MSc Program
Renewable Energy in Central & Eastern Europe

newenergy.tuwien.ac.at

Module 9: Energy Perspectives and the Environment

Arnulf Grubler

IIASA & Yale University

March 5, 2017

Energy Perspectives & Environment

Today

- Introduction
- Technological Change (Primer)
- Energy and the Environment (Overview)
- Integrative Perspectives: Scenarios (Illustration: Climate Change)

Introduction: Energy Systems

Interaction between:

-- Society

-- Economy

-- Technology

-- Policy

that shape both

-- Demand

-- Supply

in terms of quantity, quality, costs, impacts.

Part 1: Technology

Technology

- Main determinant of energy systems
  (essence: conversion for/and service provision)
- Only “man-made” resource available, determines:
  -- resource availability (what and how much)
  -- costs
  -- environmental impacts/remediation
- Key concepts:
  Innovation process and technology lifecycle
  Returns to scale
  Knowledge (learning and unlearning)

Technology

τεχνε λογοσ

Origin: the science of the art of the practical

A systems of means to particular ends that employs both technical artifacts and (social) information

Technology is...

H - Hardware (artifacts, "machines")

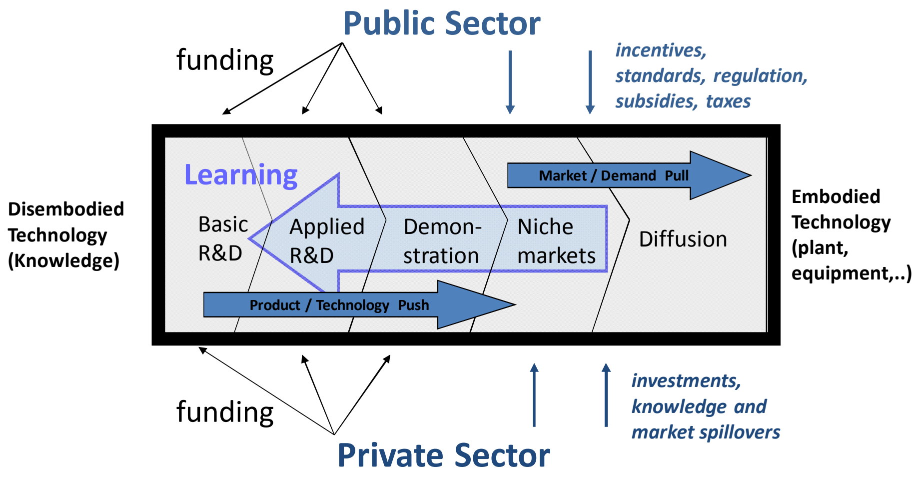
+

S - Software (know-how, "know-why")

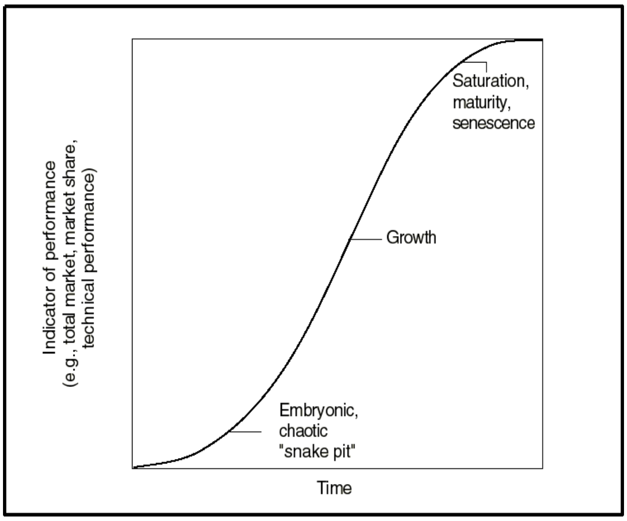
+

O -"Orgware" (institutions, regulation, "rules of the game")

The "black box" of Technology



A Stylized Technology Life Cycle Model *akin* Diffusion Curve



Technological Change: Life Cycle Model

Stage	Measure/Mechanism
Invention	Basic R&D, breakthrough
Innovation	Applied research, demonstration plants
Niche markets	Investment, learning-by-doing and using
Commercialization Pervasive diffusion	Standardization, mass production, economies of scale

Technology Growth Determinants
(both positive and negative impacts)

- New knowledge generation/depreciation (R&D)
- (Dis-)Economies of scale
  (unit, manufacturing, market)
- Learning by doing and using (knowledge)
  positive & negative learning
- Innovation System functioning (+/-):
  -- Knowledge generation & uncertainty reduction
  -- Complementary institutional & social settings
  -- Resource mobilization (investments, financing)

R&D Intensity:
(propensity to innovate * probability of success * expected return)

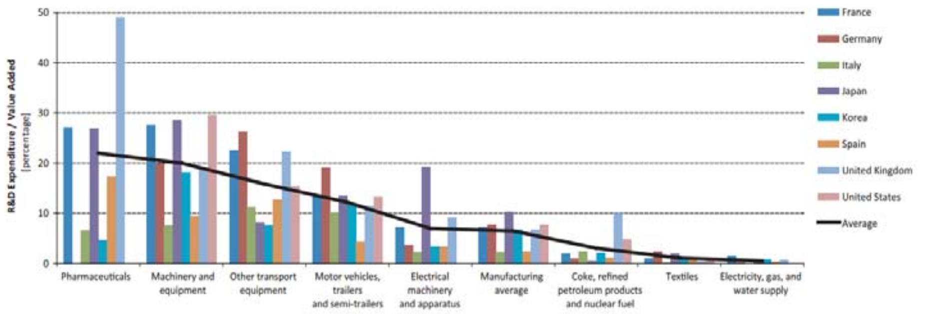


Figure 24.3 | R&D intensity (expenditures per value added, in percent) for selected sectors and OECD countries in 2002. Source: The OECD Research and Development Expenditure in Industry database and STAN Database.

Creating New Knowledge: Scherer's Rule of compounding uncertainties

Probability an R&D project gets selected**	??
Probability of technical success (once selected)*	.57
Commercialization (given technical success)*	.67
Financial success (given commercialization)*	.74
Aggregate probability	.27
Magnitude of financial success (private AND social Rates of Return)**	??

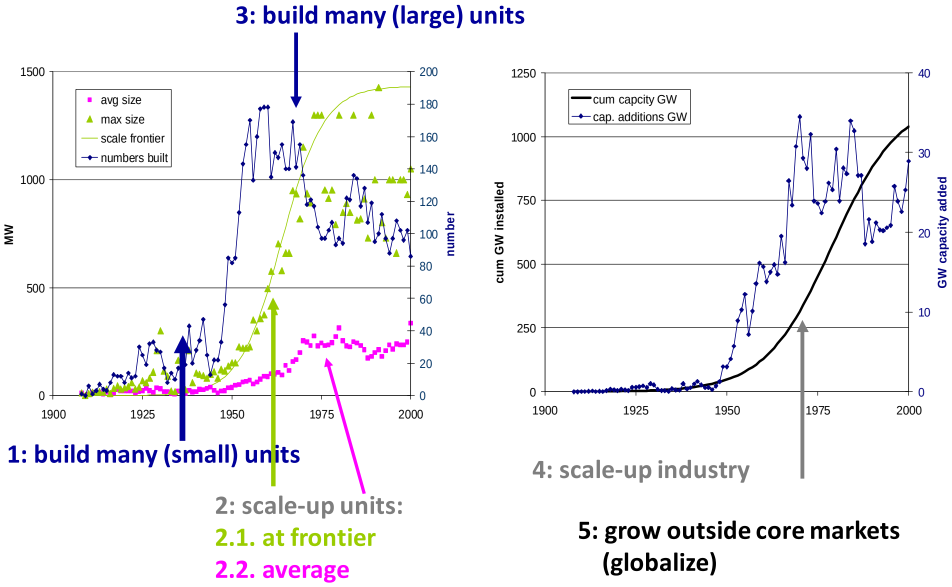
* *Based on Mansfield et al.'s empirical study of R&D project histories in US enterprises in chemical, pharmaceutical, electronics, and petroleum industries*

