Lecture - 8A

Energy Resources, Economics and Environment

Energy Resources – Renewables

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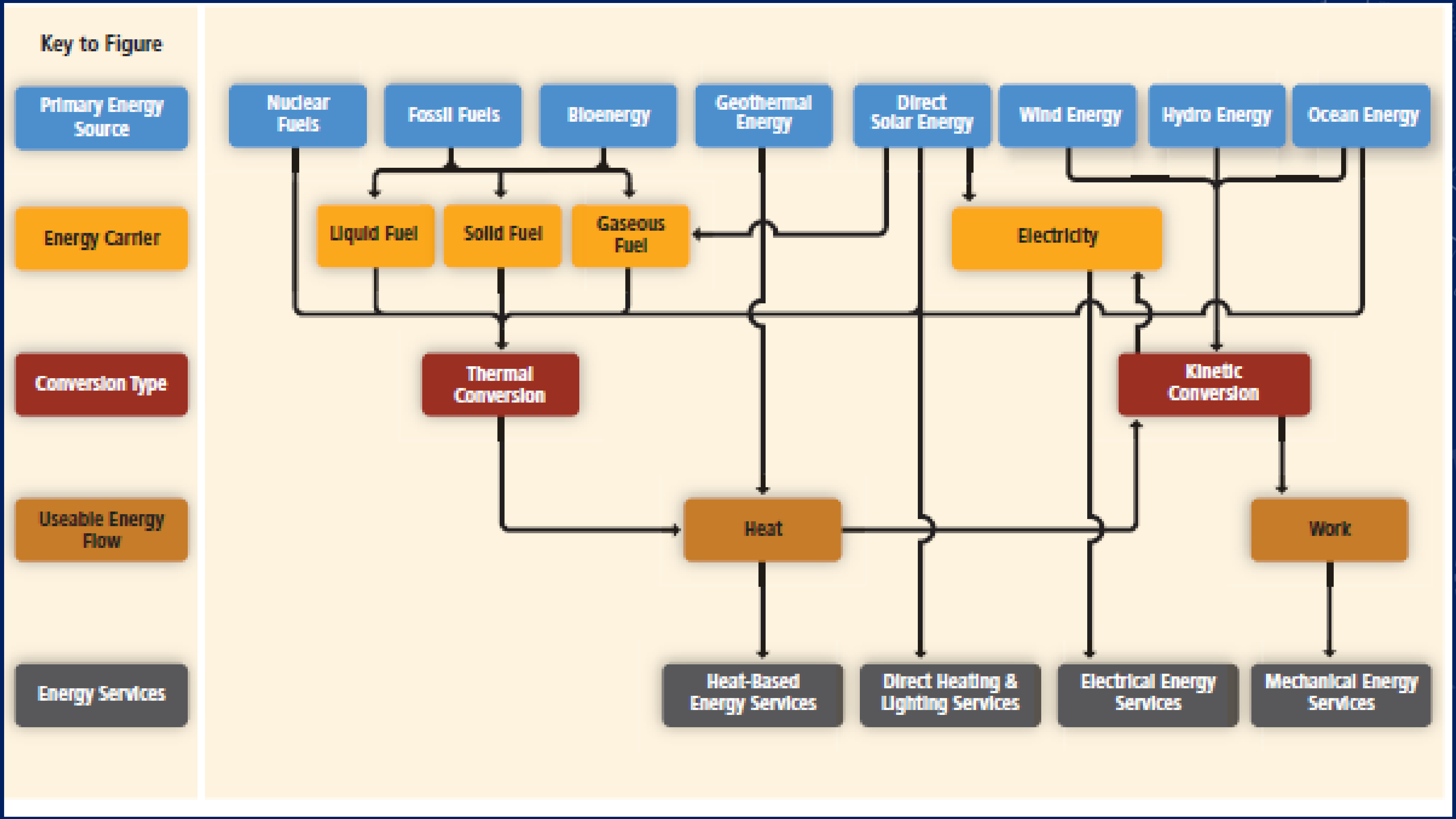
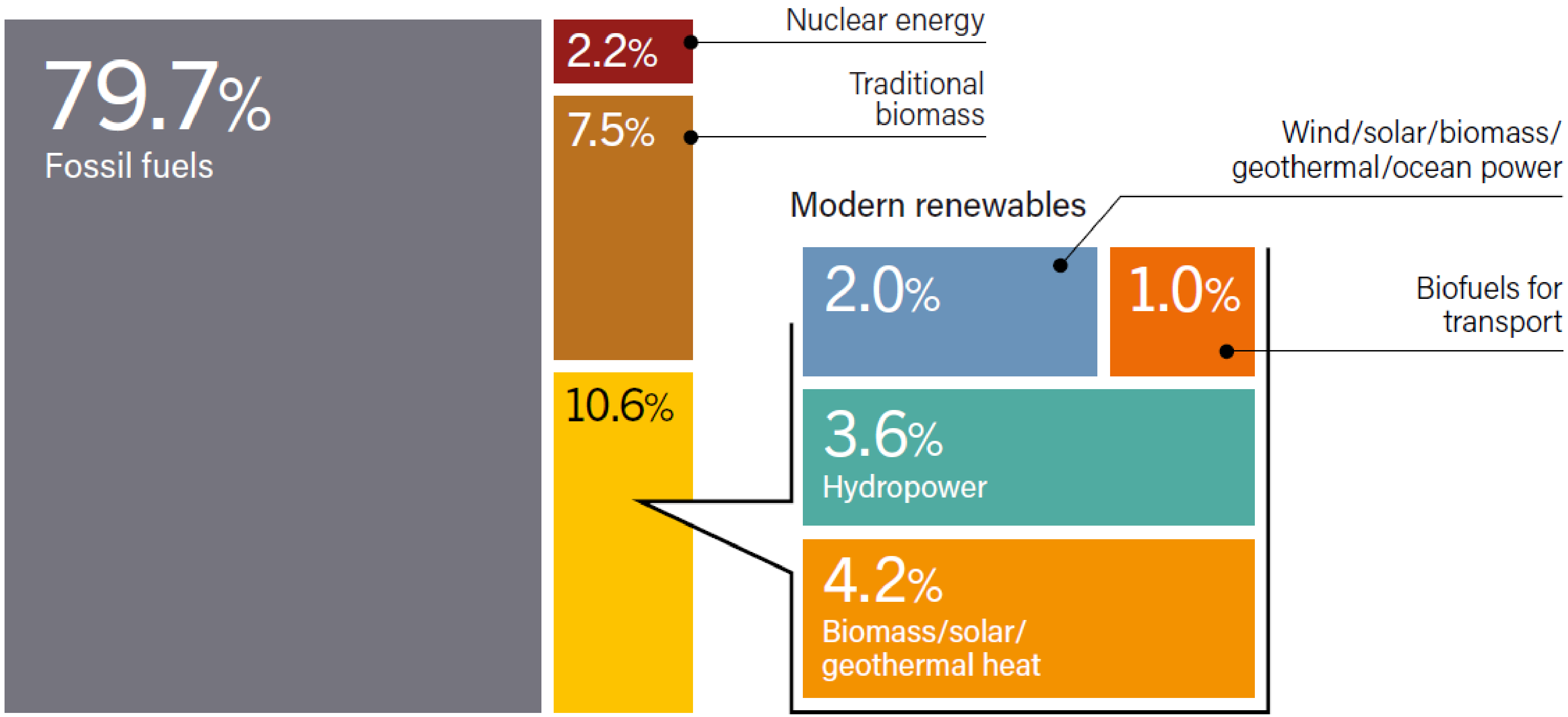
Energy Conversion Routes



Source: SRREN , IPCC

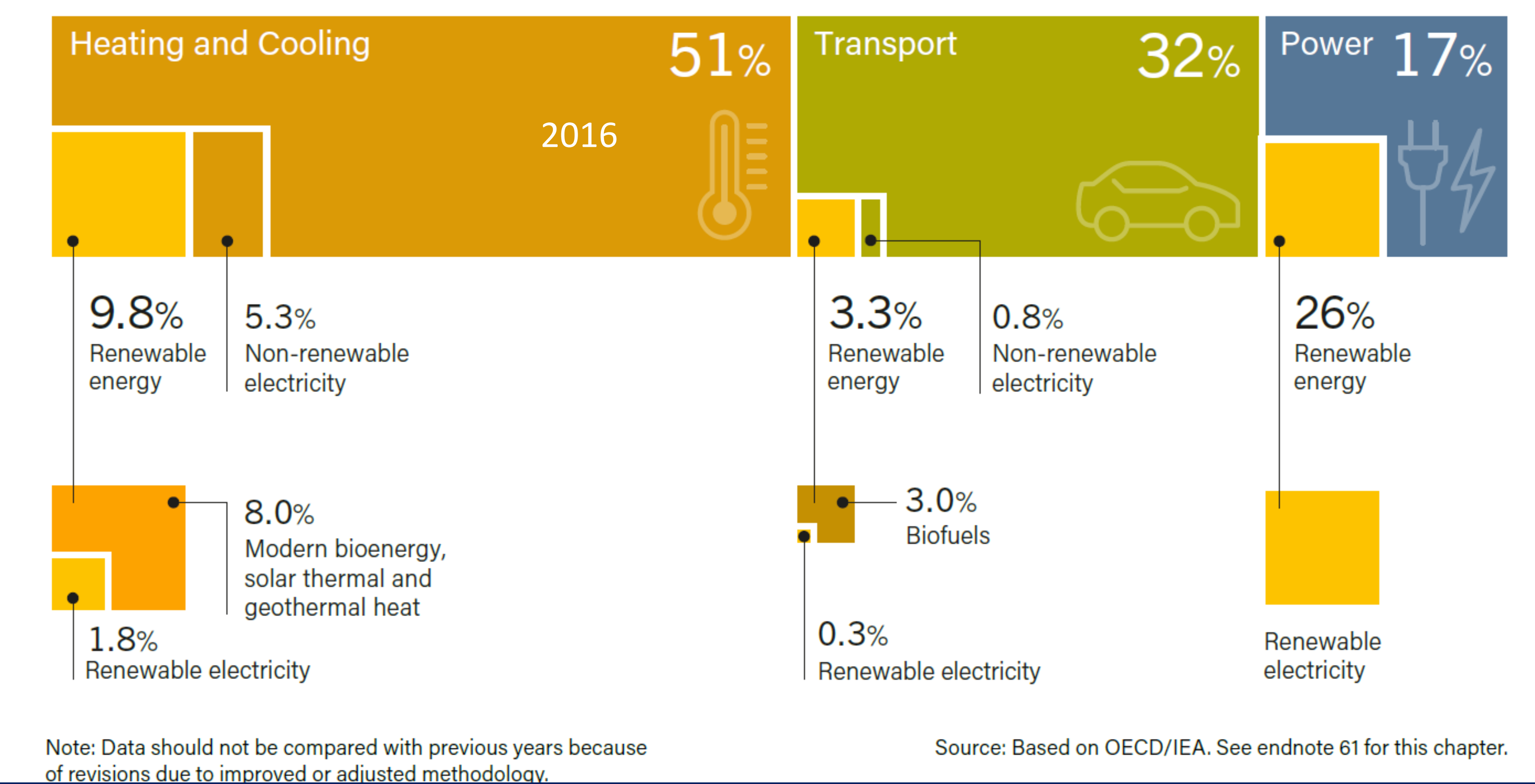
Share of Renewables- Global Final Energy Use



Note: Data should not be compared with previous years because of revisions due to improved or adjusted data or methodology. Totals may not add up due to rounding.

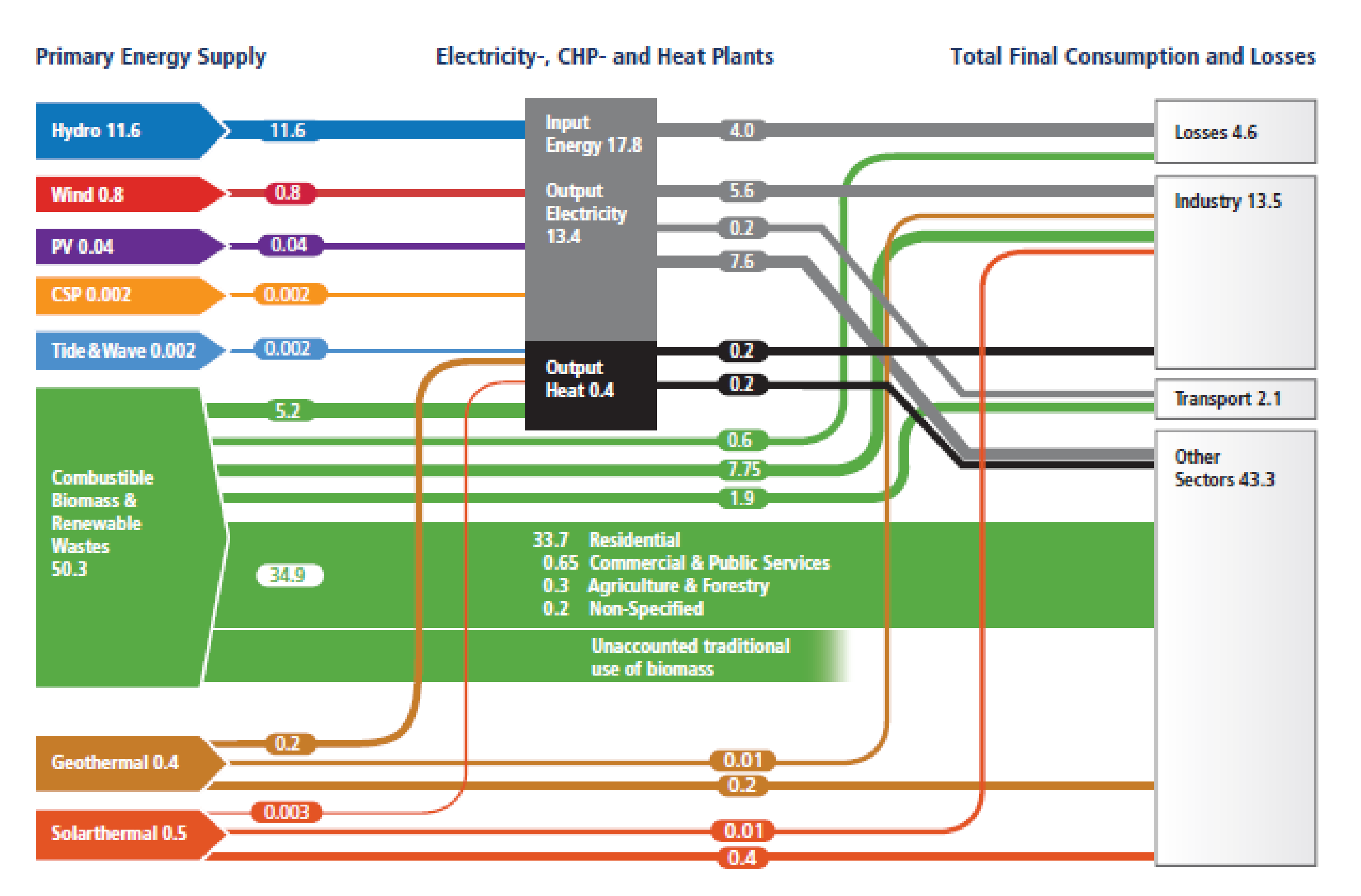
Source: Based on OECD/IEA and IEA SHC. See endnote 54 for this chapter.

Share of Renewables In End Use



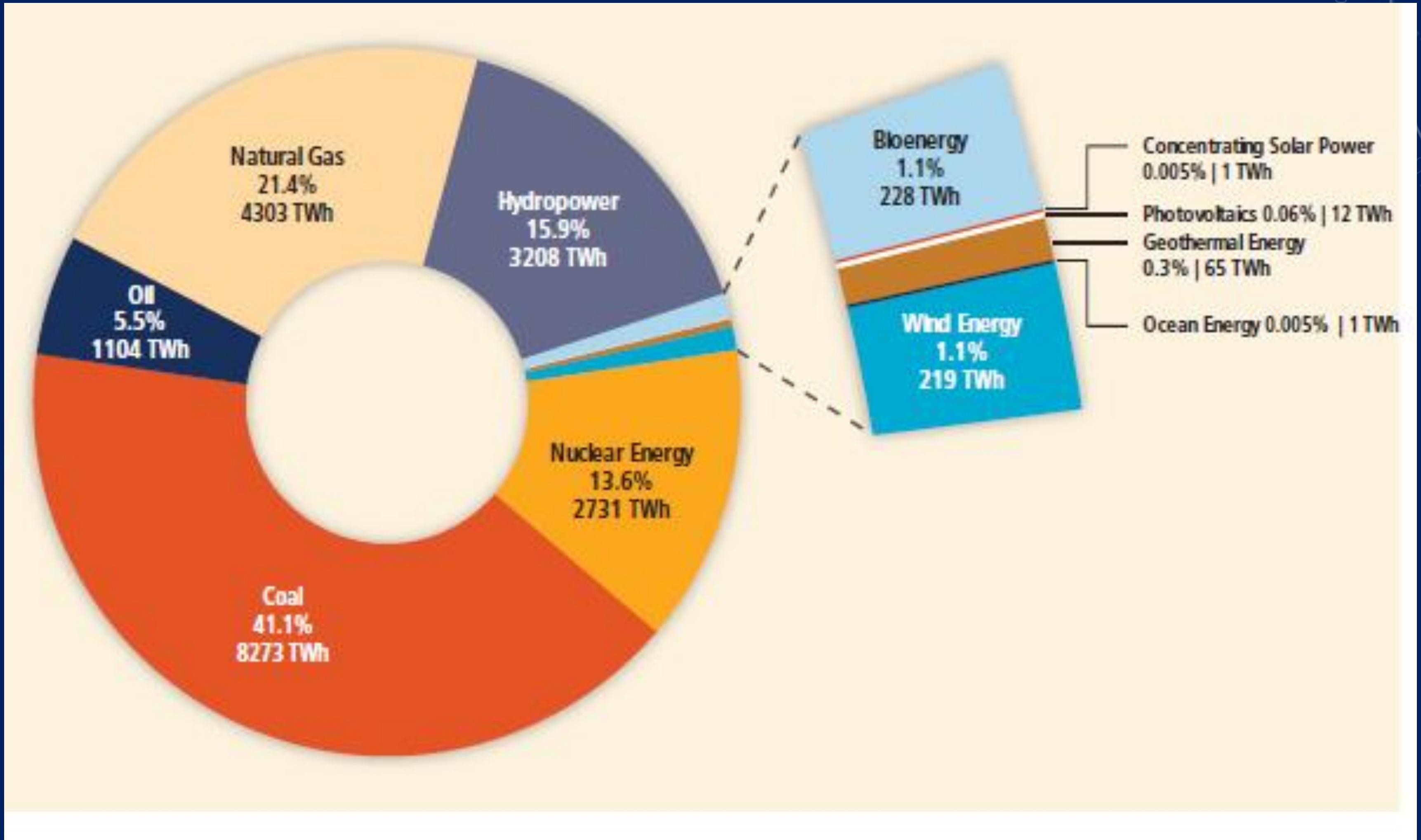
REN 21 2019 Status report

2008 Global Energy Flows in EJ

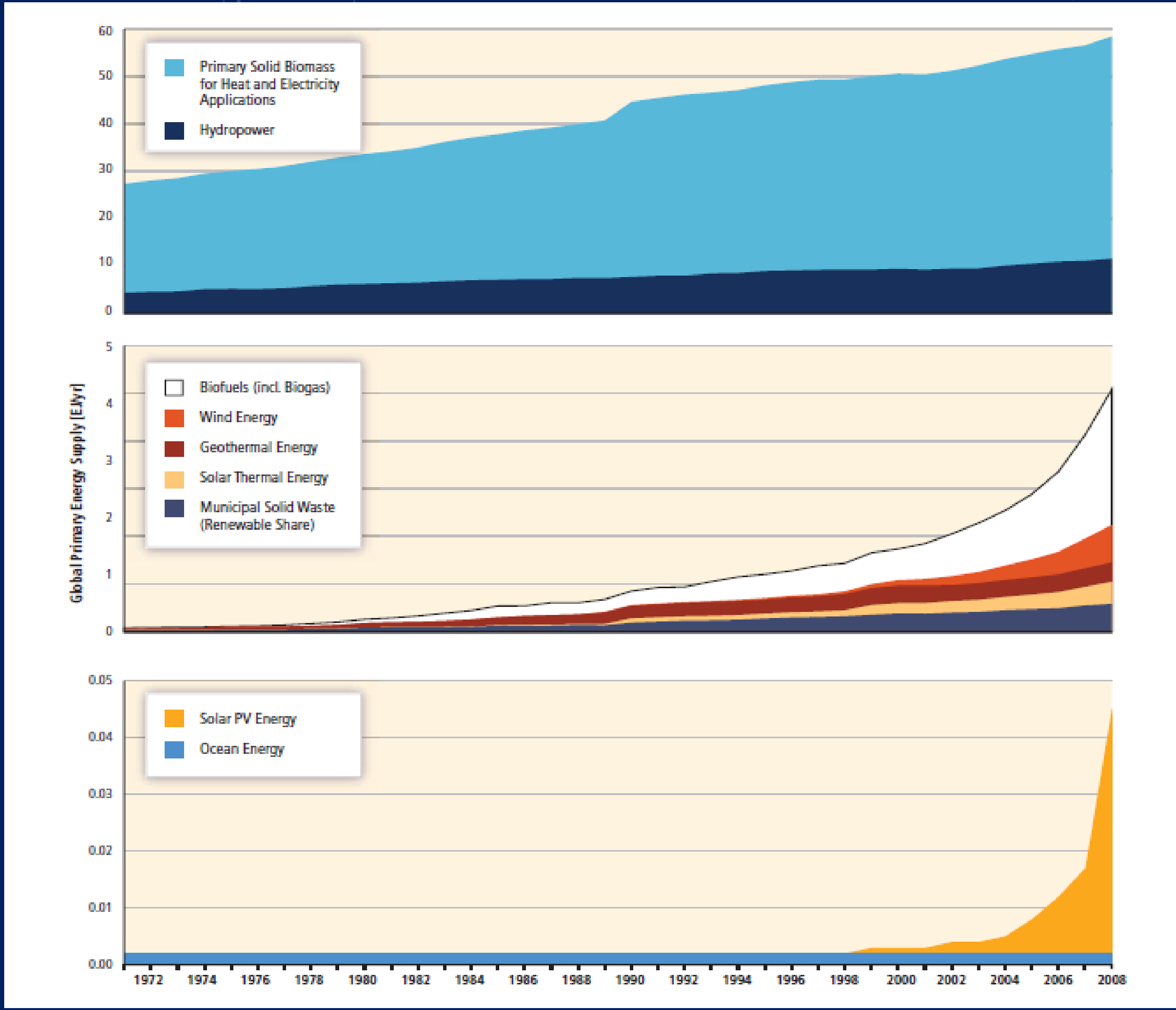


Source: SRREN , IPCC

Share of Renewables In Electricity



Source: SRREN , IPCC



Source: SRREN , IPCC

Hydropower Potential

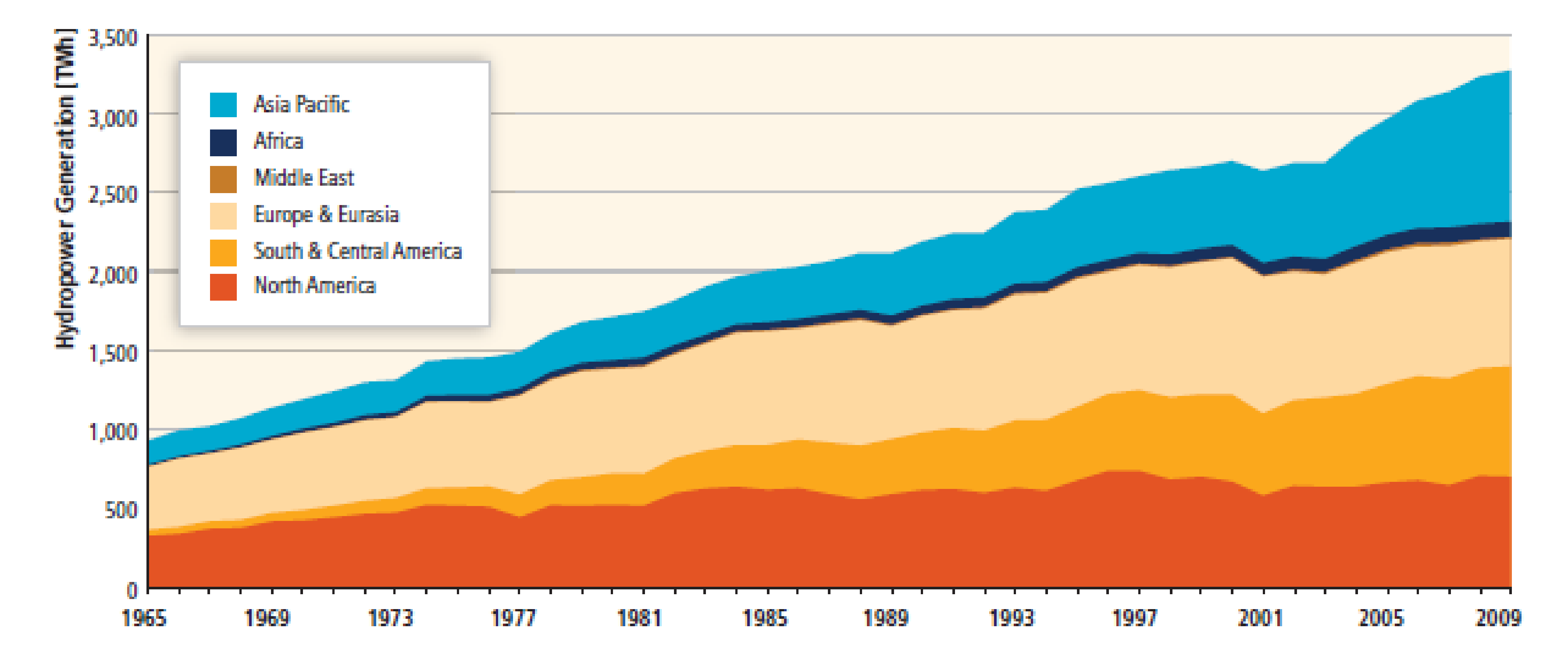
Estimation method	Comments	Hydrootential [EJ/yr]
Energy in the water cycle (Tester et al., 2005)	40,000 TW of instant solar power serving to evaporate water 40% of the time	504,000
Theoretical potential (Lehner et al., 2001)	For most rivers: mass of runoff × gravitational acceleration × height	200
Maximum technical potential, based on rivers and or sites[a]	Technical potential of known sites, assuming a very high use factor	140–145
Technical potential, based on sites at 2–20¢ per kWh[b]	Portion of technical potential, with a realistic use factor, that is sufficiently promising to justify a site assessment	50–60
Economical potential, based on sites at 2–8¢ per kWh[c]	Portion of technical potential, with a realistic use factor, that is competitive with large thermal power plants	30

