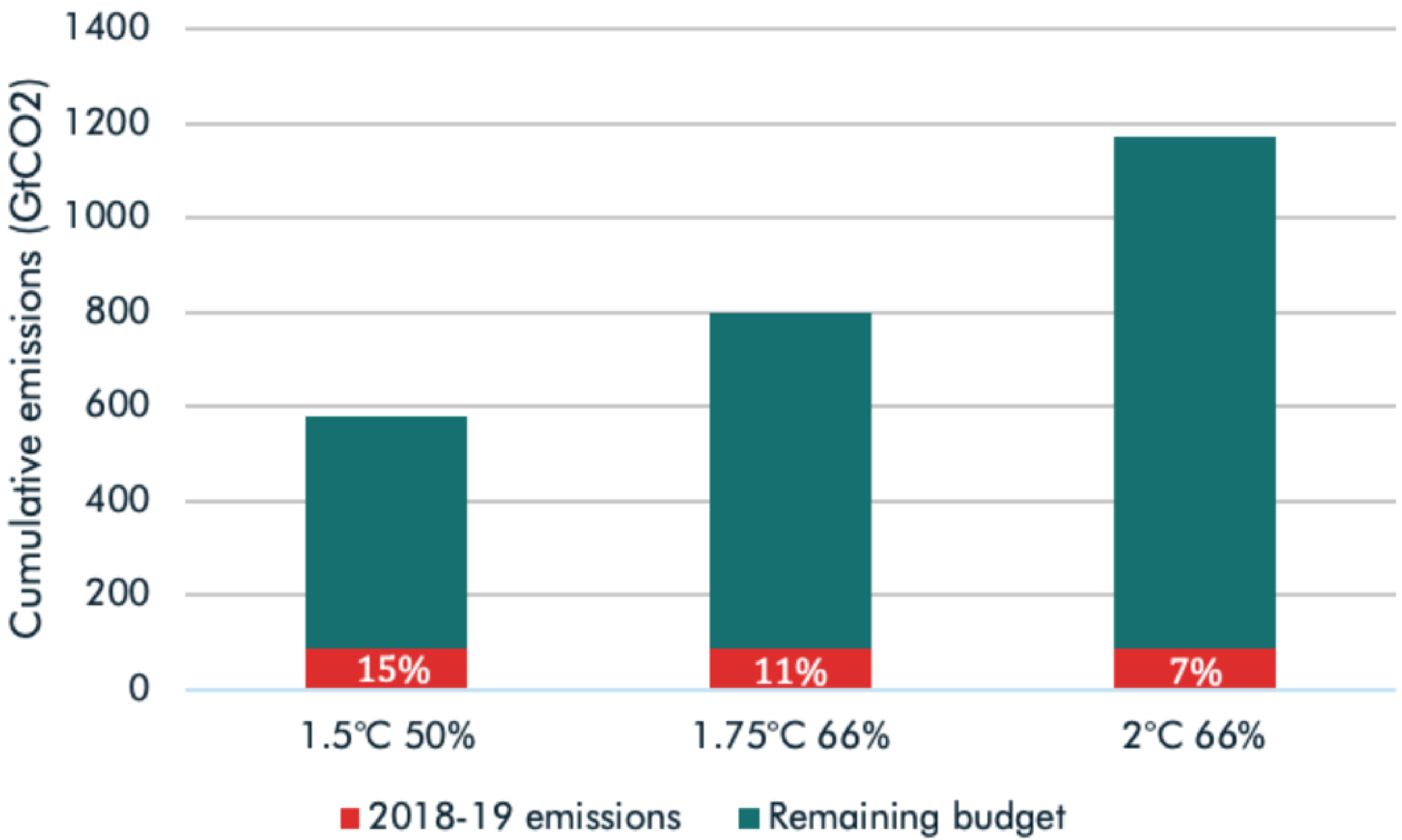
A recent update



Source: Carbon Tracker Initiative (with IPCC data)

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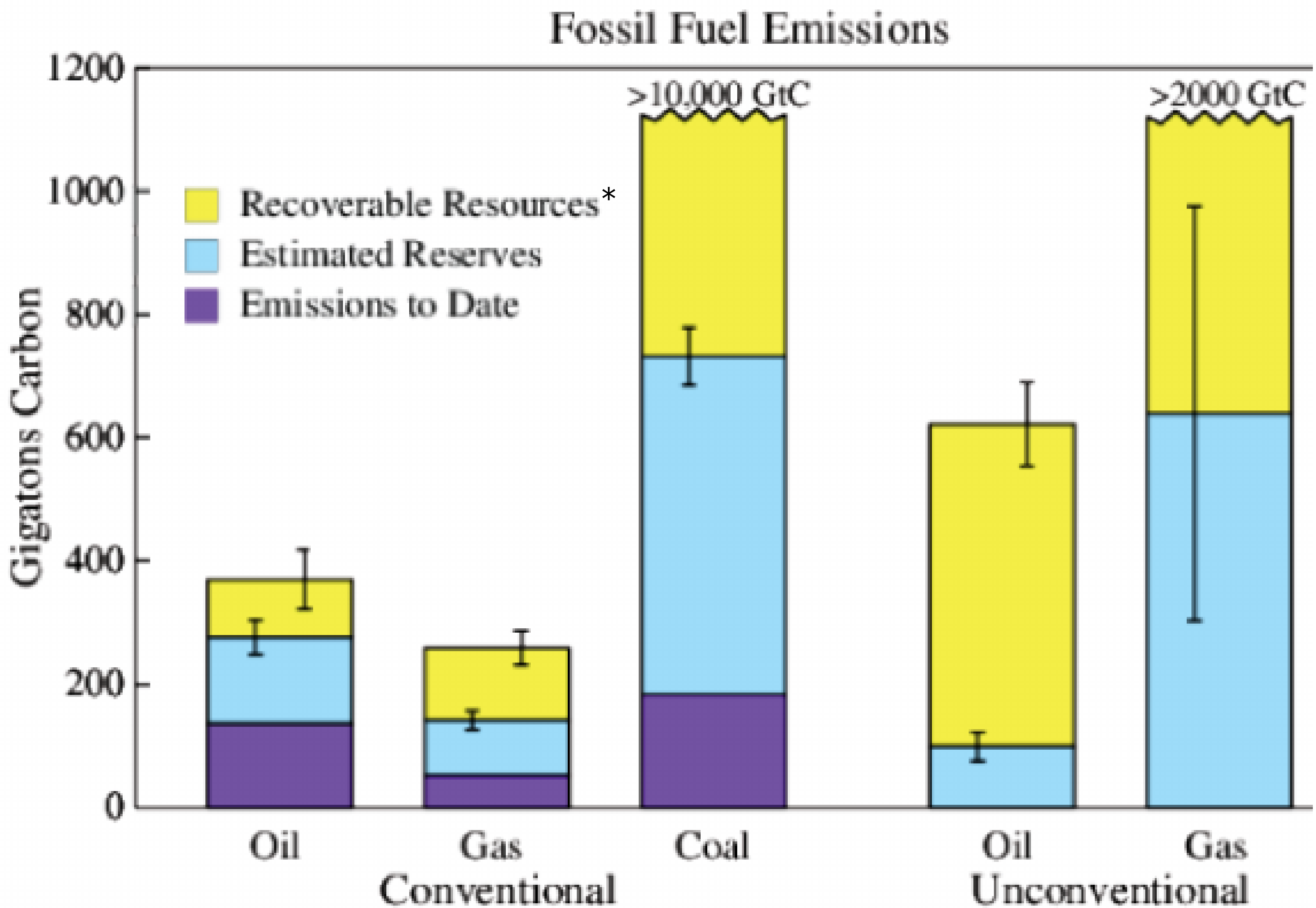
Fossil fuel reserves