***** Largest uncertainties!***

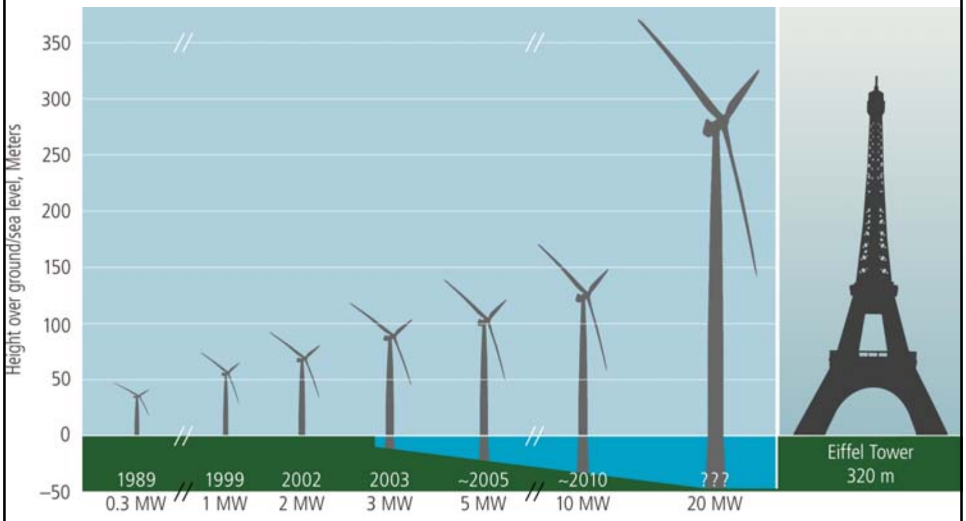
Assuming 0.5 probability for the unknown, compound probability is 0.5x0.27x0.5 = 7 % success rate

5 Phases in Scaling-up Technology:

Example Coal Power Plants



Size of Wind Turbines



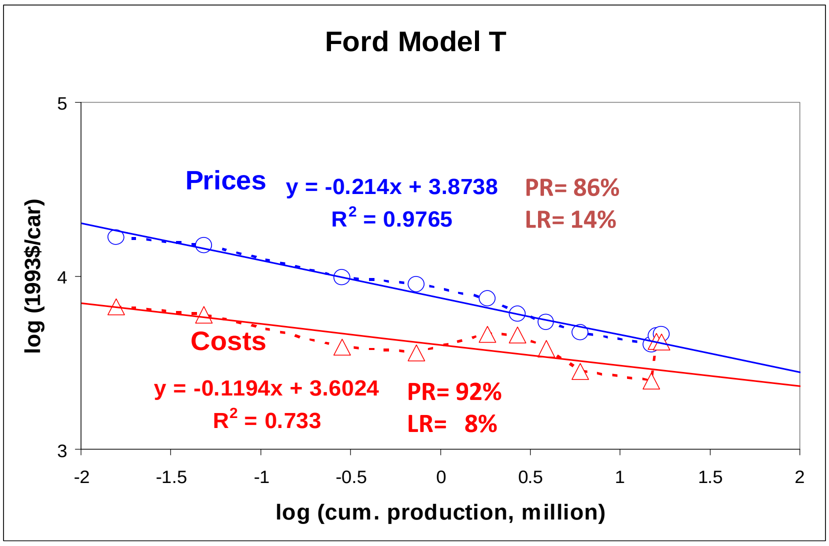
818 ETIS

Arnulf Grubler

Declining Costs per kW of German Wind Turbines:
Pure Economies of Scale: $\$_t = (kW_t/kW_{t-1})^{0.84}$ x $\$_{t-1}$

	1990	1991	1993	1998
Diameter, m	23	31	44	63
kW	150	300	600	1500
DM per kW	2538	2410	2135	1752
Million DM	.381	.723	1.281	2.628
Estimate		.682	1.294	2.766
Difference (actual/estimate)		+6.0%	-1.0%	-4.6%

Improved Economics: Prices vs. Costs



Data Source: Abernathy&Ward, 1975

Learning/Experience Curve Terminology

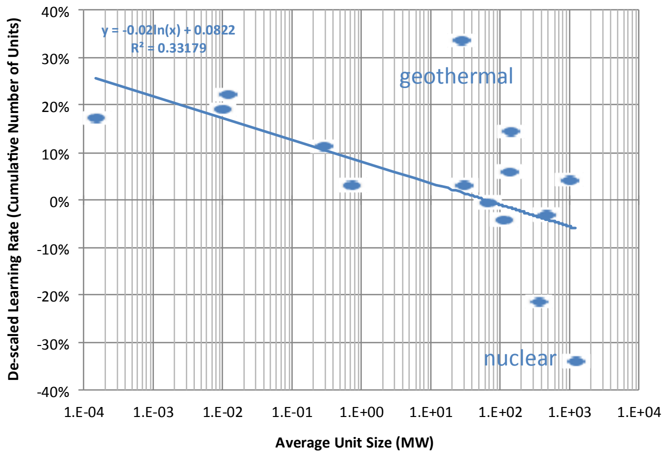
Costs: *C*
Learning Rate: *LR*
(% cost decline per doubling of output)
Progress Ratio: *PR* = 1 – *LR*
(remaining fraction of initial costs after doubling of output)
Learning parameter: *b*
Output: *O*
Learning investment: Cumulative expenditures above break-even value

$C_t = C_0 * (\Sigma_0^t O)^{-b}$
$PR = 2^{-b}$
$LR = 1 - PR$

e.g. 30% cost reduction per doubling of output:
C_o=100 C_t = 70 O_o =1 O_t = 2 LR = .3 *PR* = .7 *b* = -.51477

Mind: energy economics literature expresses cumulative Output often per cumulative Capacity installed. With increasing unit scales this confounds economies of scale and LbD, resulting in overestimation of learning rates.

Learning Rates after considering Economies of Scale



smaller units

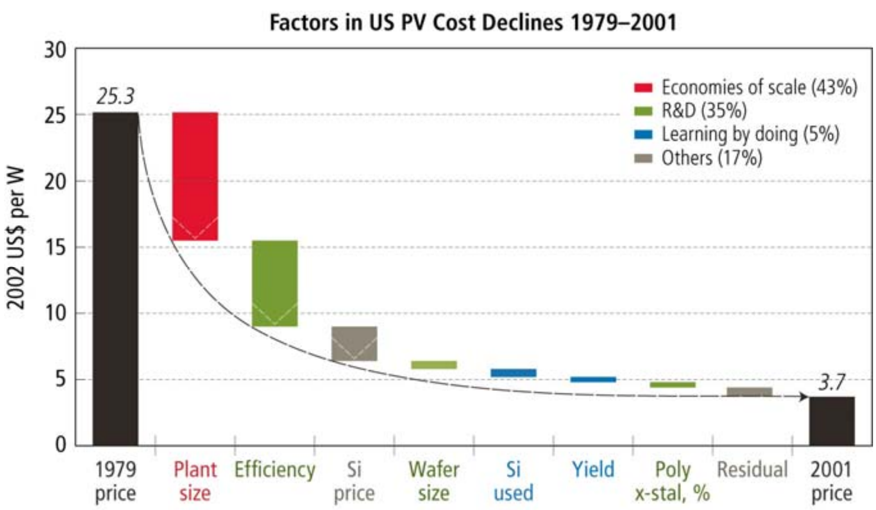
-> more units

-> more opportunities to experiment

-> more learning

Healey, S. (2015). Separating Economies of Scale and Learning Effects in Technology Cost Improvements. IR-15-009. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Drivers of Technology Improvements



Source: G. Nemet, 2008.