GEA, Chapter 7 Resources

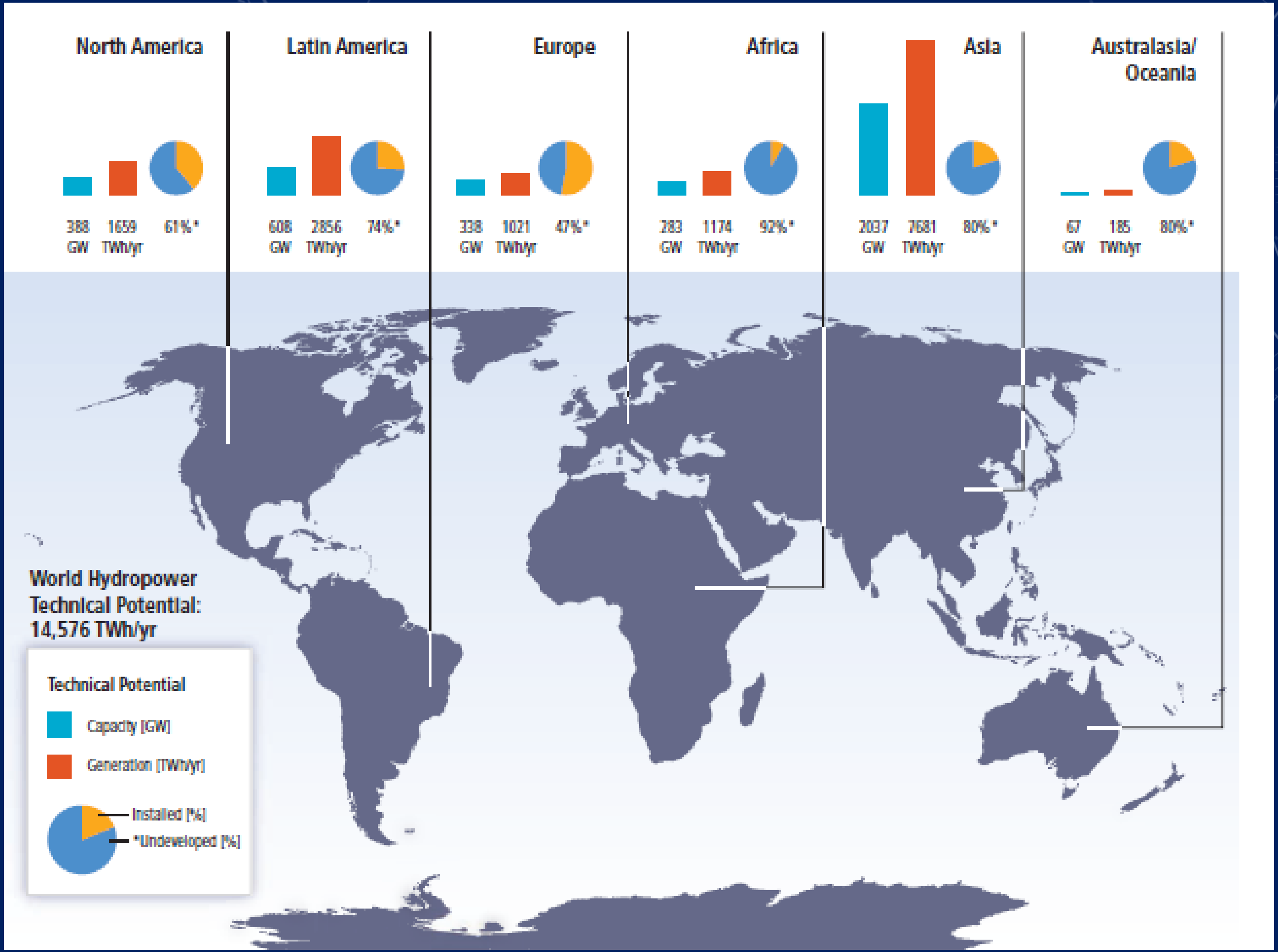
2008- 3200 TWh
16%

4200
TWh
2018

Hydropower Generation Trend



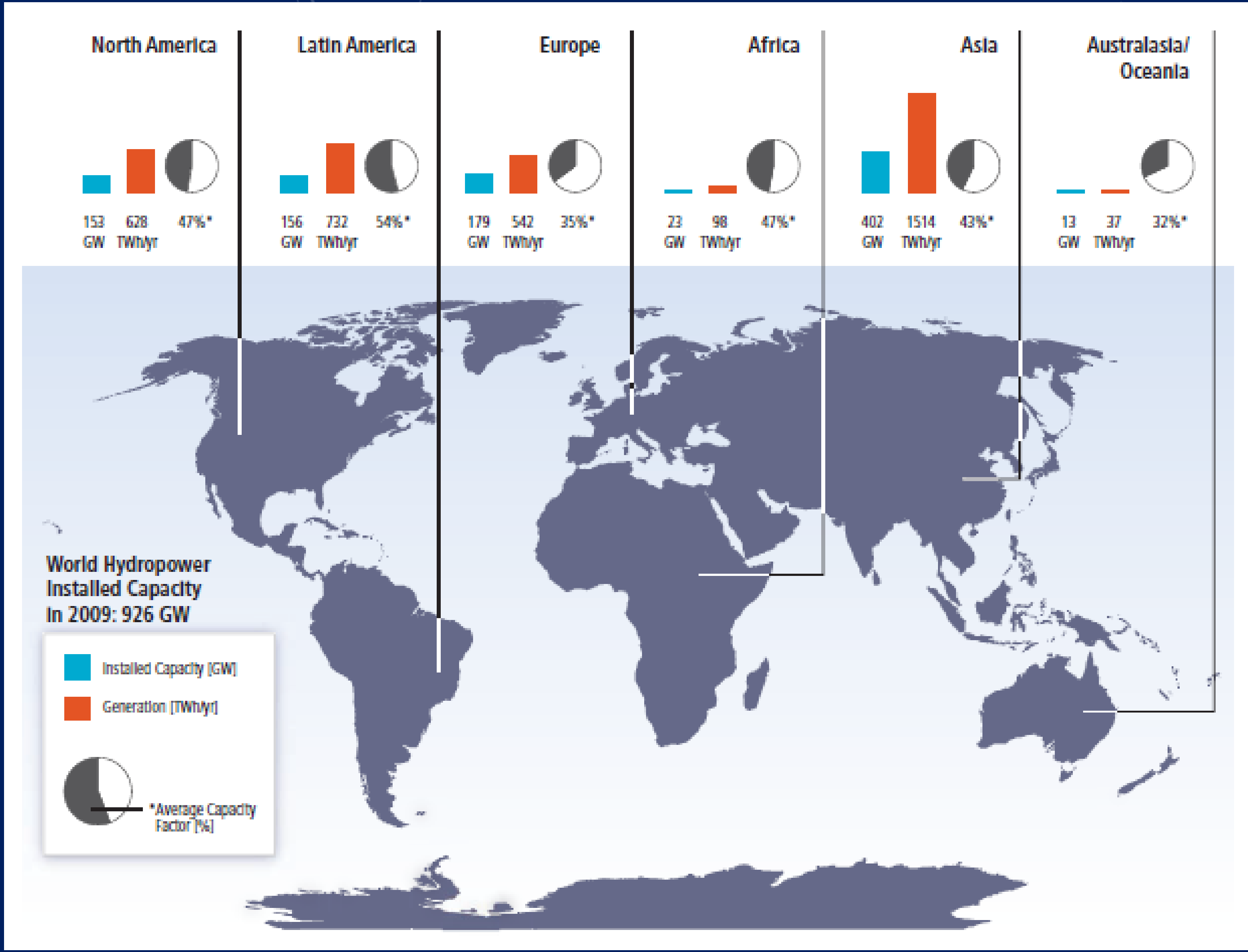
Source: SRREN , IPCC



Source: SRREN , IPCC

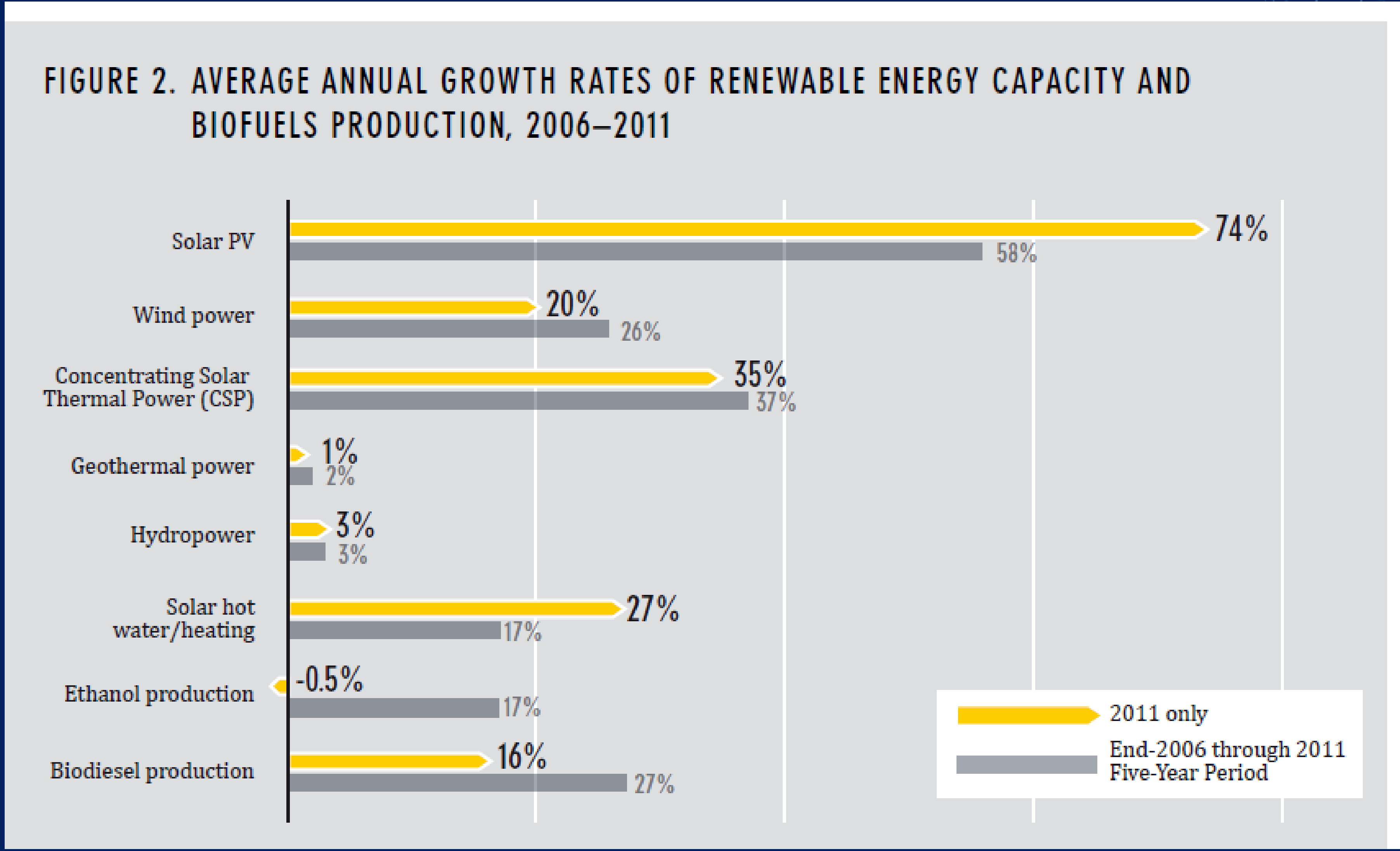
1267 GW

2017



Source: SRREN , IPCC

Renewable Energy Growth Rates



REN 21: 2012 Global Status report

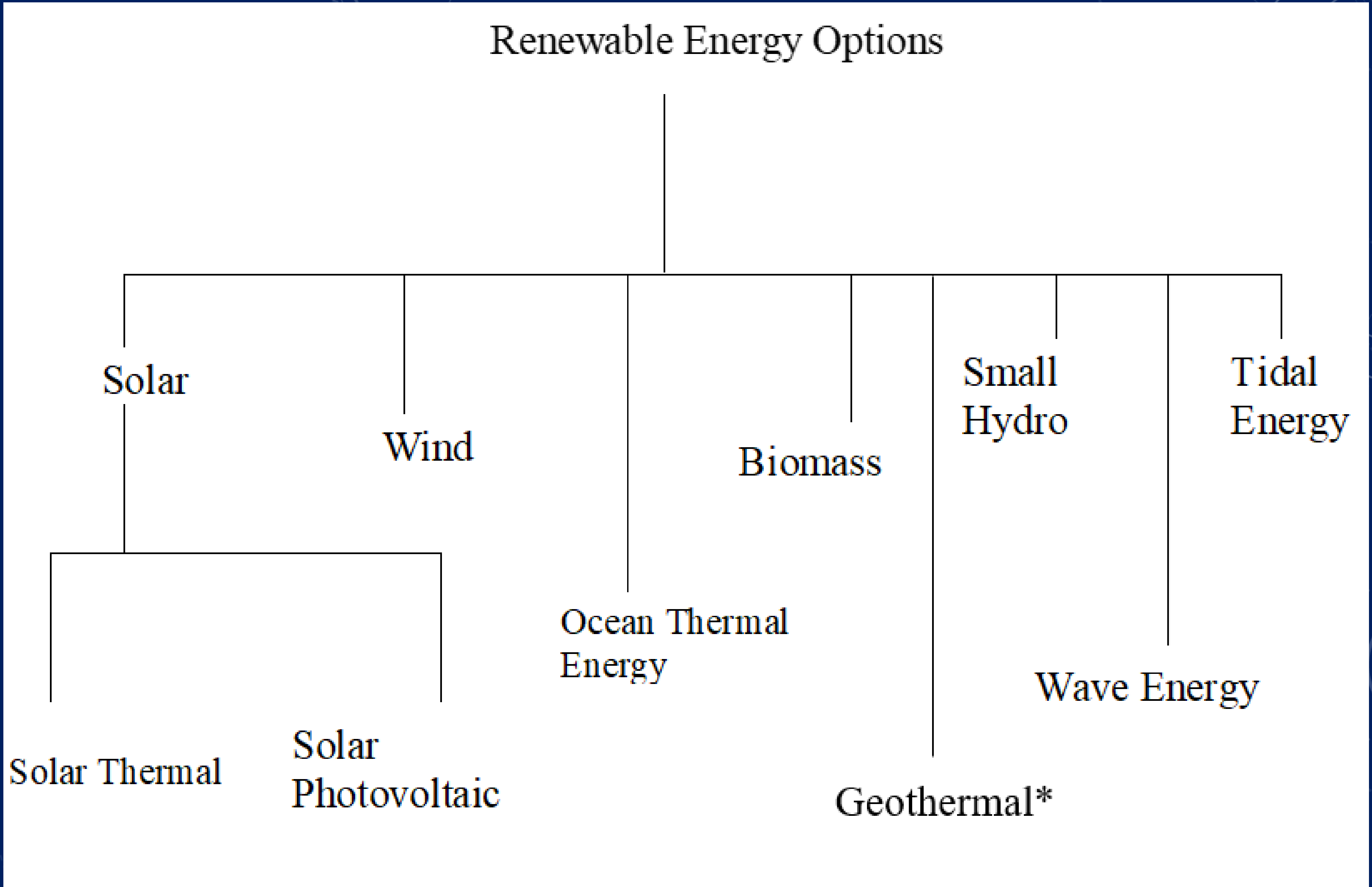
Energy Fluxes- Renewables

Renewable source	Annual Flux (EJ/yr)	Ratio (Annual energy flux/ 2008 primary energy supply)
Bioenergy	1,548[d]	3.1
Solar Energy	3,900,000[a]	7,900
Geothermal Energy	1,400[f]	2.8
Hydropower	147[a]	0.30
Ocean Energy	7,400[a]	15
Wind Energy	6,000[a]	12

Source: SRREN , IPCC

Renewable Potential

- How do we estimate the potential ?
- Flows/ Fluxes – Not stocks
- Technical/ Economic Potential
- Spatial Distribution of resource
- Daily/ Seasonal Variation
- Uncertainty


Renewable Energy Options
Solar
Wind
Ocean Thermal Energy
Biomass
Geothermal*
Small Hydro
Wave Energy
Tidal Energy
Solar Thermal
Solar Photovoltaic

Wind measurement

Wind Sock

Wind
Anemometer

http://www.weatherwizkids.com/?page_id=82

Wind Vane
Anemometer
set

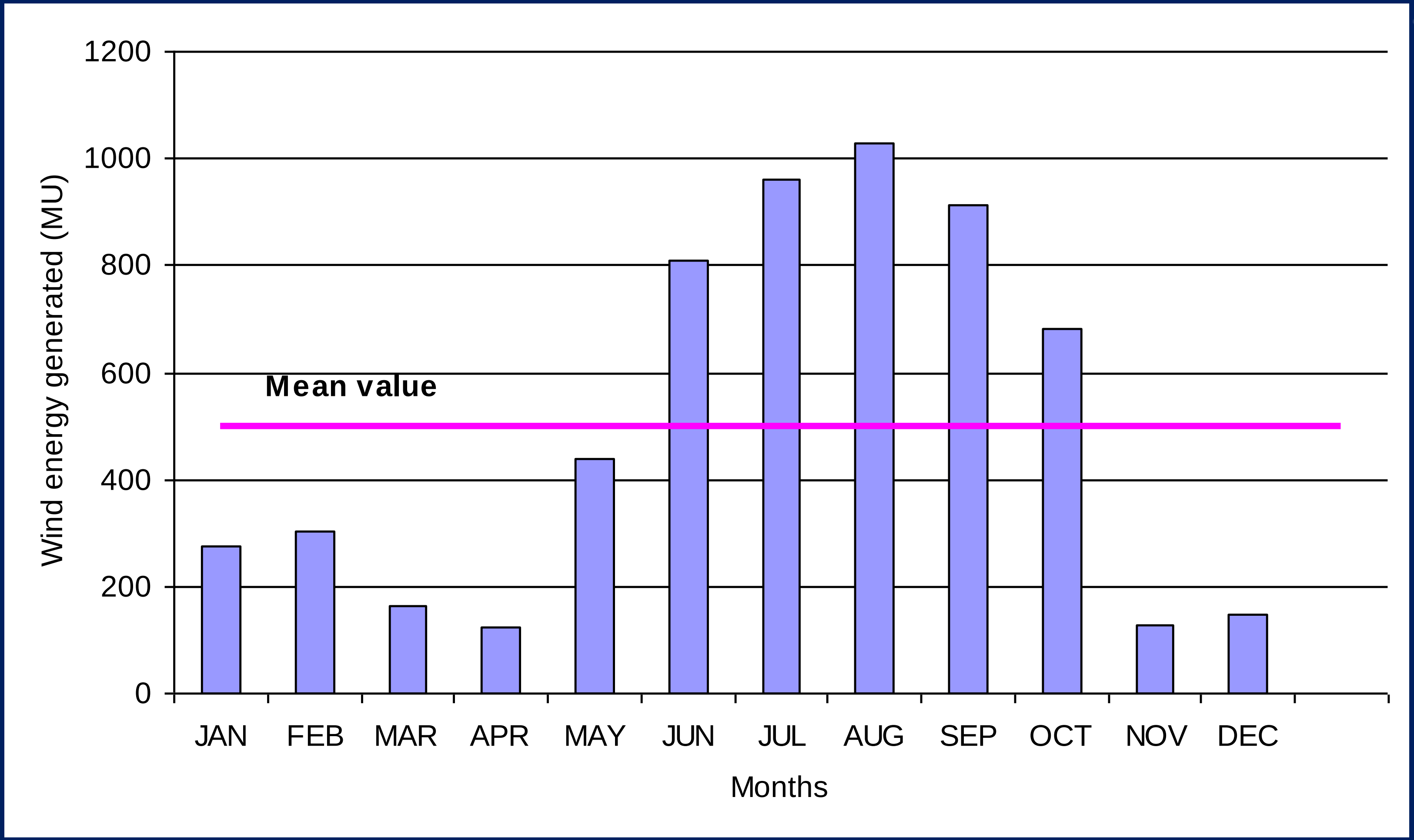
https://www.testo.com/en-IN/Parameters/Anemometer/Vane/testo-417-Set-2/p/0563%204172