* require advanced techniques and/or higher prices

Source: Hansen et al. 2013

4 major levers for abatement in industry

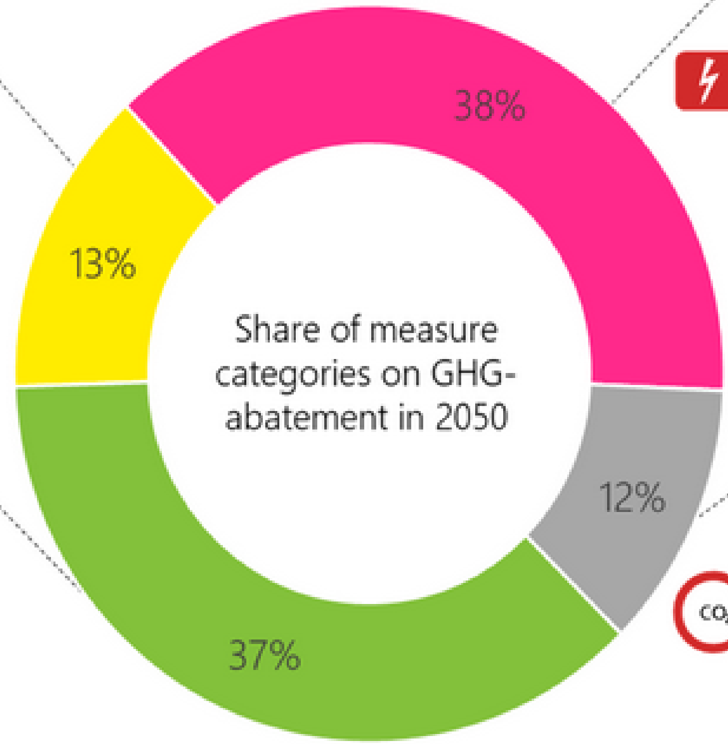
2021 ← Initial year of measure ramp-up → 2025

Energy efficiency (99)*

- Processes such as the production of chlorine and cement
- Cross-sectional technologies such as compessors and pumps
- Generic, without technology modeling

Electrification (6)

- 6.8 million tons of electrical glass, 22 million t of recycled steel
- Complete electrification SH&HW and process heat <100 ° C
- Largely electrification of process heat <500 ° C



Renewable fuels (10)

- Process route change in the steel industry on H_2-route (10 million tons H_2-steel)
- Burner replacement in the cement and lime industry to use gas
- Change of energy carrier without technology change from coal to biomass, high temperature

CO_2-Capture (2)

- 11 million tonnes of CO_2-capture in cement industry

2025 ← Initial year of measure ramp-up → 2030

*Number of individual measures deposited in SmInd

Country: Germany
Source: Hübner 2020

Methane abatement measures (examples)

- energy
  - flaring of landfill gas
  - electricity generation from landfill gas
  - utilization of gas from coal mines
  - gas flaring or utilization in oil extraction
- agriculture
  - rice management
  - improved feeding practices
  - anaerobic digestion