Global Resource Mobilization for Energy Technology Innovation & Diffusion

(Billion $)

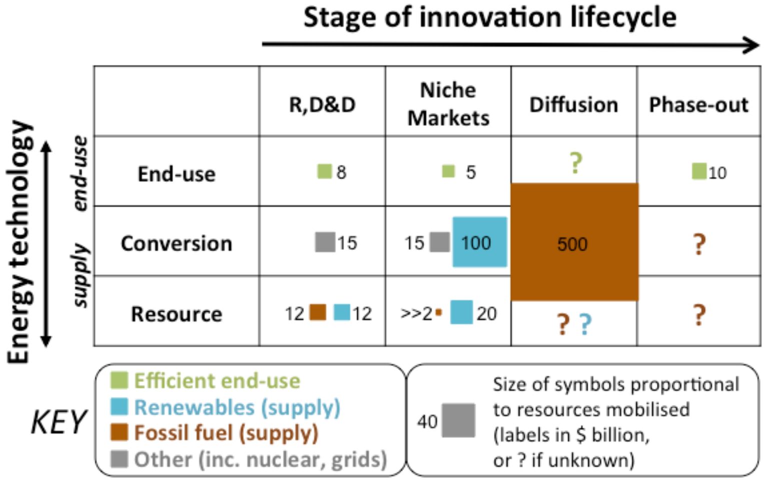
	innovation (RD&D)	market formation	diffusion
End-use & efficiency	>>8	5	300-3500
Fossil fuel supply	>12	>>2	200-550
Nuclear	>10	0	3-8
Renewables	>12	~20	>20
Electricity (Gen+T&D)	>>1	~100	450-520
Other*	>>4	<15	n.a.
Total	>50	<150	1000 - <5000
non-OECD	~20	~30	~400 - ~1500
non-OECD share	>40%	<20%	40% - 30%

* hydrogen, fuel cells, other power & storage technologies, basic energy research

GEA, 2012

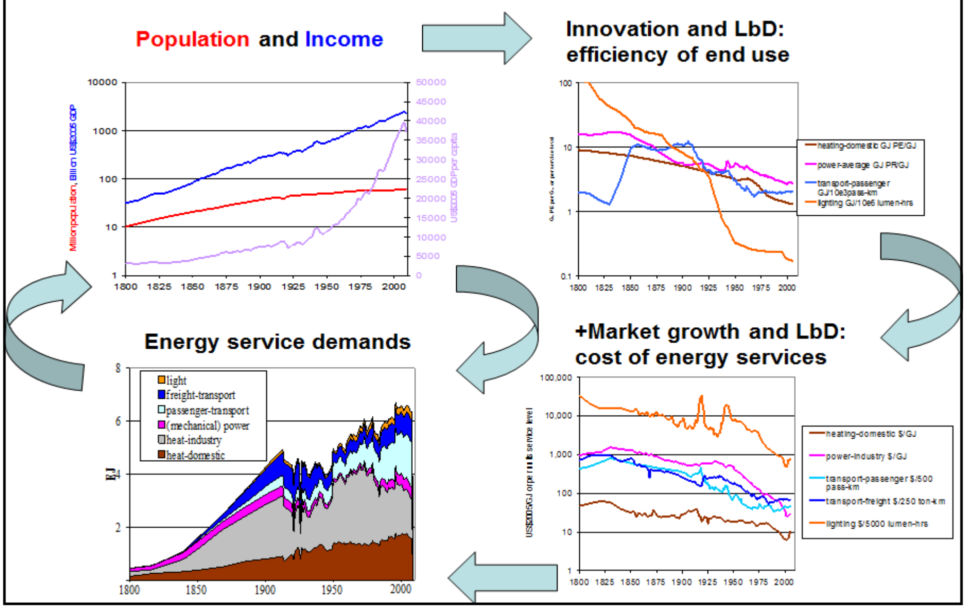
Public Policy-induced ETIS Investments

billion US$2005



Wilson et al. *Nature CC,* 2012

UK Energy History – Innovation-driven Growth (LbD=Learning by Doing)



Synthesis Technology

- Main driver for past evolution
- Main driver for future scenarios
- Creating technological knowledge: Systemic process: Actors/institutions + resource mobilization + knowledge generation = innovation and improvements
- Requirements for policy: Alignment, stability, allow experimentation (and failure), globalize

Part 2: Environment

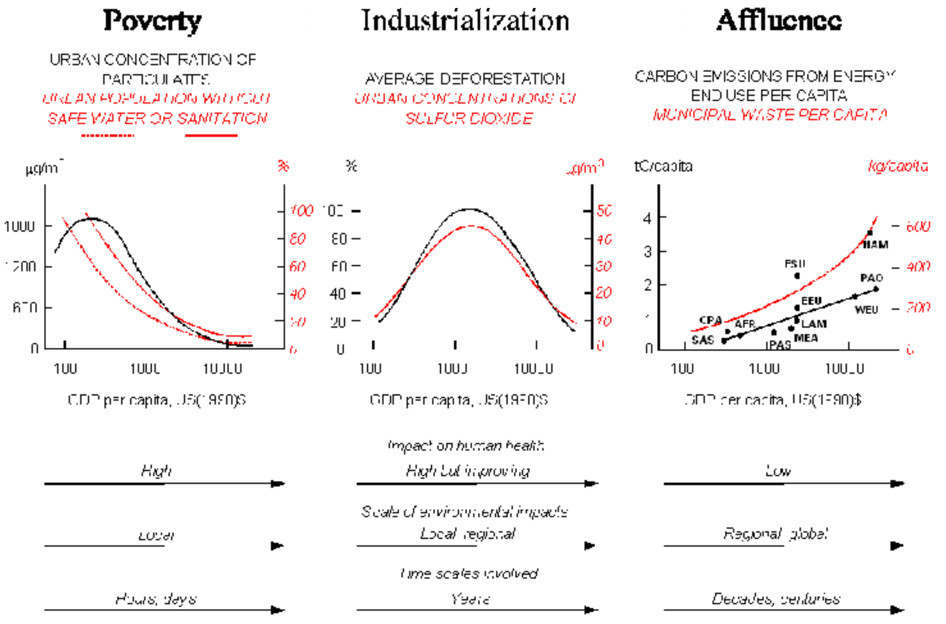
Energy & Environment

(Energy dominant stressor in 9/18 cases)

		impacting:						
environmental stressor	**caused mainly by:**	resources	biodiversity	land	soil	water	air	climate
Resource use:								
extraction of fossil fuels	Energy	X	X	X	X	X	X	X
extraction of minerals	Industry	X	X	X	X	X	X	
land use	Agriculture		X	X	X	X		
water use	Agriculture					X		
Nutrient cycles and impacts on land and water:								
nitrogen fixation	Agriculture				X	X		X
phosphorous cycle	Agriculture				X	X		
Pollutant emissions:								
Oil spills	Energy					X		
Cadmium	Industry				X	X		
Mercury	Energy				X	X		
Lead	Industry				X	X		
Sulfur	Energy				X (1)	X (1)	X	X
Nitrogen (NOx)	Energy				X (1)	X (1)	X	X
Carbon (BC/OC/CO)	Energy						X	X
var. chemicals (VOCs)	Energy						X	X
Particulates	Energy						X	
Greenhouse gases:								
CO2	Energy					X (2)		X
CH4	Agriculture							X
N2O	Agriculture							X

(1) acidic deposition (2) ocean acidification

A Taxonomy of Environmental Problems (after WB, 1992):



Environmental Problems of Energy

1: Poverty, ignorance, and lack of capacity

Particulate Concentrations and Human Exposure in 8 Environments

Exposure = People x Time x Concentration

Group of nations	Concentrations ($\mu g/m^3$) Indoor	Outdoor	Exposures (GEE)[a] Indoor	Outdoor	Total
Developed					
Urban	100	70	5	<1	6
Rural	60	40	1	<1	1
Developing					
Urban	255	278	19	7	26
Rural	551	93	62	5	67
Total			87	13	100

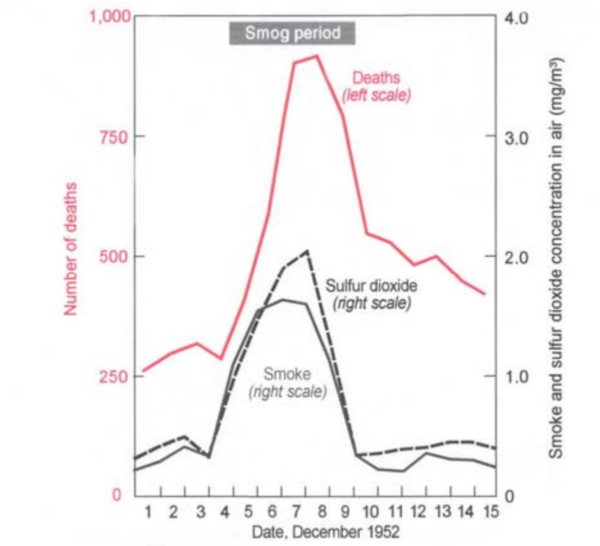
[a]GEE = Global Exposure Equivalent.
Source: Adapted from Smith (1993:545).

