The development-energy-environment-climate challenge: Transforming energy systems: Spain

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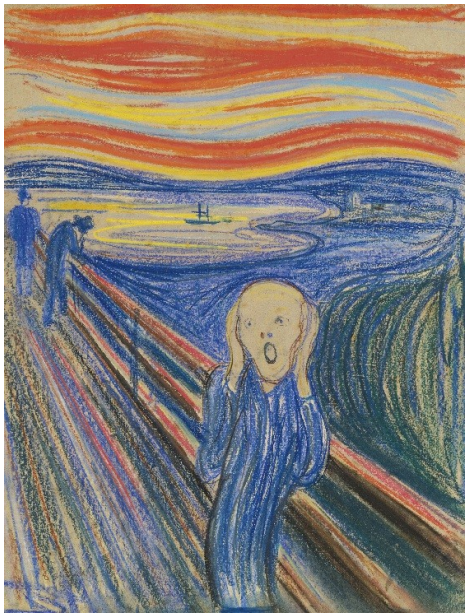
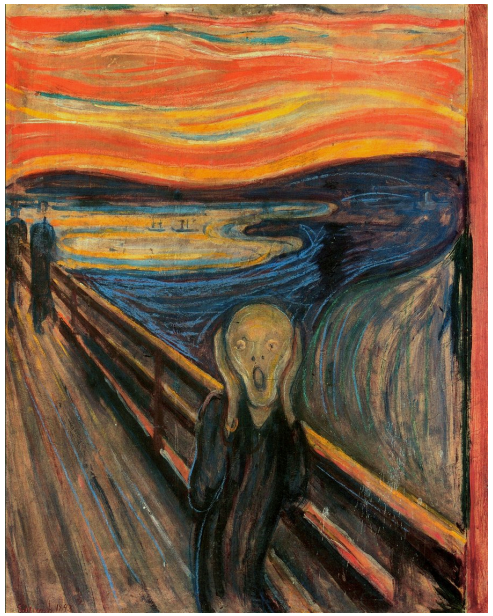
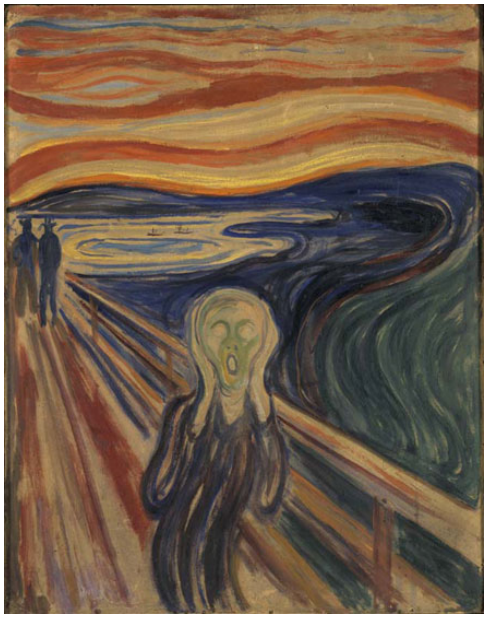

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Abstract

This talk provides an outline of the global development-energy-environment-climate challenge. It then examines the energy systems of Spain and how they can (are) reduce emissions of green house gases. It concludes with a discussion of future options and global trends.

Outline

- The challenges
- The rules of the game
- Energy mix of Spain
- Where we are (and should be) headed
- Options
- Some concluding remarks

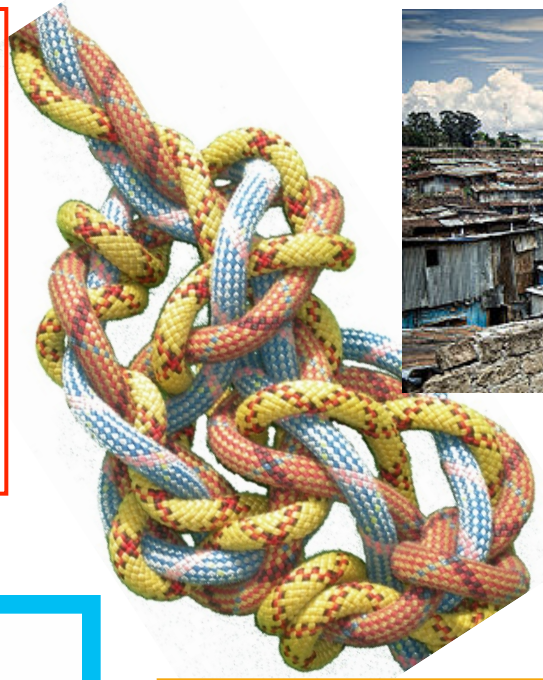
Sustainable Development:
The development-energy-environment-climate challenge

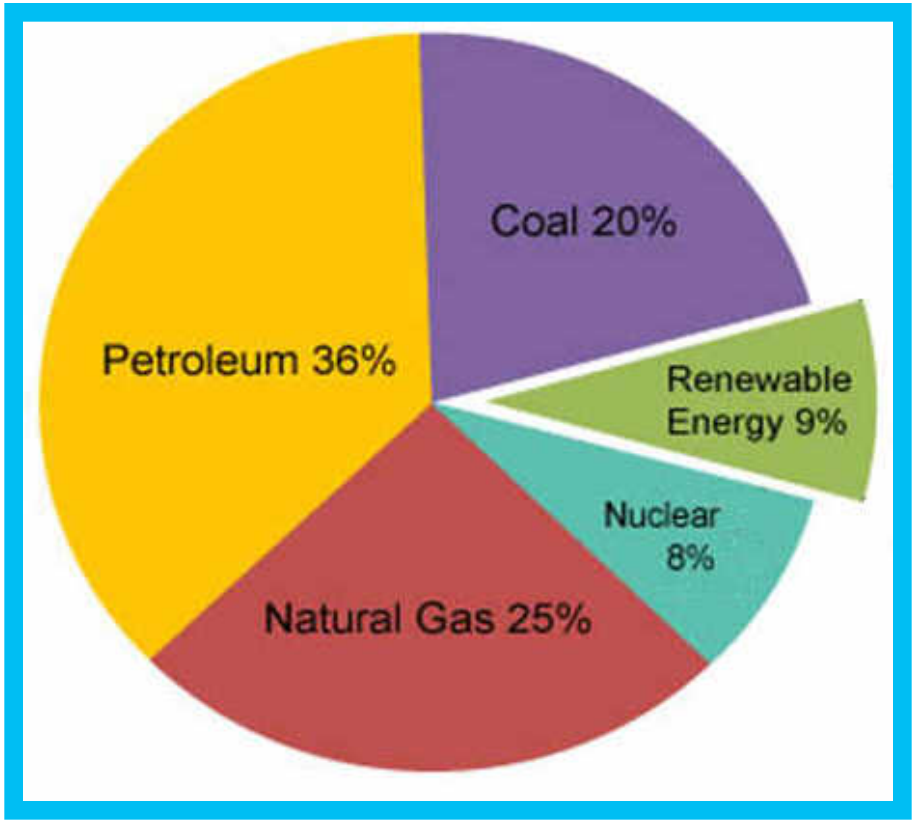
- Development: moral imperative, creates resilient societies, facilitates transformations, *drives politics*
- Energy: basis of modern technological societies
- Water: basis of life, non-fungible
- Environment: health and sustainability
- *Climate: the driver of the need to transform to carbon-neutral energy and transportation systems*

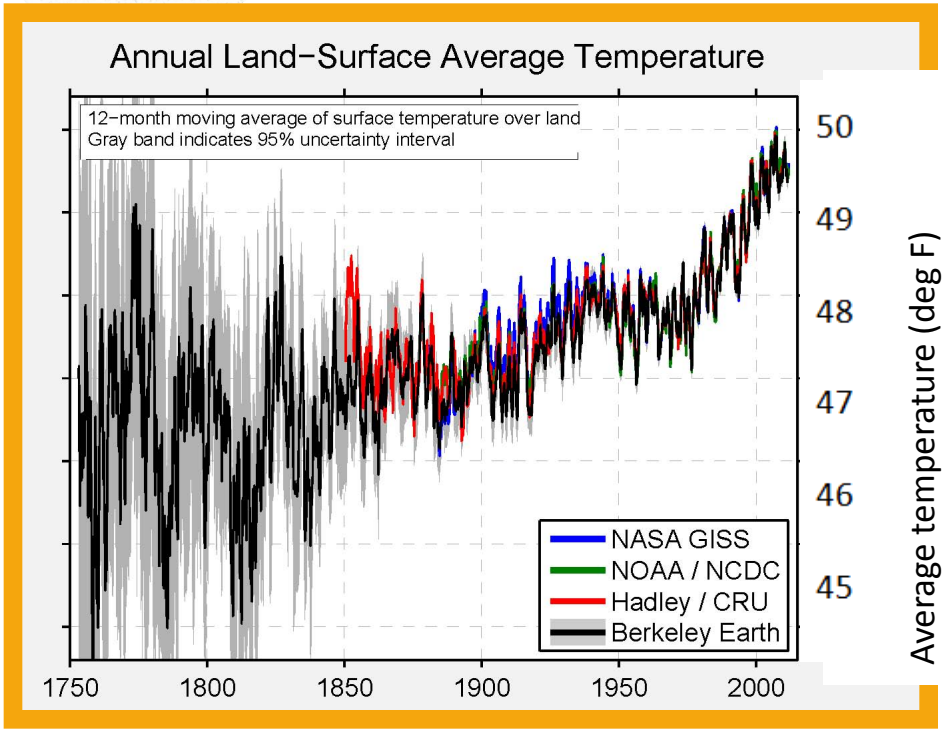
Climate Change: Impacts are global, long-term and likely catastrophic

A daunting knotty challenge:
Economic Development,
Energy Security, Climate.

No easy/ideal solution!
What should/will we do?







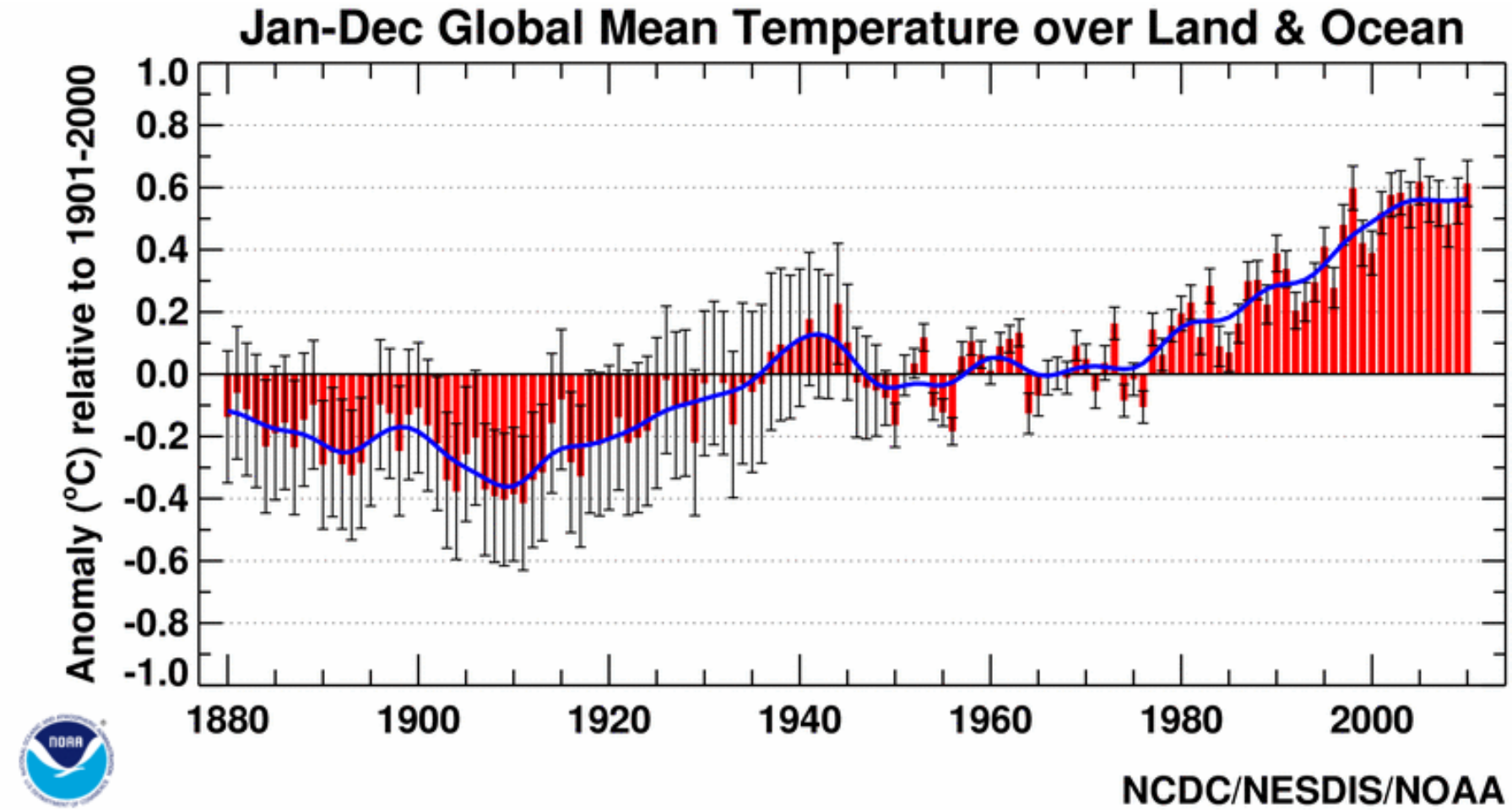
The challenge is ensuring energy security, and economic security, and climate security

- Underdeveloped world:
  - Survival by exploiting muscle power
  - 3 kWh / person / day
- Developed world:
  - Knowledge worker
  - 40+ kWh / person / day

Why change the global energy system?

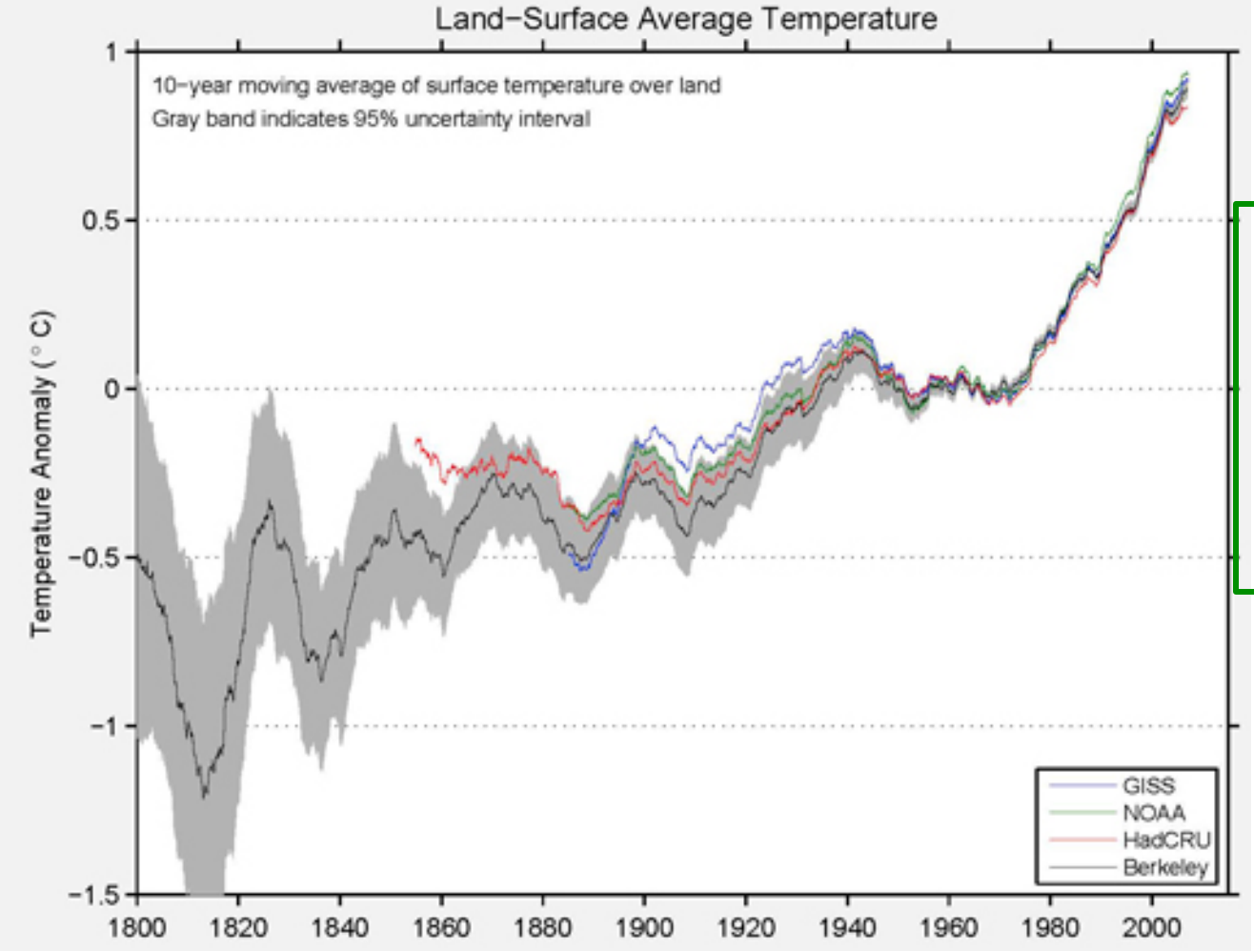
Why act now?