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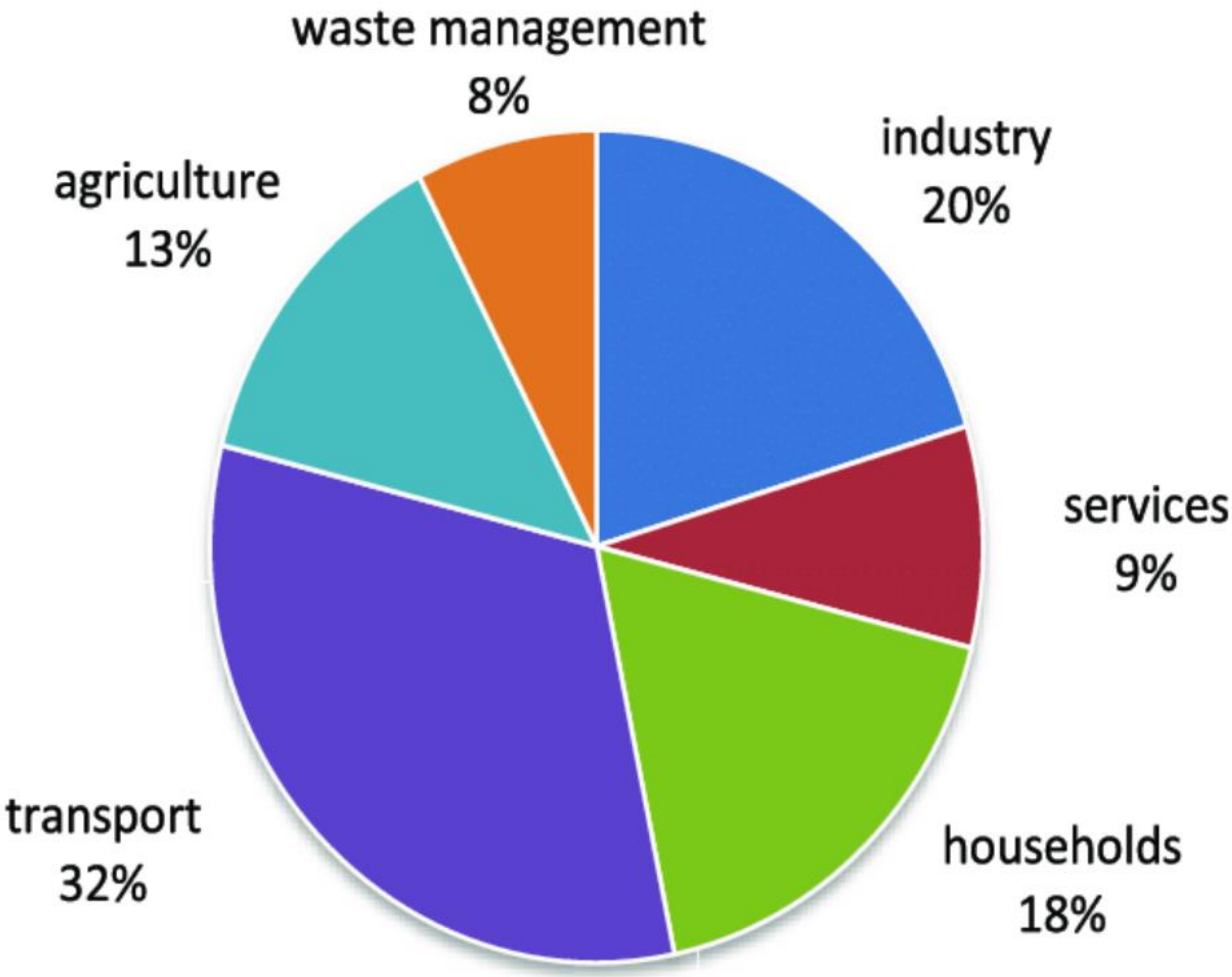
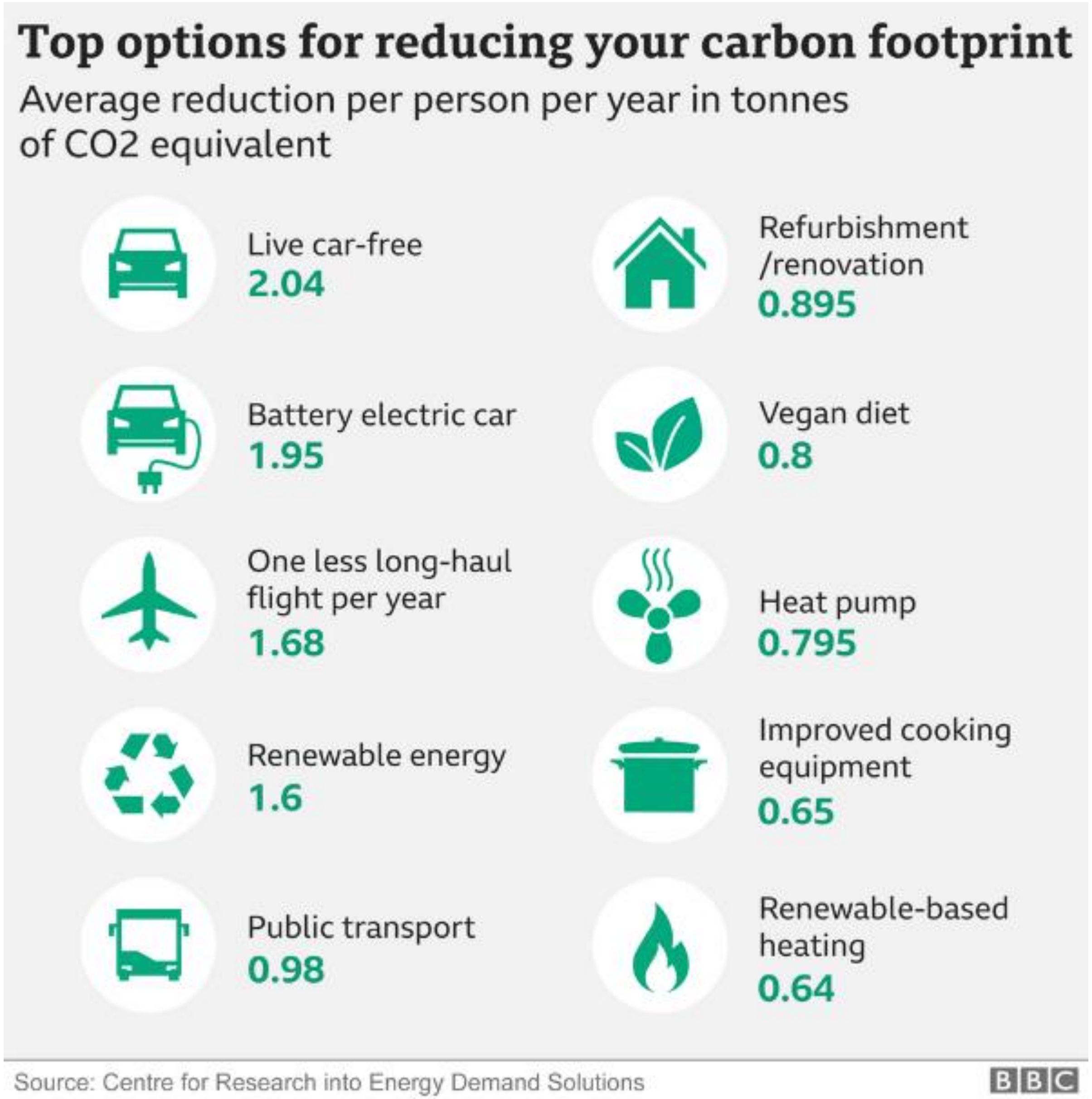
Swiss CO_2 emissions by source (2015)



Source: Baier et al. 2018 with FOEN data

Mitigation

Levers for abatement in consumption



And ...

buy less / reuse / repair

travel less

stream less

buy regional products (in most cases)

reduce packaging

avoid very emissions intensive products (beef)

what else?