Environmental Problems of Energy

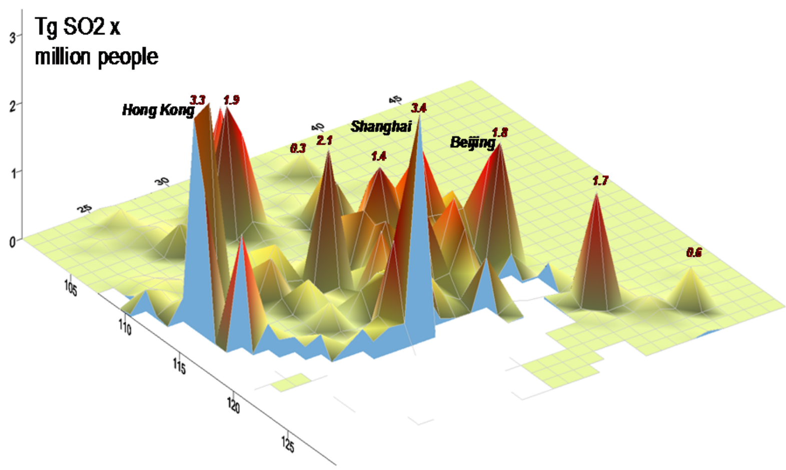
2: Industrialization, growing awareness, regionalization

London - December 1952

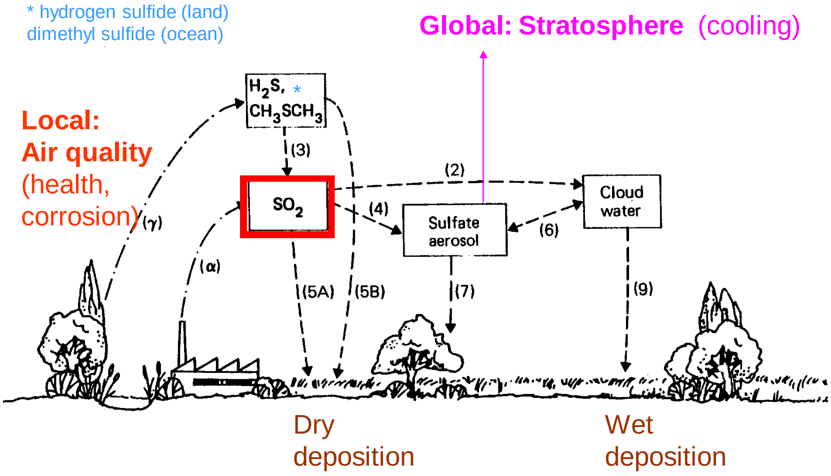
Urban Air Quality and Mortality



China - Air Pollution (SO_2) Exposure

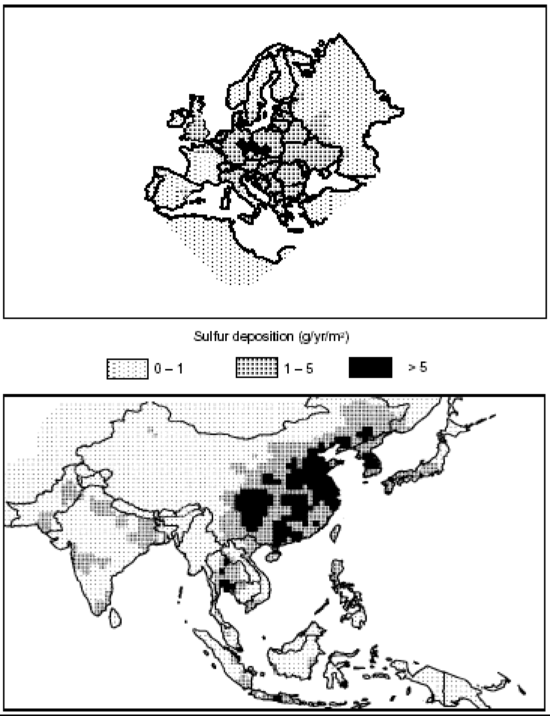


Sulfur Cycle
Local, Regional, and Global Impacts



Based on Crutzen&Graedel, 1986.

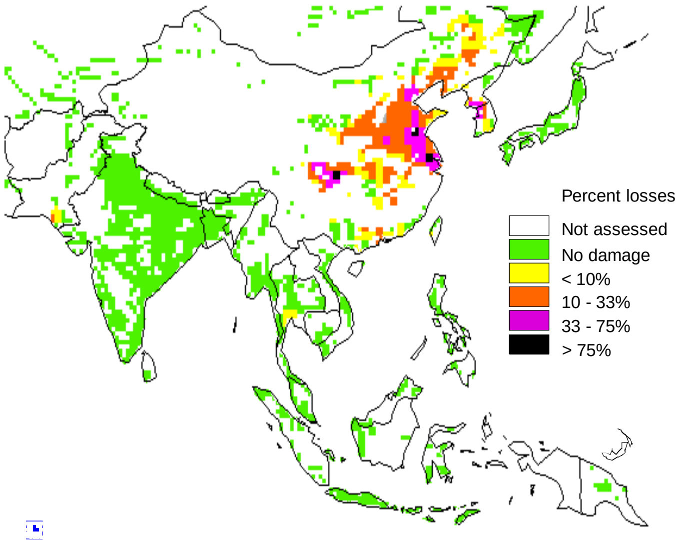
Sulfur Deposition (gS/m^2)



Europe, ca. 1990

China,
A2 Projection for 2020

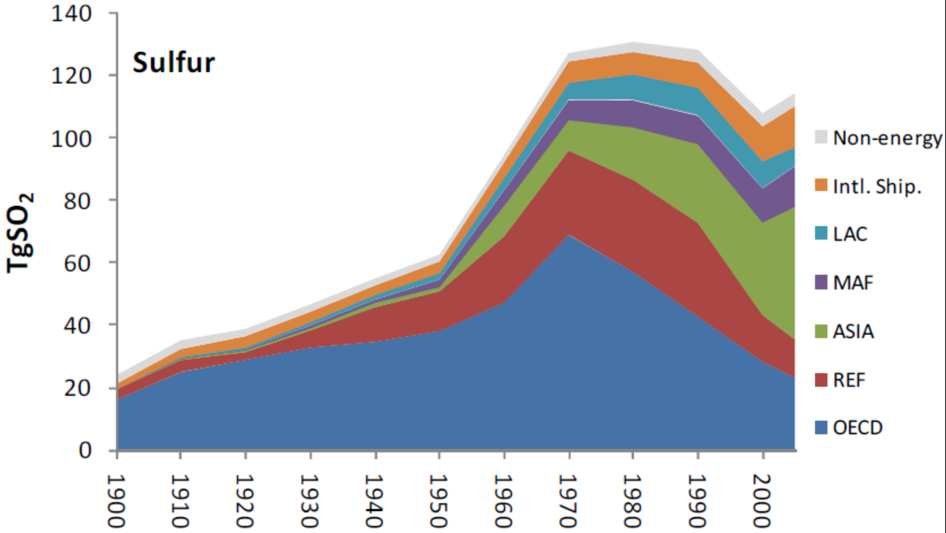
A2 Acidification Impacts on Food Production Loss