Wind speed vs height

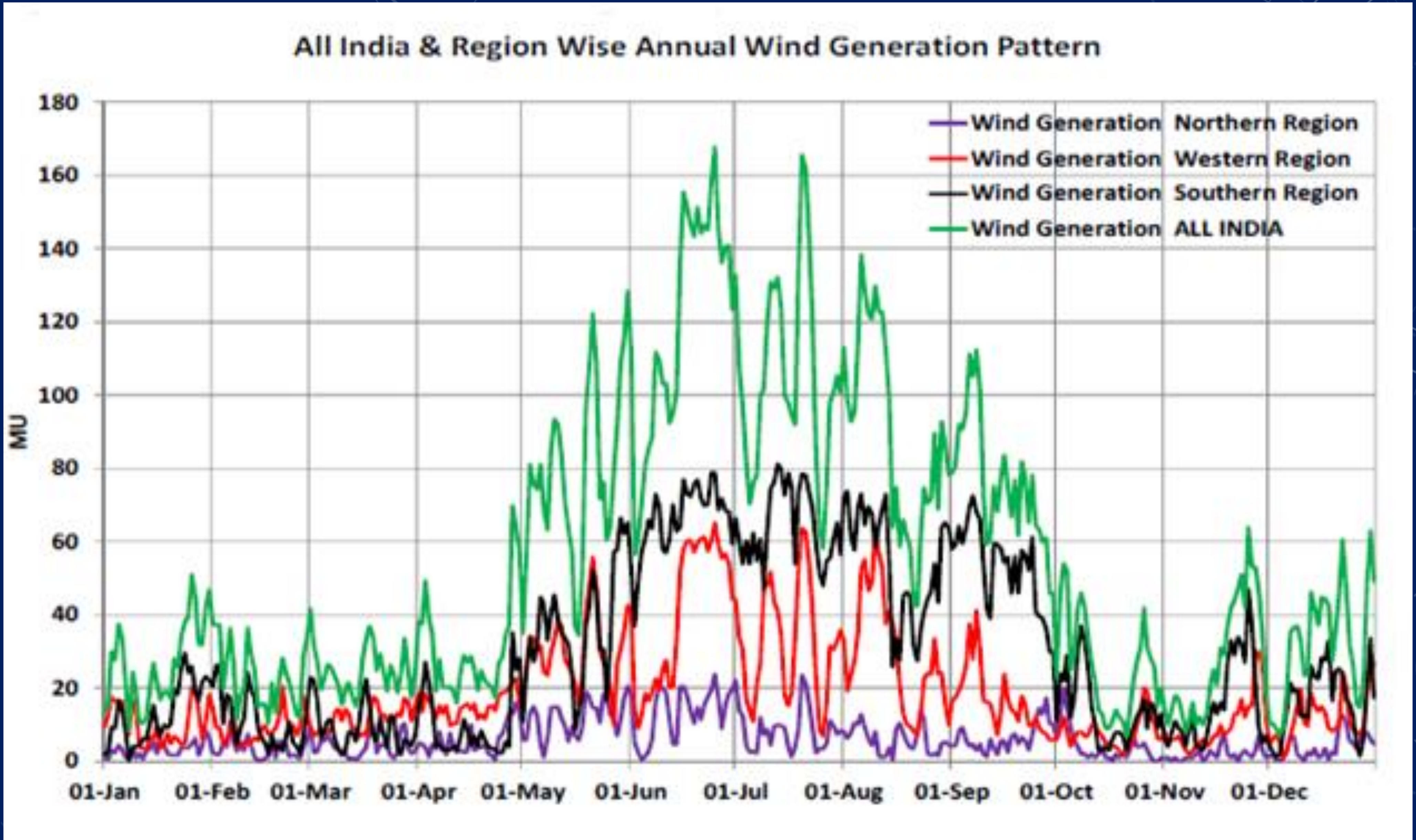
- Wind speed varies with height from ground
- $V_2/V_1 = (z_2/z_1)^{\alpha}$ where α ranges from 0.1-0.4 depending on terrain - smooth 0.1, rough 0.4 valid at heights up to 150m

- For site - speed frequency distribution, speed duration curve

Wind Monthly Average- Tamil Nadu (2007)

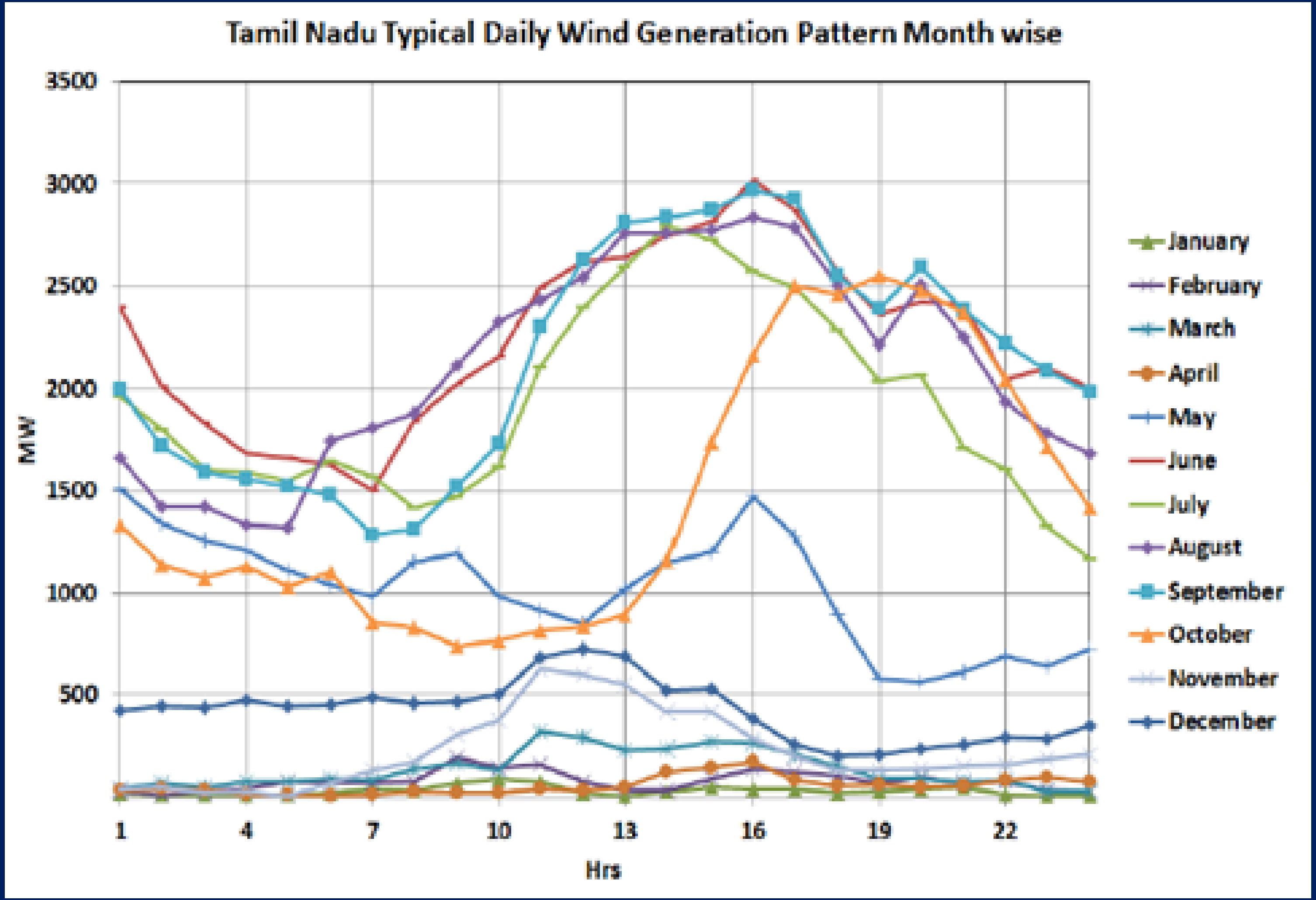


Source: George M. and Banerjee R. (2011)



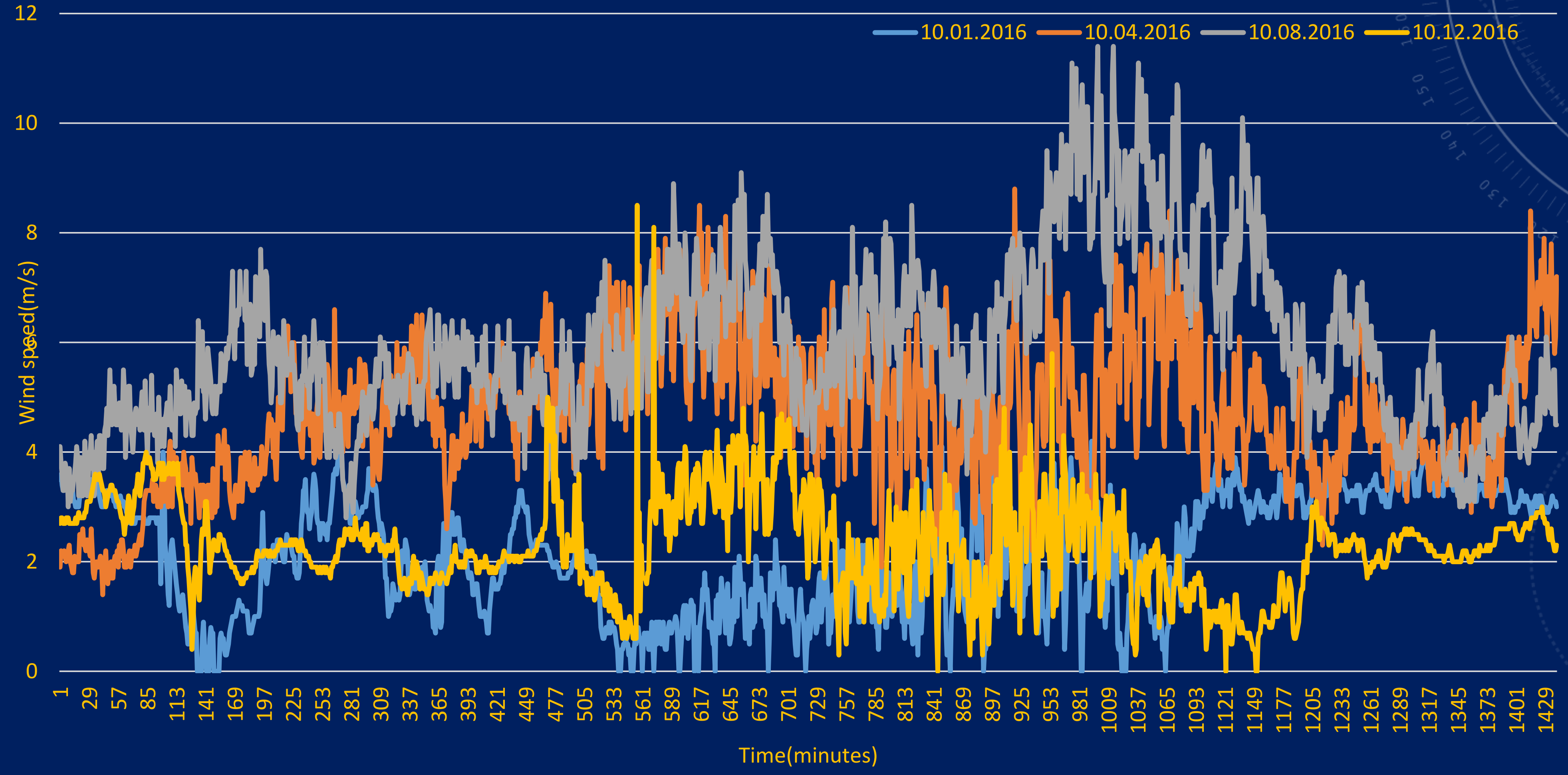
Source: Powergrid (2012)

Wind – Daily Variation Tamil Nadu



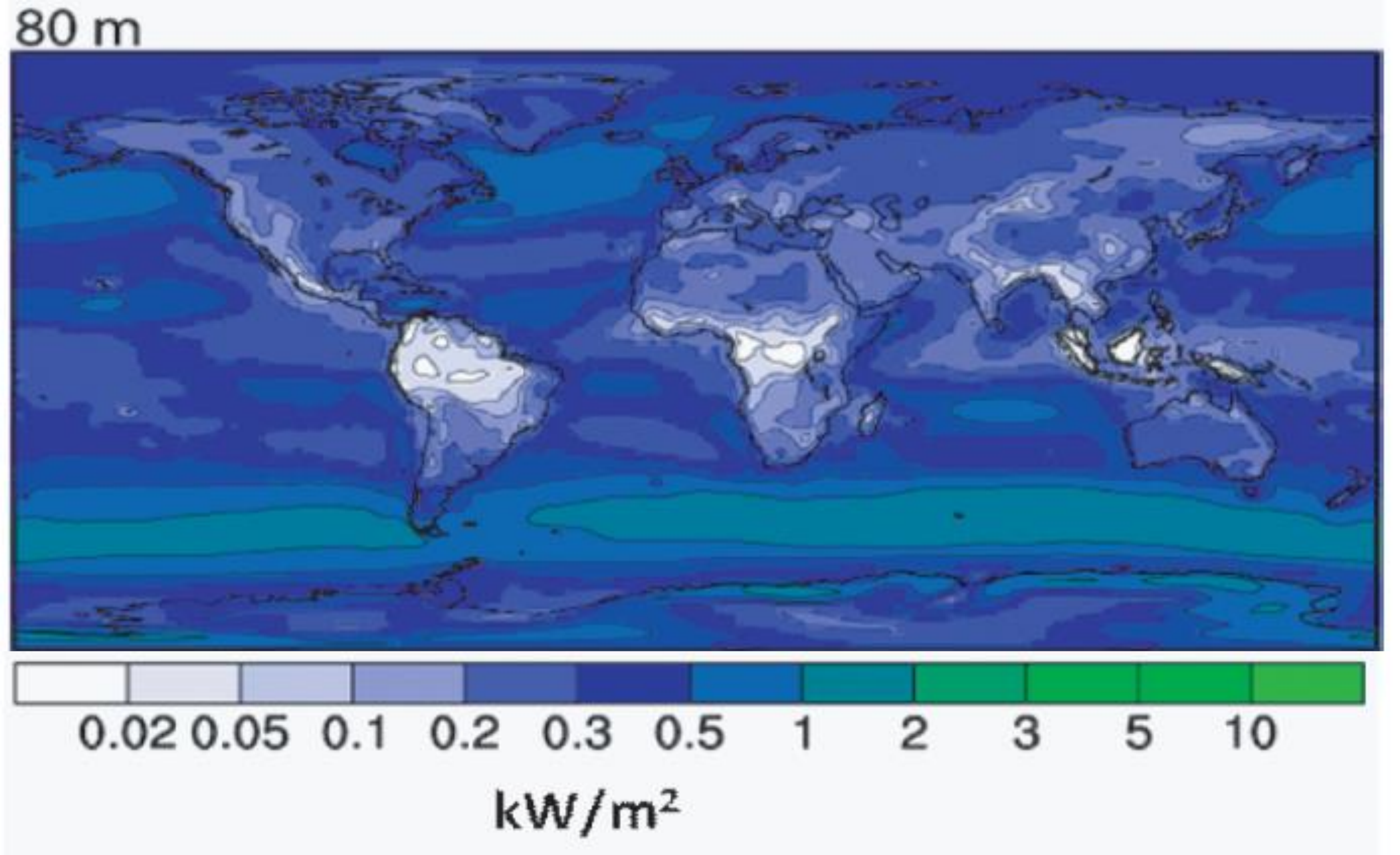
Source: Powergrid (2012)

Variation in Wind Speed



Wind speed(m/s) measured at 10m at Chandrodi station, Kutch Gujarat

Map of Median Wind Power density



Source: GEA Chapter 7

References

- GEA, 2012: Global Energy Assessment - Toward a Sustainable Future, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria. Chapter 7, Available online: https://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter7_resources_lowres.pdf
- George M., and Banerjee R. (2011), A methodology for analysis of impacts of grid integration of renewable energy, Energy Policy, 39, 1265-1276, https://doi.org/10.1016/j.enpol.2010.11.054
- Powergrid (2012), Transmission Plan for Envisaged Renewable Capacity, Vol-1, Report by Power Grid Corporation of India Ltd., July 2012, Available online: https://www.powergridindia.com/sites/default/files/Our_Business/Smart_Grid/Vol_1.pdf
- REN21: Renewables 2019 Global Status Report, available online: https://www.ren21.net/gsr-2019/
- REN21: Renewables 2012 Global Status Report Available online: http://ren21.net/Portals/0/documents/Resources/GSR2012_low%20res_FINAL.pdf
- SRREN, IPCC: Renewable Energy Sources and Climate Change Mitigation, Special Report of the Intergovernmental Panel on Climate Change, 2012, available online: http://www.ipcc-wg3.de/report/IPCC_SRREN_Full_Report.pdf

Lecture - 8B

Energy Resources, Economics and Environment

Energy Resources – Renewables

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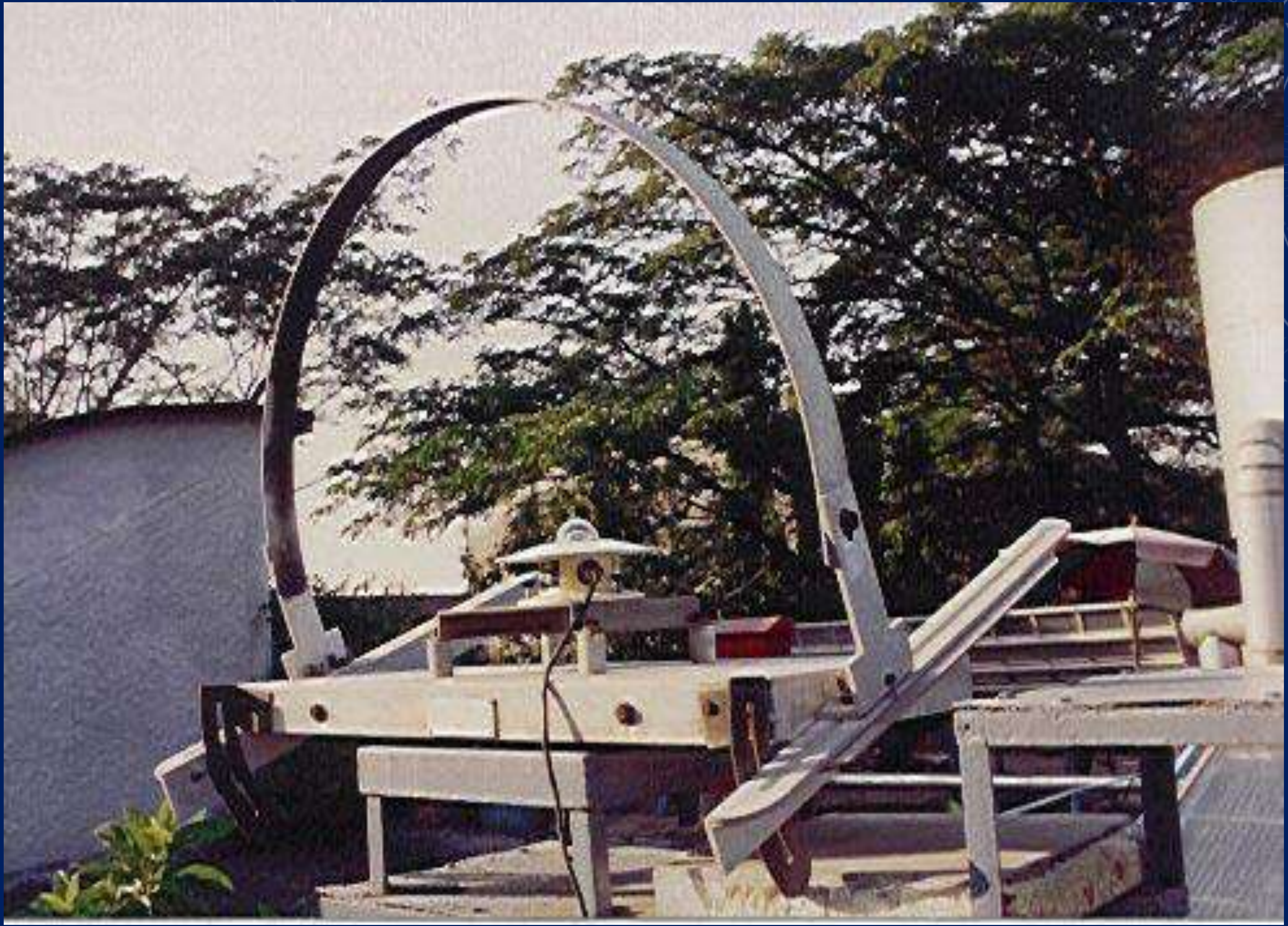
Pyrheliometer