Agricultural products

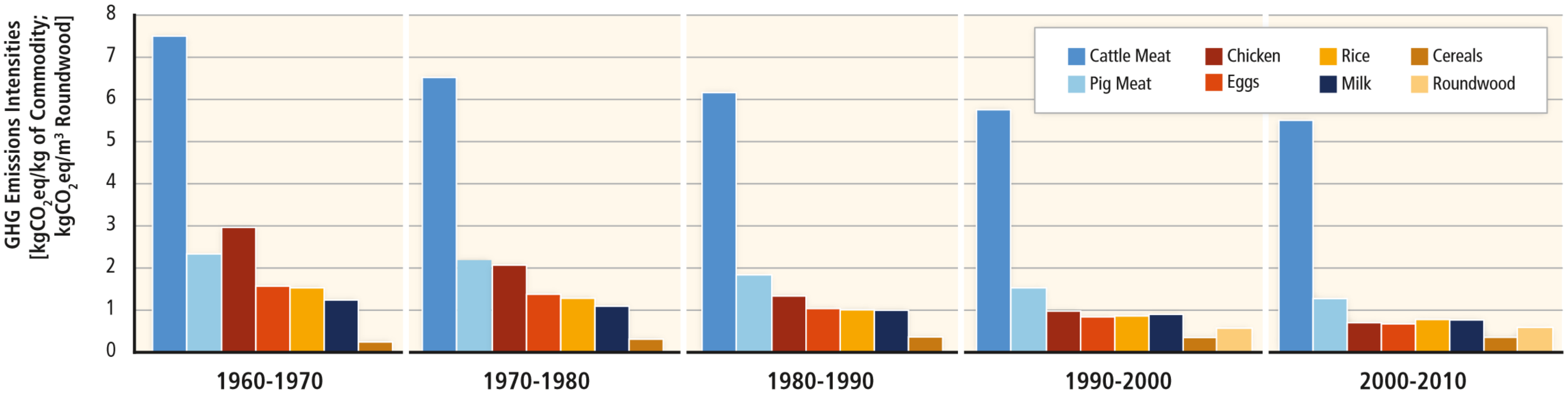


Figure TS.30 | GHG emissions intensities of selected major AFOLU commodities for decades 1960s–2000s. (1) Cattle meat, defined as GHG (enteric fermentation + manure management of cattle, dairy and non-dairy)/meat produced; (2) pig meat, defined as GHG (enteric fermentation + manure management of swine, market and breeding)/meat produced; (3) chicken meat, defined as GHG (manure management of chickens)/meat produced; (4) milk, defined as GHG (enteric fermentation + manure management of cattle, dairy)/milk produced; (5) eggs, defined as GHG (manure management of chickens, layers)/egg produced; (6) rice, defined as GHG (rice cultivation)/rice produced; (7) cereals, defined as GHG (synthetic fertilizers)/cereals produced; (8) wood, defined as GHG (carbon loss from harvest)/roundwood produced. [Figure 11.15]