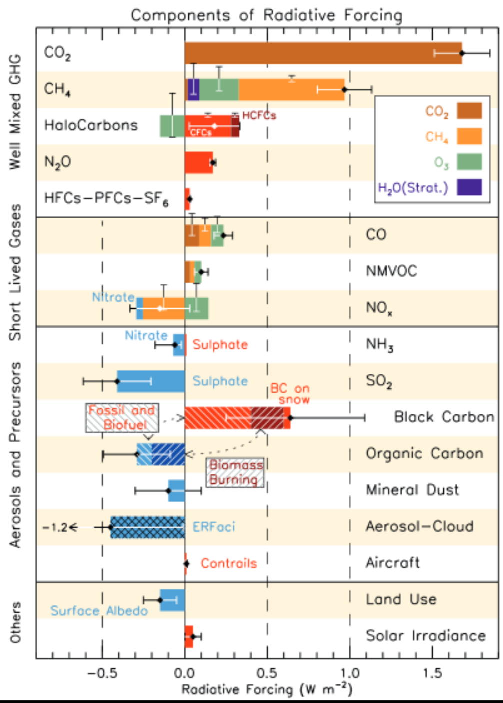


814 Energy Systems Analysis

Arnulf Grubler

World – Sulfur Emissions by Region





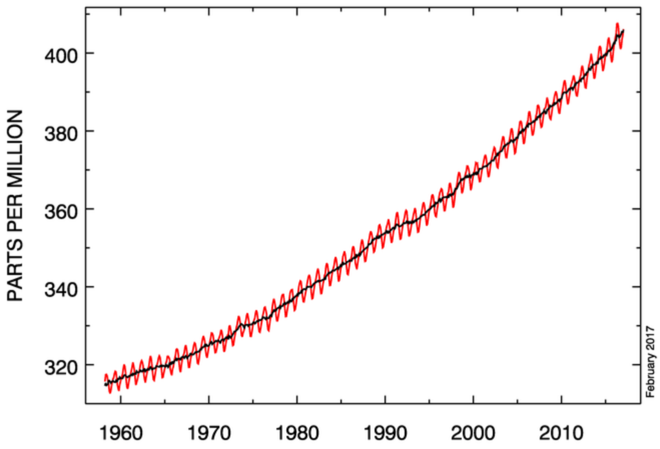
IPCC WGI AR5
Radiative Forcing
Change
1750-2011

Environmental Problems of Energy

3: Affluence, deep uncertainty, globalization

Atmospheric CO_2 Concentration (Mauna Loa)

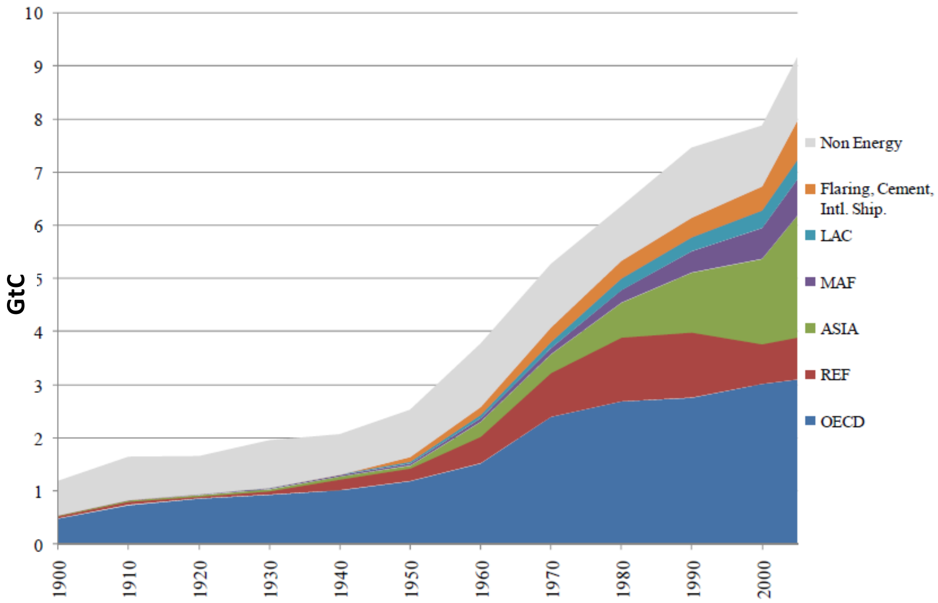
1 ppm= 2.12 GtC (7.8 $GtCO_2$), change 2015/2014: +2.3 ppm
atmospheric increase = emissions x Airborne Fraction
= 10.7 GtCx2.12=5 ppm x 0.46 =2.3 ppm



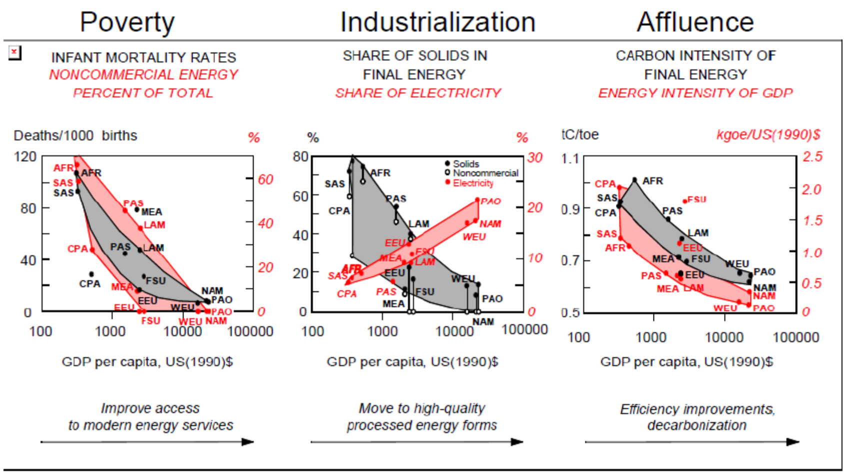
NOAA, 2017.

Carbon Emissions by Region

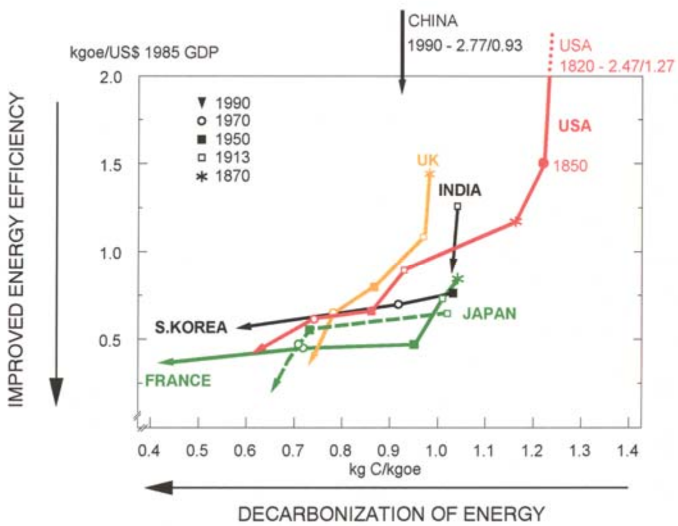
GtC (Gigatons elemental carbon) x 3.67 = tons CO_2



Energy – Environment Strategies



Improvements in Efficiency and Decarbonization: Diverse Paths



Synthesis Environment

- Multiple impacts, drivers as organizing principle (not environmental media):
  poverty, industrialization, affluence
- Environmental strategies:
  - generic (efficiency improvements, decarbonization)
  - "add on" (end-of-pipe)
  - remediation ("fix")
- Largest policy successes:
  - demonstrated benefits for human health
  - better alternatives and business models available
  - uncertainty "managed" (e.g. insurance, research)

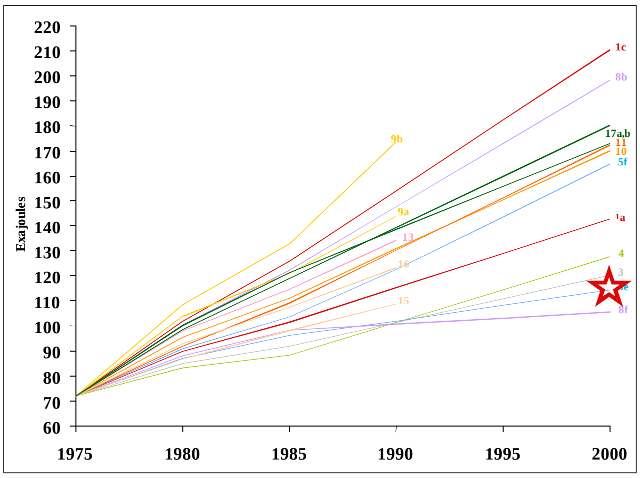
Hence: climate change as biggest challenge to date

Part 3: Energy Perspectives (Scenarios)

Why Look into the Future?