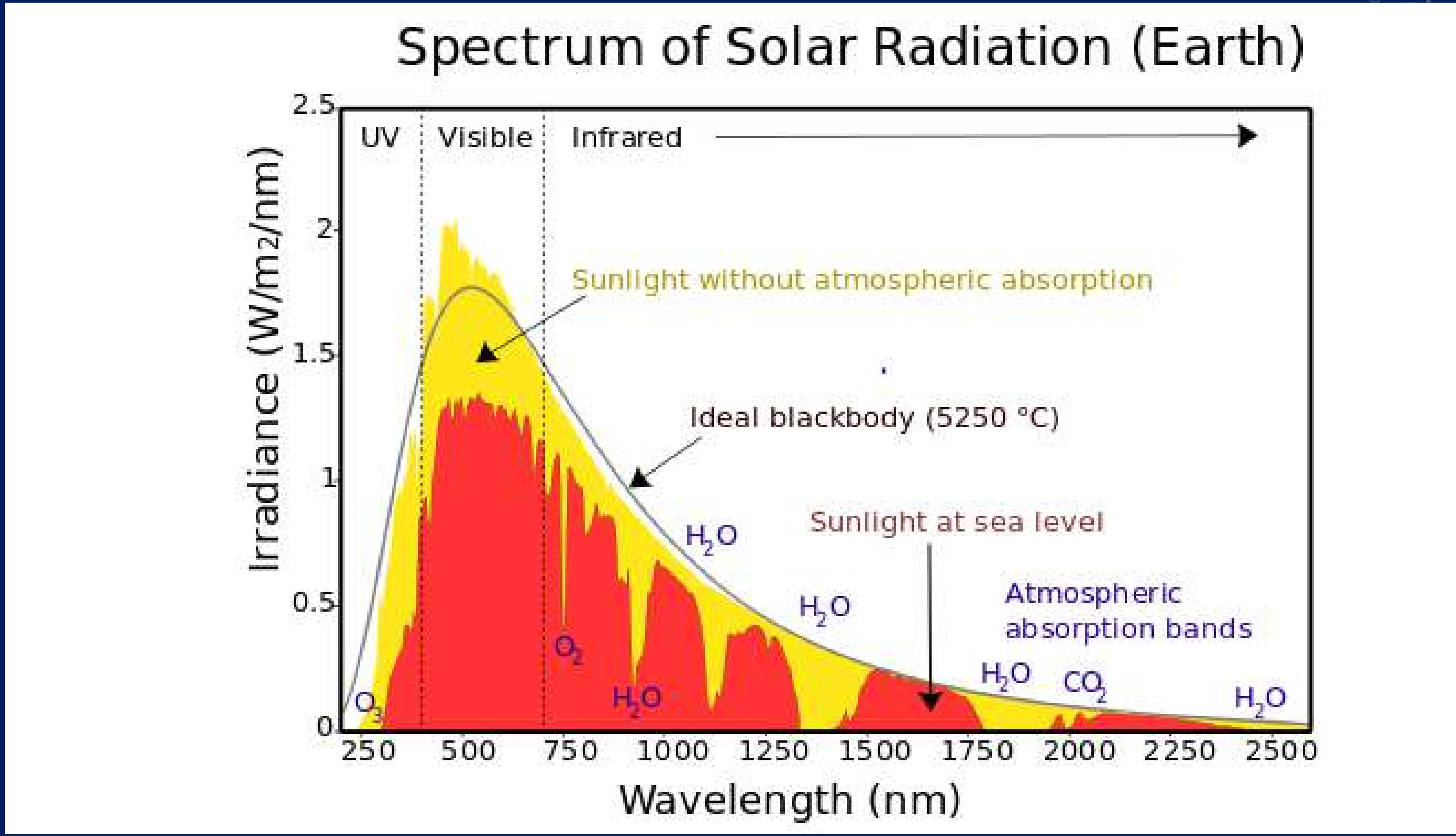


Pyranometer

Solar Radiation basics

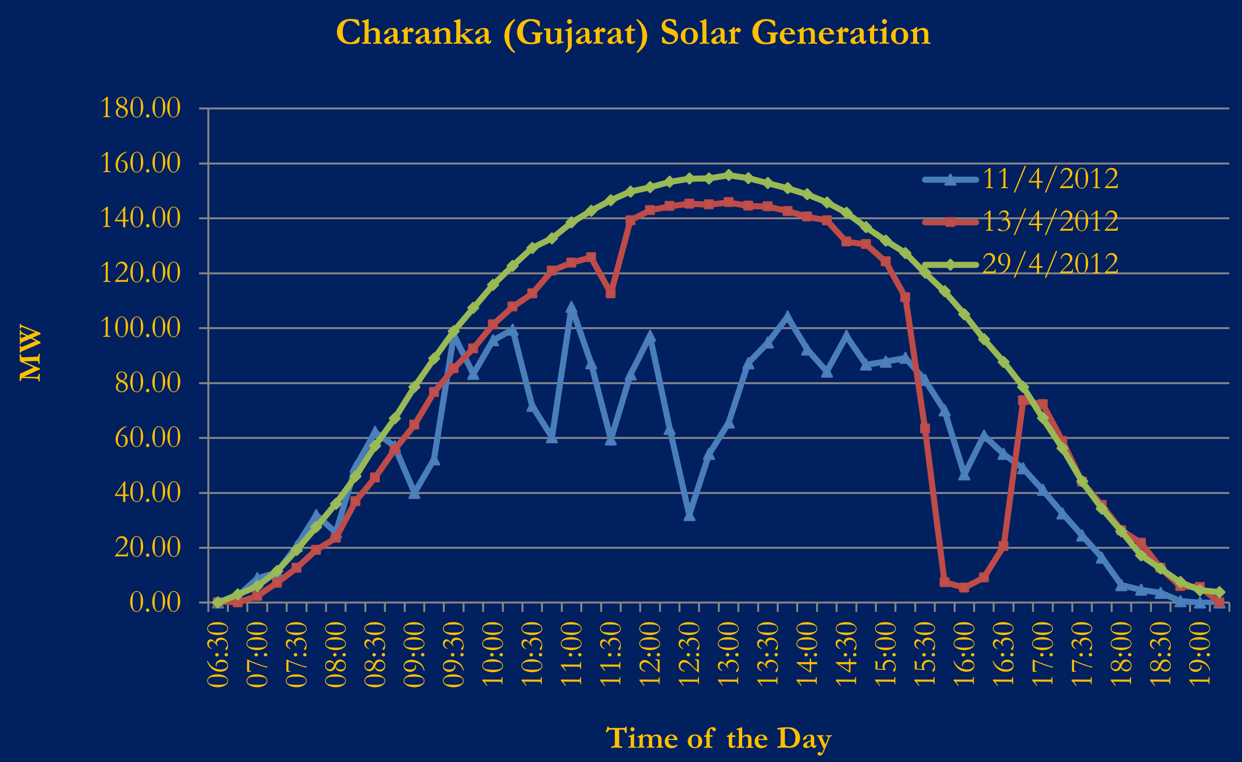
- Extraterrestial Radiation 1361 W/m^2
- Direct Normal Irradiance ~Peak 1000 W/m^2
- Direct normal irradiance (DNI) is the flux density of direct (un-scattered) light from the sun measured on a flat plane perpendicular to the sun's rays.

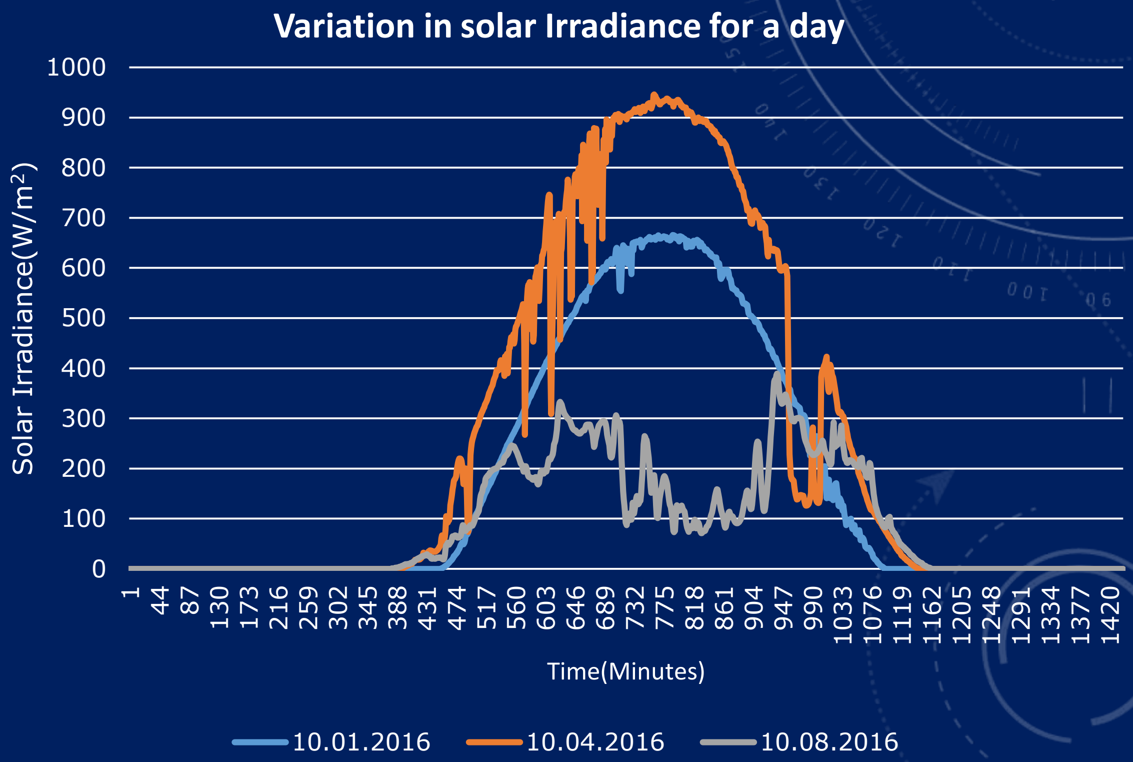
Spectrum of Solar Radiation



Credit: Nick84 [CC BY-SA 3.0], via Wikimedia Commons

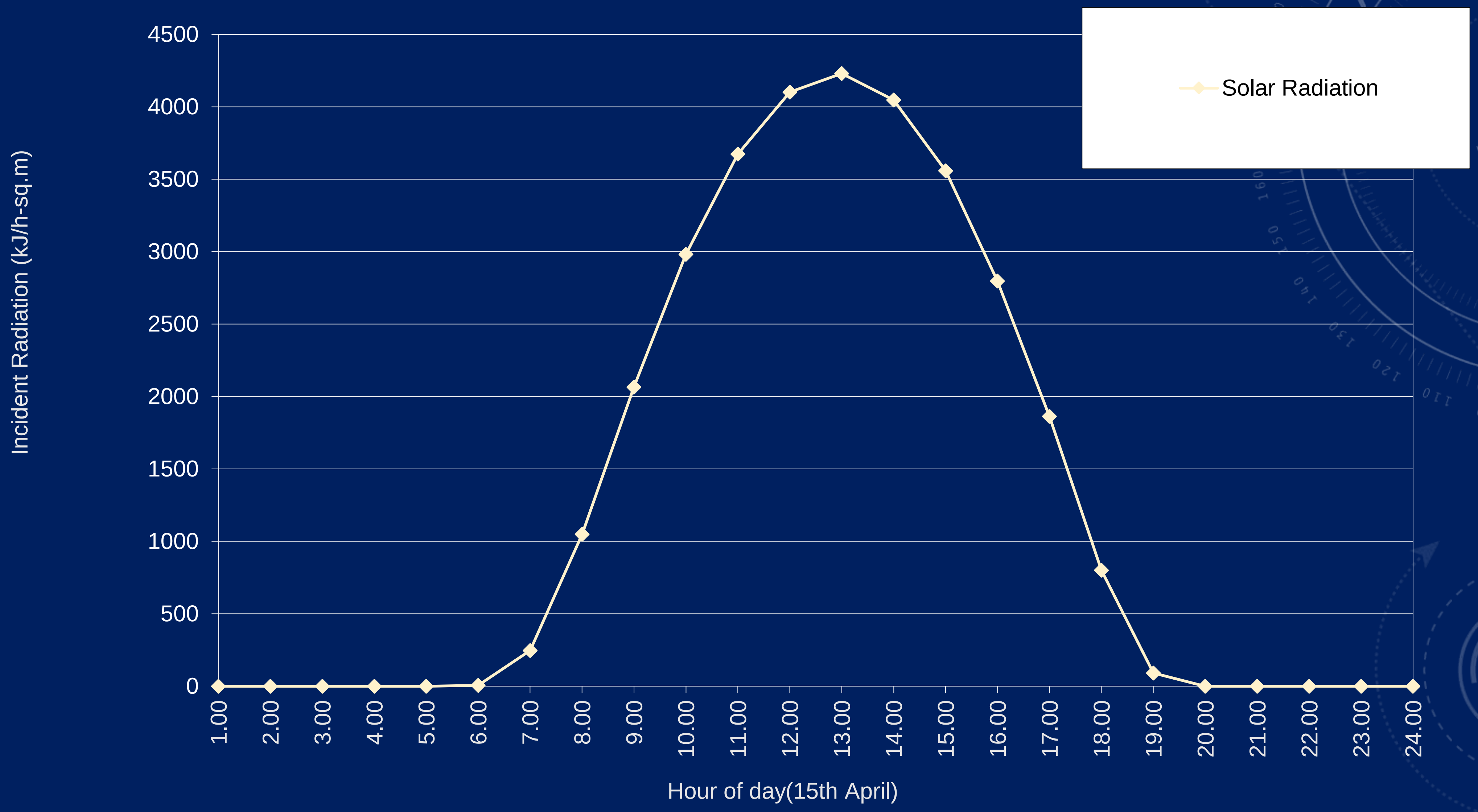
Solar PV Variation





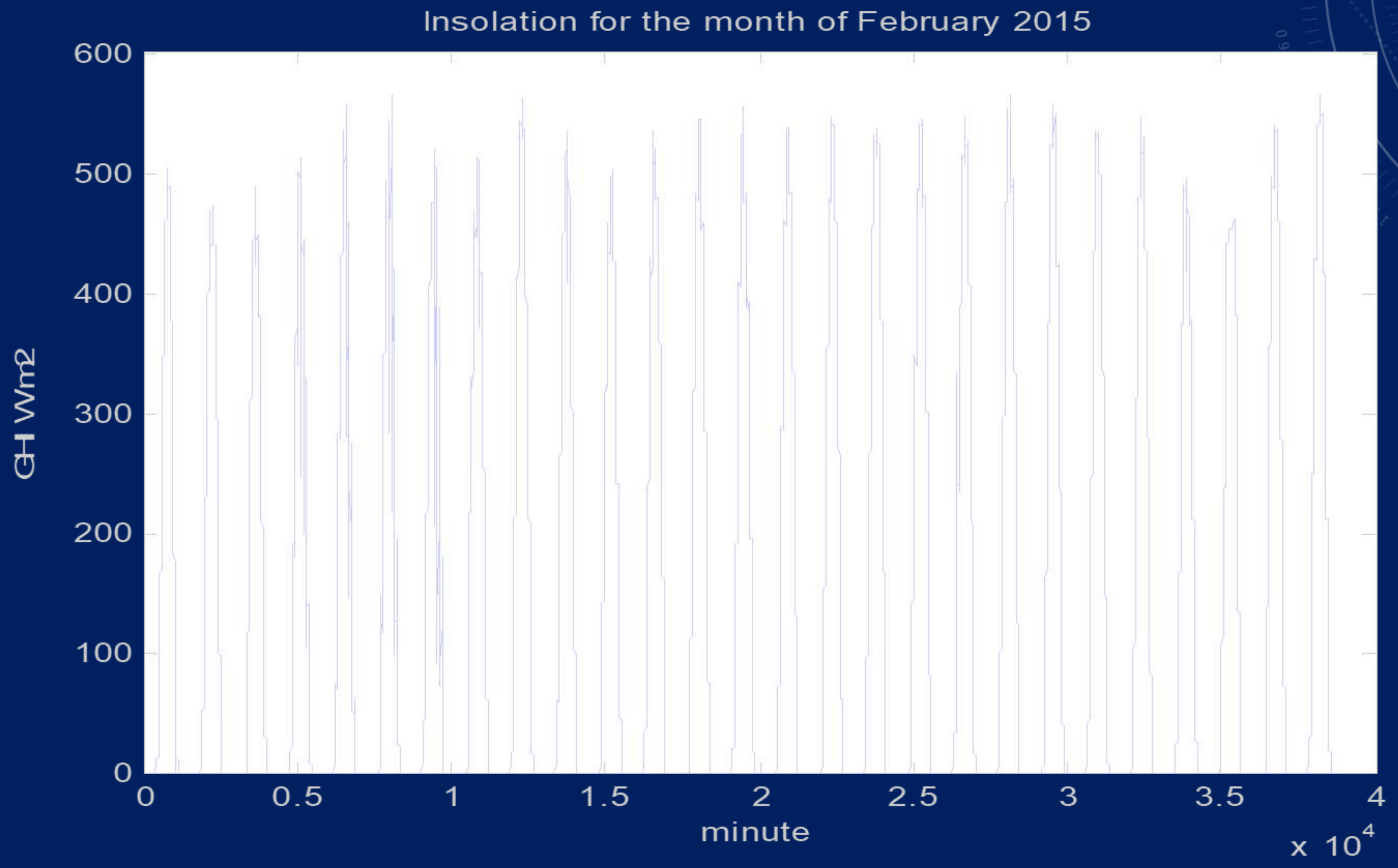
Source: Gujarat SLDC

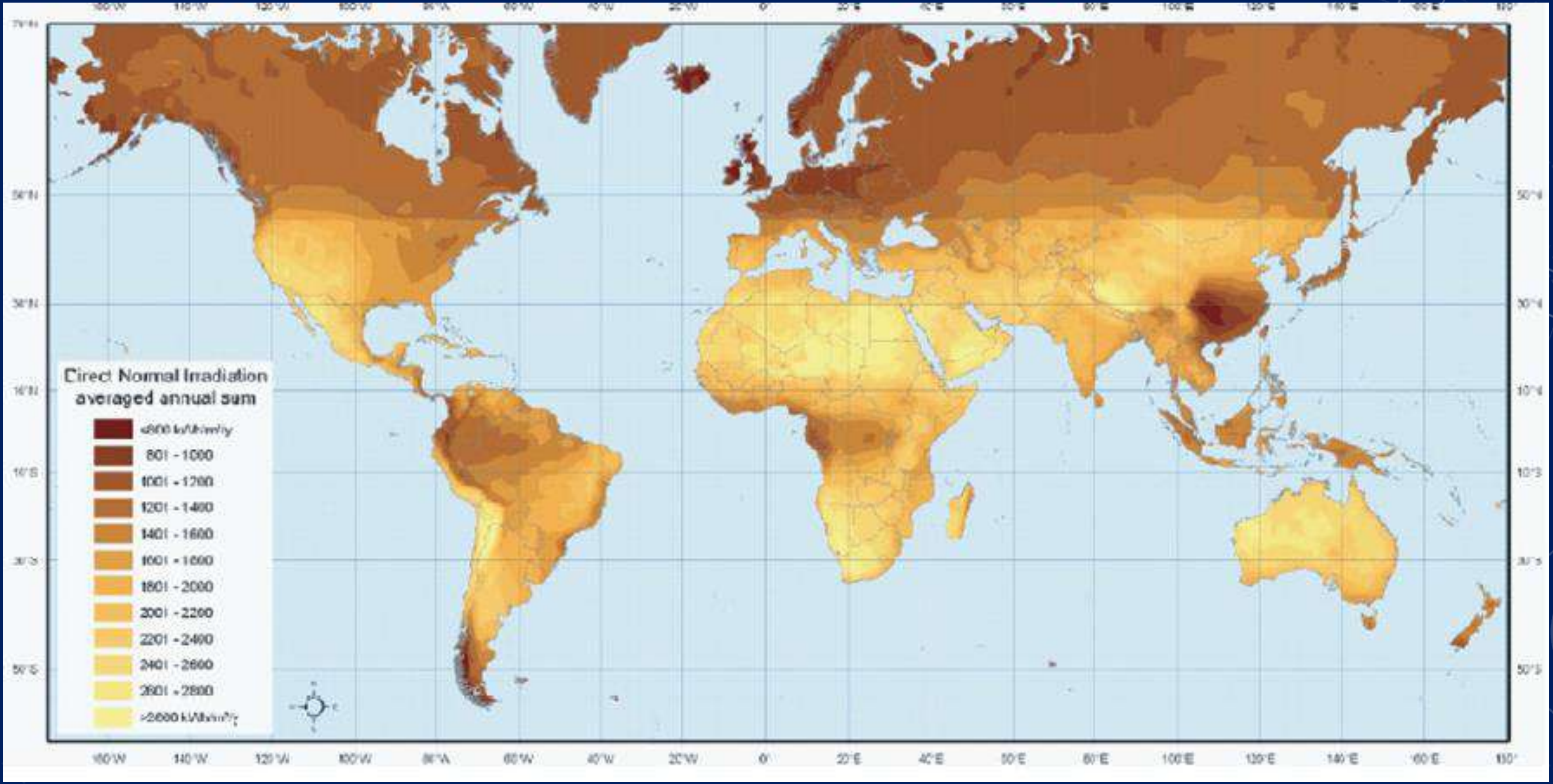
GHI(W/m^2)measured at Chandrodi station, Kutch Gujarat



Energy flow/ Solar Radiation for a typical day of April

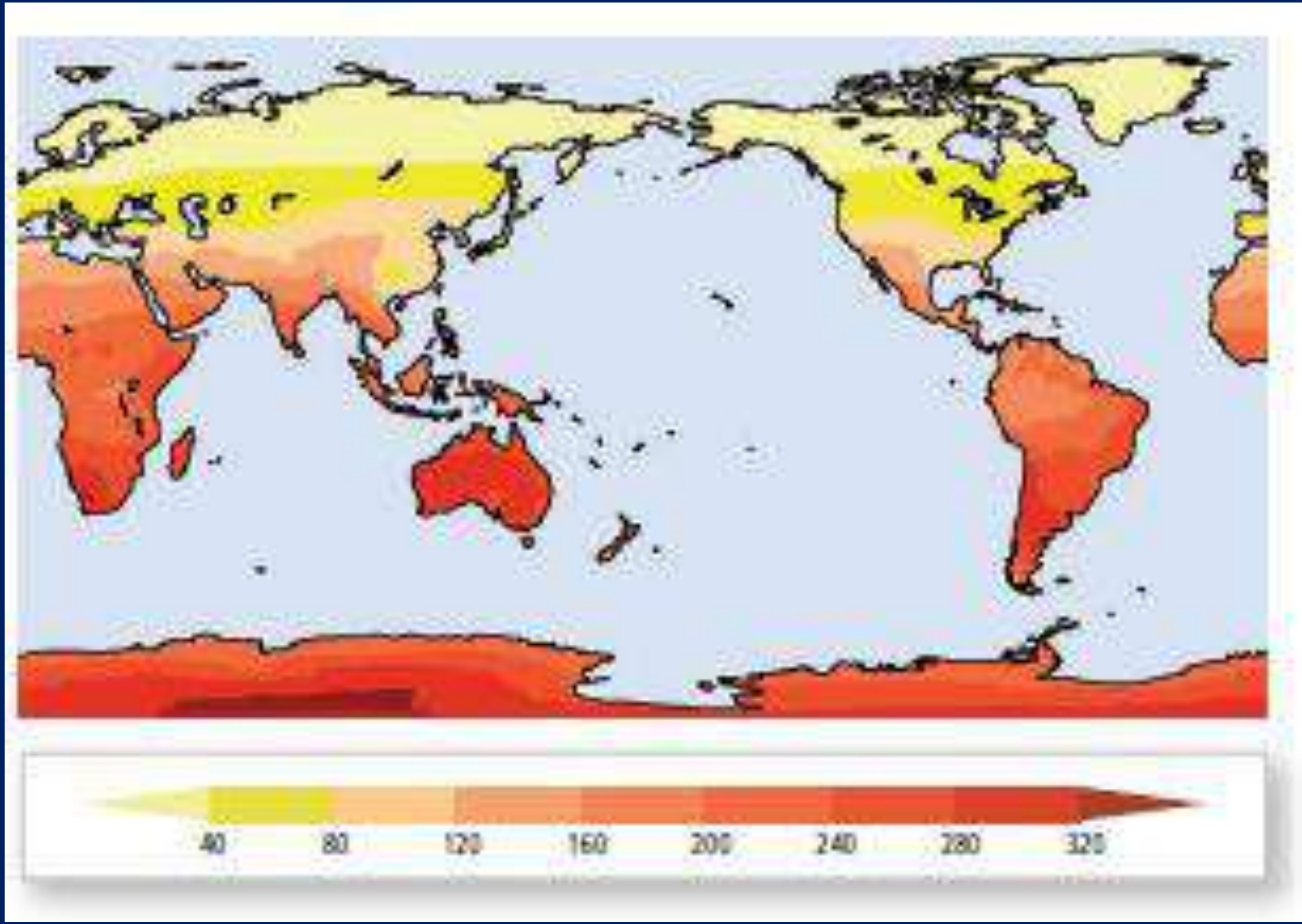
GHI for the month of February 2015 at IIT Bombay