The mean temperature is changing



Mean temperature rise since 1900 ~ 0.74°C

Rise of Land Temperature

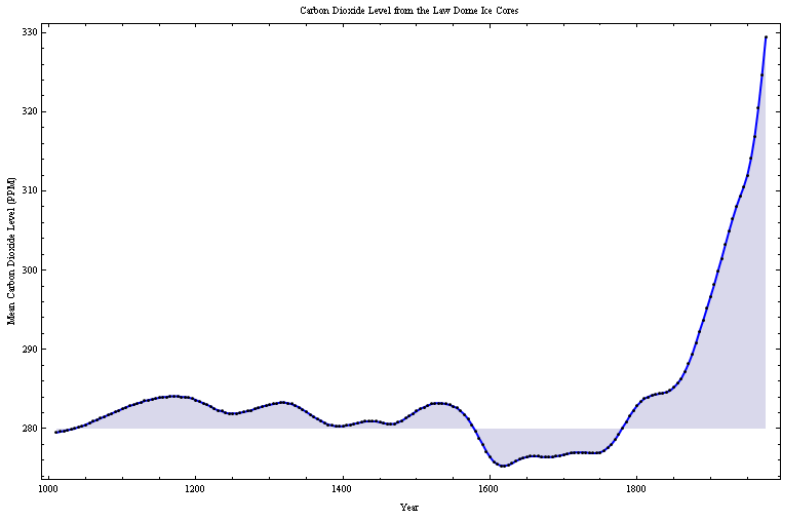


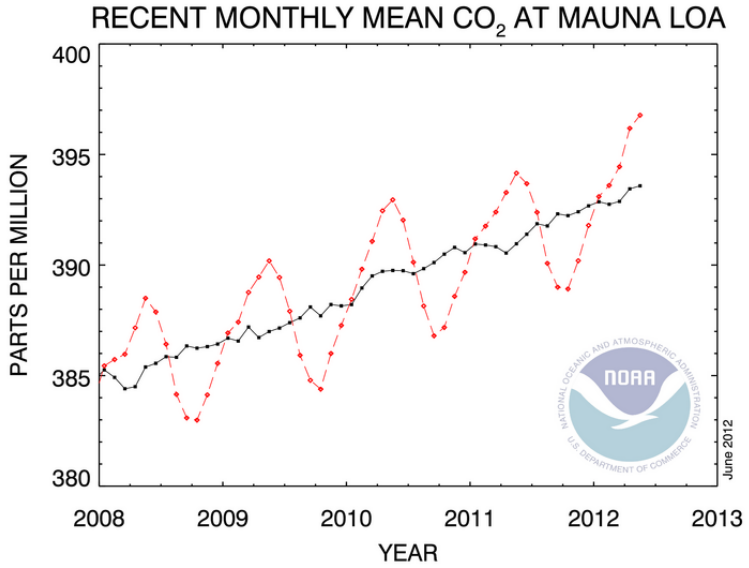
We do not know the full consequences of current 395 ppm of CO_2!!!

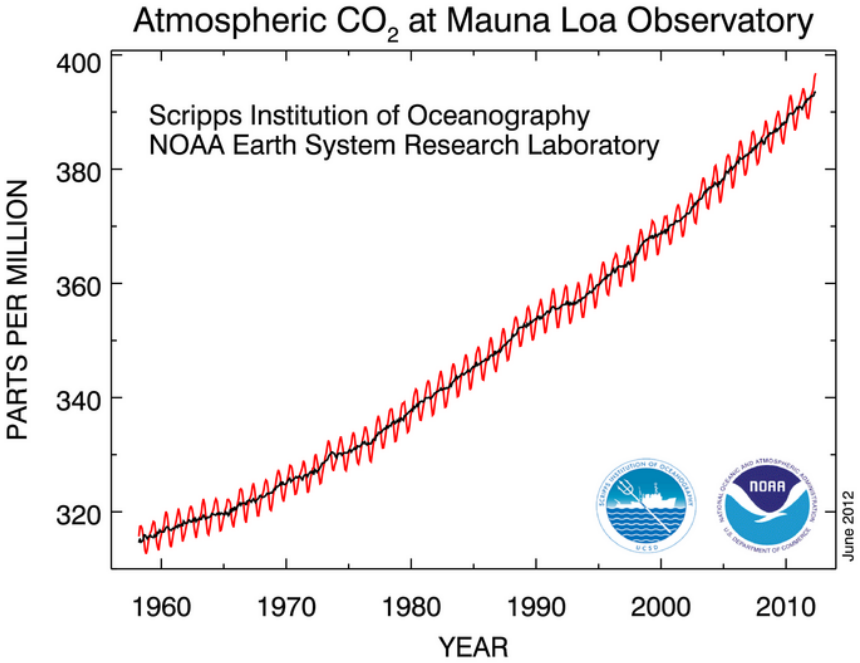
A change in T_{av} (land) from 20 year patterns between 1800-1960 to a uniform growth after 1970. Rise in mean temperature since 1970 ~ 0.9°C

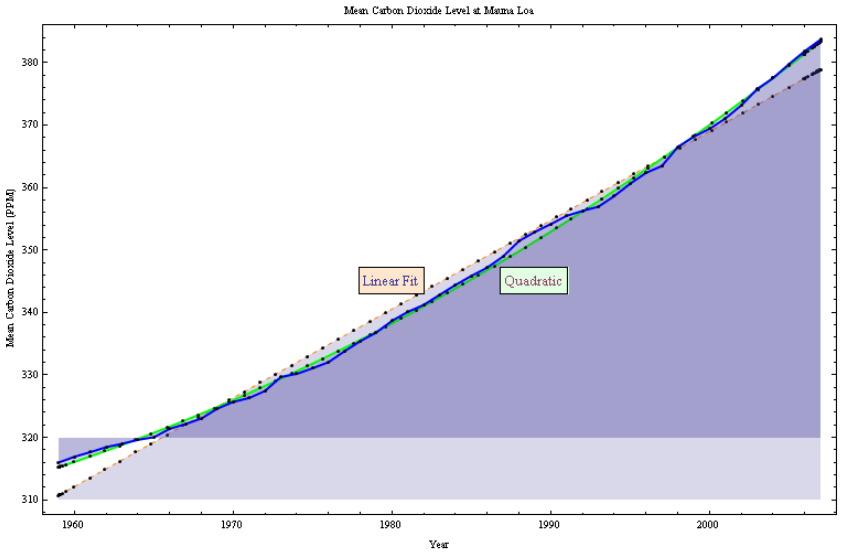
Source: http://berkeleyearth.org/analysis/

Rising CO_2 levels

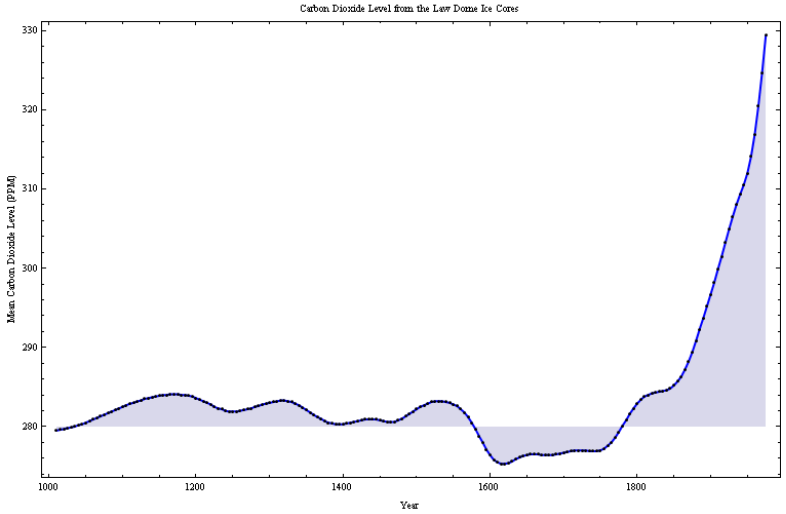


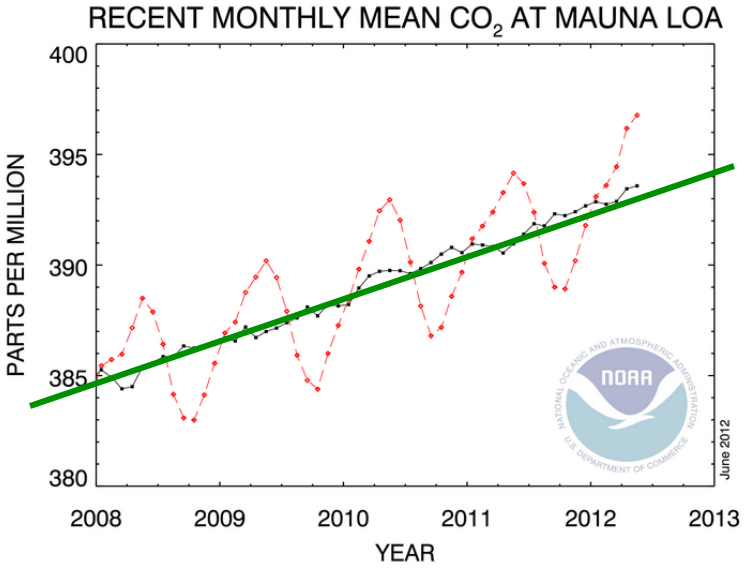


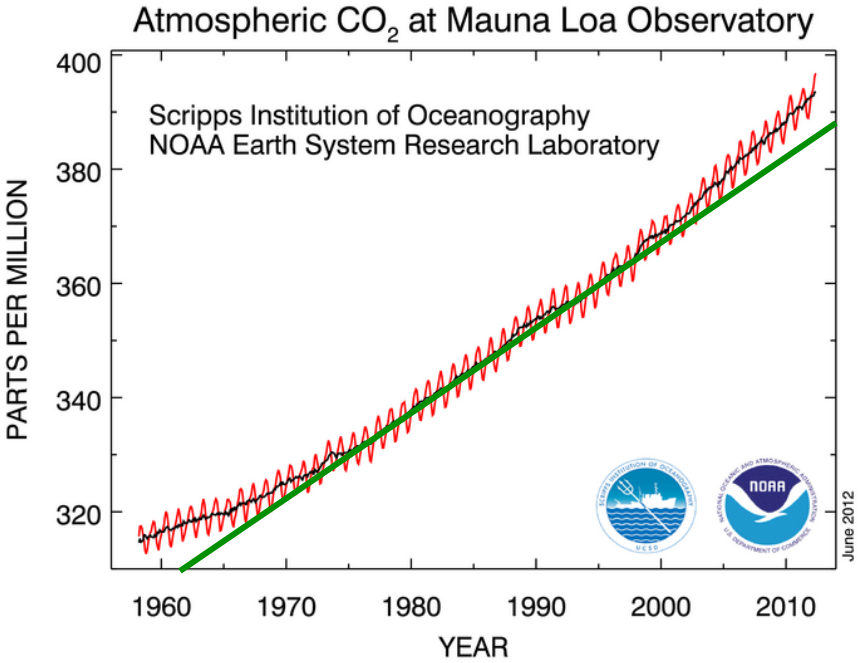


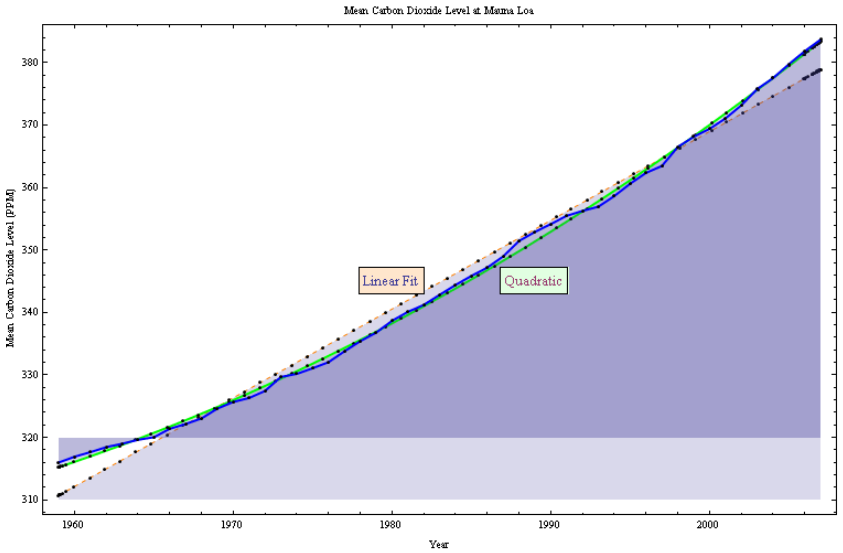


Rising CO_2 levels









Anthropogenic Emissions of Green House Gases

- 2011 Emissions of CO_2 = 32-34 Gigatonnes/year
- ? Natural recycling = 16-18 Gigatonnes/year
- 2012 concentrations = 393 parts per million (ppm)
- Increase in CO_2 levels ~ 2.0 ppm/year
- 1^{o}C rise in temp ~ 100 ppm (parts per million)

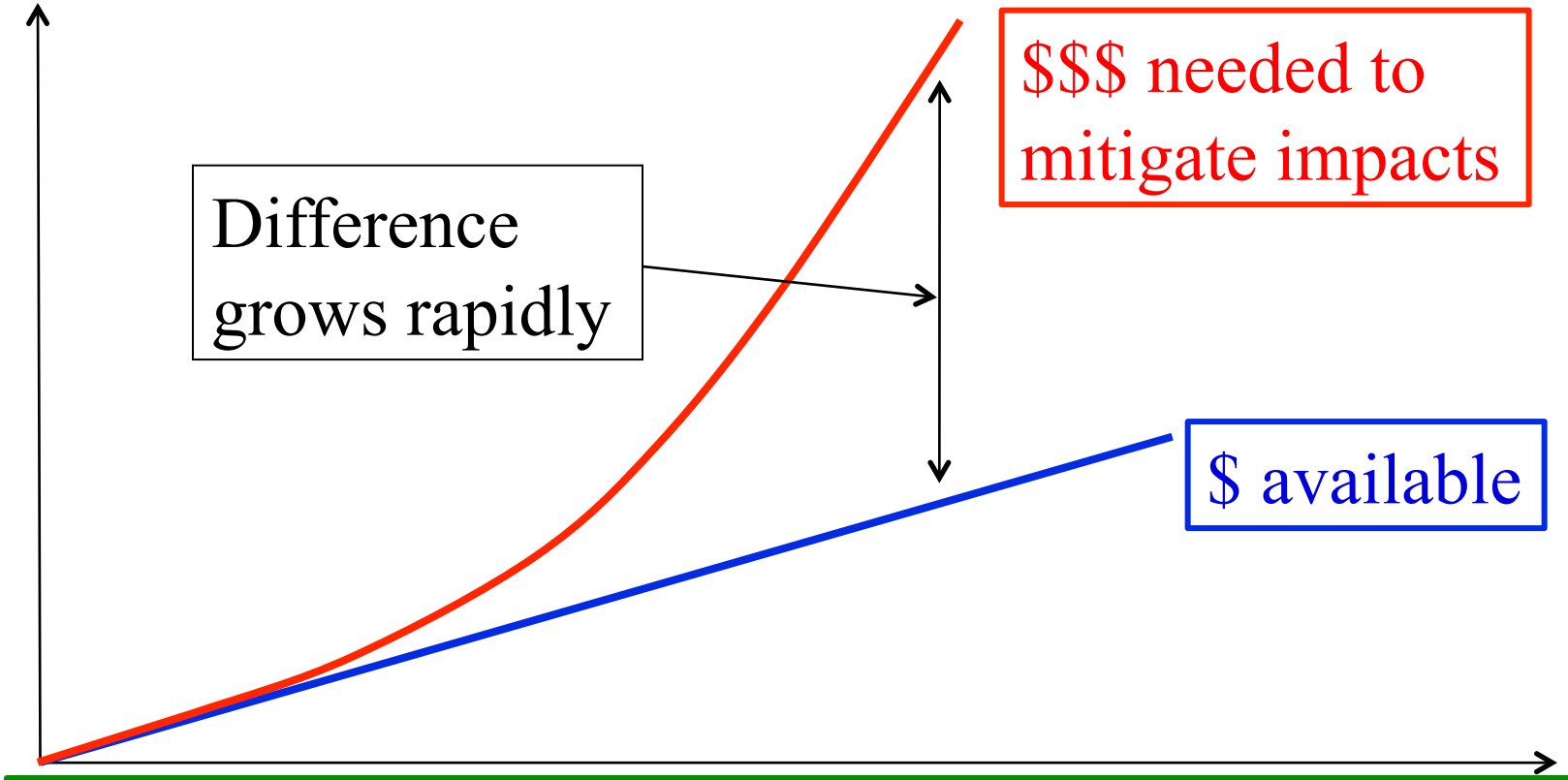
To stabilize CO_2 levels ~ 3 Gigatonnes/year

Requires > 90% Decarbonization

Climate security requires almost zero further use of fossil fuels since lifetime of CO_2 in the atmosphere is 100s-1000s of years

Why we must act now?