- Planning for R&D, investment, marketing
- Reconcile growing mismatch in temporal rhythms of society:
  -- accelerating rates of change in innovation and knowledge obsolescence
  -- slowing rates of change in social systems and technological infrastructures (increasing inertia)
- Anticipate and plan for disruptive change (e.g. climate change)
- Exercise pro-active rather than re-active management

US Energy Demand Projections

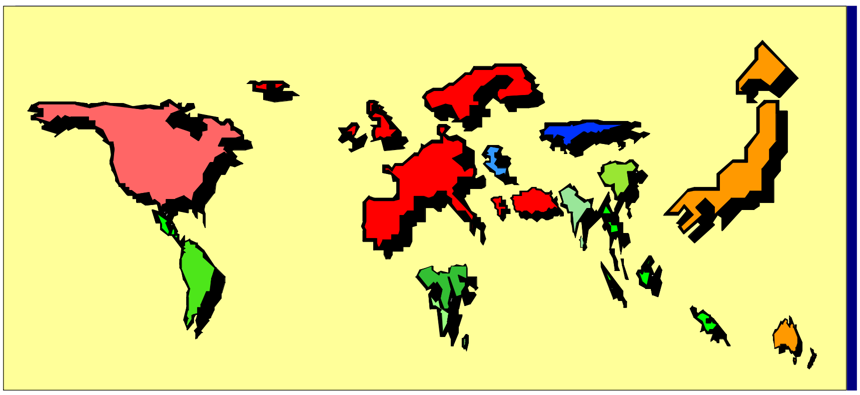


Scenarios are a tool for helping managers plan for the future – or rather for different possible futures. They help us focus on critical uncertainties. On the things we don't know about which might transform our business. And on the things we do know about in which there might be unexpected discontinuities. They help us understand the limitations of our 'mental maps' of the world – to think the unthinkable, anticipate the unknowable and utilise both to make better strategic decisions.

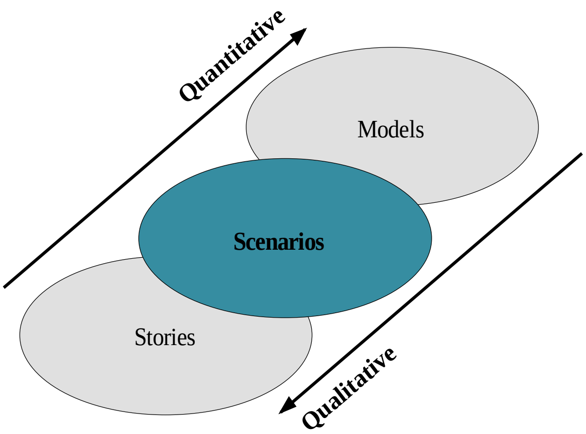
Source: Shell, 2001

World Economic Map

Areas of Regions Proportional to 1990 GDP (mer)



Alternative Scenario Formulations



How to Deal with Scenarios

- Robustness: Which trends unfold across even a wide range of scenarios?
  (Demographic ageing, geo-econoomic shift to "South", urbanization)
- Divergence: Which short- to medium-term trends/actions yield long-term differences across scenarios
- Implications: Which of "bifurcation triggers" are external (e.g. oil prices) or internal (e.g. innovation) for my firm/sector/country?

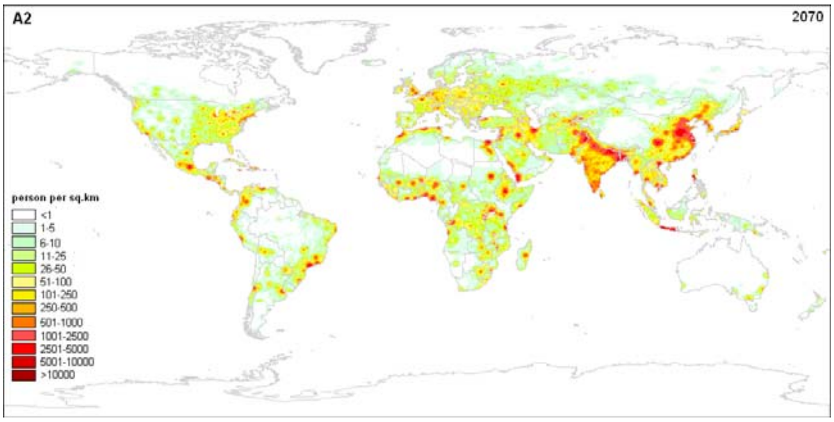
Futures: Major Uncertainties

- Demographic (growth & composition)
- Economic (growth, structure, disparities)
- Social (values, lifestyles, policies)
- Technologic (rates & direction of change)
- Environmental (limits, adaptability)
- Geopolitical (globalization vs. regionalization)

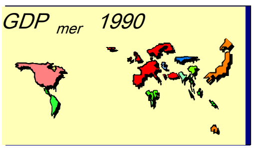
Summary of IIASA-GGI Scenario Characteristics

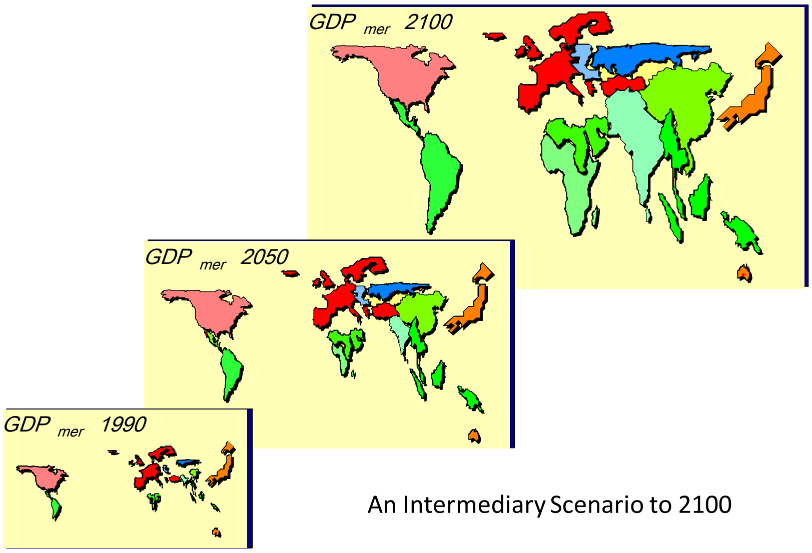
	1800	1900	2000	2100
Population (billion)	1	1.6	6	7-12
GDP (trillion $)	0.5	2	35	190-330
Primary Energy (EJ)	13	40	440	1050-1750
Emissions Energy (GtC) all GHGs (GtC_{equiv})	 0 0.3	 0.5 1.0	 7 11	 7-27 10-35

Population Density: 1990 and 2070 B1 and A2R



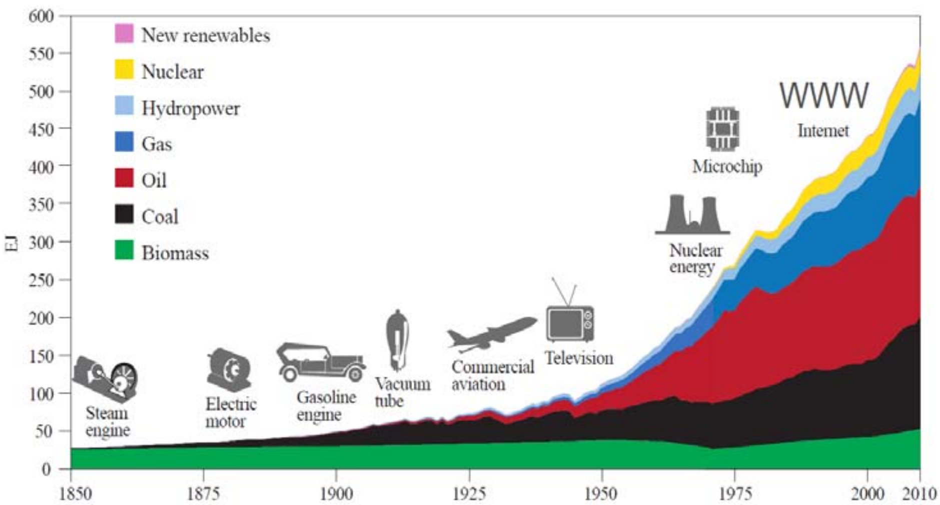
World Economic Map
Areas of Regions Proportional to 1990 GDP (mer)