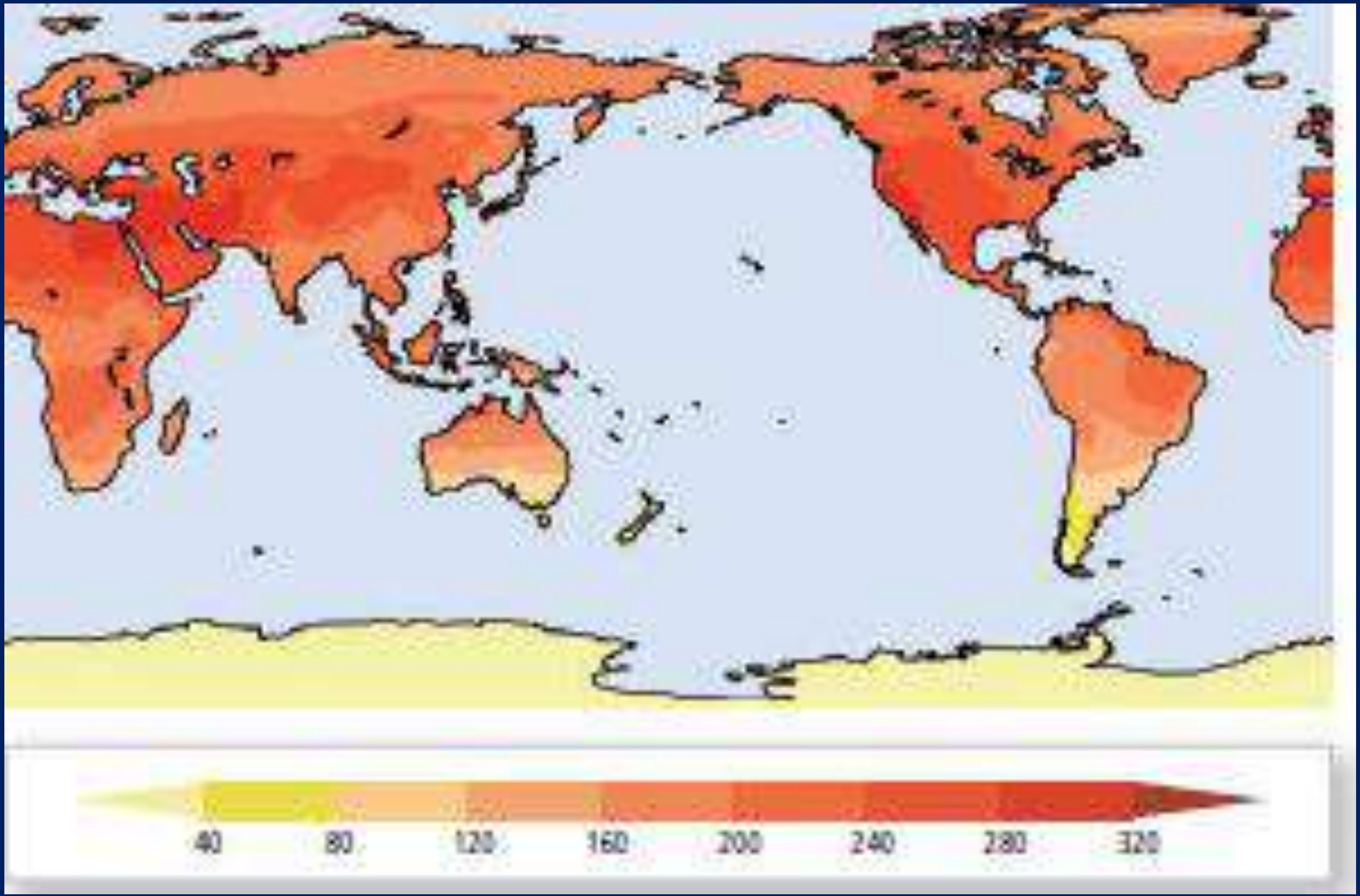
Source: GEA Chapter 7

Global Solar Irradiance – Dec, Jan, Feb



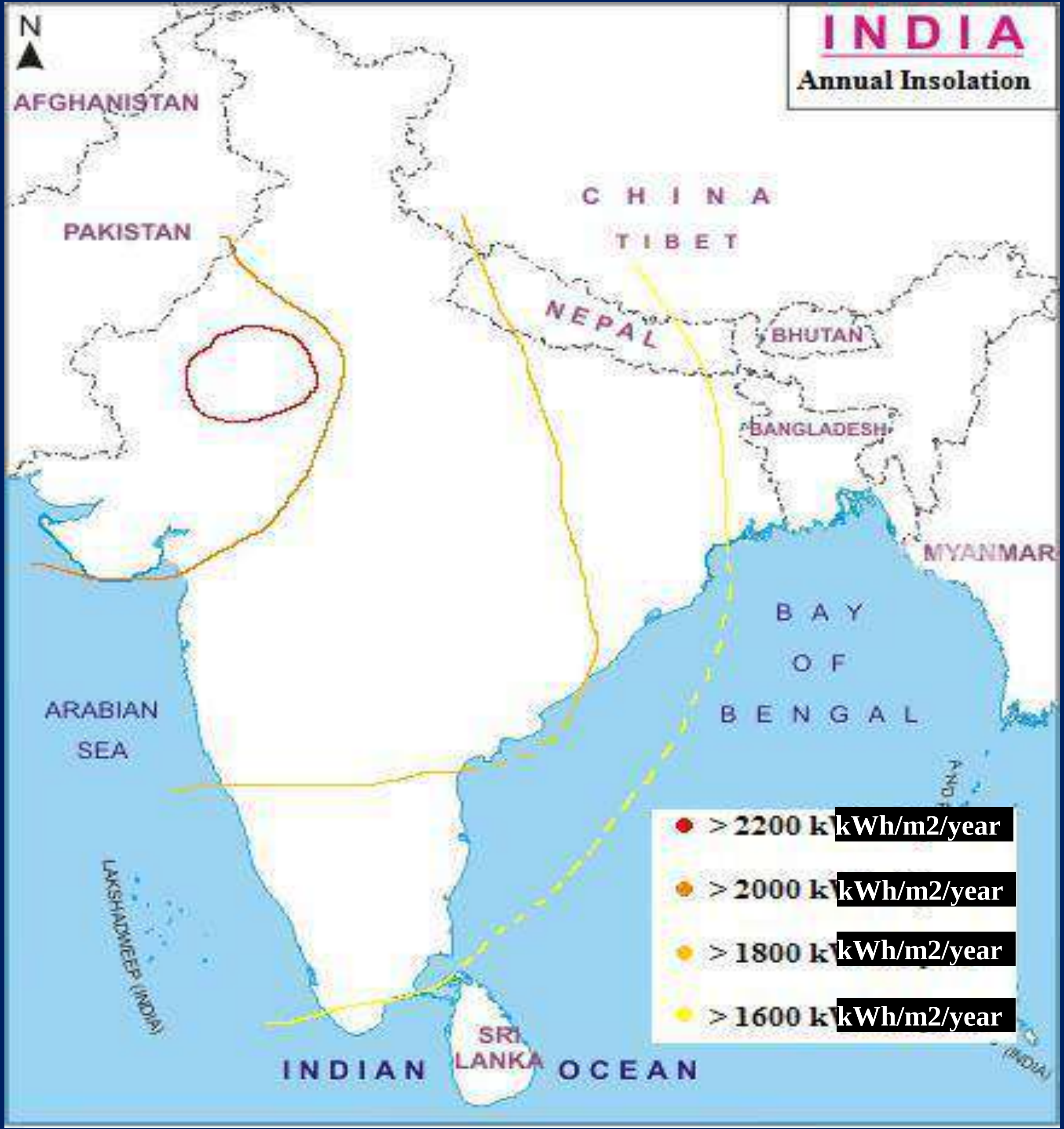
Source: SRREN , IPCC

Global Solar Irradiance – June, July, Aug



Source: SRREN , IPCC

Annual Insolation

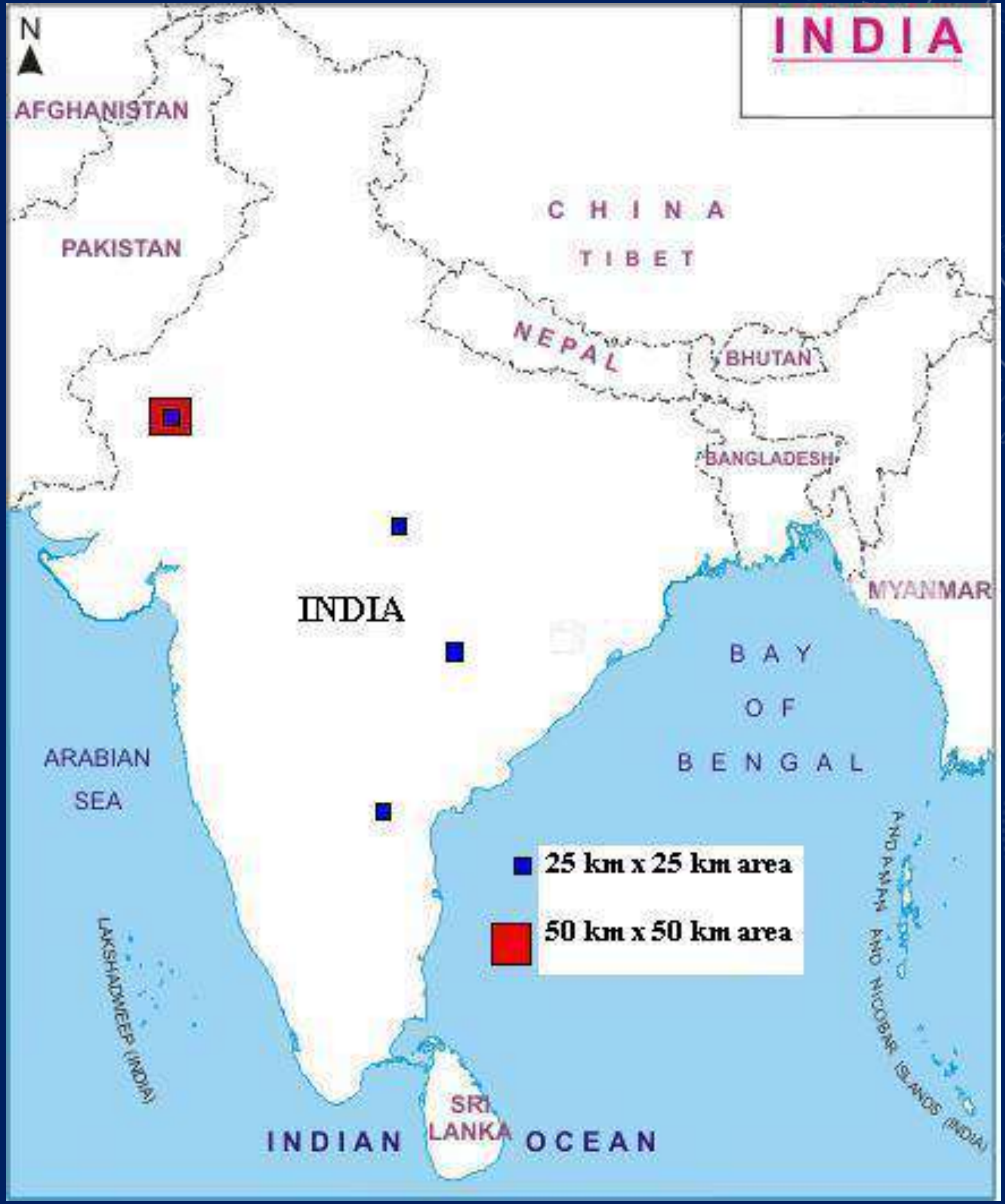


Area for Power Generation

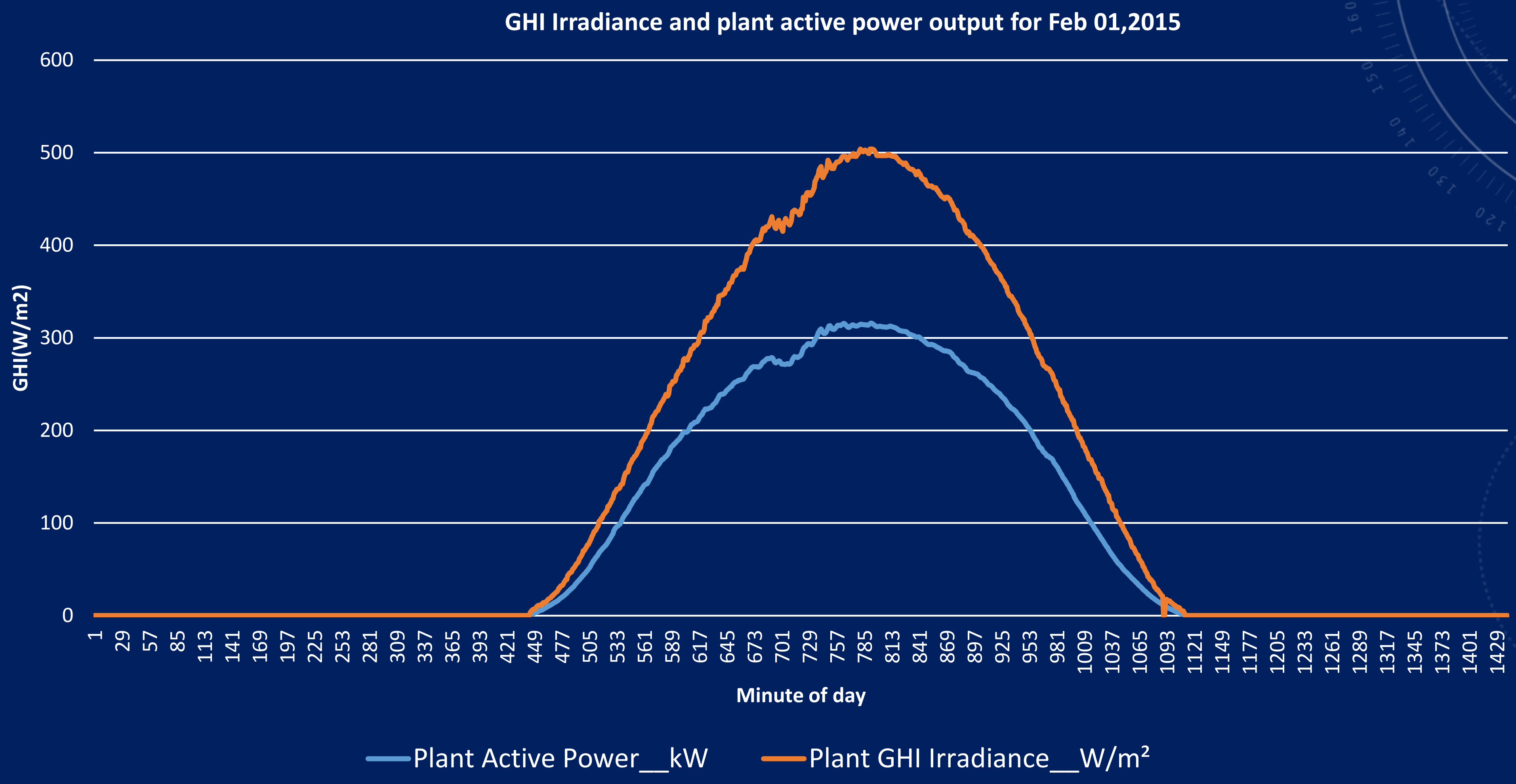
India's present electricity requirement approx. 500 billion kWh, can be met by installing **2500** sq. km of solar field.

A square of 50km x 50km, or

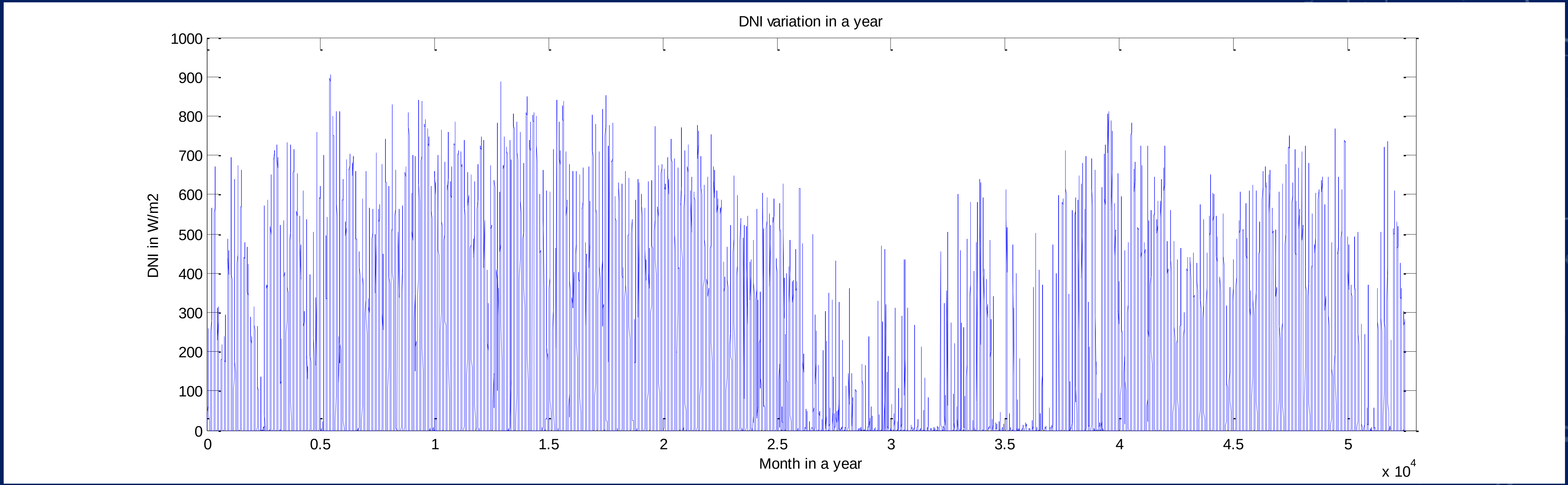
4 smaller squares of 25km x 25km.