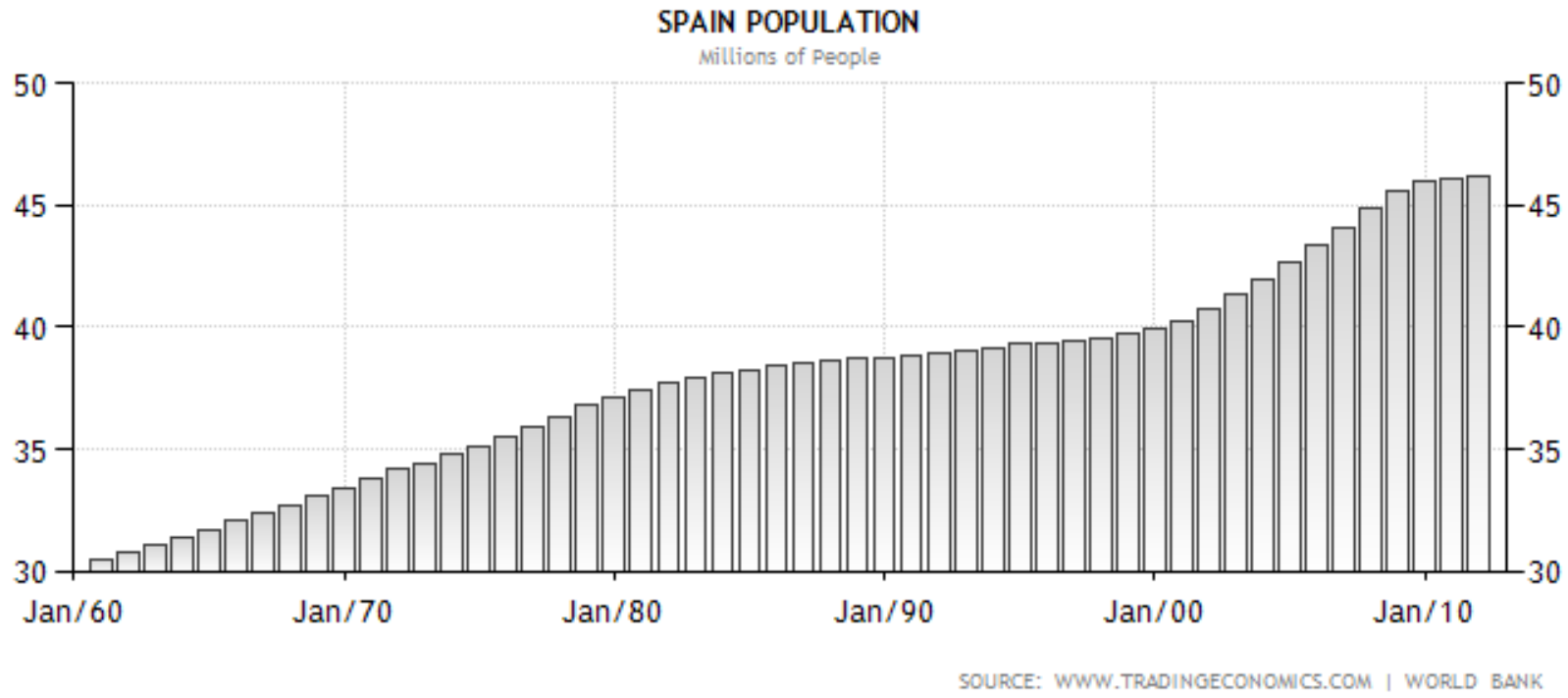
We don't know if/when/how highly coupled natural systems will collapse



Do not even know where we are today since the full warming effect due to the current 395 ppm of CO_2 is unknown!

Spain

Spain: a developed country with ~0% population growth



Stable developed population

- Don't need additional generation capacity
- Replacement of current systems by carbon neutral ones

A developed Spain with a stable population of 47 million needs

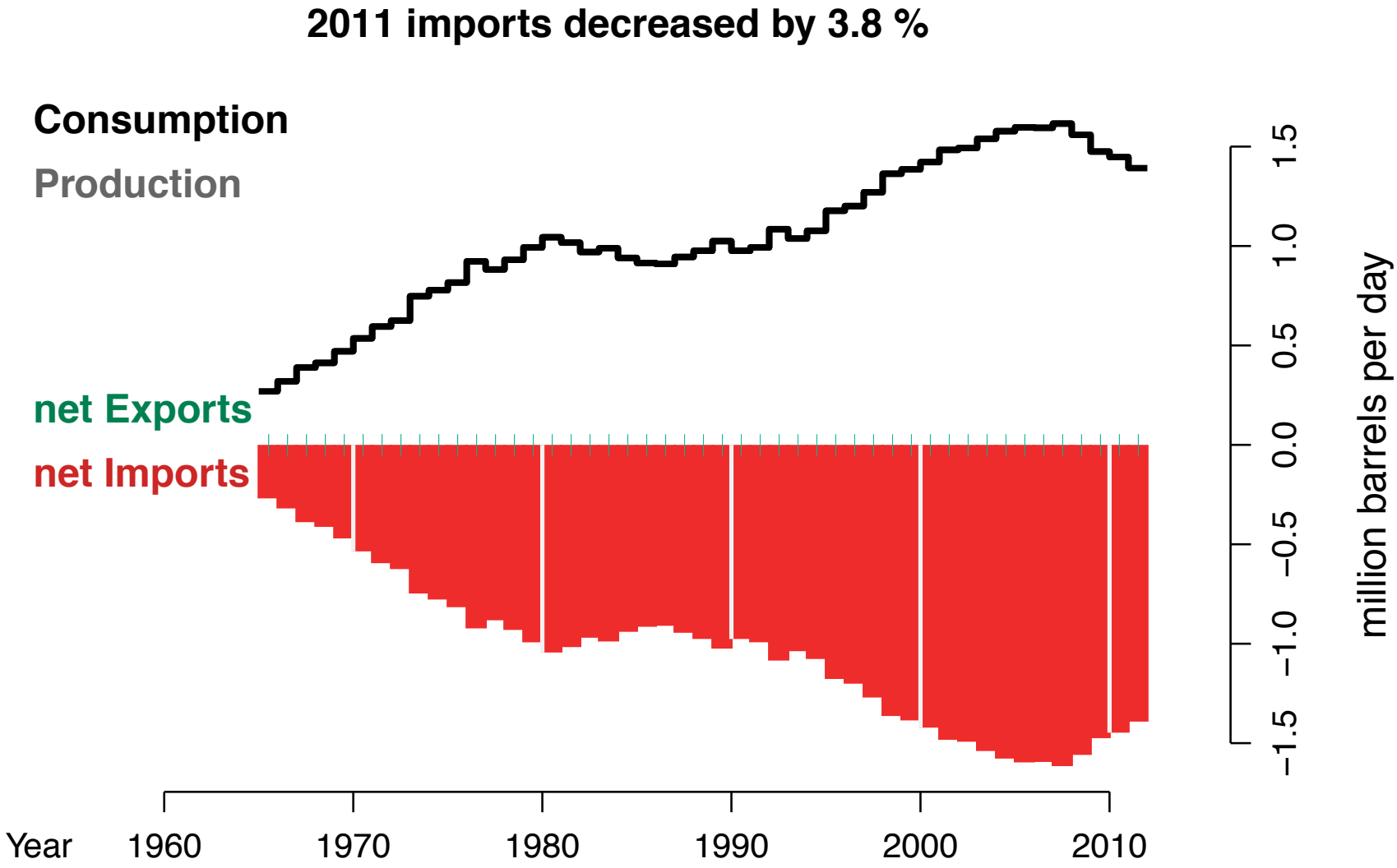
- ~100 GW electric power generation capacity
- 300 TW hours/year → **16 kWh/person/day**

- **Transportation fuels**
  → 1.5 Million barrels Oil/day
- **Electric vehicles**
  → increase power generation (~2x)

Planning for energy security has to be based on the recognition that

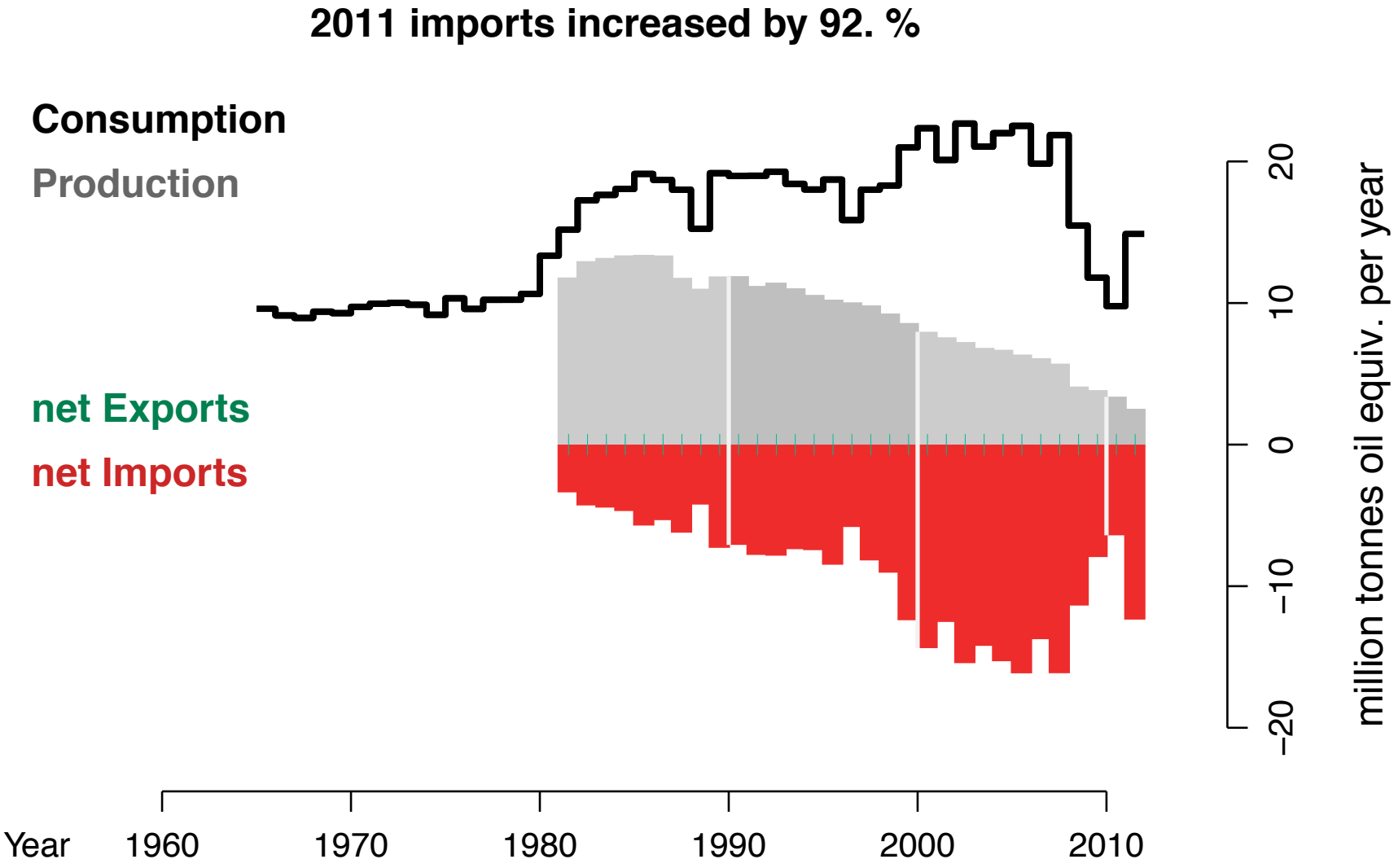
Spain does not have significant fossil fuel resources