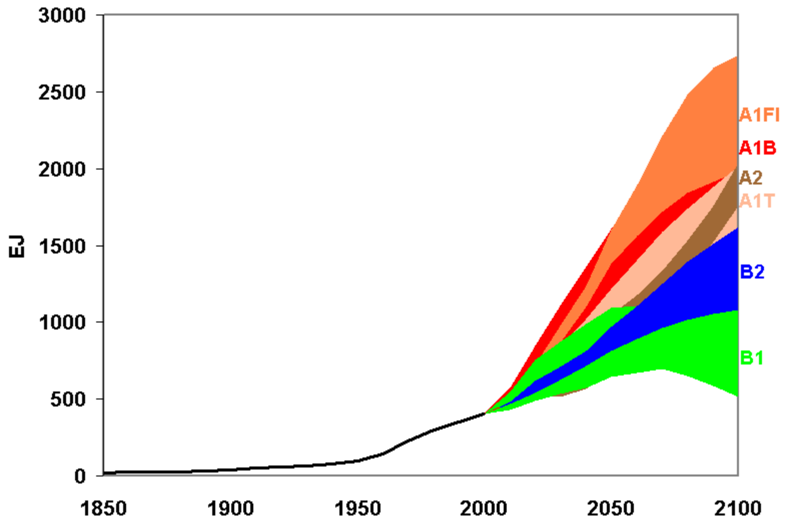


An Intermediary Scenario to 2100

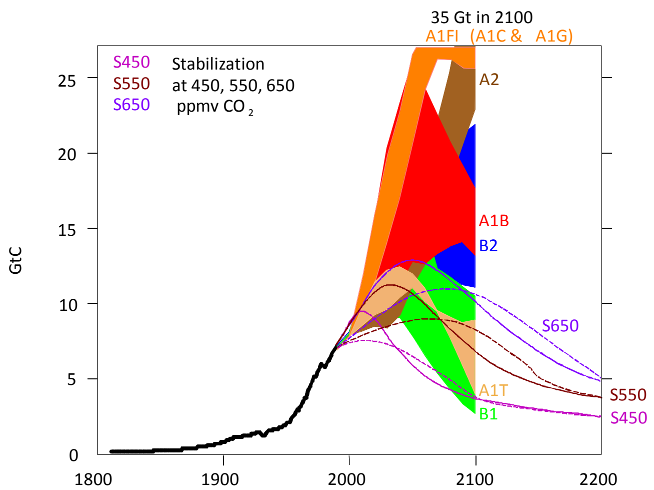
World Primary Energy Supply

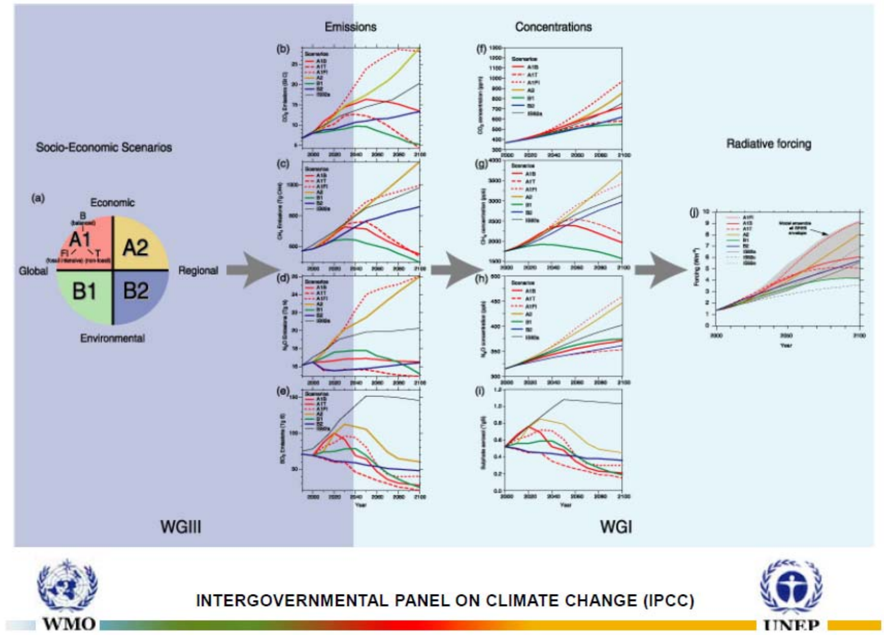


Global Primary Energy Scenarios

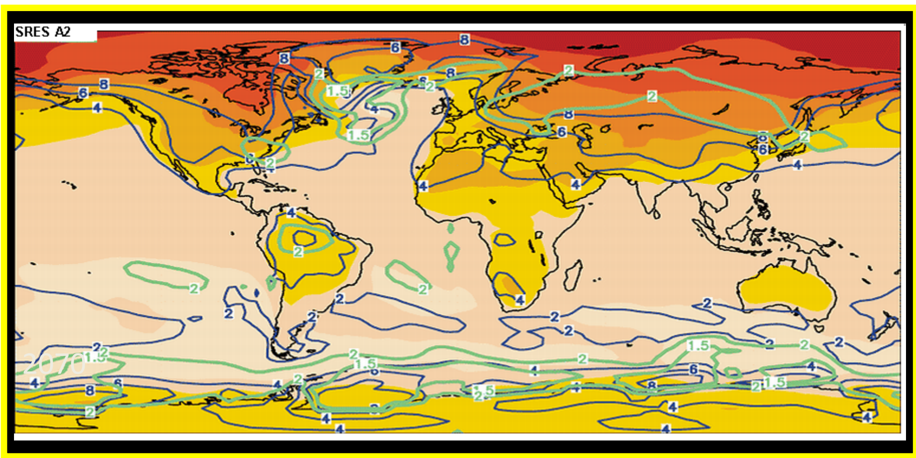


Carbon Emissions: IPCC-SRES Scenarios and IPCC-TAR Stabilization Profiles

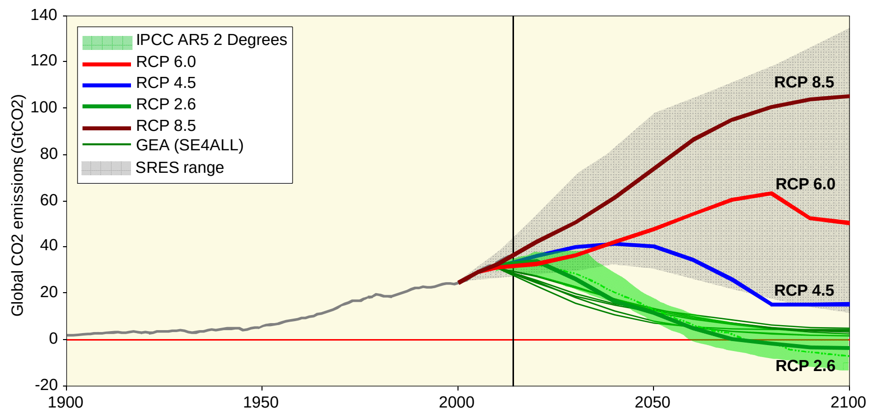




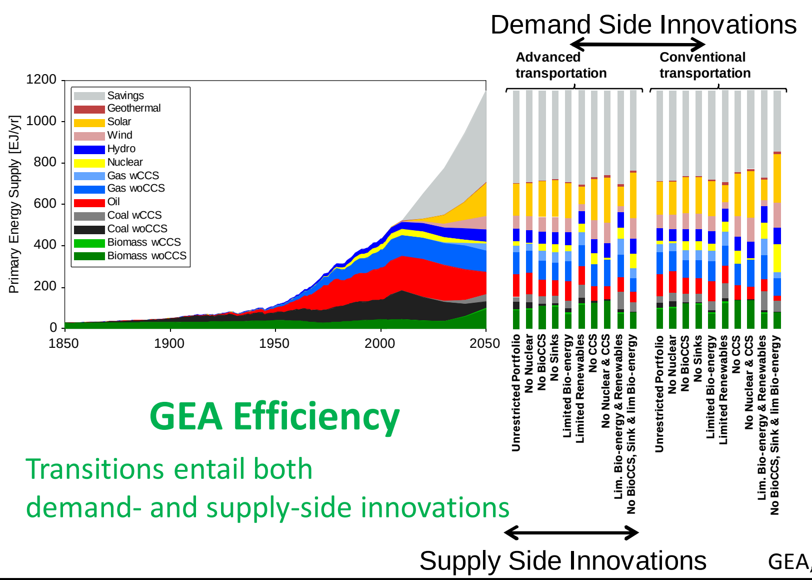
Δ Temperature (high A2 scenario)