Daily GHI and Power Output comparison at IIT Bombay

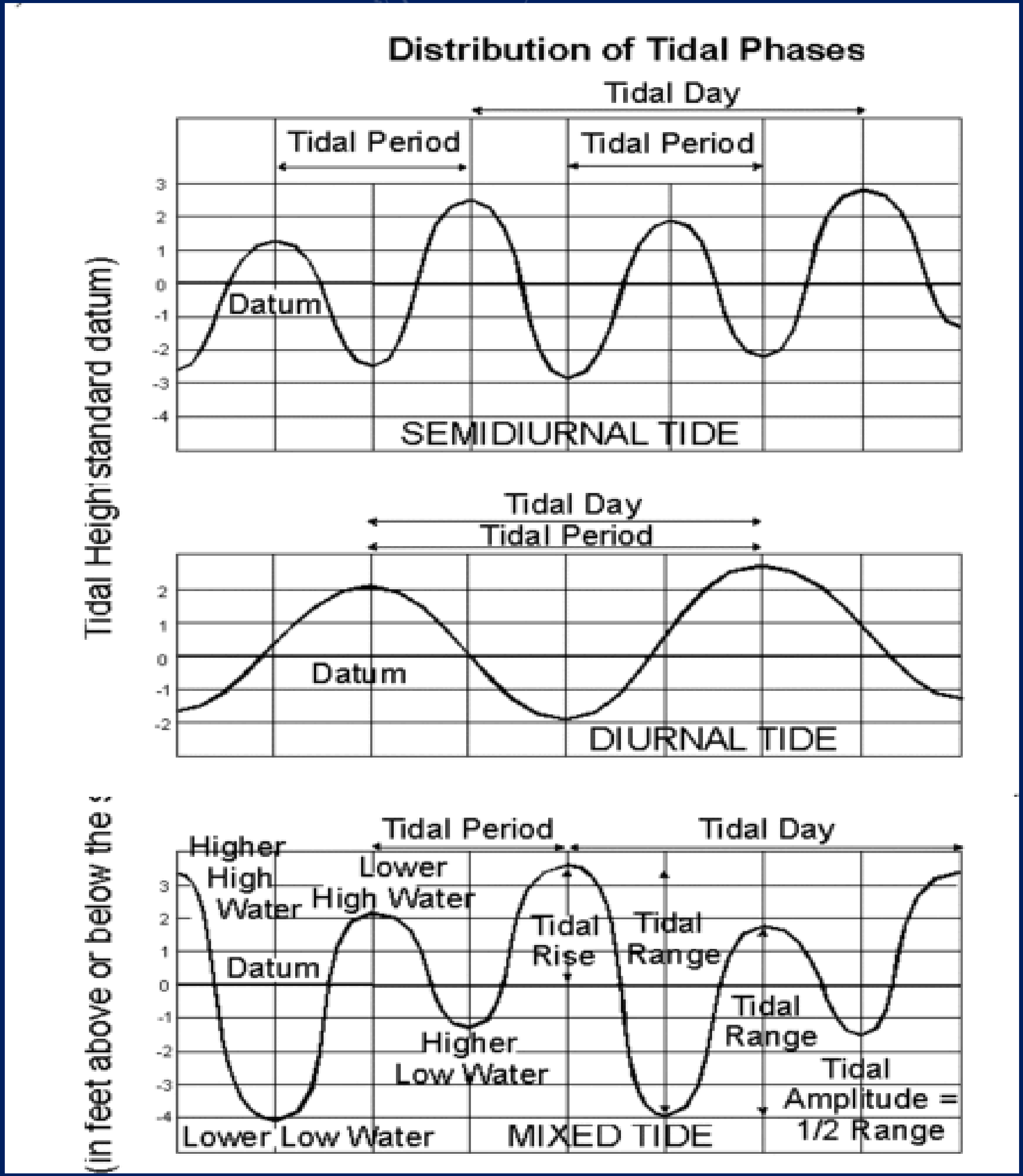


Yearly(2015)-10 min duration DNI Variation at Noida



Jan March May July Sep Dec

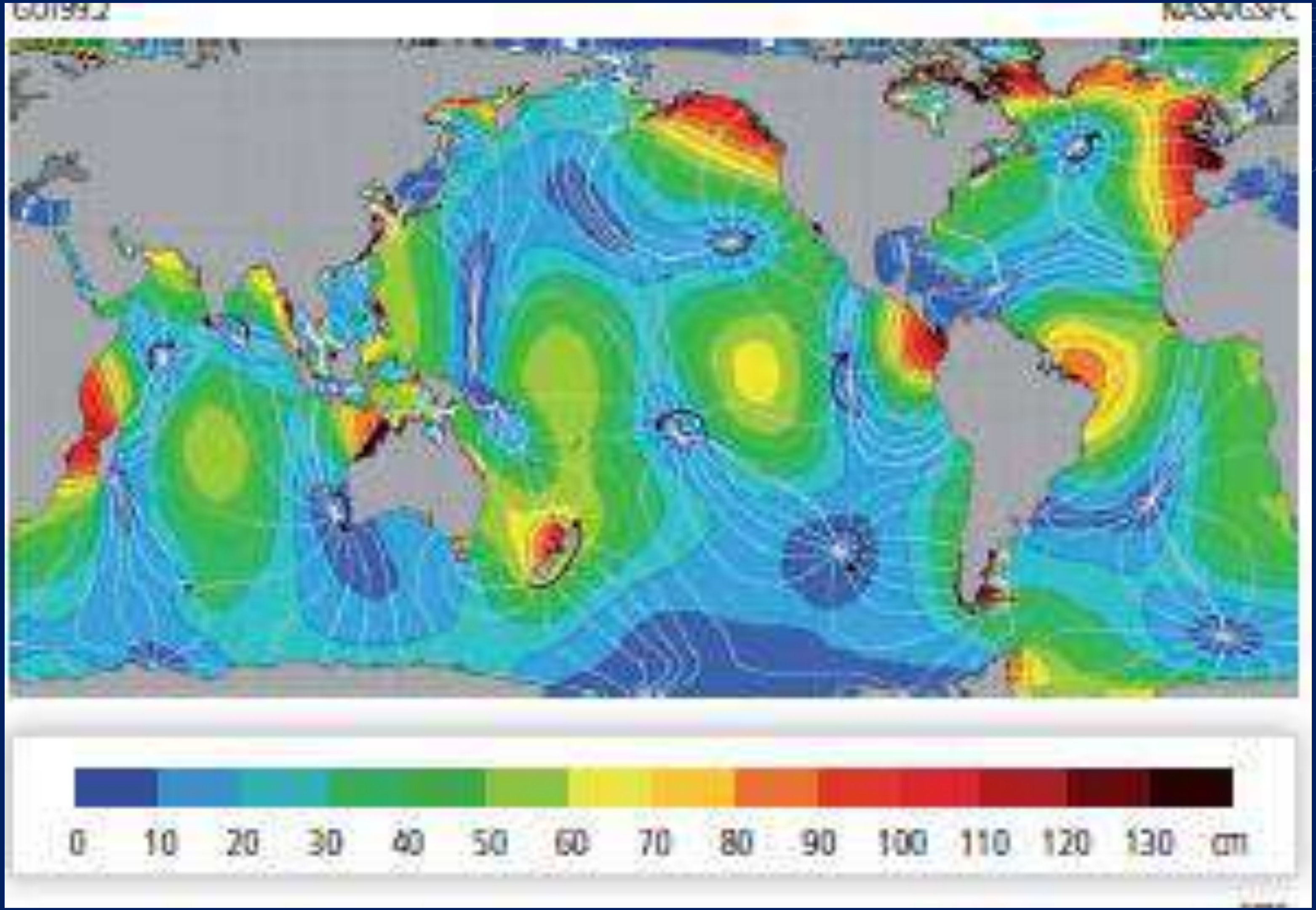
Source:NETRA



Difficult to estimate the tide period and Range of period

Source: wikipedia.org

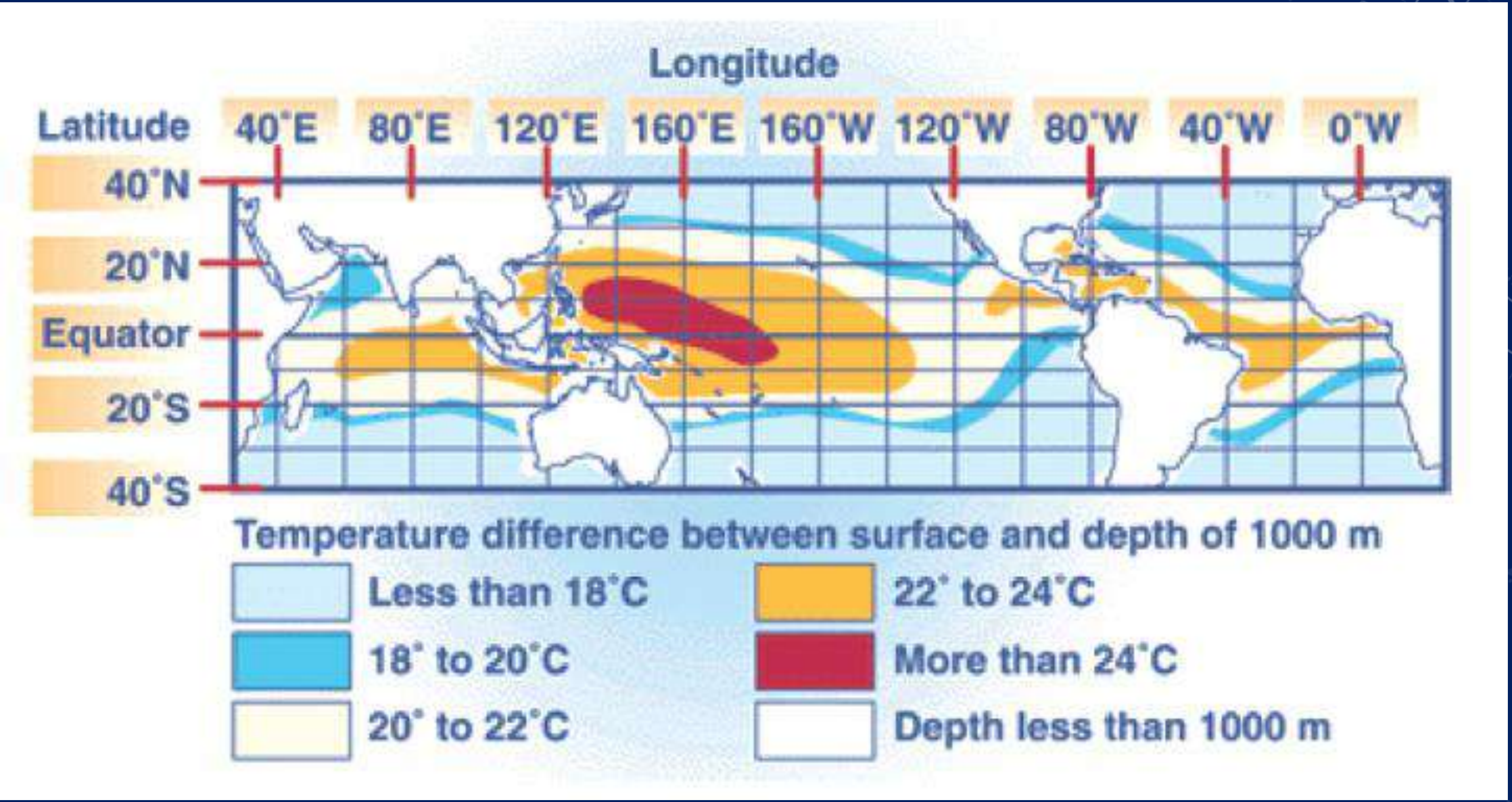
Tidal Range Map



Source: SRREN , IPCC

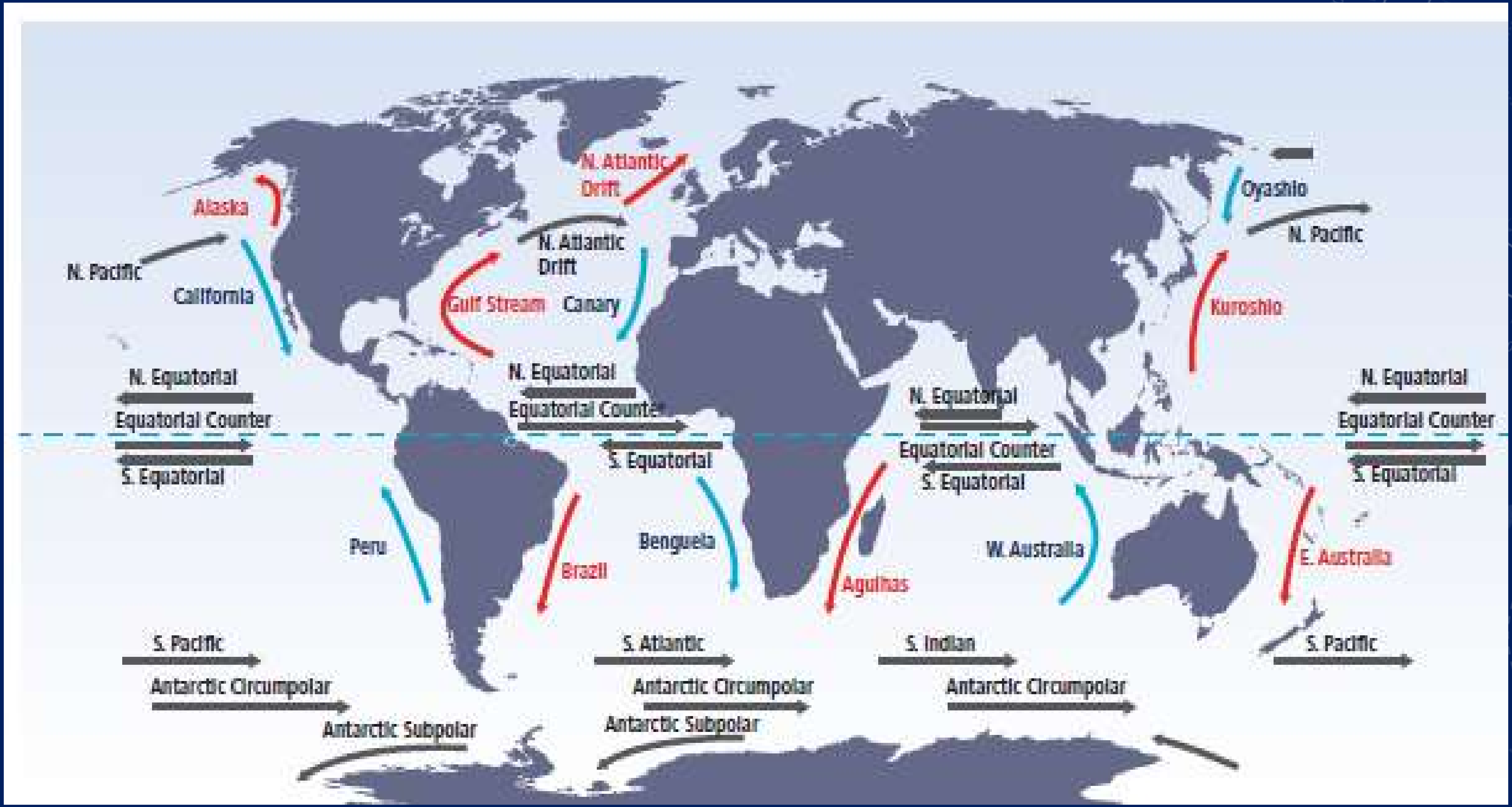
Barrage	Country	Capacity (MW)	Power generation (GWh)	Construction costs (million USD)	Construction costs per kW (USD/kW)
Operating					
La Rance	France	240	540	817[1]	340
Sihwa Lake	Korea	254	552	298	117
Proposed/planned					
Gulf of Kutch	India	50	100	162	324
Wyre barrage	UK	61.4	131	328	534
Garorim Bay	Korea	520	950	800	154
Mersey barrage	UK	700	1 340	5 741	820
Incheon	Korea	1 320	2 410	3 772	286
Dalupiri Blue	Philippines	2 200	4 000	3 034	138
Severn barrage	UK	8 640	15 600	36 085	418
Penzhina Bay	Russia	87 000	200 000	328 066	377

http://www.irena.org/DocumentDownloads/Publications/Tidal_Energy_V4_WEB.pdf



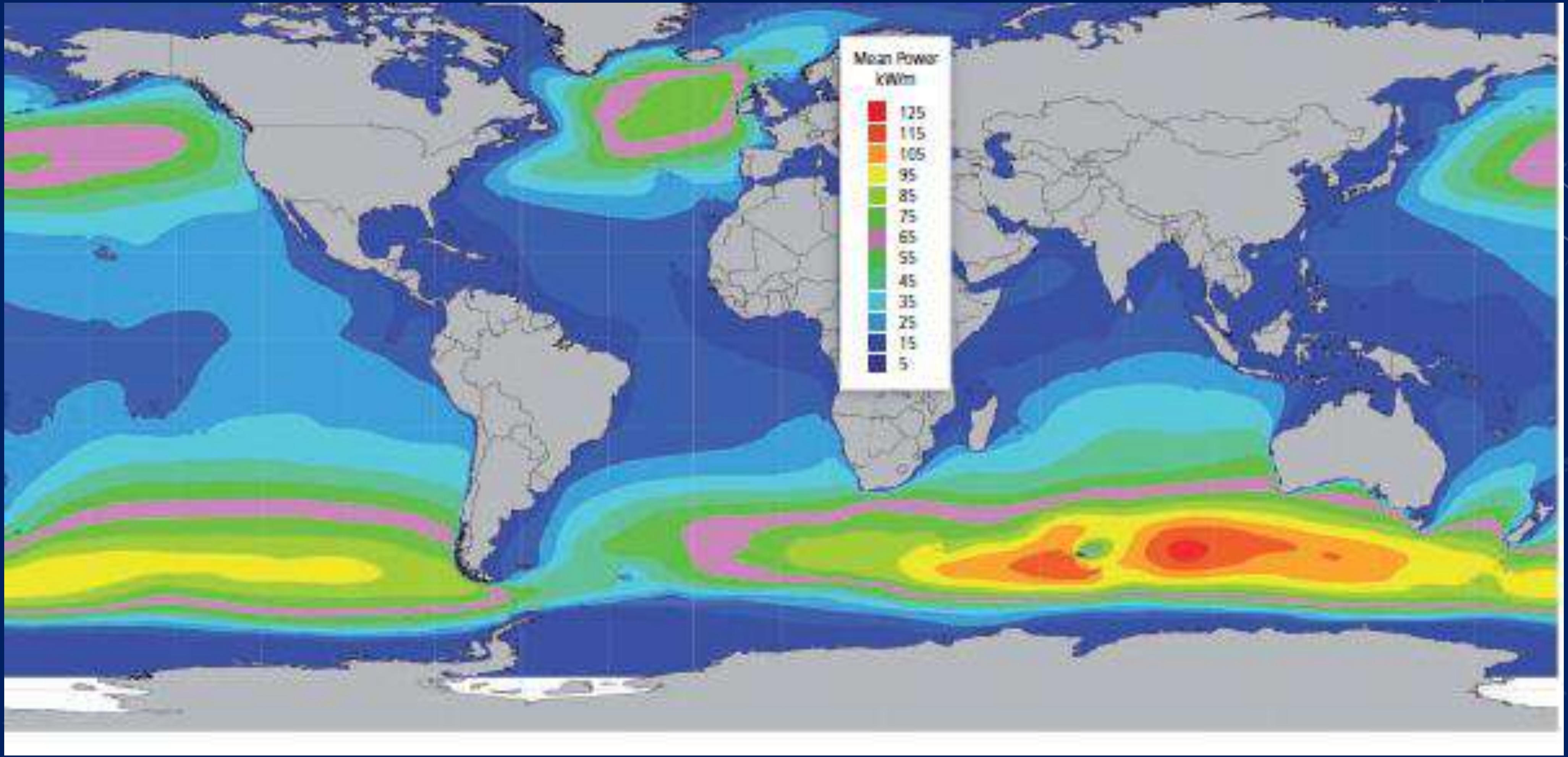
Source: GEA Chapter 7

Ocean Current Map



Source: SRREN , IPCC

Wave Power Distribution

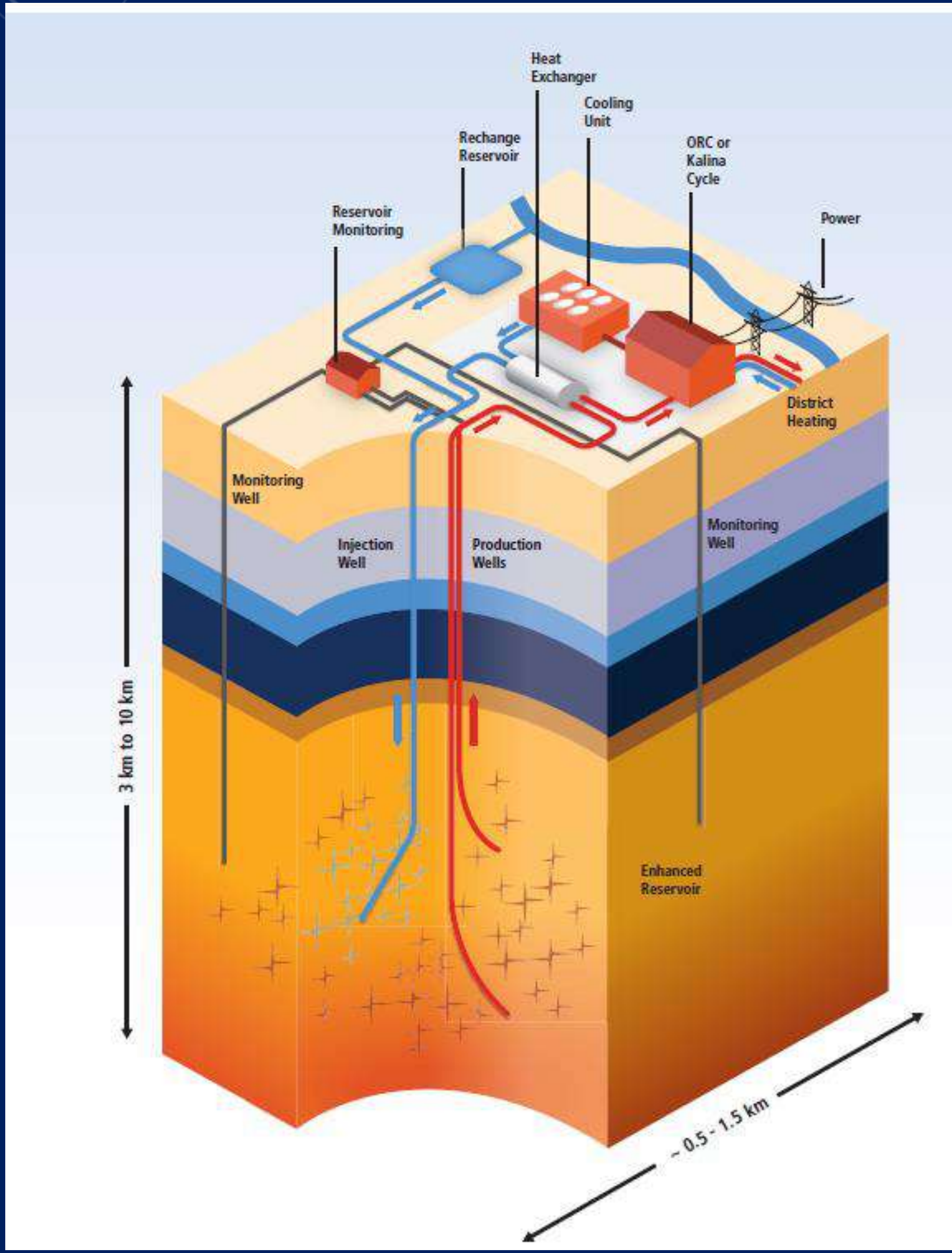


Source: SRREN , IPCC

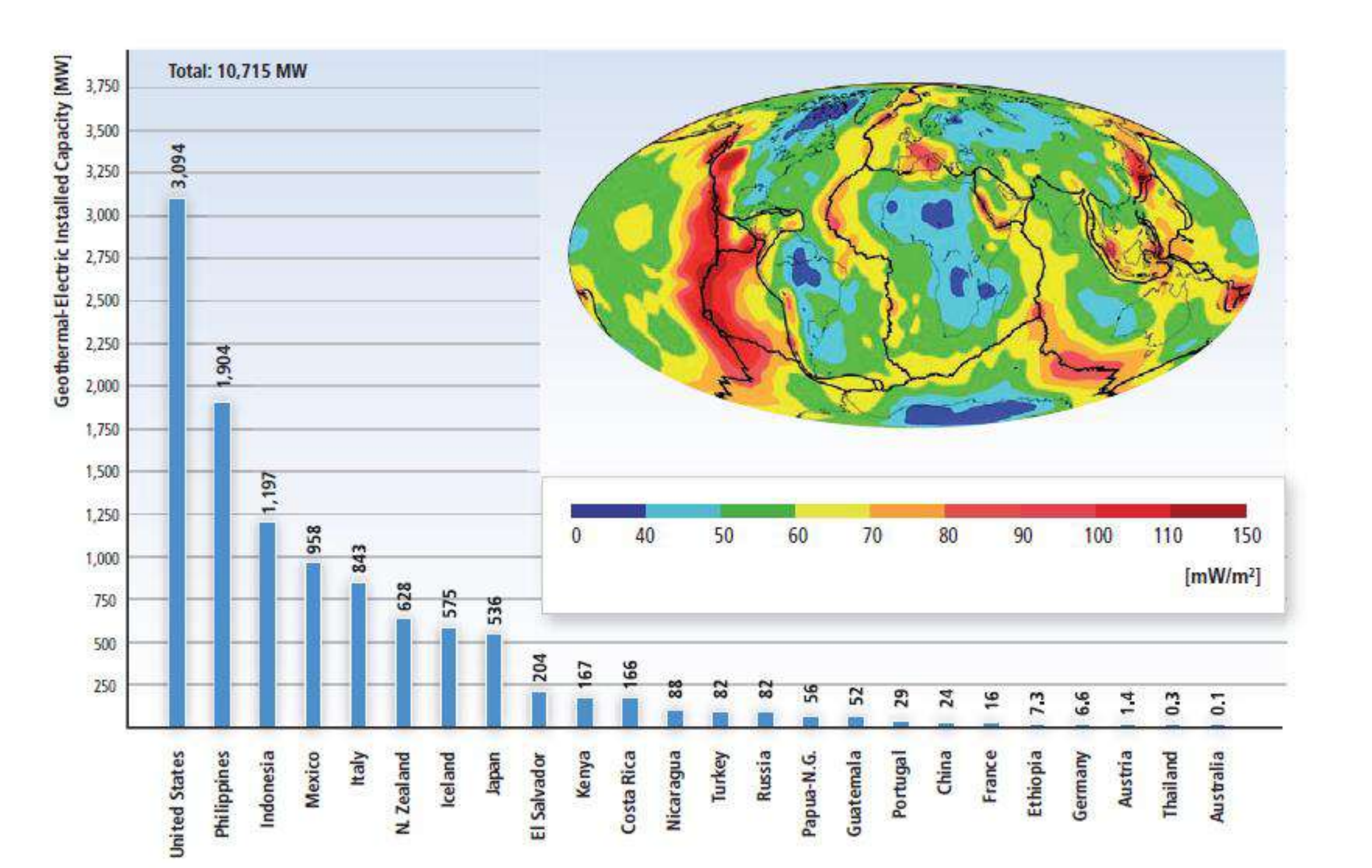
Wave Energy Potential

REGION	Wave Energy TWh/yr (EJ/yr)
Western and Northern Europe	2,800 (10.1)
Mediterranean Sea and Atlantic Archipelagos (Azores, Cape Verde, Canaries)	1,300 (4.7)
North America and Greenland	4,000 (14.4)
Central America	1,500 (5.4)
South America	4,600 (16.6)
Africa	3,500 (12.6)
Asia	6,200 (22.3)
Australia, New Zealand and Pacific Islands	5,600 (20.2)
TOTAL	29,500 (106.2)