Petroleum Imports



Data: BP Statistical Review 2012 Graphic: mazamascience.com

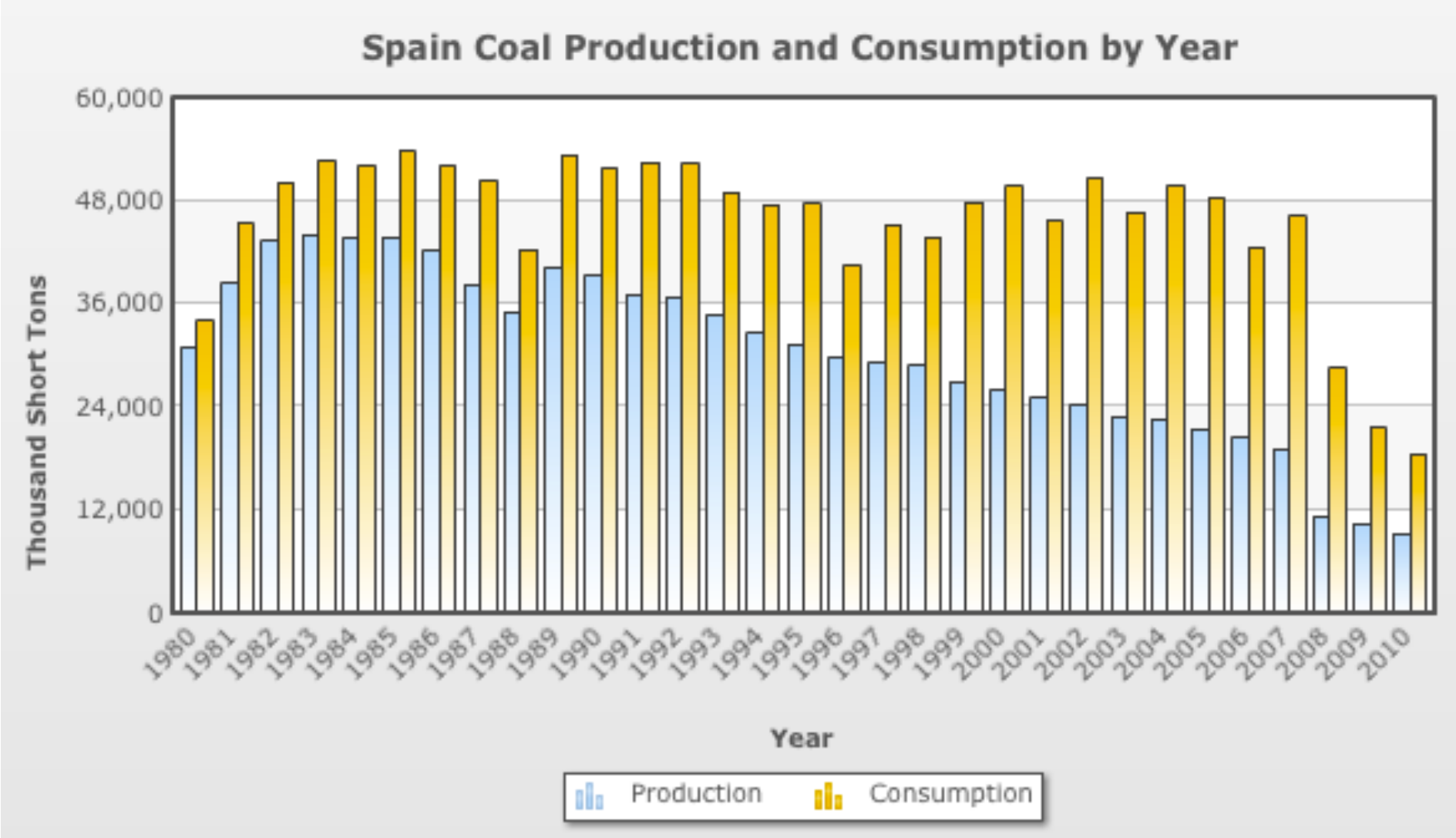
Coal



Data: BP Statistical Review 2012 Graphic: mazamascience.com

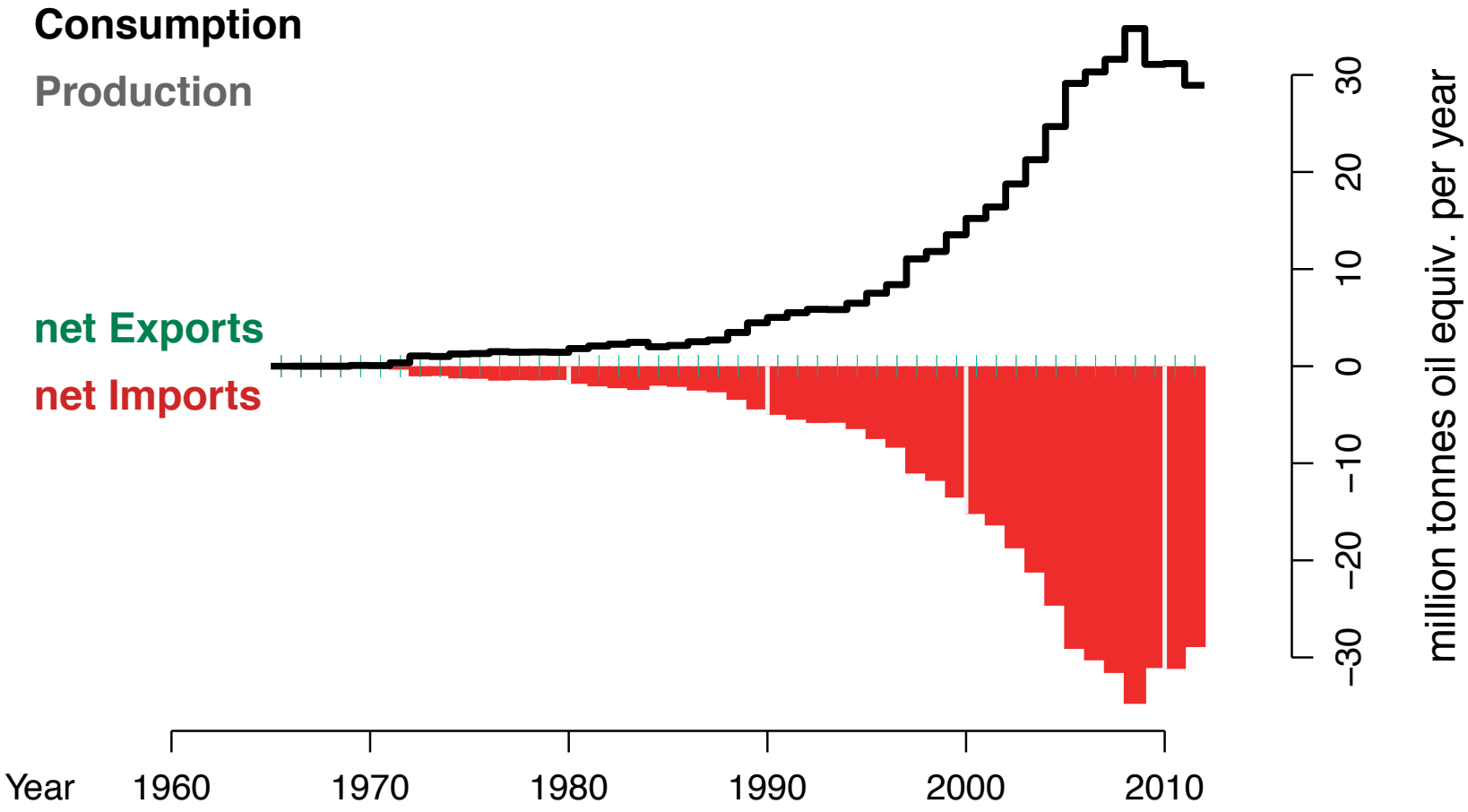
Source: US EIA

Coal Production and Consumption



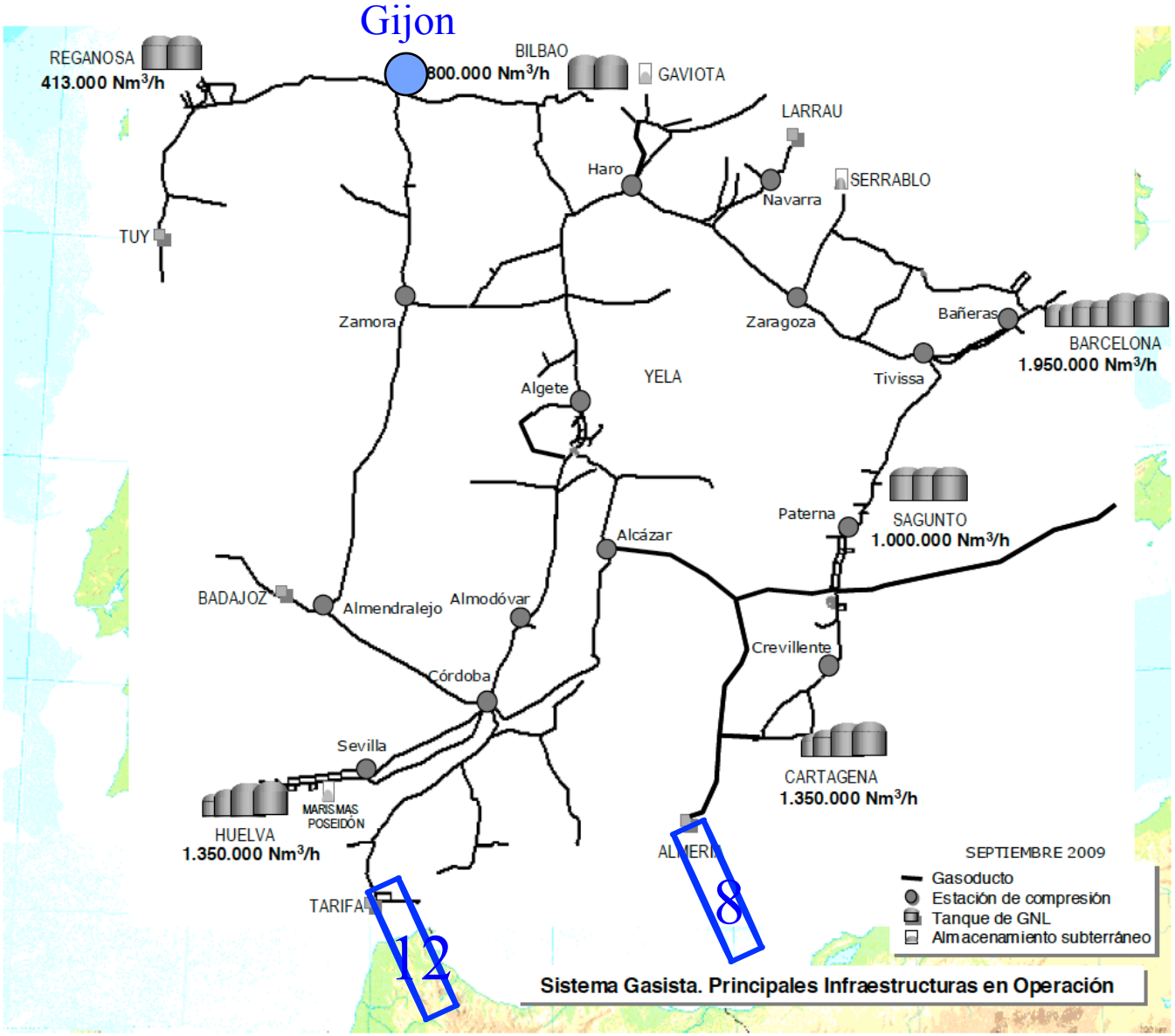
Natural Gas Imports

2011 imports decreased by 7.2 %



Data: BP Statistical Review 2012 Graphic: mazamascience.com

Spanish Natural Gas System



Unlike Oil, LNG prices have large variance

World LNG Estimated March 2012 Landed Prices

Source: *Waterborne Energy, Inc.* Data in $US/MMBtu

February 2012

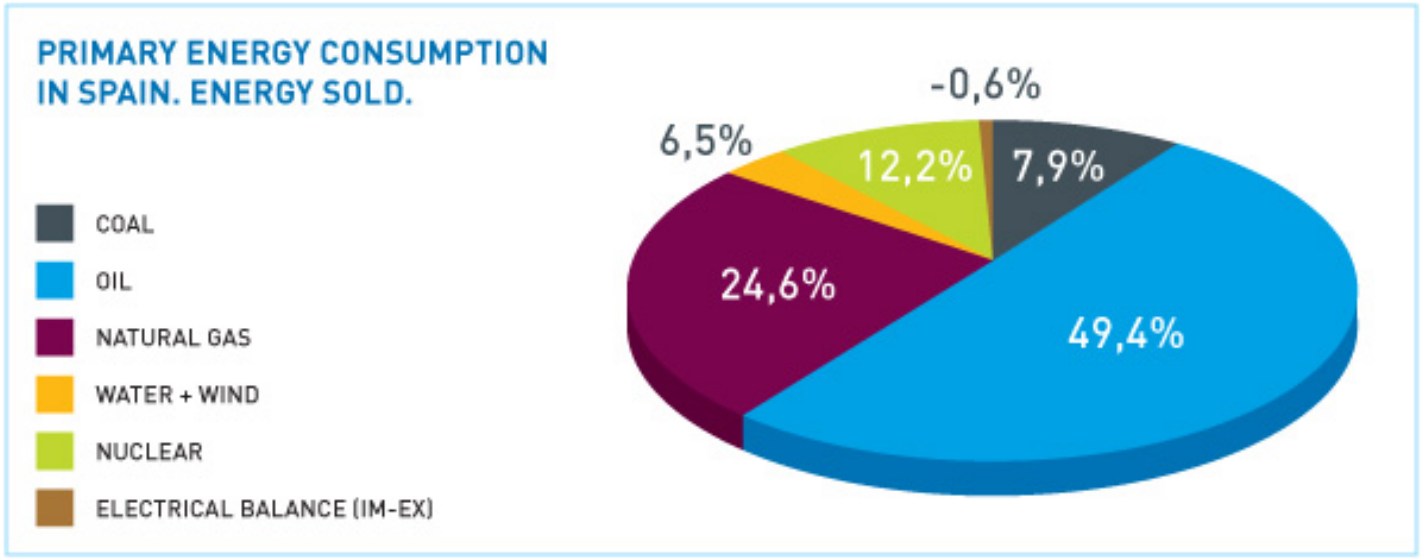
Updated: February 14, 2012 3024

Energy imports and their costs

	2011 Imports (Approx)	Approx. Cost in Billion $	Imported from Countries	Production Consumption rate
Oil	1.5 Mb/ day	55	Saudi Arabia, Iran, Iraq, Nigeria, United Arab Emirates, …	P: ~0 Mb/day C: 1.5 Mb/day
Gas/LNG	30 MMT	15	Algeria, Nigeria, Peru, Norway, Trinidad & Tobago, Egypt, Qatar …	P: ~0 C: 115Mm^3/day
Coal	24 MMT	2	South Africa, Russia, Indonesia, US, Australia, Colombia, …	P: 6.6 MT C: 40 MT

Imports of fossil fuels accounts for ~80% of trade deficit

Long-term concerns of many countries: increasing cost of importing fossil fuels and paying for these imports?



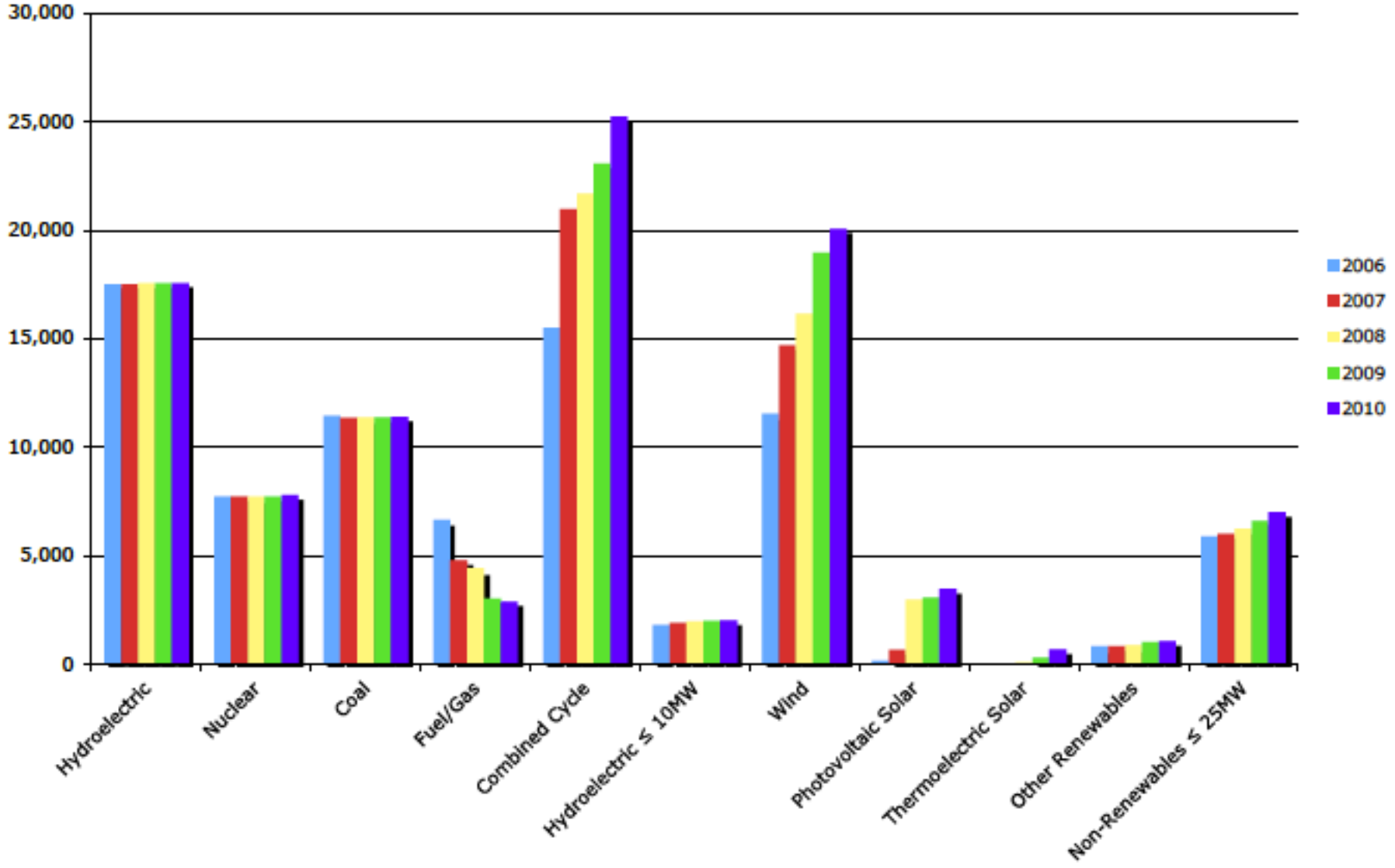
Major Exports and Imports of Spain

Exports: machinery, motor vehicles, chemicals, wine, foodstuffs

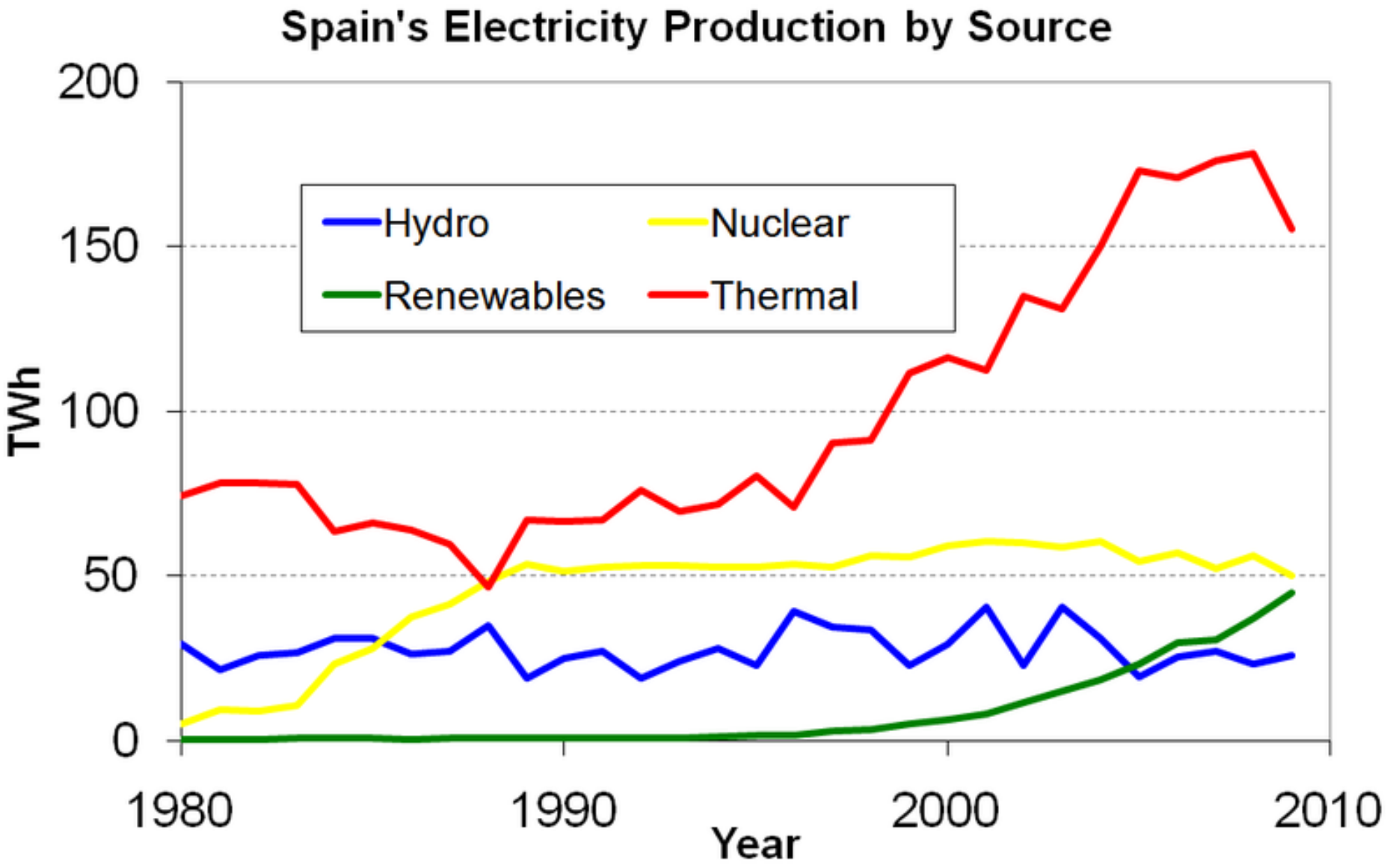
Imports: machinery and equipment, fossil-fuels, chemicals, semi finished goods, foodstuffs, consumer goods

Electric Energy Generation

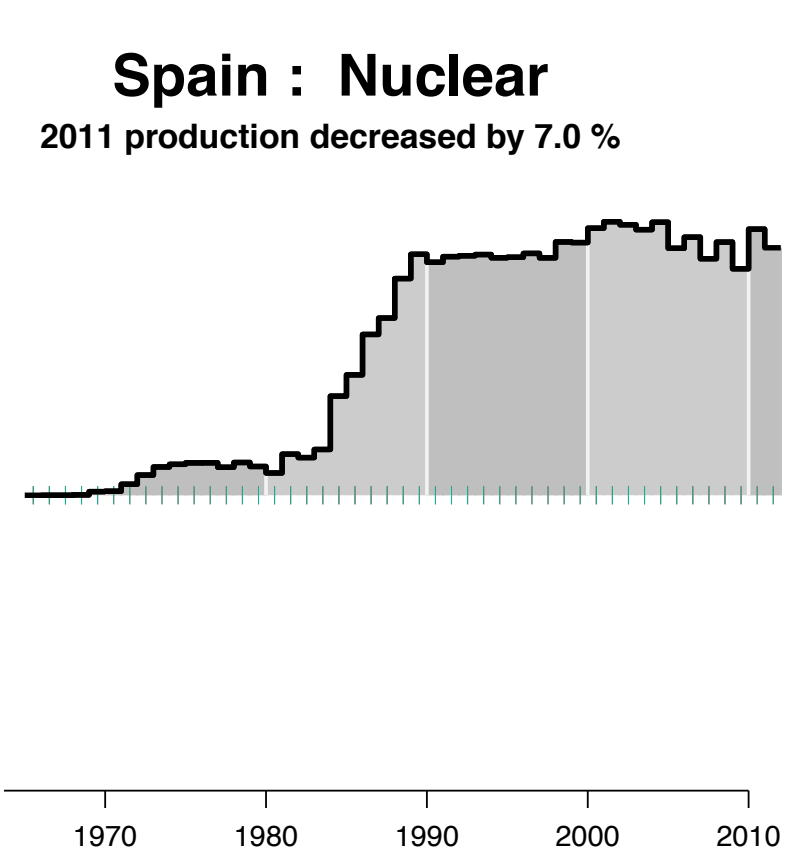
Installed Capacity (MW)