Source: IPCC 5AR TS WG3

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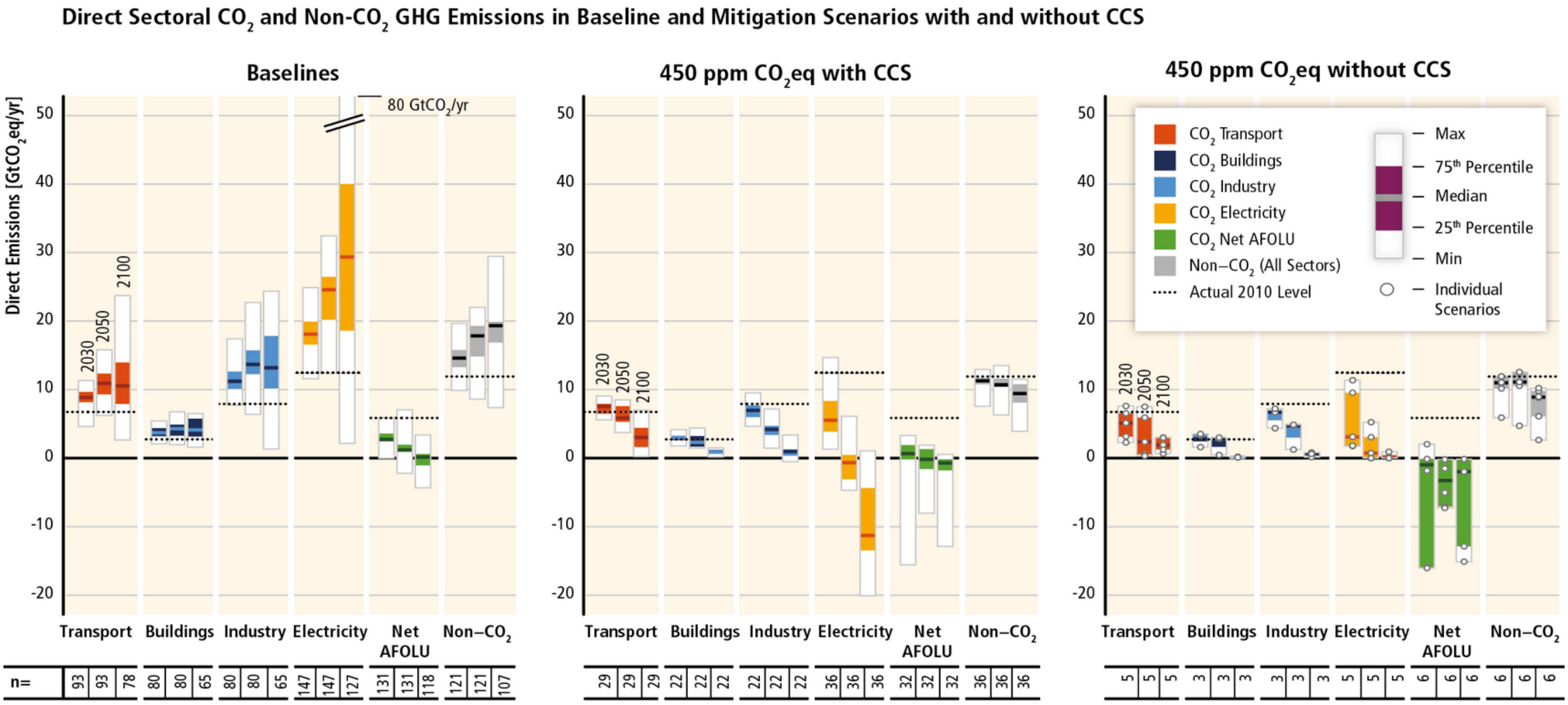
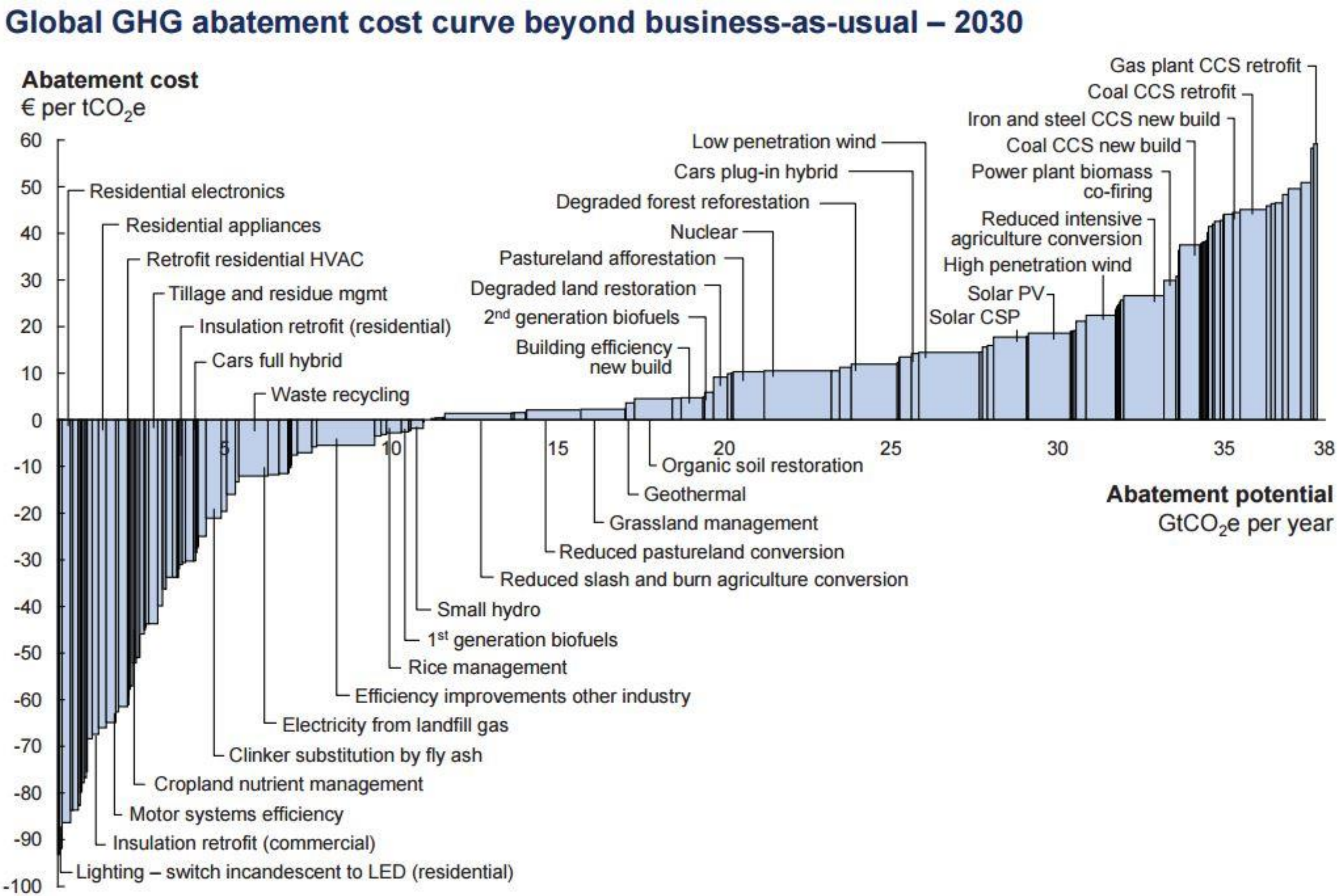
GHG emissions abatement by sector