Global CO_2 Emissions IPCC & GEA Scenarios



GEA Transition Pathways

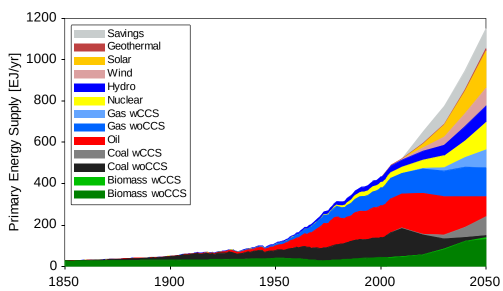


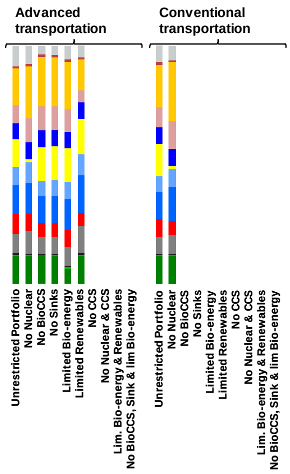
GEA Efficiency

Transitions entail both
demand- and supply-side innovations

GEA, 2012

GEA Transition Pathways





GEA Supply

Lack of innovation in efficiency, constrains supply side flexibility

GEA, 2012

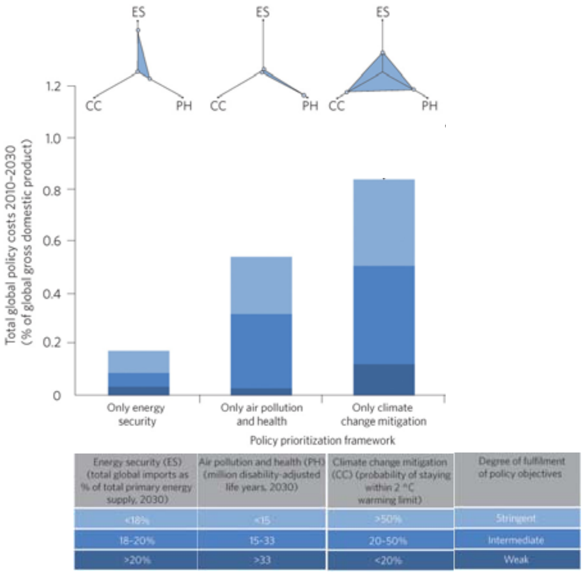
New CC Policy Perspectives

- Traditional CC policy framework:
  -- "additionality"
  -- opportunity costs (crowding out)
  -- costs & benefits separated
  (in space and time)

- New perspectives:
  -- integration of policy frameworks
  -- significant synergies possible
  (if CC is used as entry point)

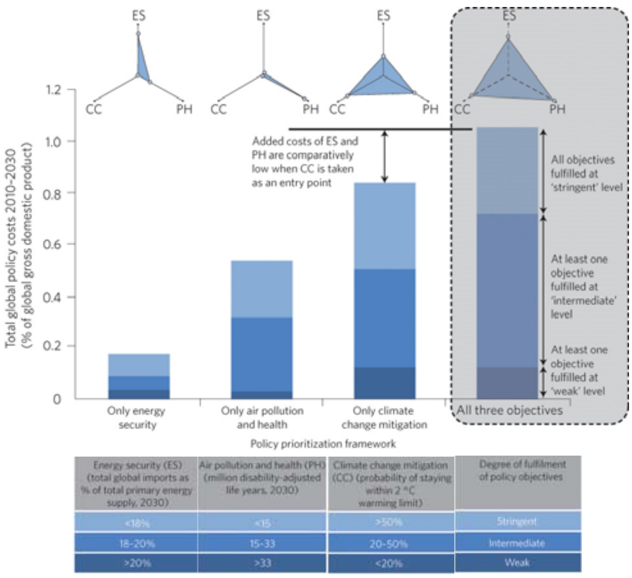
Synergies between Climate Change, Energy Security, and Air Pollution Policy Objectives

McCollum et al., 2013*Climatic Change* DOI 10.1007/s10584-013-0710-y

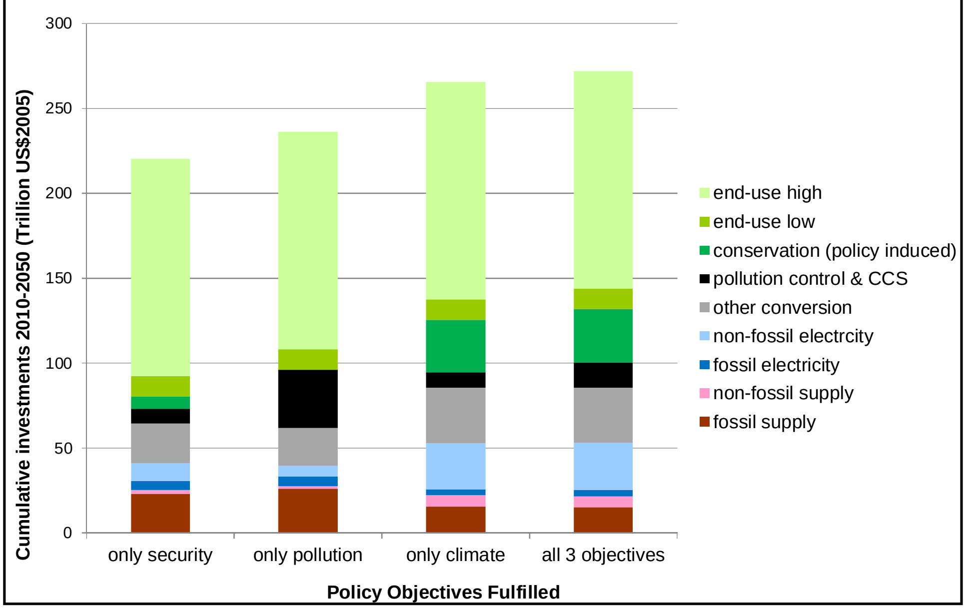


Synergies between Climate Change, Energy Security, and Air Pollution Policy Objectives

McCollum et al., 2013*Climatic Change* DOI 10.1007/s10584-013-0710-y



Cumulative Investments for single & multiple policy objectives



Some Scenario Findings

- Demographics: Lowering of population projections, ageing, education, urbanization
- Geopolitics: Pervasive move to "South" (urban population, GDP, energy, emissions,…)
- Structural Change in Energy I: Change is constructed via R&D and investment choices
- Structural Change in Energy II: Demand (& lifestyle) management (change) is key in energy security, resilience, and emissions reduction
- Climate Change: Minimum committed warming: ~1.5 °C
- Mitigating Climate Change: Uncertainty in targets, *early action*, *induced technological change*, and *policy integration* can lower costs substantially

Main Messages Scenarios

- Forecasting both impossible and innovation counterproductive
- Use of scenario techniques instead
- Opportunities and threats vary depending on which alternative future will unfold

- Response strategies:
  -- Uncertainty needs optimal portfolio of
  measures and contingency
  (best AND worst case planning)
  -- innovation as key technique, in:
  technology (R&D),
  human capital (education)
  institutional (adaptation)