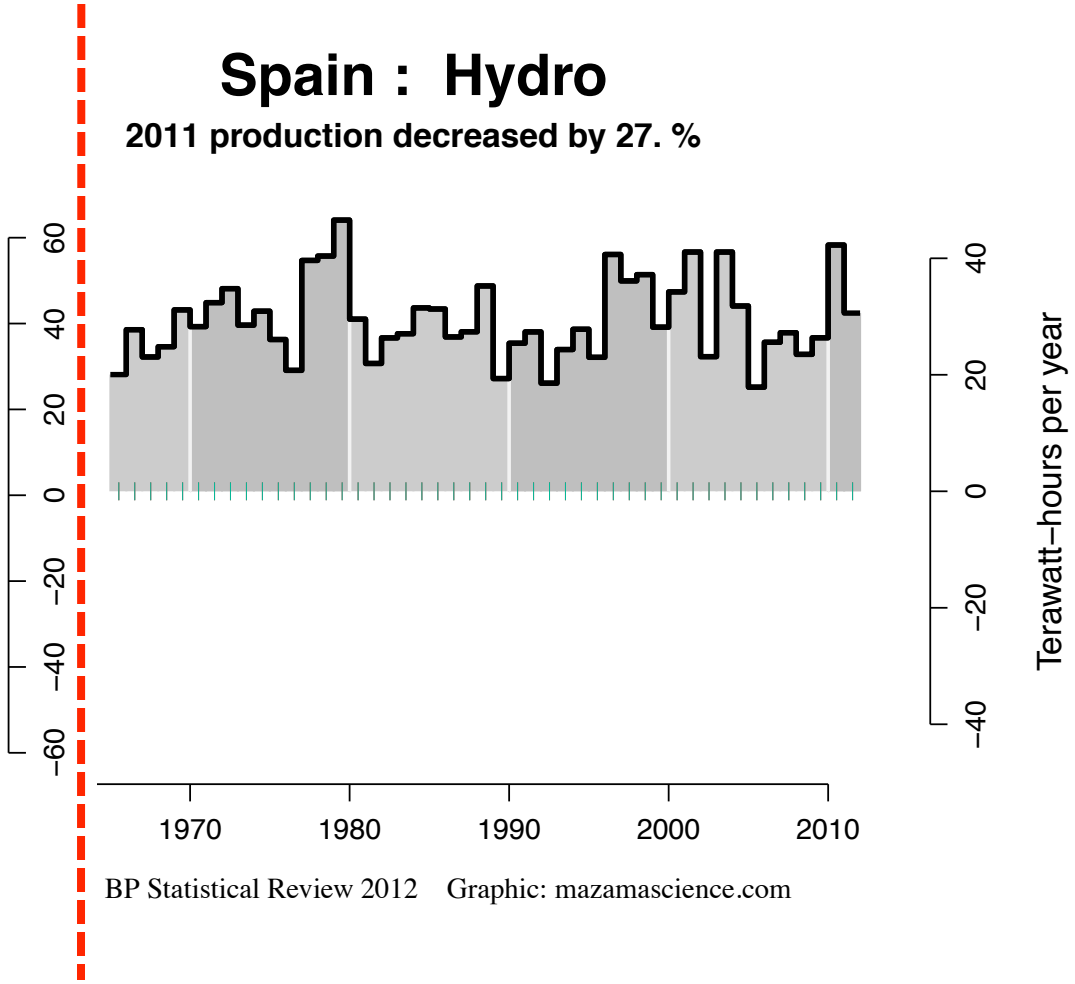


Source: Red Eléctrica de España


Spain's Electricity Production by Source
200
150
100
50
0
TWh
Hydro
Nuclear
Renewables
Thermal
1980
1990
2000
2010
Year

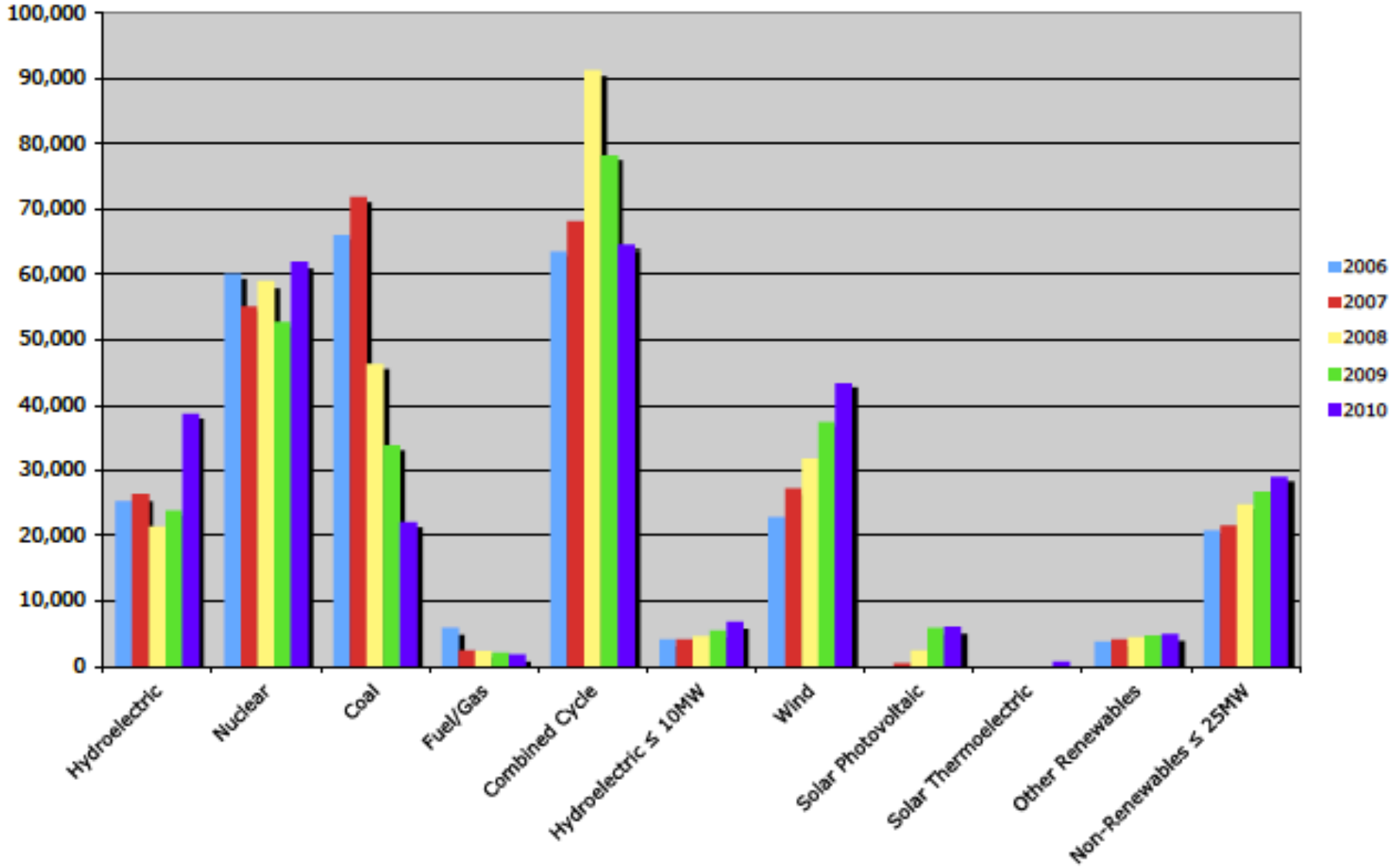
Power Generation: TWh per year





Total: ~100TWh/year

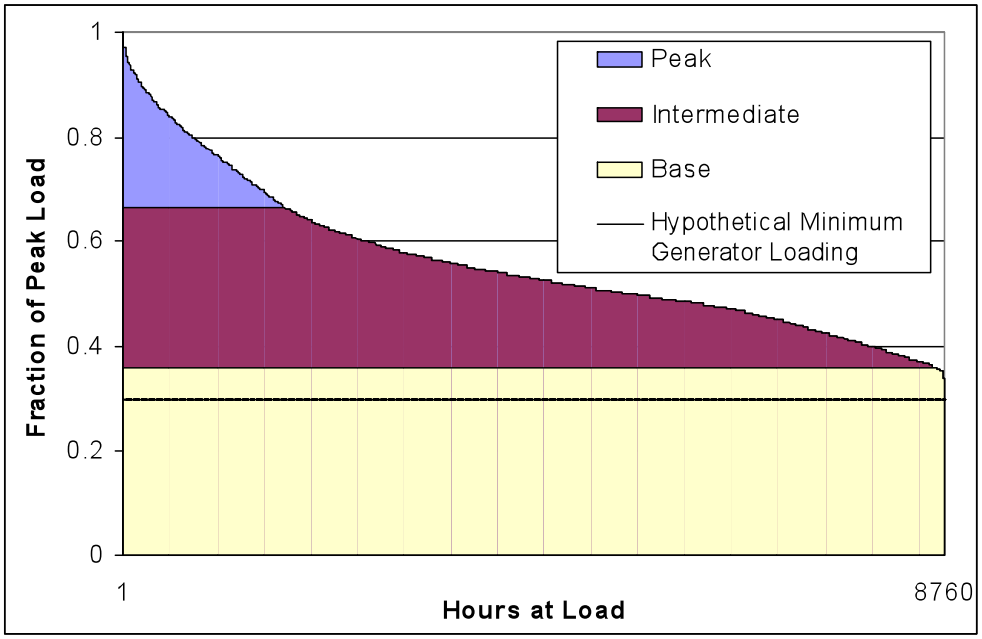
Spain: Evolving energy mix (GWh)

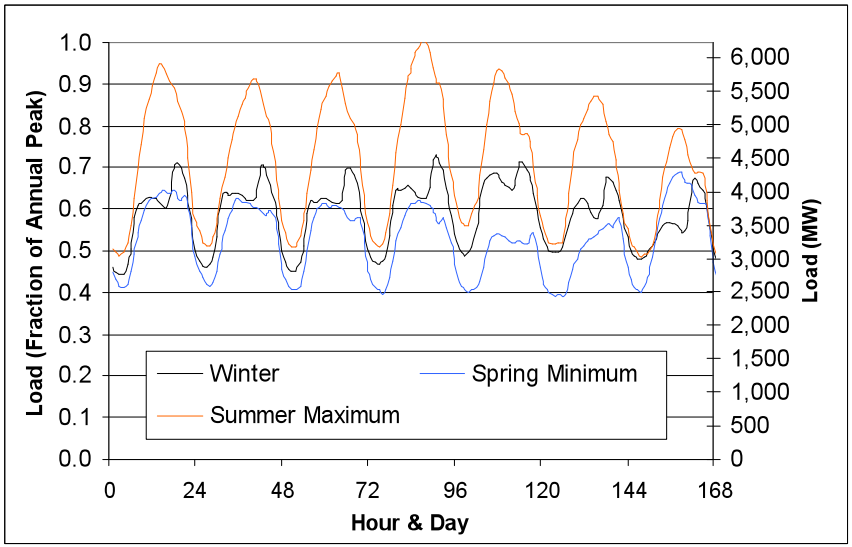


Source: Red Eléctrica de España

Looking Ahead
Fossil Fuels

Profile of demand & generation





- Day, week and seasonal variations in demand and generation
- Total dispatchable capacity > highest peak load (~110%)
- Ability to manage load (→ smart grid) reduces capacity needed

Source: Paul Denholm, NREL

Decarbonizing the global economy

$$CO_2 = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Energy}}{\text{GDP}} \times \frac{CO_2}{\text{Energy}}$$

+ 1% + 4% − 1.5% − 0.1%

Population stabilization: a political hard sell

Prosperity: historically it has driven people, policy and politicians

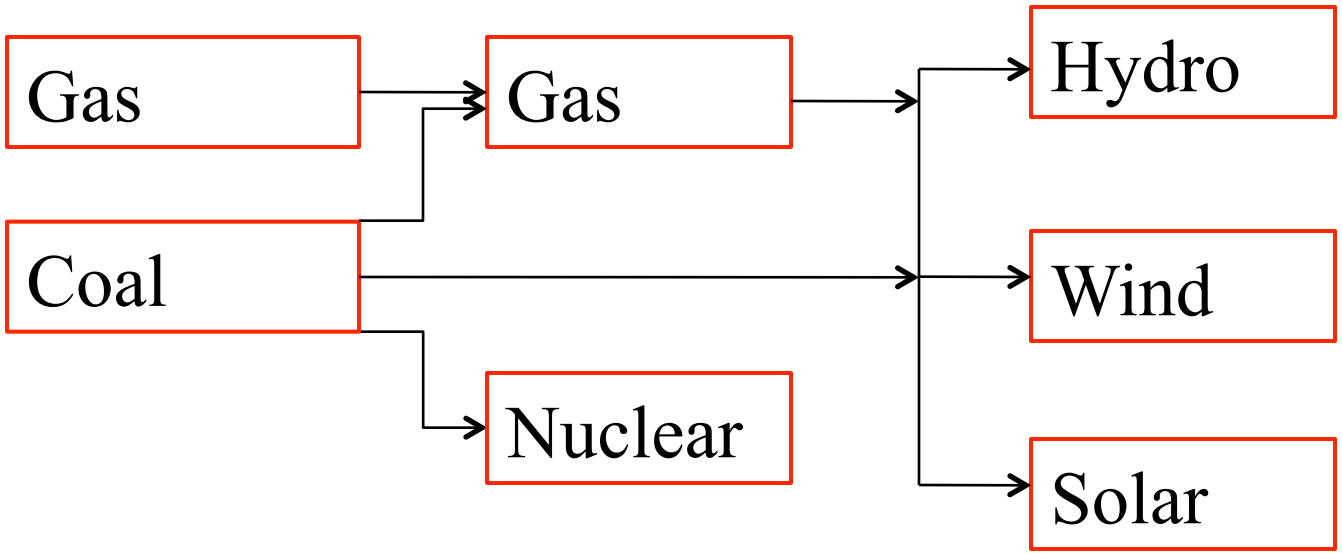
Energy Intensity: Efficiency

Carbon Intensity: De-carbonize technology

Reading: "The Science and Politics of Global Climate Change", Dessler and Parson, Cambridge University Press;
"The climate fix", Roger Pielke Jr., Basic Books, 2010