Source: IPCC

Mitigation
Abatement measures

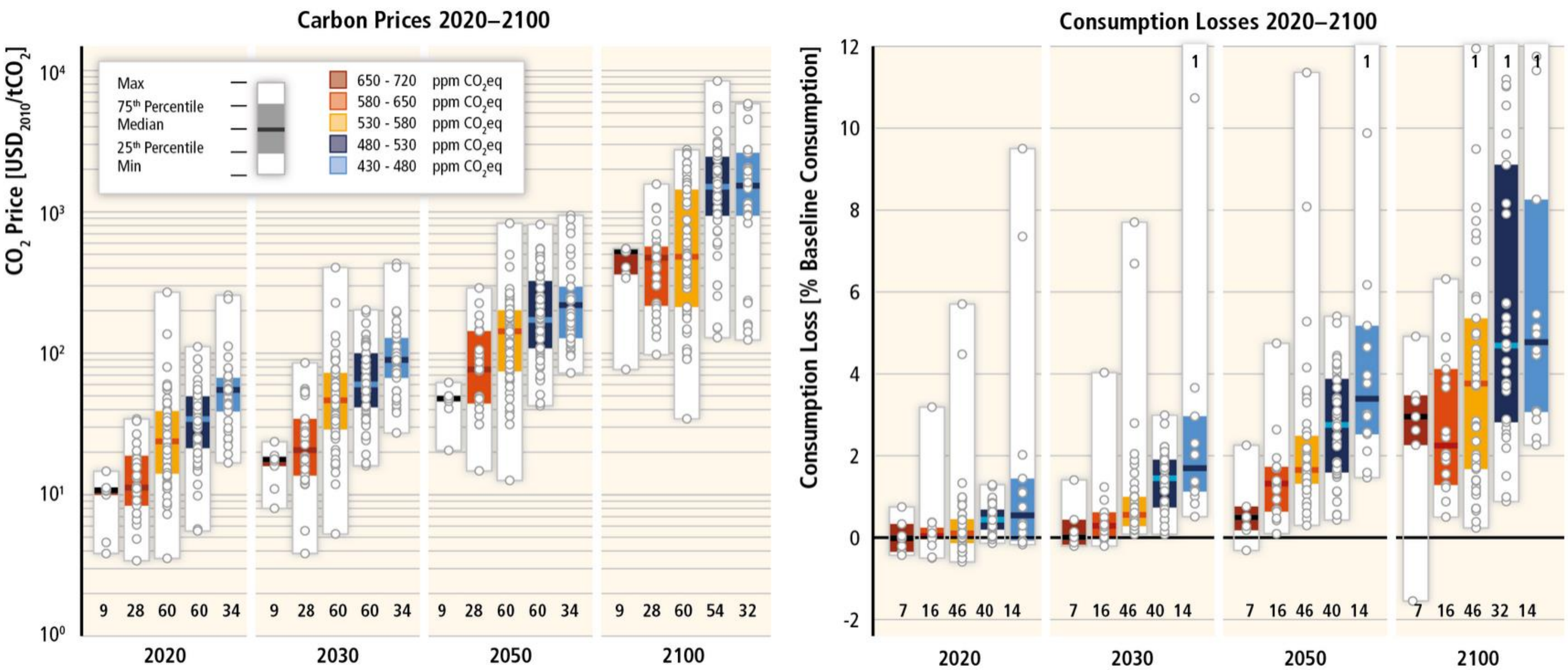


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

Source: McKinsey 2013

Mitigation

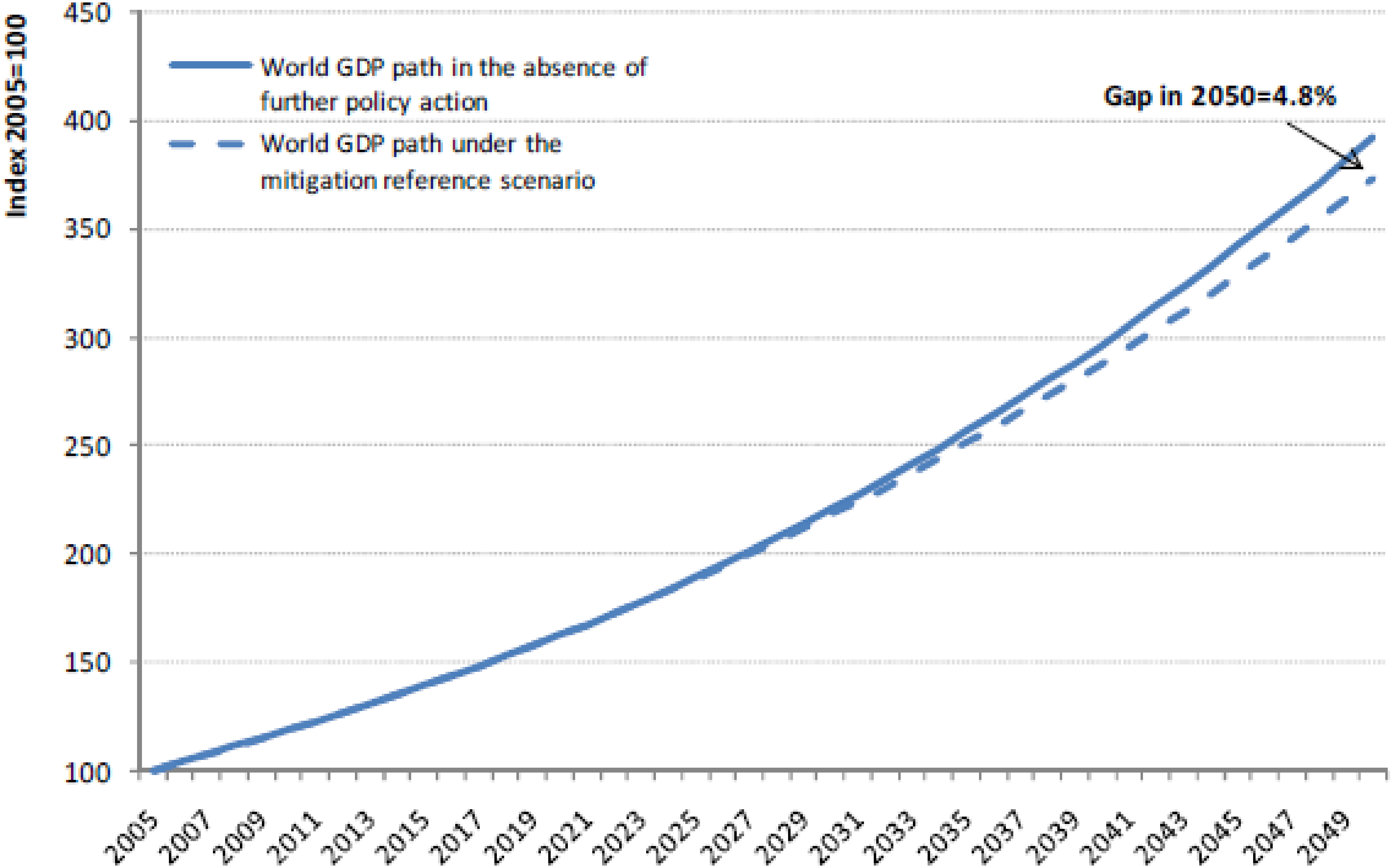
Carbon prices and consumption losses



Source: IPCC

Mitigation

Economic growth and abatement costs



Source: OECD 2008

Cost of mitigation

	Consumption losses in cost-effective scenarios[1]						Increase in total discounted mitigation costs in scenarios with limited availability of technologies			
	[% reduction in consumption relative to baseline]			[percentage point reduction in annualized consumption growth rate]			[% increase in total discounted mitigation costs (2015–2100) relative to default technology assumptions]			
Concentration in 2100 [ppm CO_2eq]	2030	2050	2100	2010–2030	2010–2050	2010–2100	No CCS	Nuclear phase out	Limited Solar/Wind	Limited Bioenergy
450 (430–480)	1.7 (1.0–3.7) [N: 14]	3.4 (2.1–6.2)	4.8 (2.9–11.4)	0.09 (0.06–0.2)	0.09 (0.06–0.17)	0.06 (0.04–0.14)	138 (29–297) [N: 4]	7 (4–18) [N: 8]	6 (2–29) [N: 8]	64 (44–78) [N: 8]
500 (480–530)	1.7 (0.6–2.1) [N: 32]	2.7 (1.5–4.2)	4.7 (2.4–10.6)	0.09 (0.03–0.12)	0.07 (0.04–0.12)	0.06 (0.03–0.13)	N/A	N/A	N/A	N/A
550 (530–580)	0.6 (0.2–1.3) [N: 46]	1.7 (1.2–3.3)	3.8 (1.2–7.3)	0.03 (0.01–0.08)	0.05 (0.03–0.08)	0.04 (0.01–0.09)	39 (18–78) [N: 11]	13 (2–23) [N: 10]	8 (5–15) [N: 10]	18 (4–66) [N: 12]
580–650	0.3 (0–0.9) [N: 16]	1.3 (0.5–2.0)	2.3 (1.2–4.4)	0.02 (0–0.04)	0.03 (0.01–0.05)	0.03 (0.01–0.05)	N/A	N/A	N/A	N/A