Source: SRREN , IPCC

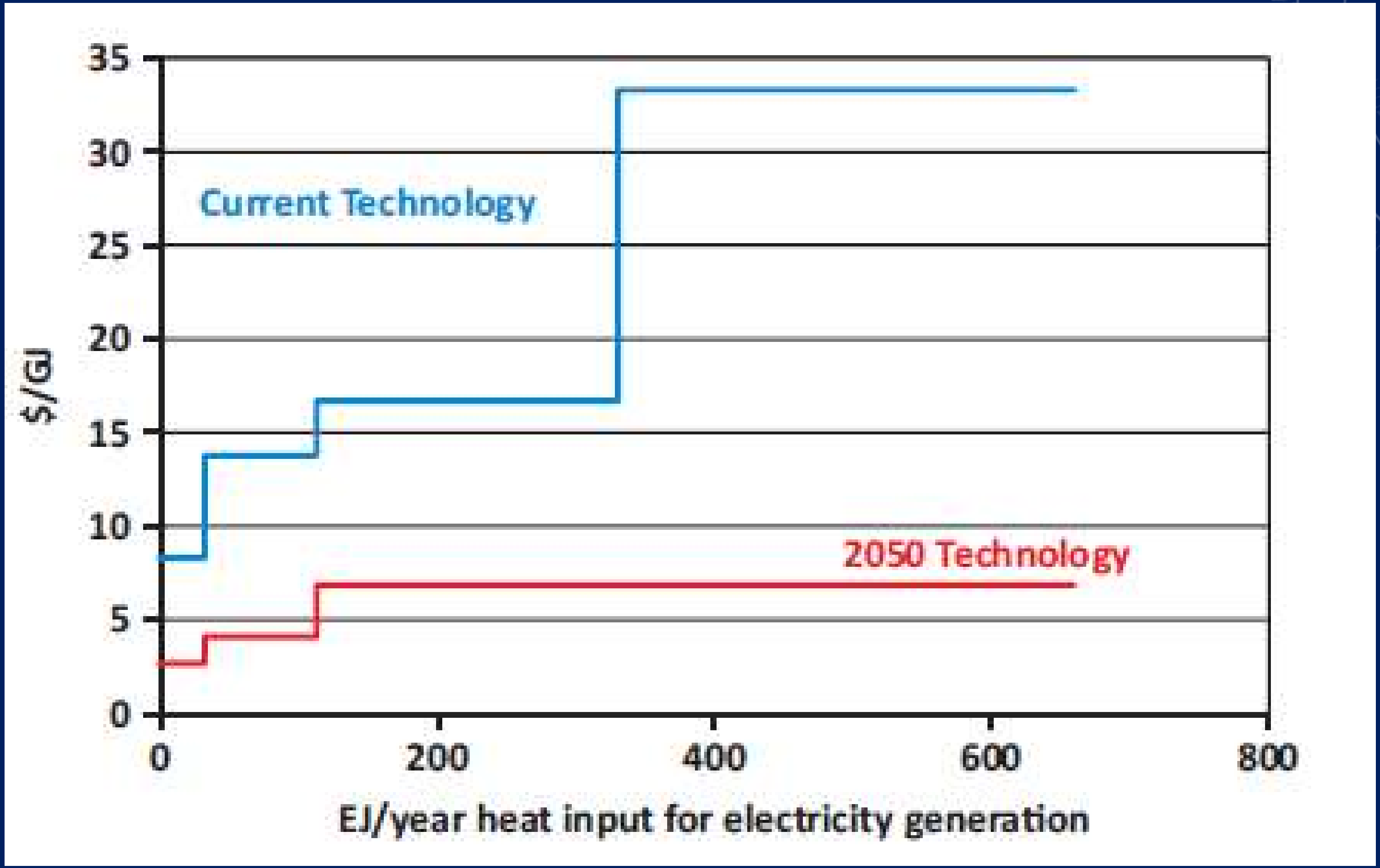


Source: SRREN , IPCC



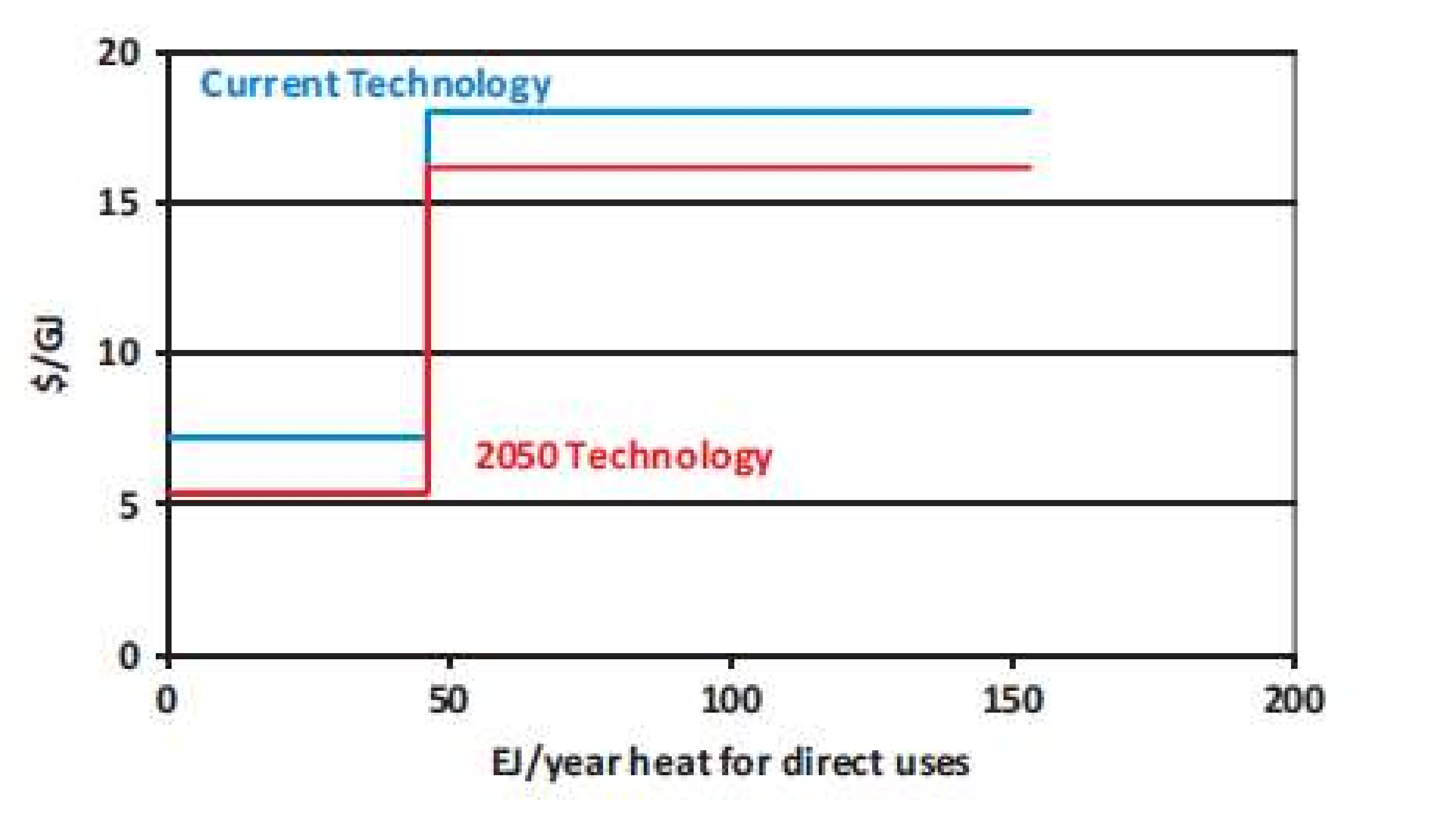
Source: SRREN , IPCC

Supply Curve Geothermal Electricity



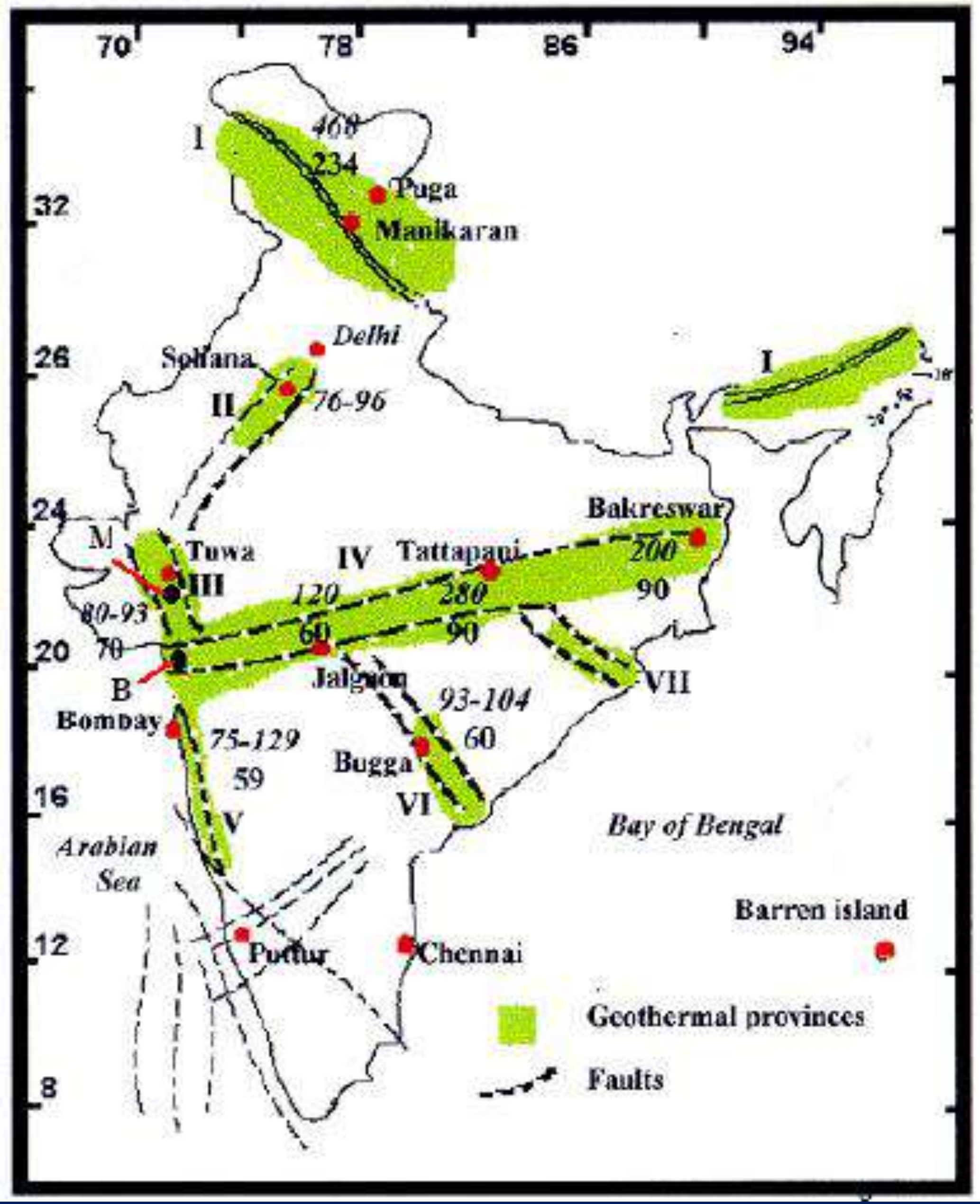
Source: GEA Chapter 7

Supply Curve Geothermal Heat



Source: GEA Chapter 7

Map of India showing the geothermal provinces



Source: Geothermal Energy Potential in India

Biomass

Bagasse - fibre residue from milling of sugarcane

Energy content of biomass

Biomass type	Ash content %	Energy content of fuel (MJ/kg)	
		Moisture content 0%	Moisture content 13%
Wood	1	18.7	16
Crop residues	5	16.5	14.2
	10	15.8	13.5
	20	14.1	11.9
Animal dung	20	17	14.5
	25	16	13.6

Table 2.1. Crop Residues: Residue Ratios, Energy Produced, Current Uses

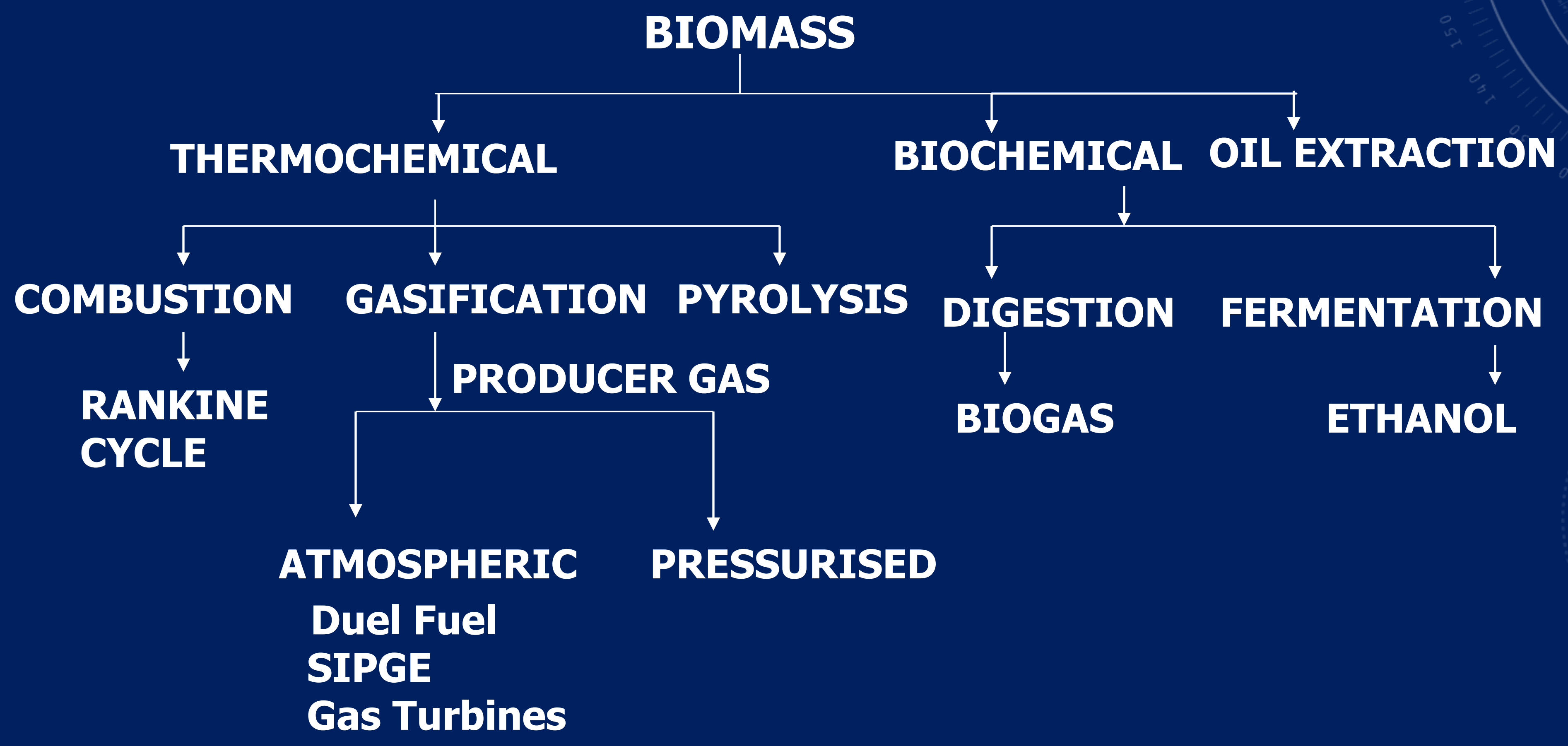
Crop	Residue	Residue ratio[a]	Residue energy (MJ/dry kg)[b]	Typical current residue uses[c]
Barley[d]	straw	2.3	17.0	
Coconut	shell	0.1 kg/nut	20.56	household fuel
Coconut	fibre	0.2 kg/nut	19.24	mattress making, carpets, etc.
Coconut	pith	0.2 kg/nut		
Cotton	stalks	3.0	18.26	household fuel
Mustard Cotton	gin waste	0.1	16.42	fuel in small industry
Groundnut	shells	0.3		fuel in industry
Groundnut	haulms	2.0		household fuel
Maize	cobs	0.3	18.77	cattle feed
Maize	stalks	1.5	17.65	cattle feed, household fuel
Millet	straw	1.2		household fuel
seed	stalks	1.8		household fuel
Other seeds	straws	2.0		household fuel
Pulses	straws	1.3		household fuel
Rapeseed	stalks	1.8		household fuel

Source: Kartha and Larson, Bioprimer

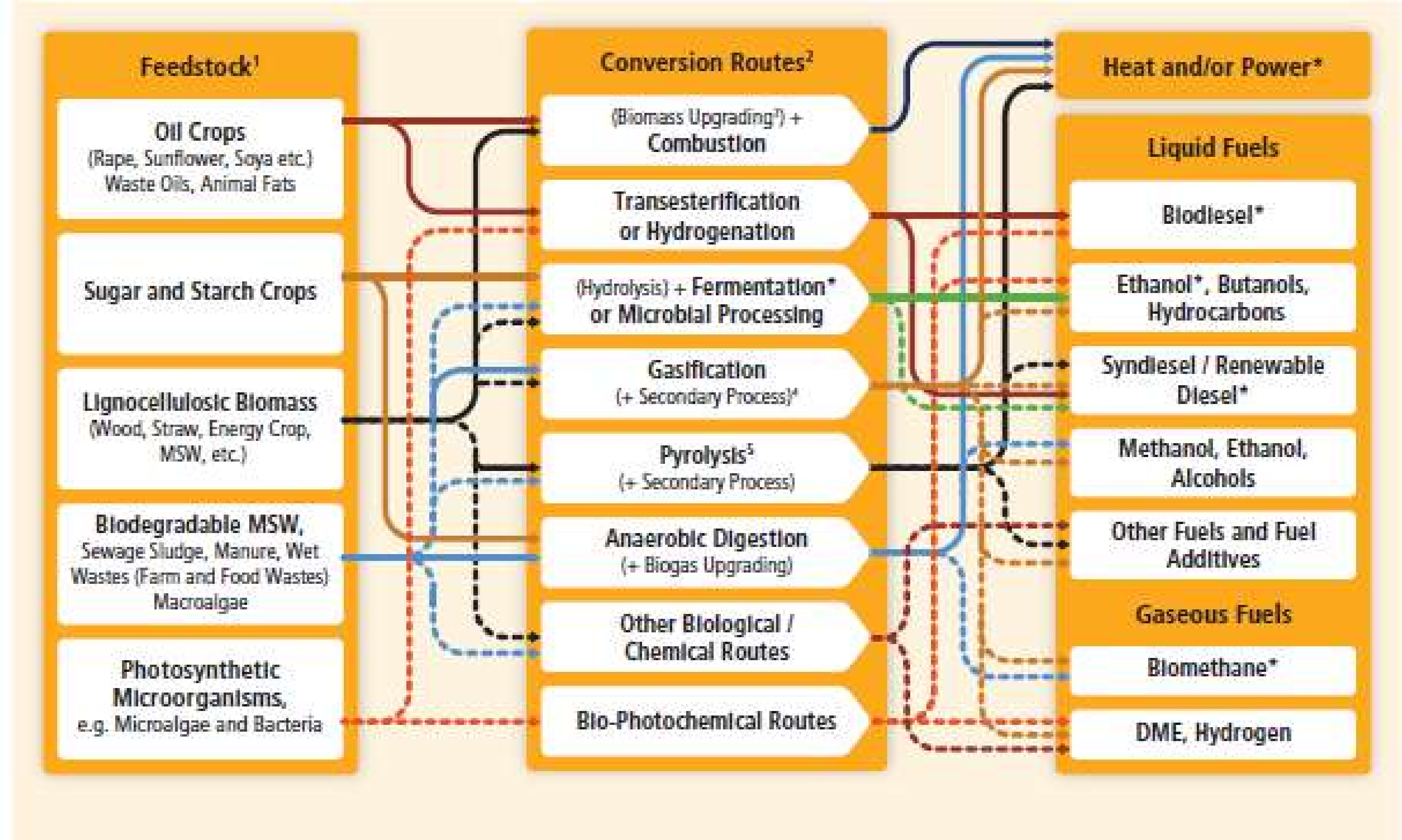
Crop	Residue	Residue ratio[a]	Residue energy (MJ/dry kg)[b]	Typical current residue uses[c]
Rice	straw	1.5	16.28	cattle feed, roof thatching, field burned
Rice	husk	0.25	16.14	fuel in small industry, ash used for cement production
Soybeans[e]	stalks	1.5	15.91	
Sugarcane	bagasse	0.15	17.33	fuel at sugar factories, feedstock for paper production
Sugarcane	tops/leaves	0.15		cattle feed, field burned
Tobacco	stalks	5.0		heat supply for tobacco processing, household fuel
Tubers[e]	straw	0.5	14.24	
Wheat	straw	1.5	17.51	cattle feed
Wood products[f]	waste wood	0.5	20.0	