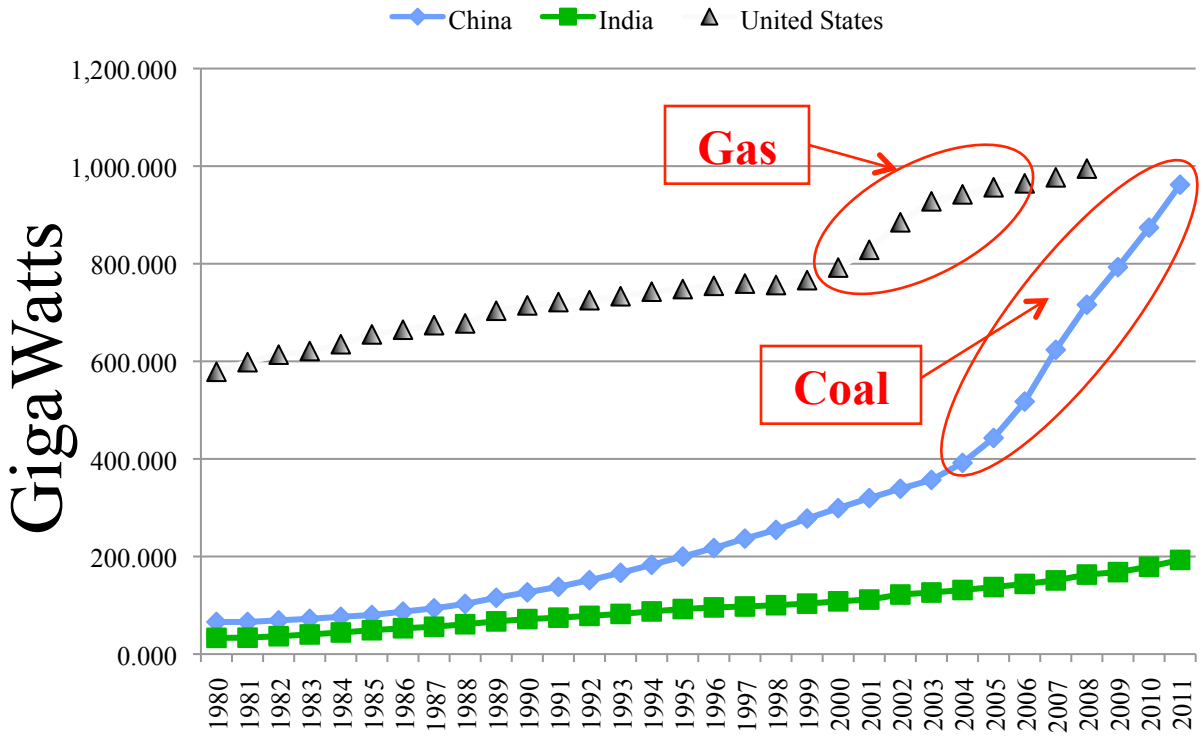
De-carbonizing Coal

- Fuel Substitution



- Higher Efficiency units (28% → 45%)
- Carbon capture and storage

Total Installed Capacity: China, India, USA

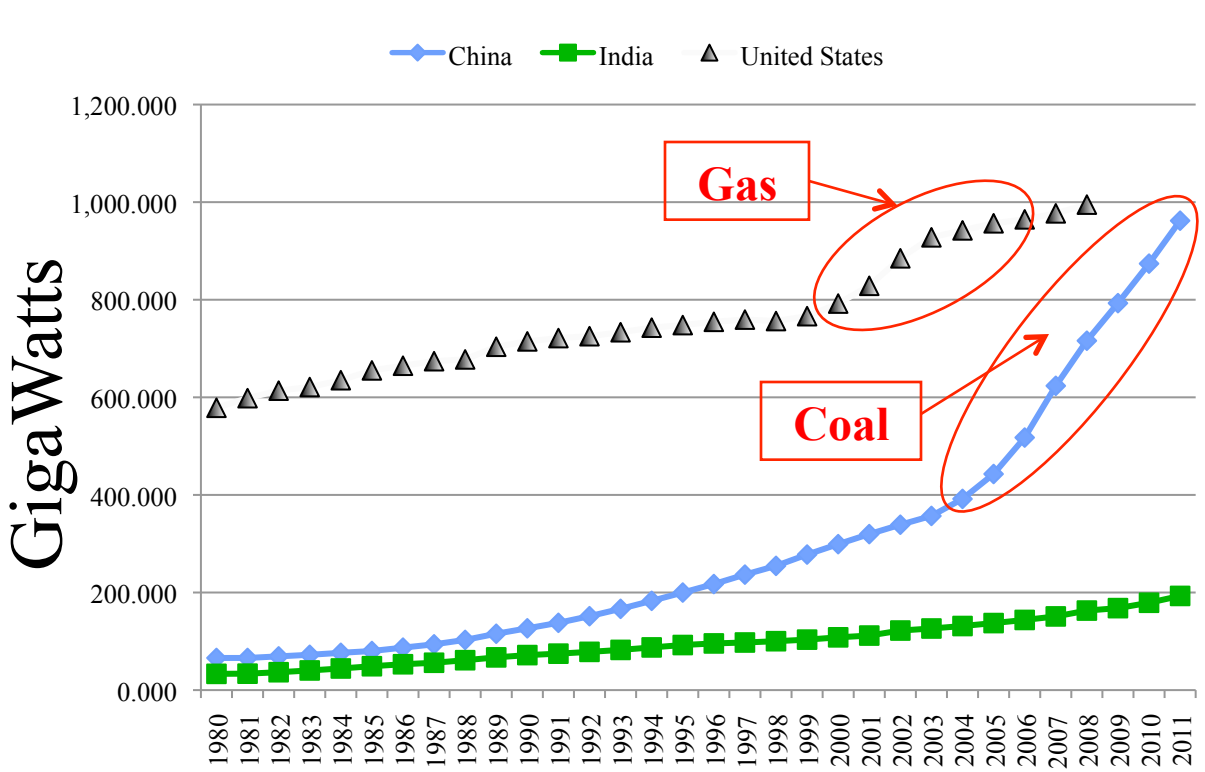


Electric Power Generation:
USA: 50% Coal
China: 80% Coal
India: 70% Coal

Coal capacity will saturate in China & India → each country plans 500+ GW of nuclear capacity in addition to coal and gas to meet their power needs

Source: EIA, http://www.world-nuclear.org/info/inf63.html

Cheap gas in the U.S. is replacing coal



35%

Electric Power Generation:

USA: ~~50~~% Coal

China: 80% Coal

India: 70% Coal

Current coal reserves give a R/P ~ 30 years for

China → 600GW

India → 300GW

Source: EIA, http://www.world-nuclear.org/info/inf63.html

Coal-fired power: 21 Countries

- USA (1000/230000)
- UK (18/228)
- Spain (6/1000)
- Germany (183/41000)
- Poland (135/5700)
- Czech, Ukraine, Bulgaria, Romania, Greece, Turkey (350/42000)
- Russia (325/157000)
- Kazakhstan (110/33000)
- China (3250/114000)
- Japan, Korea, Taiwan (35%)
- Vietnam (45/150)
- Australia (424/76000)
- Indonesia (306/5500)
- India (570/60000)
- South Africa (255/30000)

(#/#) =(Annual produced/Reserves) MT (%) % power generated by coal:

(BP2011)

By 2050 only 7/21 coal "rich" countries

- USA (1000/230000)
- ~~UK~~ (18/228)
- ~~Spain~~ (6/1000)
- Germany (183/41000)
- ~~Poland~~ (135/5700)
- ~~Czech~~, Ukraine, ~~Bulgaria~~, ~~Romania~~, ~~Greece~~, ~~Turkey~~ (350/42000)
- Russia (325/157000)
- Kazakhstan (110/33000)
- ~~China~~ (3250/114000)
- ~~Japan~~, ~~Korea~~, ~~Taiwan~~ (35%)
- ~~Vietnam~~ (45/150)
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- ~~India~~ (570/60000)
- South Africa (255/30000)

(#/#) =(Annual produced/Reserves) MT (%) % power generated by coal:

(BP2011)

Spain: Nuclear Can Replace Coal

- Current Capacity: ~7.5 GW → **60 TWh**
  - Gen III reactors commissioned 1984+ (other than Garona)
- Goal to replace coal: 15-17 GW → **120 TWh**

Issues

- Public opposition
- Safety and Security (does a culture of safety exist?)
- Uranium supplies
- Cost

All baseload can then be met with Nuclear

Countries that can switch to gas relatively easily

- USA
- UK
- Spain
- Germany
- Poland
- Czech, Ukraine, Bulgaria, Romania, Greece, Turkey
- Russia
- Kazakhstan
- China — Growth using shale gas
- Japan, Korea, Taiwan
- Vietnam
- Australia — Need one Pipeline
- Indonesia
- India
- South Africa — Growth using shale gas

Most of these countries have/will have nuclear power plants. ??GW??

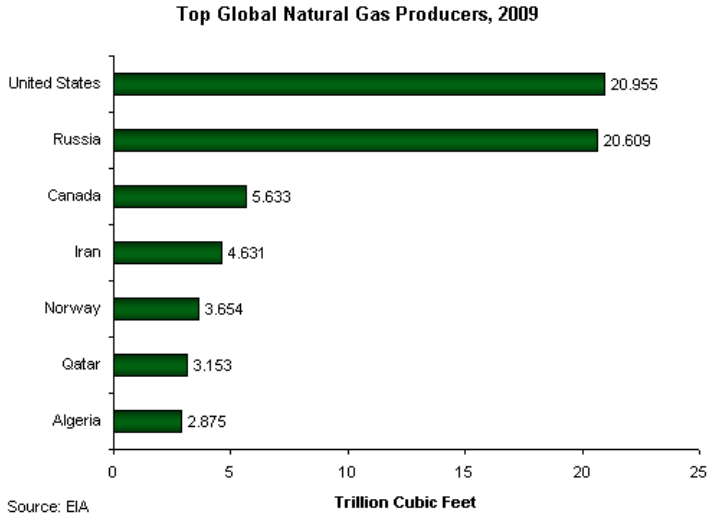
Natural Gas: the new multi-purpose fuel

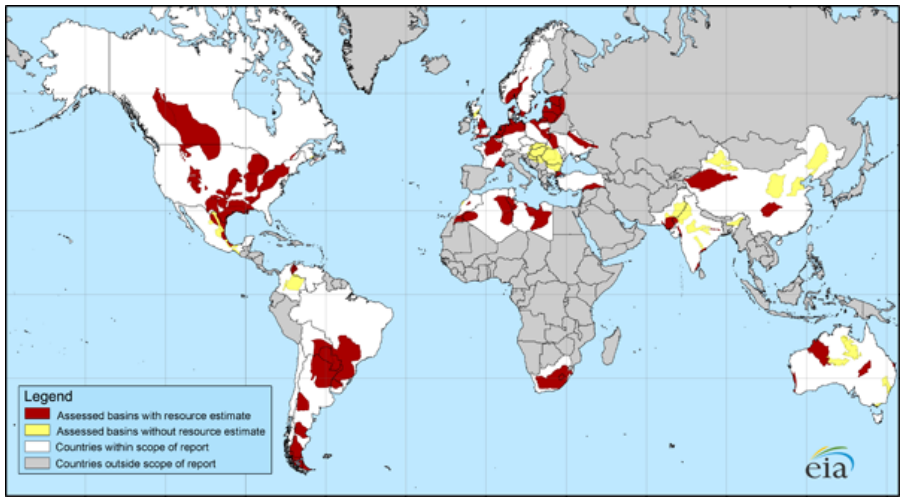
Dominant in

- South America (after Hydro)
- North Africa
- Middle East
- Central Asia, Iran
- Russia

Major fuel in

- North America
- Europe
- South-east Asia
- Australia
- China (Shale Gas)





Shale Gas: USGS

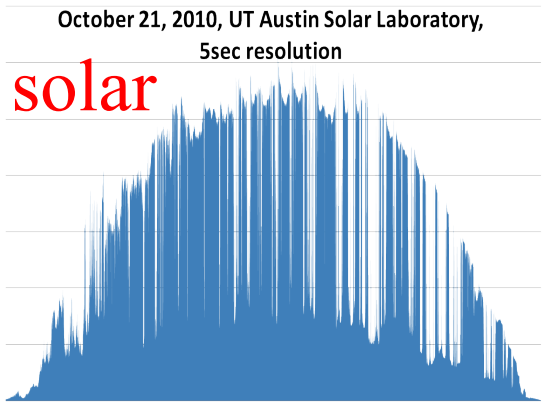
Solar and Wind Energy Systems

Solar and Wind: USA

- On a purely kWh cost basis (2012)
  - Wind @ \$1/Watt$_p$ is competitive at
    - \$0.10-0.12/kW-hour
  - Solar is 2-3X more expensive: For sustainability (assuming utility capital costs = \$2/Watt$_p$ installed)
    - \$0.20-0.25/kWh

In Europe retail is already at \$0.20-0.30/kWh

- Intermittency & daily/seasonal variations are key challenges

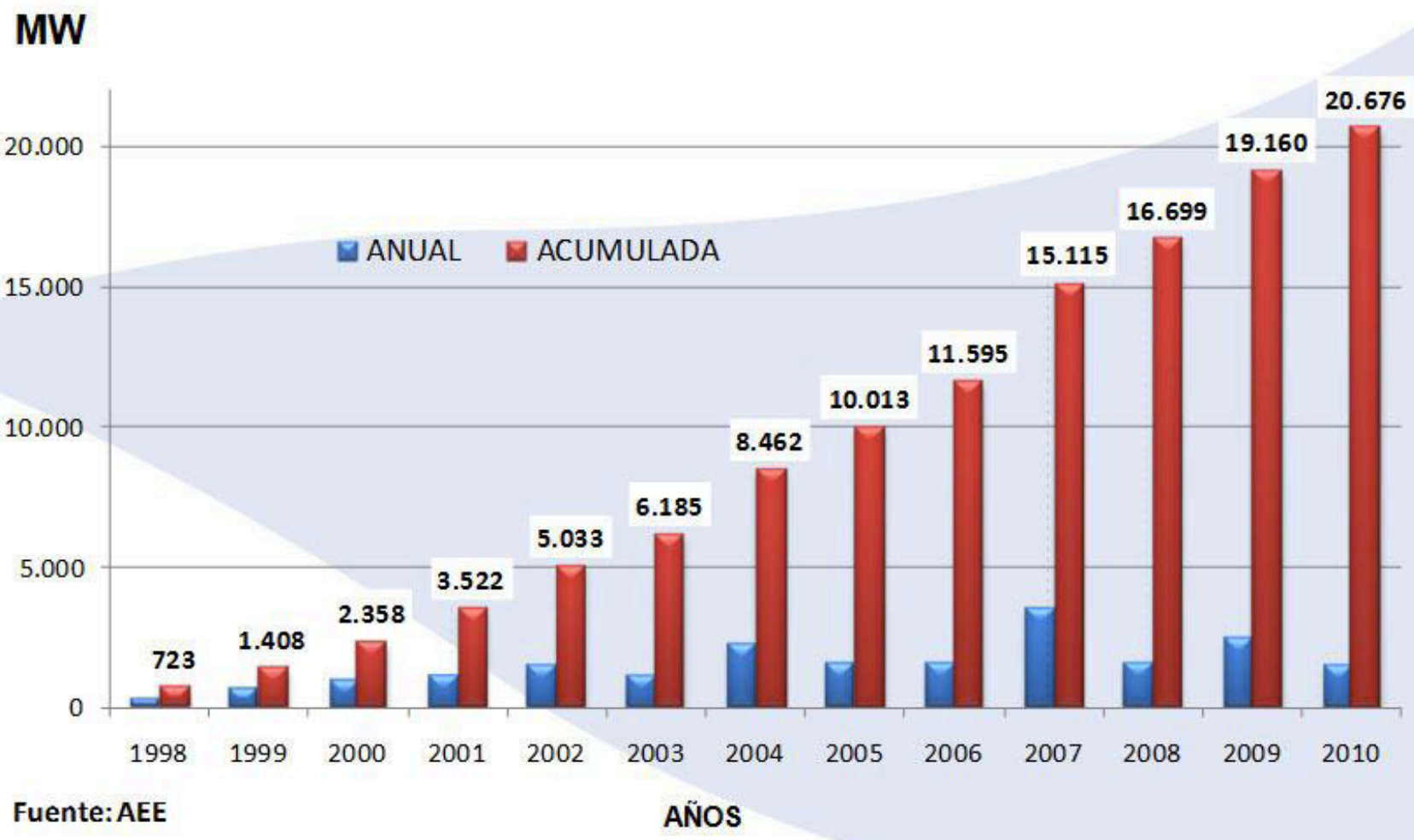


Installed Wind Capacity – Top 10 Countries

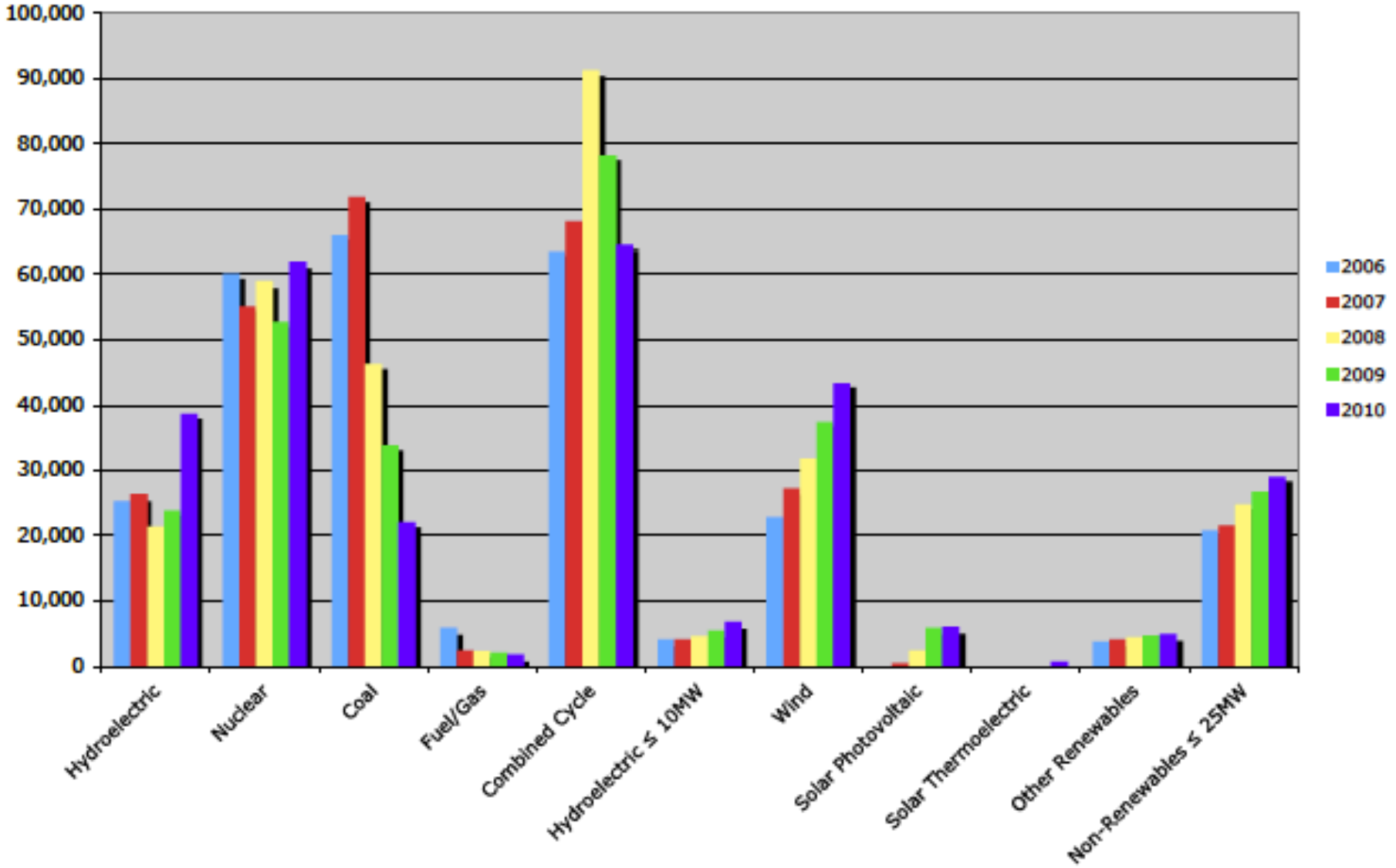
Source: Global Wind Energy Council

Compiled by Curtt Ammerman and RG

Spain wind capacity: cumulative and annual additions



Spain: Evolving Energy Mix (GWh)