Source: IPCC 5AR TS WG3

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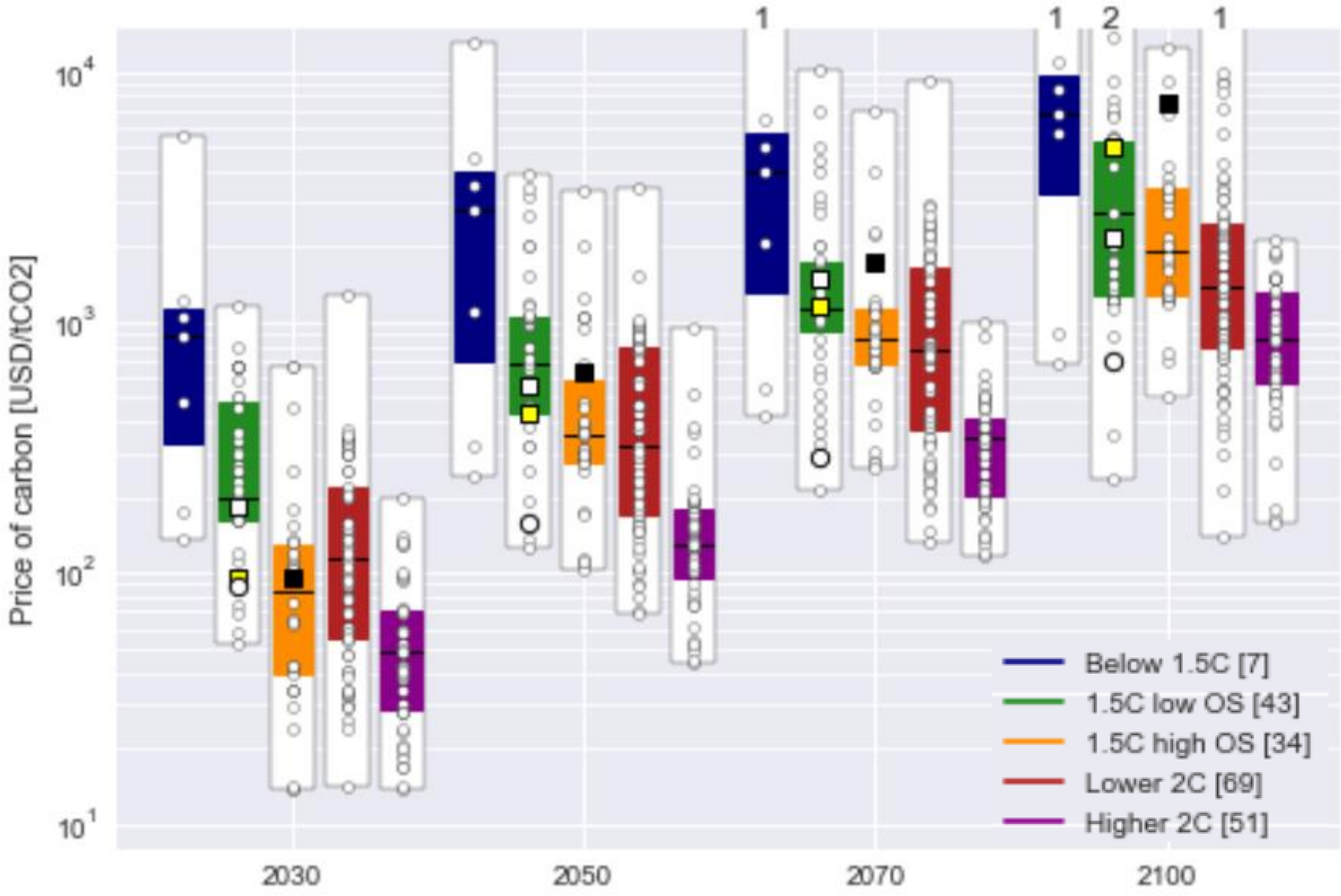
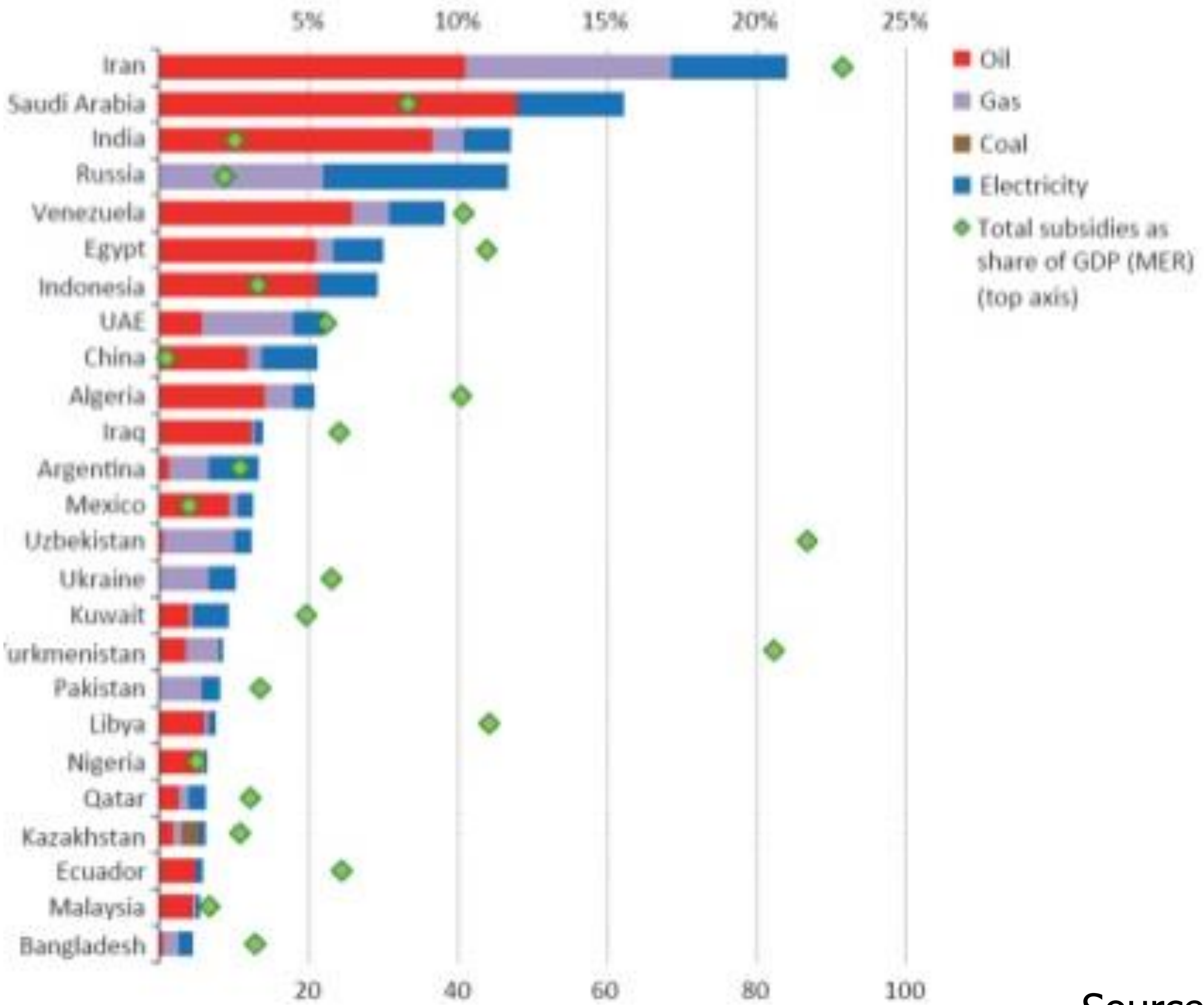
Carbon prices for 1.5°C