Source: Red Eléctrica de España

Integrating Solar and Wind Energy Systems

Grid scale storage for wind & solar

- Gas Combustion Turbines
  - CO_2 emissions
- Pumped Storage Hydro
  - Not enough capacity locally or globally
- Dams with reservoirs
  - Environmental impacts
  - Vulnerable to weather patterns, droughts, climate change
- Concentrated Solar Plants
  - \+ Thermal storage

Anytime

≤ 24 hours

Seasonal

Demonstration Stage

Hydroelectric Potential & Usage: Spain

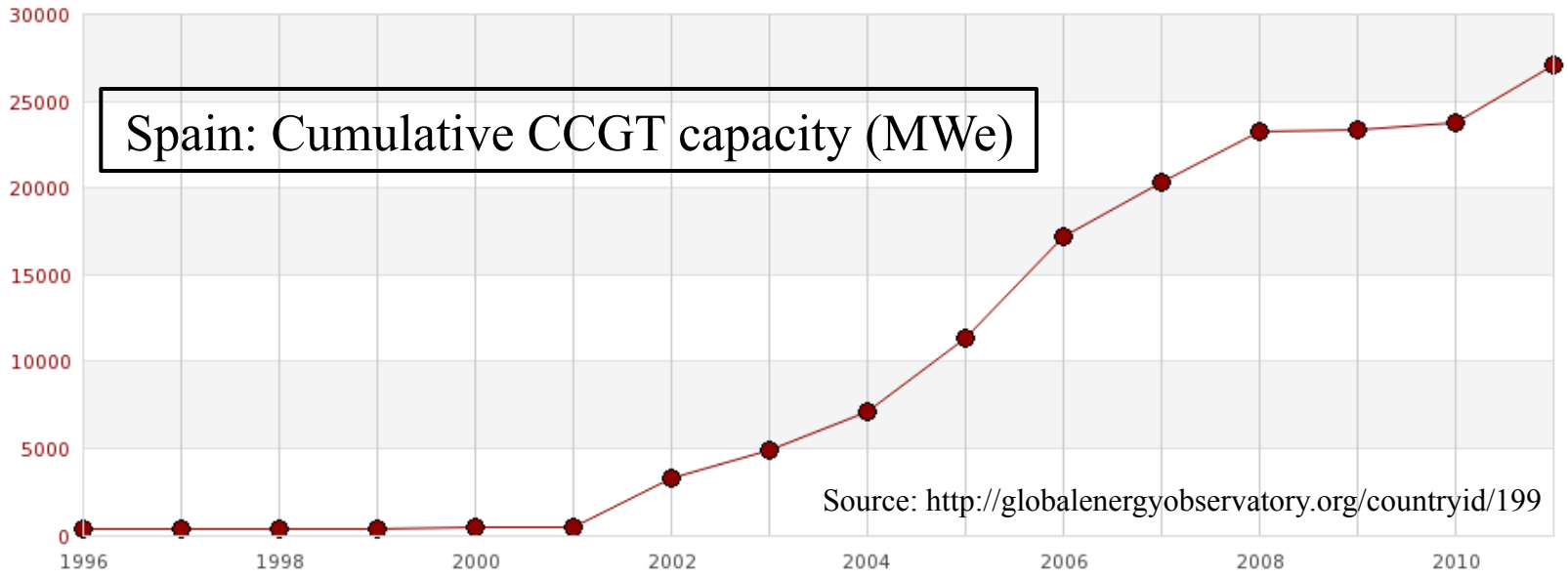
- Technically feasible: ~138 GWh
- Economically feasible: ~64 GWh
-
- Current capacity ~18 GW
- Capacity addition ~0 GW/year
- Generation 20-40 TW hours
- Average load factor ~30%

Reservoir based & Pumped Storage Hydroelectric plants can be used to integrate solar and wind

Source: http://*www./REN_Spain_Nigel_PBMfinal*

CCGT: Spain's power backbone

- Various utility companies added about 25 GW of CCGT capacity during 2001-2008
- CCGT provide backup to solar and wind systems
- Can facilitate any of three scenarios
- Tied to import of natural gas via 2 pipelines from Algeria and 6 LNG terminals – usage will depends on ability/interest to pay for these imports versus other options



Meeting 300+ TWh demand: Option 1 – BAU

	Installed Capacity GW	Plant Load Factor	Energy Generated GWh	Load met
Nuclear	7.5	85%	60	Base load
Coal	12	35%	40	Base load
Hydroelectric	19	15-25%	20-40	Backup to Solar and Wind
CCGT	27	50%	120	Intermediate/Base load Peak Backup to Solar and Wind
Wind	22 → **40**	20%	40 → **80**	Use all available generation Use to charge batteries
Solar	5 → **?**	15%	7	PV/hot water for homes Use all available generation Use to charge batteries

Grow renewables to meet growing demand with backup provided by CCGT power plants

Meeting 300+ TWh: Option 2 – no coal

	Installed Capacity GW	Plant Load Factor	Energy Generated GWh	Load met
Nuclear	7.5 → **16**	85%	60 → **120**	Base load
Hydroelectric	18	15-25%	20-40	Backup to Solar and Wind
CCGT	27	25-35%	60-80	Intermediate Peak Backup to Solar and Wind
Wind	22 → **40**	20%	40 → **80**	Use all available generation Use to charge batteries
Solar	5 → **?**	15%	7	PV/hot water for homes Use all available generation Use to charge batteries

Grow nuclear and wind: 300 TWh will result in emitting ~33 Million Tonnes of CO_2 from CCGT plants by consuming ~12M tonnes of LNG @ $7 billion in fuel costs/yr

300+ TWh: Option 3 – No coal No nuclear

	Installed Capacity GW	Plant Load Factor	Energy Generated GWh	Load met
Hydroelectric	18	15-25%	20-40	Backup to Solar and Wind
CCGT	27	60%	140	Base load Peak Backup to Solar and Wind
Wind	22 → **80**	20%	40 → **160**	Use all available generation Use to charge batteries
Solar	5 → **?**	15%	7	PV/hot water for homes Use all available generation Use to charge batteries

CCGT plants provide all base load demand, and backup to solar and wind

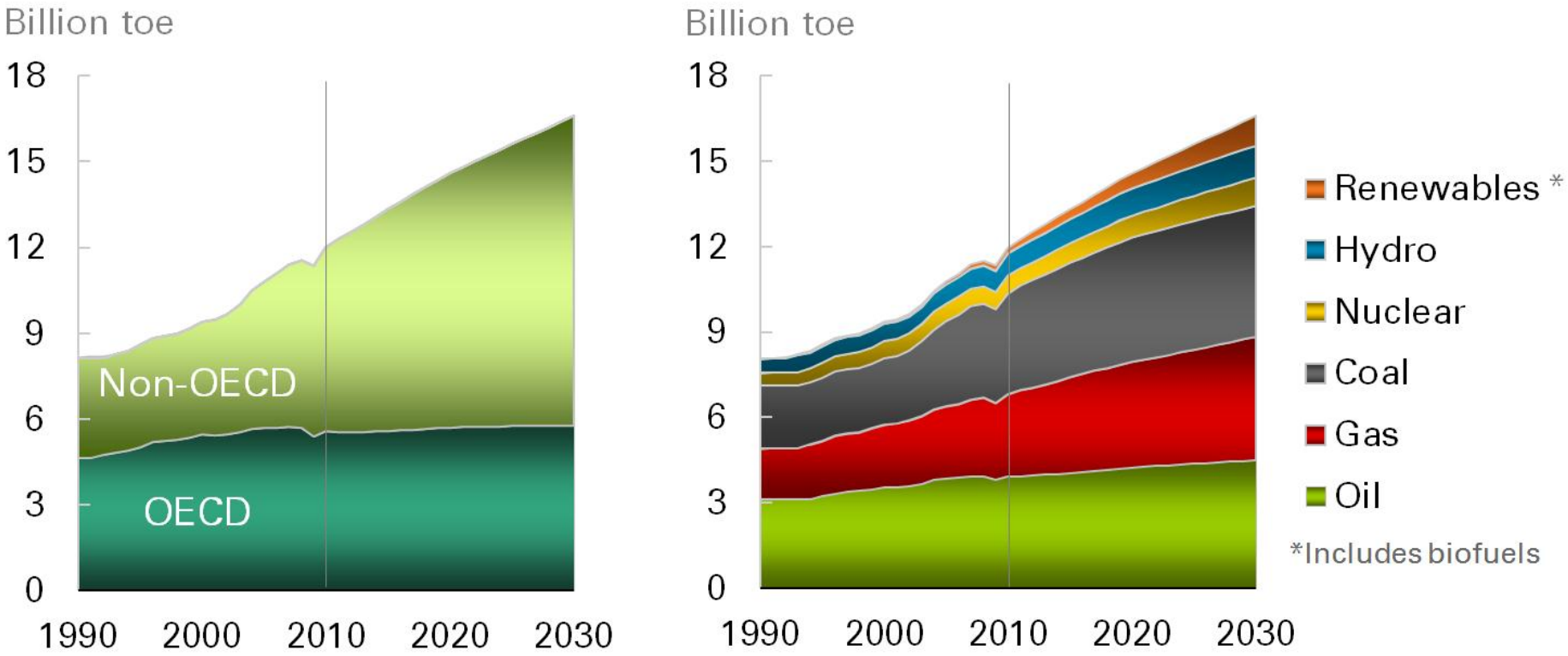
Spain: Summary of options

Overbuilt CCGT capacity allows all three options

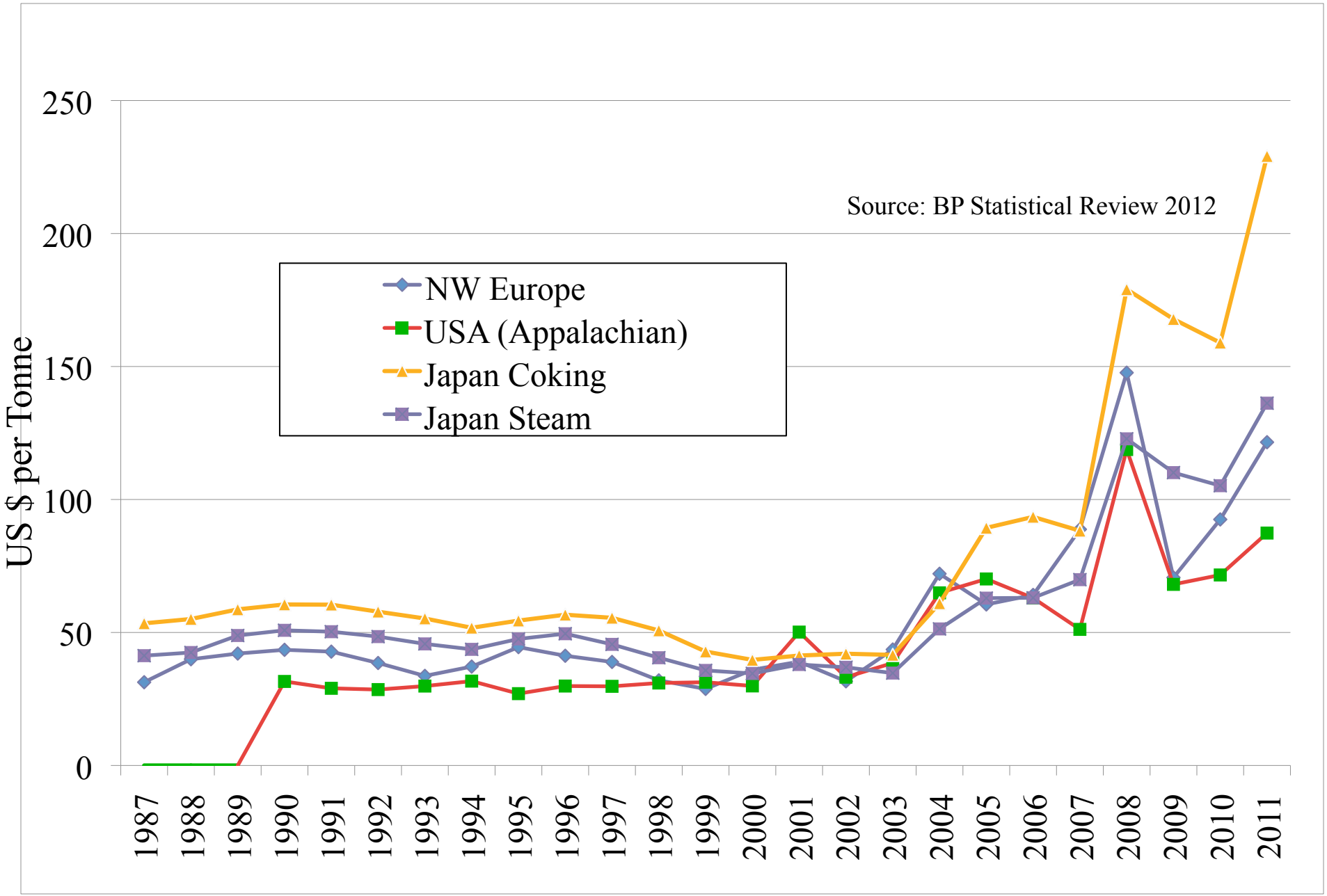
- Option 1
  - Grow only renewables
  - Keep existing coal and nuclear for base load
- Option 2
  - Grow wind and nuclear (to eliminate coal)
  - Least fuel cost (natural gas for CCGT)
- Option 3
  - No coal No nuclear (phase them out)
  - Grow wind and other renewables
  - Higher utilization of CCGT

Future of fossil-fuels?

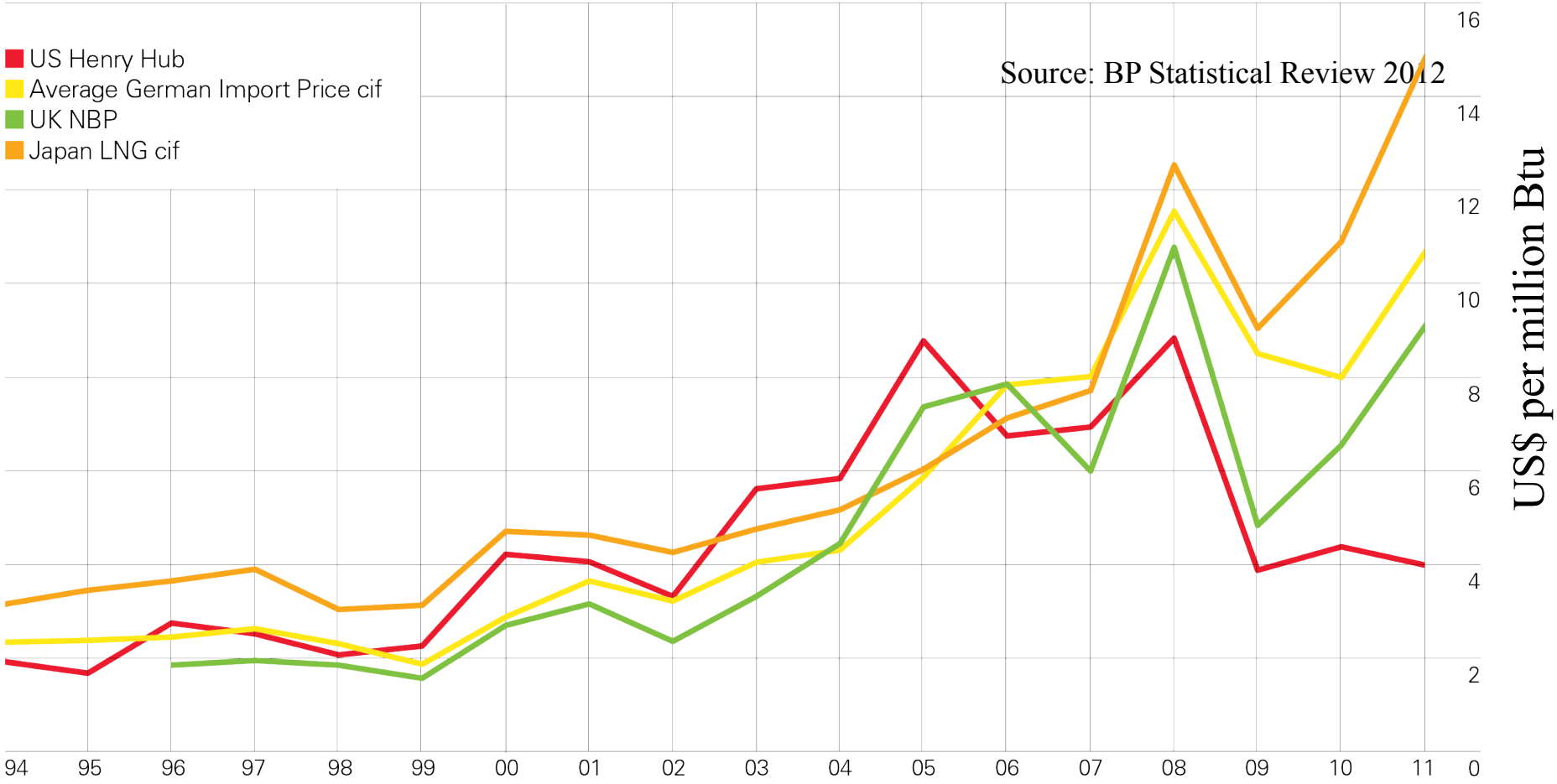
Global energy & fossil fuel use will increase until 20??