Source: IPCC SR1.5

Mitigation

Fossil fuel subsidies (in % of GDP & bio. US$, 2013)



Source: OECD/IEA 2014

Determinants of abatement cost estimates

- baseline projections
  - population
  - GDP
  - energy resources and prices
  - emissions
- technical potential
  - availability and potentials of measures
  - substitution possibilities
  - rate of technological change
- discount rate
- ancillary benefits of GHG abatement
- climate policy regime
  - stringency & flexibility
  - policy instruments and revenue recycling

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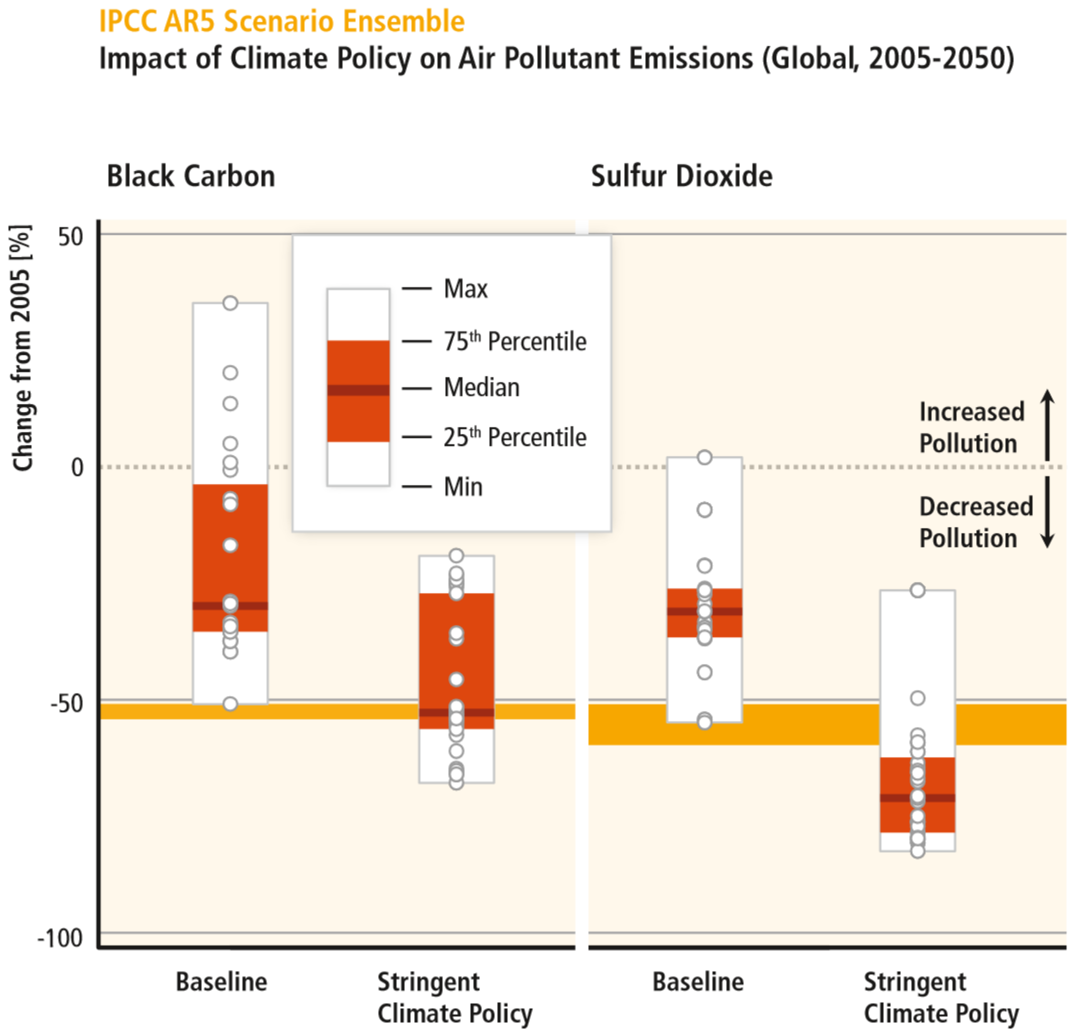
Ancillary benefit: reduced air pollution



Quelle: IPCC 5AR TS WG3

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