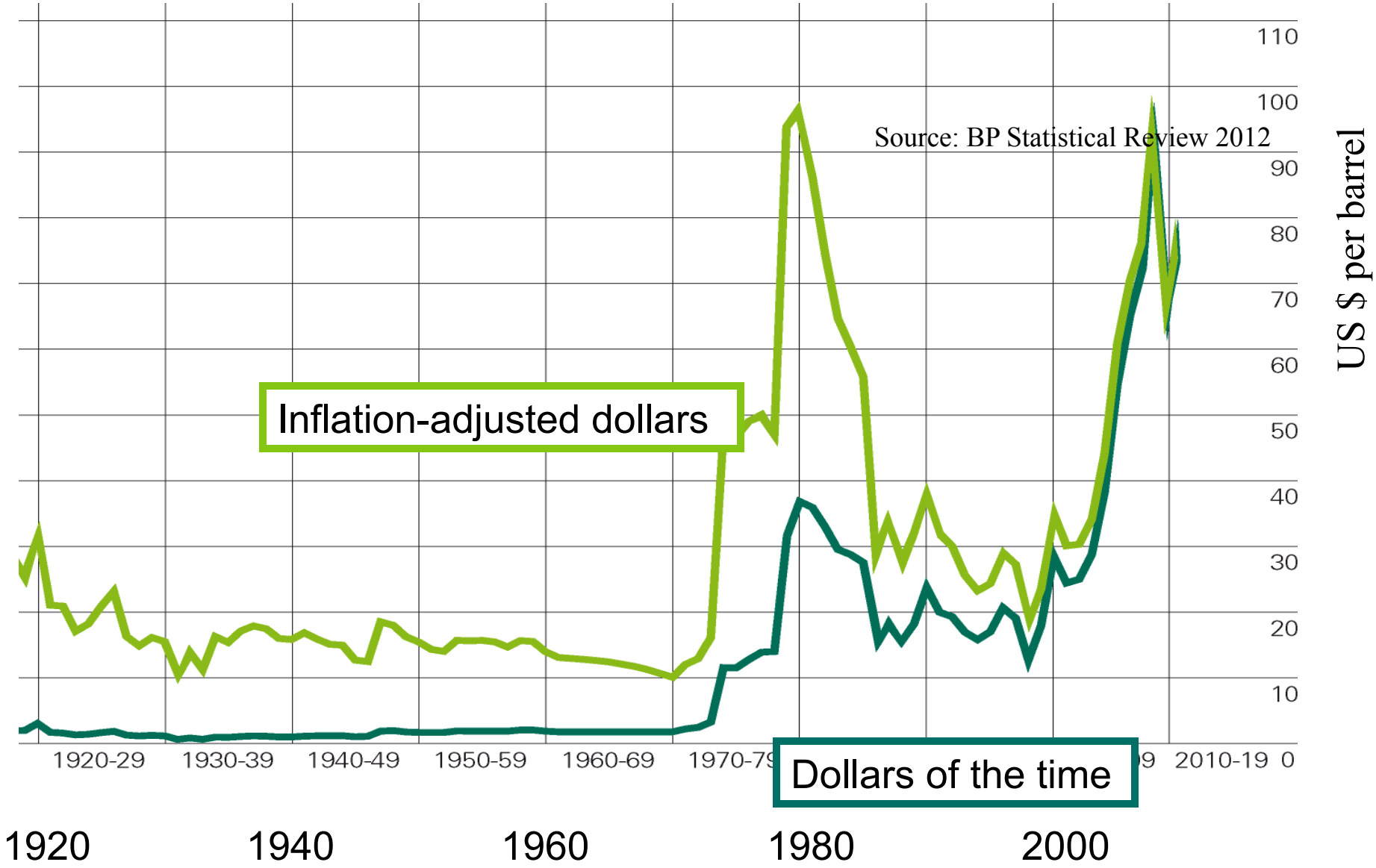
Expect volatility in price --- coal



Expect volatility in price --- natural gas



Expect volatility in price --- oil



Options:

Business as usual

Pushing all natural systems to their breaking point

How many can nature sustain?

OECD, BRIC, …

or

OECD + (China or India or …)

or

only OECD

And at what level of resource use?

How many can nature sustain?

OECD, BRIC, …	**9 Billion**
or	
OECD + (China or India or …)	**3 Billion**
or	
only OECD	**1.5 billion**

At U.S. or EU or Brazil's level?

How many can nature sustain?

OECD, BRIC, …

or

OECD + (China or India or …)

or

only OECD

9 Billion
(Brazil)

3 Billion
(EU)

1.5 billion
(USA)

BUT: Climate security requires carbon-neutral energy

Available Options:

High efficiency use of energy

4 Infrastructure (Efficiency) Priorities

- Cities and communities planned around energy efficiency
- Public transport & electric long-haul railway
  - Reduce distance travelled / goods transported
  - Higher mileage vehicles (diesels, hybrids, electric)
- Energy efficient buildings
- Solar/geothermal heat pumps for heat-ventilation-AC (HVAC) and hot water systems

Transformational Options

Innovation Fund:

Broad-based R&D in energy-climate science and technology

If I was allowed to pick only 5 Priorities

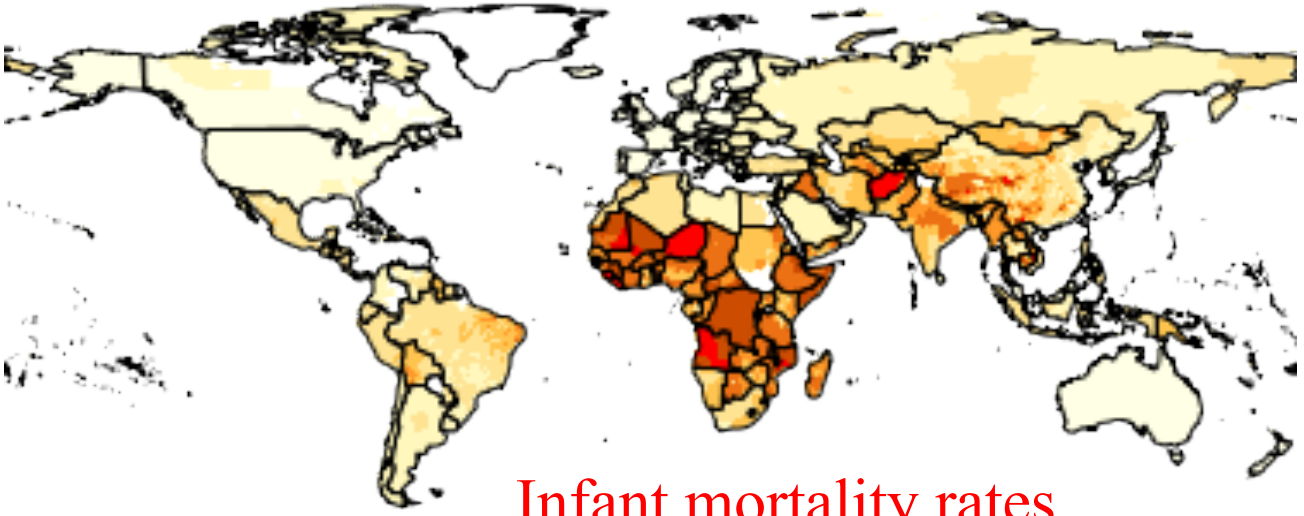
- Storage: 3X Battery for cars (goals: higher power and energy density and longer life). ***Fuel cells?*** ***Grid scale storage?***
- Solar PV at \$1-2/$Watt_p$ installed & 200 GW/yr manufacturing capacity (16 x 2012). *Address the issue of rare Energy Critical Elements*
- Forecasting and control systems
  - *Smart Grid* to integrate solar and wind & manage load:
- Carbon Capture and Storage (CCS)
- Nuclear Fuel Cycle: reprocessing & waste management

What lies ahead

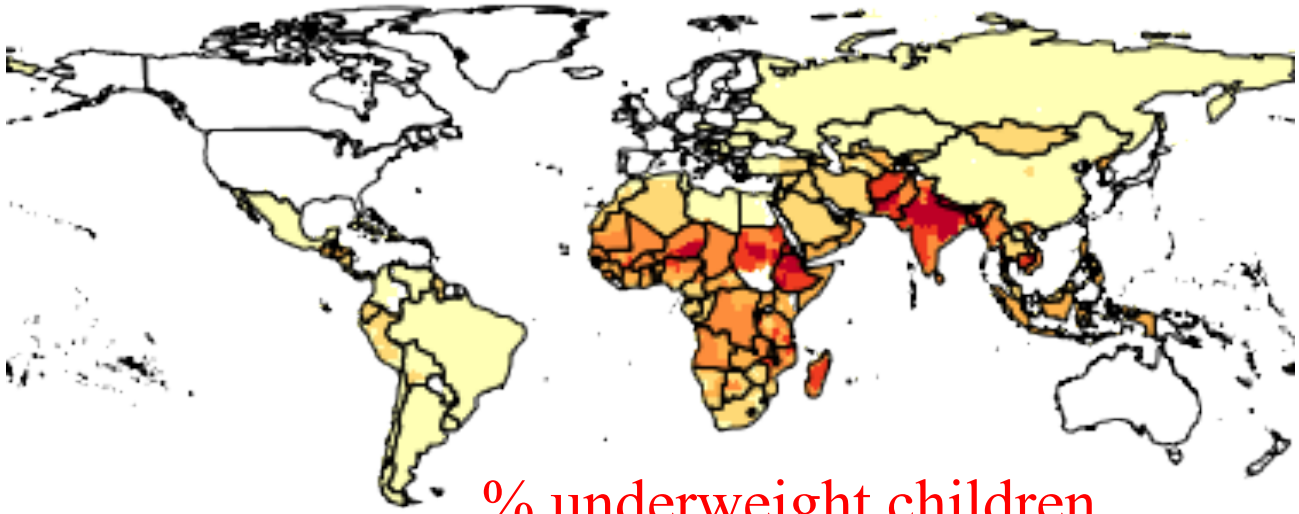
- Environmental degradation & loss of ecosystems/species
- Water shortages in large parts of China and India
- Accumulating evidence of Climate Change
  - Impacts of intense heat & storms on infrastructure & agriculture
- Uncertainty in timeline of scale/magnitude of solar and wind
  - Uncertainty in date & height of peak in GHG emissions
- Volatility in price of fossil fuels for many countries
  - Many countries will continue to not be able to afford clean (or even fossil) energy systems and lack Energy Security

Policy will have to be made under uncertainty & stress

Huge development challenges in Africa and South Asia



Infant mortality rates



% underweight children

Source: http://sedac.ciesin.columbia.edu/povmap/

Nature cares about only one number:
the amount of greenhouse gases in the atmosphere

- We are at 395 ppm of CO_2 (2012)
- Highly unlikely we can prevent 550 ppm
- Timely and global action will determine stabilization point between 550 and 1000 ppm
- We don't know the long-term consequences of even 395 ppm!
- Nature will enforce consequences

Playing dice with nature:

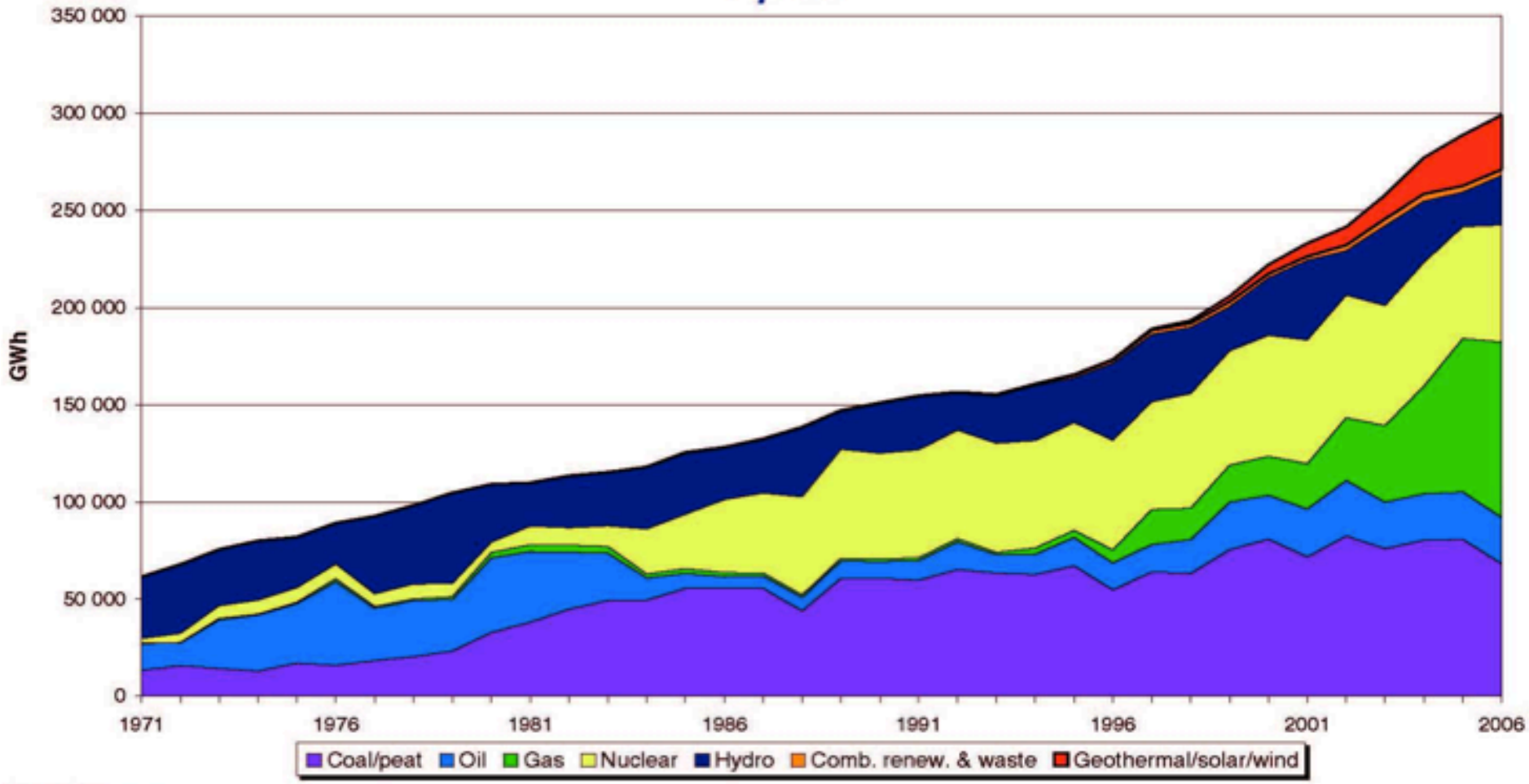
All faces are the same & scary:

Nature gets to call

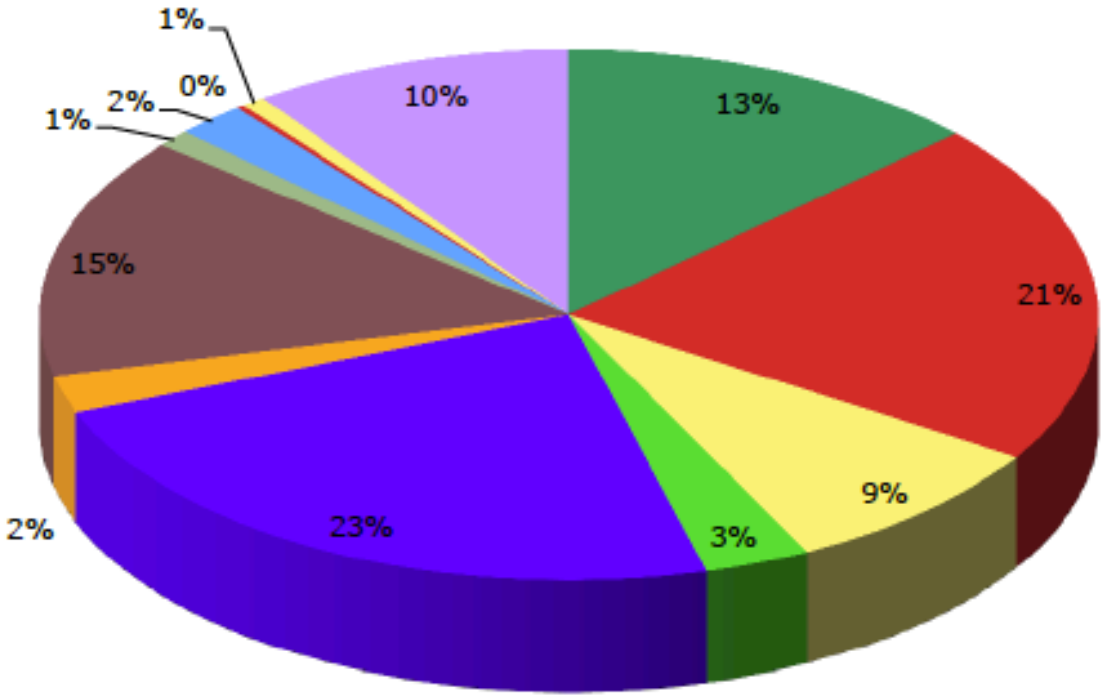
Extras

Electricity generation by fuel

Spain



Meeting energy needs and the evolving fuel mix



2010 data

Hydroelectric
Nuclear
Coal
Fuel/Gas
Combined Cycle
Hydroelectric ≤ 10MW
Wind
Biomass
Photovoltaic Solar
Thermoelectic Solar
Other Renewables
Non-Renewables ≤ 25MW

Source: Red Eléctrica de España