Source: Kartha and Larson, Bioprimer

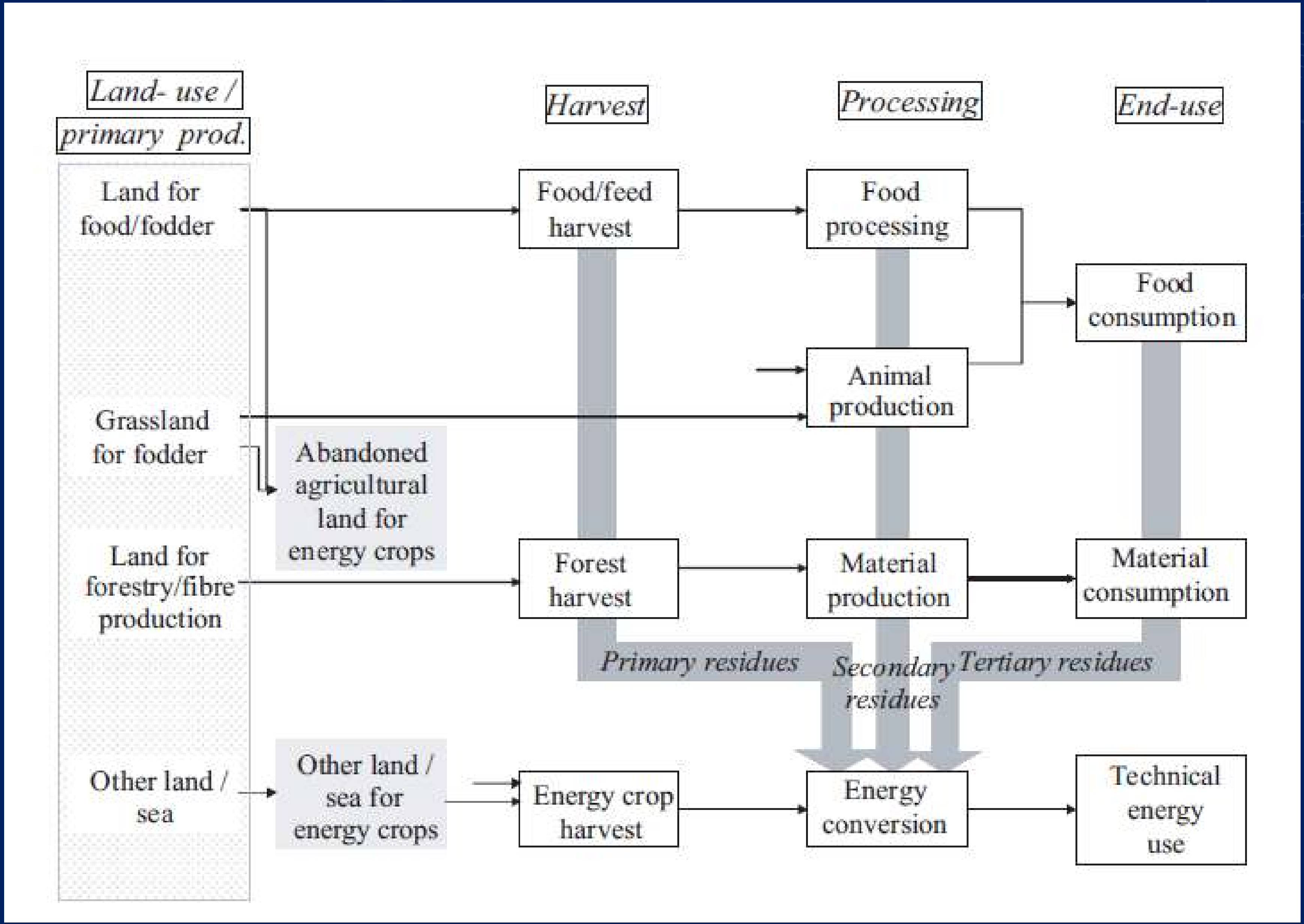
BIOMASS CONVERSION ROUTES



Biomass Conversion Routes

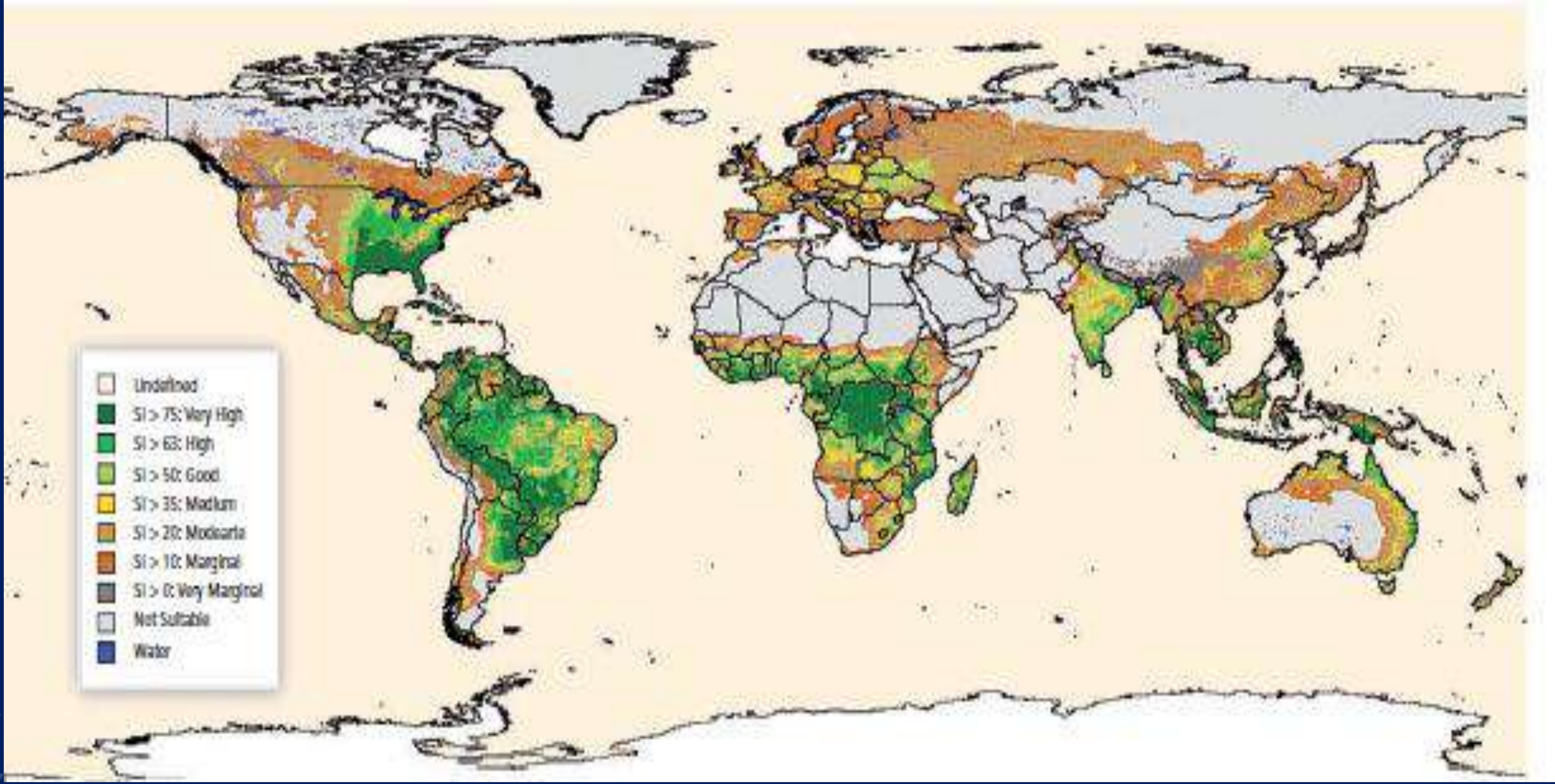


Source: SRREN , IPCC



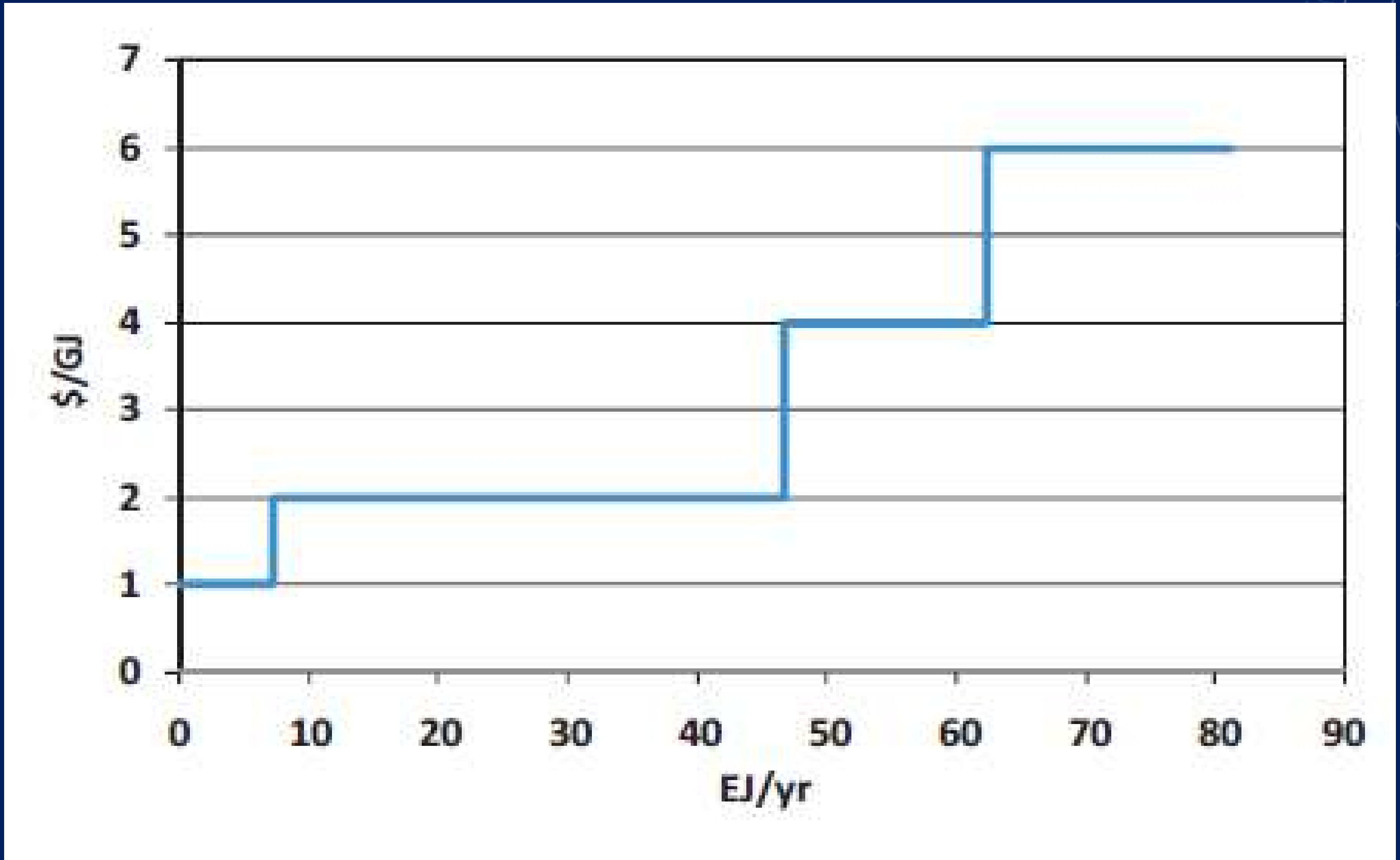
Source: GEA Chapter 7

Biomass Plantation



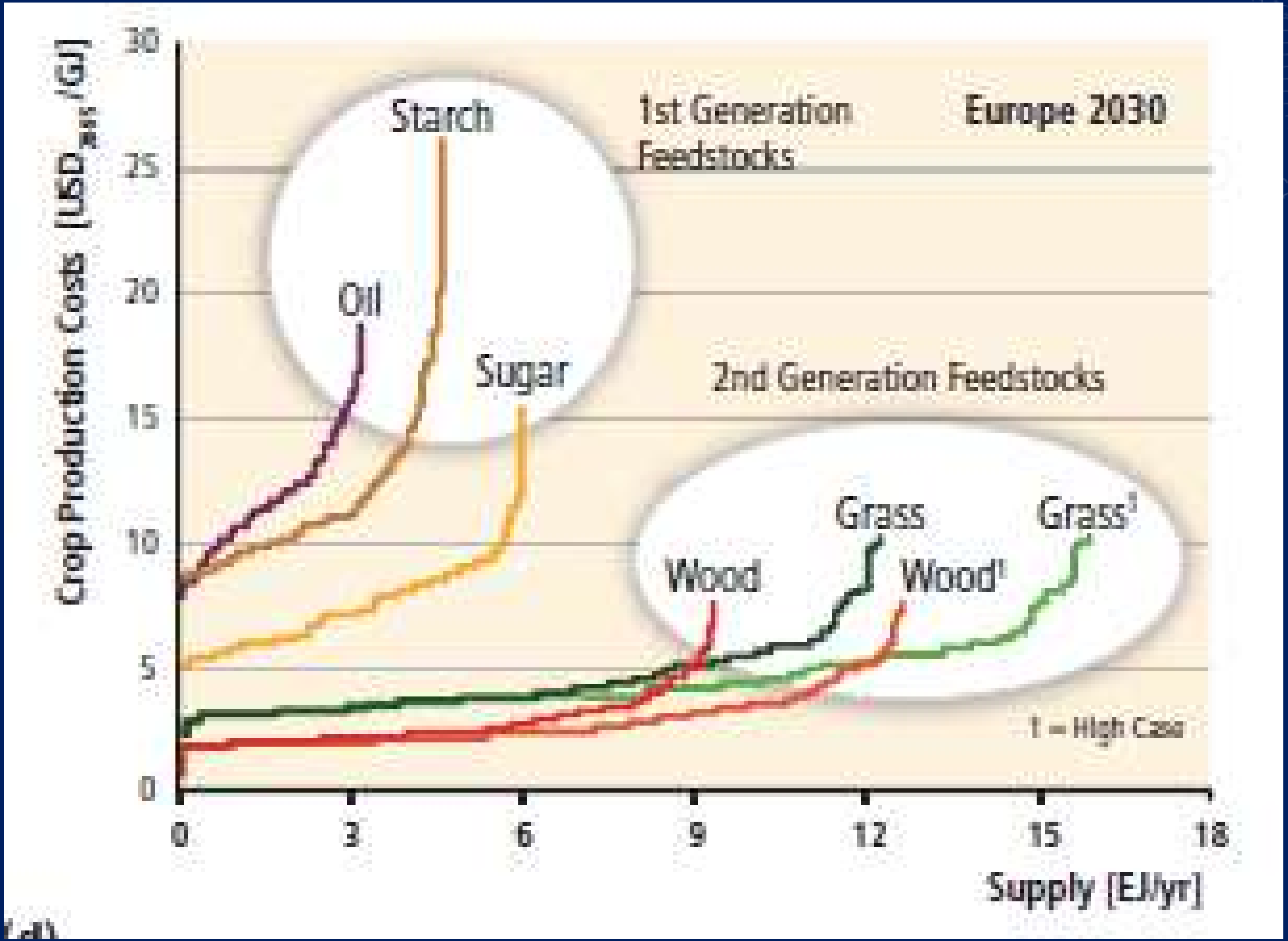
Biomass category	Comment	2050 Technical potential (
Category 1. **Residues from agriculture**	By-products associated with food/fodder production and processing, both primary (e.g., cereal straw from harvesting) and secondary (e.g., rice husks from rice milling) residues.	15 – 70
Category 2. **Dedicated biomass production on surplus agricultural land**	Includes both conventional agriculture crops and dedicated bioenergy plants including oil crops, lignocellulosic grasses, short-rotation coppice and tree plantations. Only land not required for food, fodder or other agricultural commodities production is assumed to be available for bioenergy. However, surplus agriculture land (or abandoned land) need not imply that its development is such that less total land is needed for agriculture: the lands may become excluded from agriculture use in modelling runs due to land degradation processes or climate change (see also 'marginal lands' below). Large technical potential requires global development towards high-yielding agricultural production and low demand for grazing land. Zero technical potential reflects that studies report that food sector development can be such that no surplus agricultural land will be available.	0 – 700
Category 3. **Dedicated biomass production on marginal lands**	Refers to biomass production on deforested or otherwise degraded or marginal land that is judged unsuitable for conventional agriculture but suitable for some bioenergy schemes (e.g., via reforestation). There is no globally established definition of degraded/marginal land and not all studies make a distinction between such land and other land judged as suitable for bioenergy. Adding categories 2 and 3 can therefore lead to double counting if numbers come from different studies. High technical potential numbers for categories 2 and 3 assume biomass production on an area exceeding the present global cropland area (ca. 1.5 billion ha or 15 million km^2). Zero technical potential reflects low potential for this category due to land requirements for, for example, extensive grazing management and/or subsistence agriculture or poor economic performance if using the marginal lands for bioenergy.	0 – 110
Category 4. **Forest biomass**	Forest sector by-products including both primary residues from silvicultural thinning and logging, and secondary residues such as sawdust and bark from wood processing. Dead wood from natural disturbances, such as fires and insect outbreaks, represents a second category. Biomass growth in natural/semi-natural forests that is not required for industrial roundwood production to meet projected biomaterials demand (e.g., sawn wood, paper and board) represents a third category. By-products provide up to about 20 EJ/yr implying that high forest biomass technical potentials correspond to a much larger forest biomass extraction for energy than what is presently achieved in industrial wood production. Zero technical potential indicates that studies report that demand from sectors other than the energy sector can become larger than the estimated forest supply capacity.	0 – 110
Category 5. **Dung**	Animal manure. Population development, diets and character of animal production systems are critical determinants.	5 – 50
Category 6. **Organic wastes**	Biomass associated with materials use, for example, organic waste from households and restaurants and discarded wood products including paper, construction and demolition wood; availability depends on competing uses and implementation of collection systems.	5 – >50
Total		<50 – >1000

Bioenergy crops Supply Curve

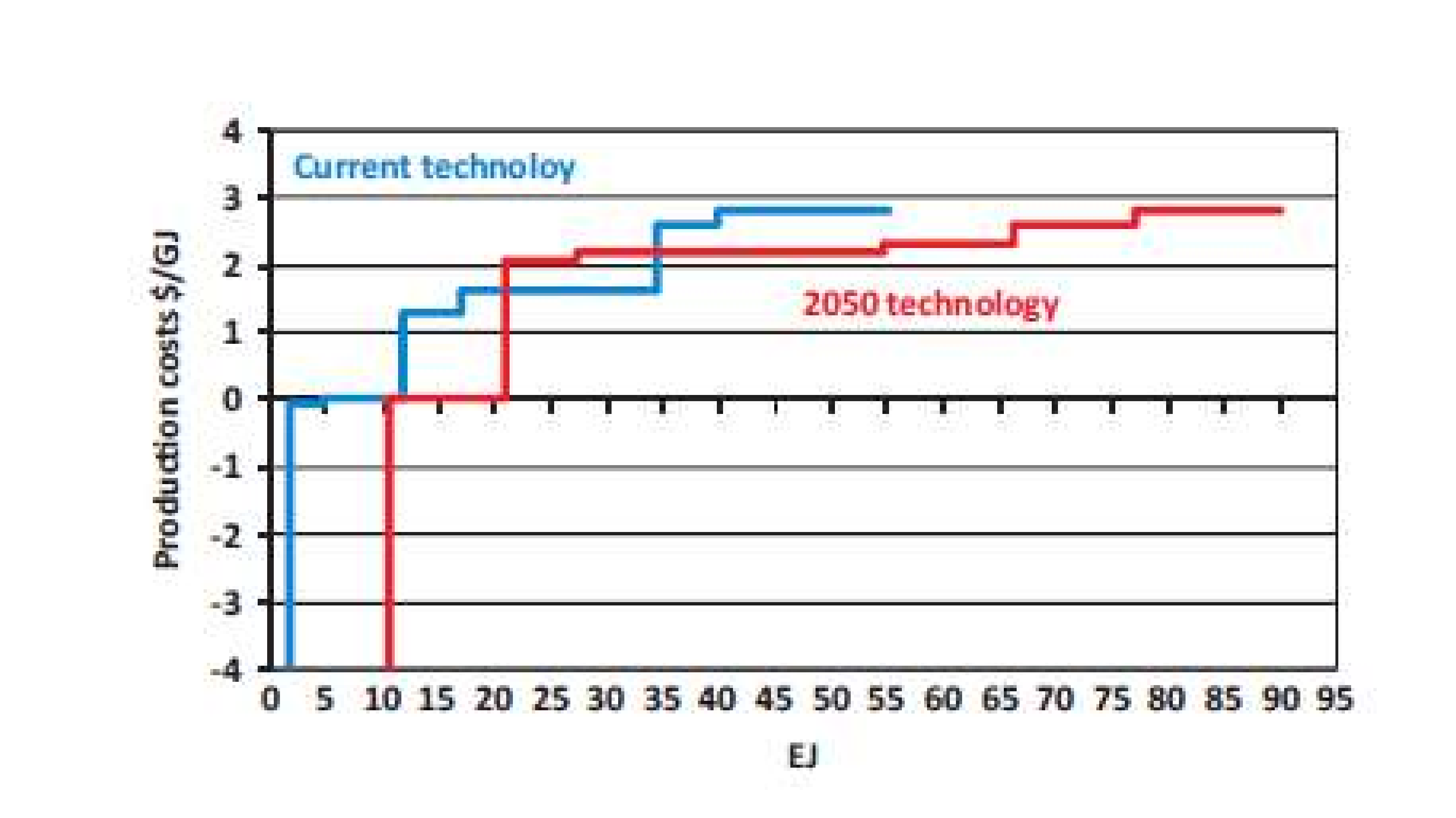


Source: GEA Chapter 7

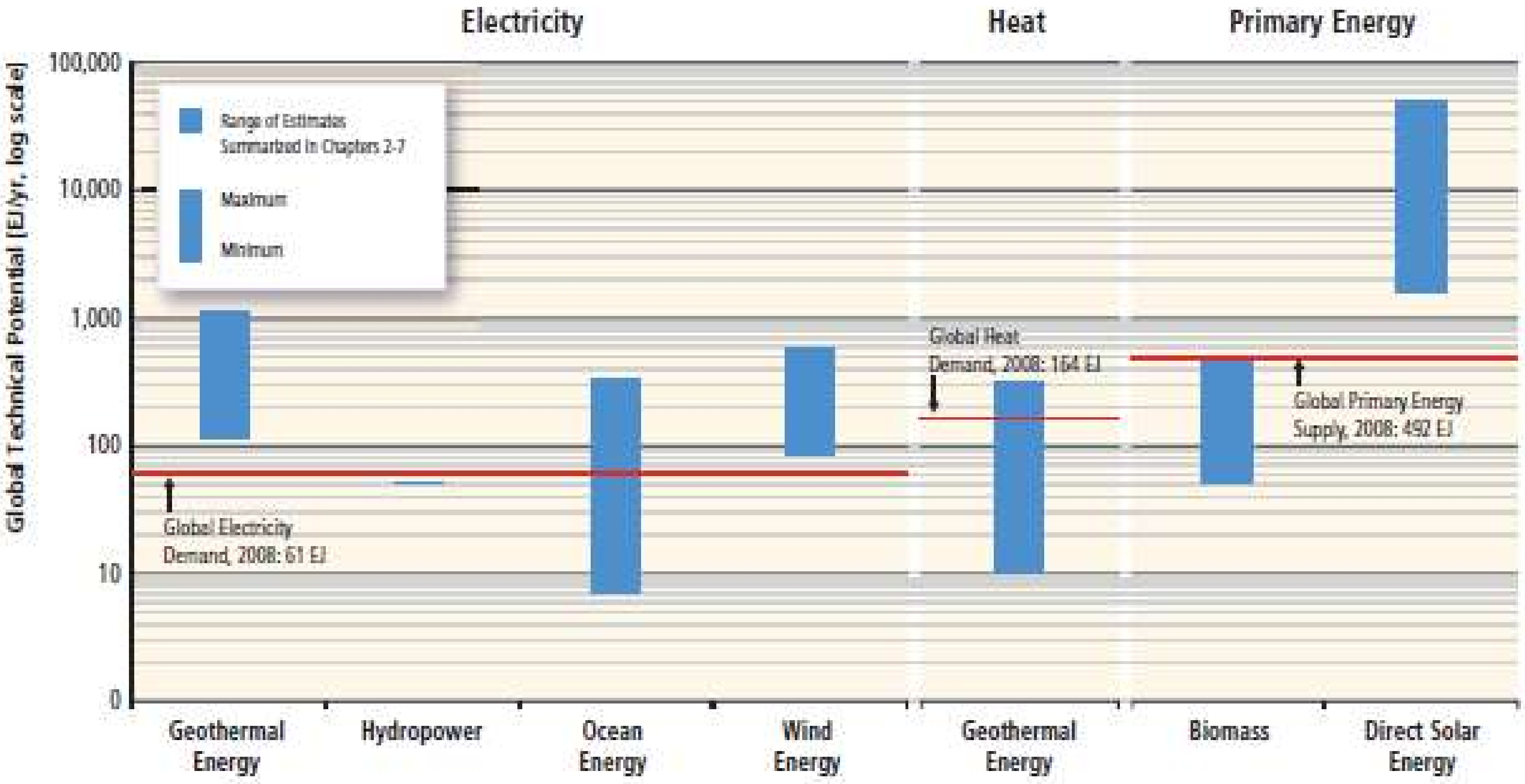
Fuel Supply Curve- Europe



Aggregate Supply Curve MSW, Animal wastes, crop residues



Source: GEA Chapter 7

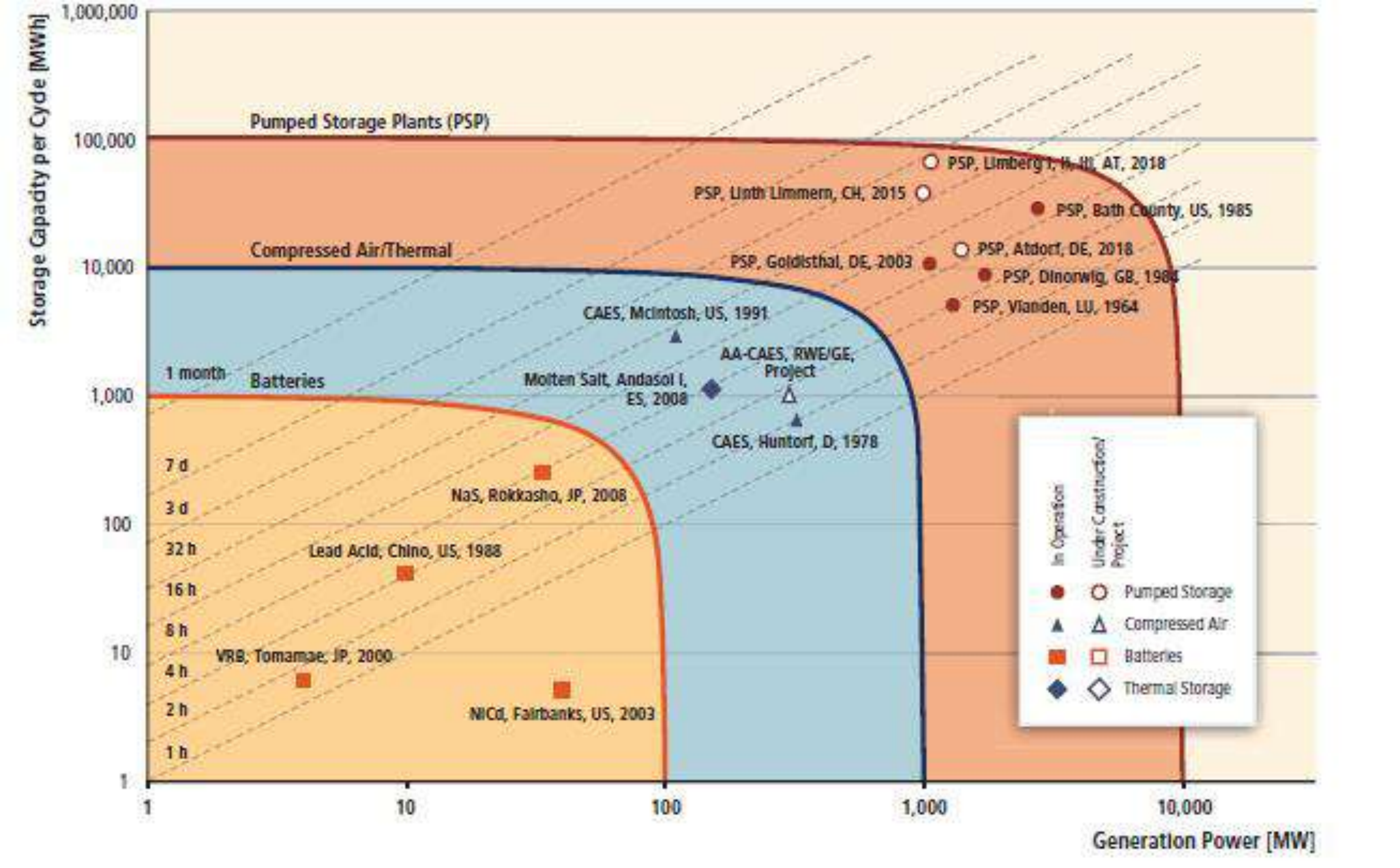


Range of Estimates of Global Technical Potentials

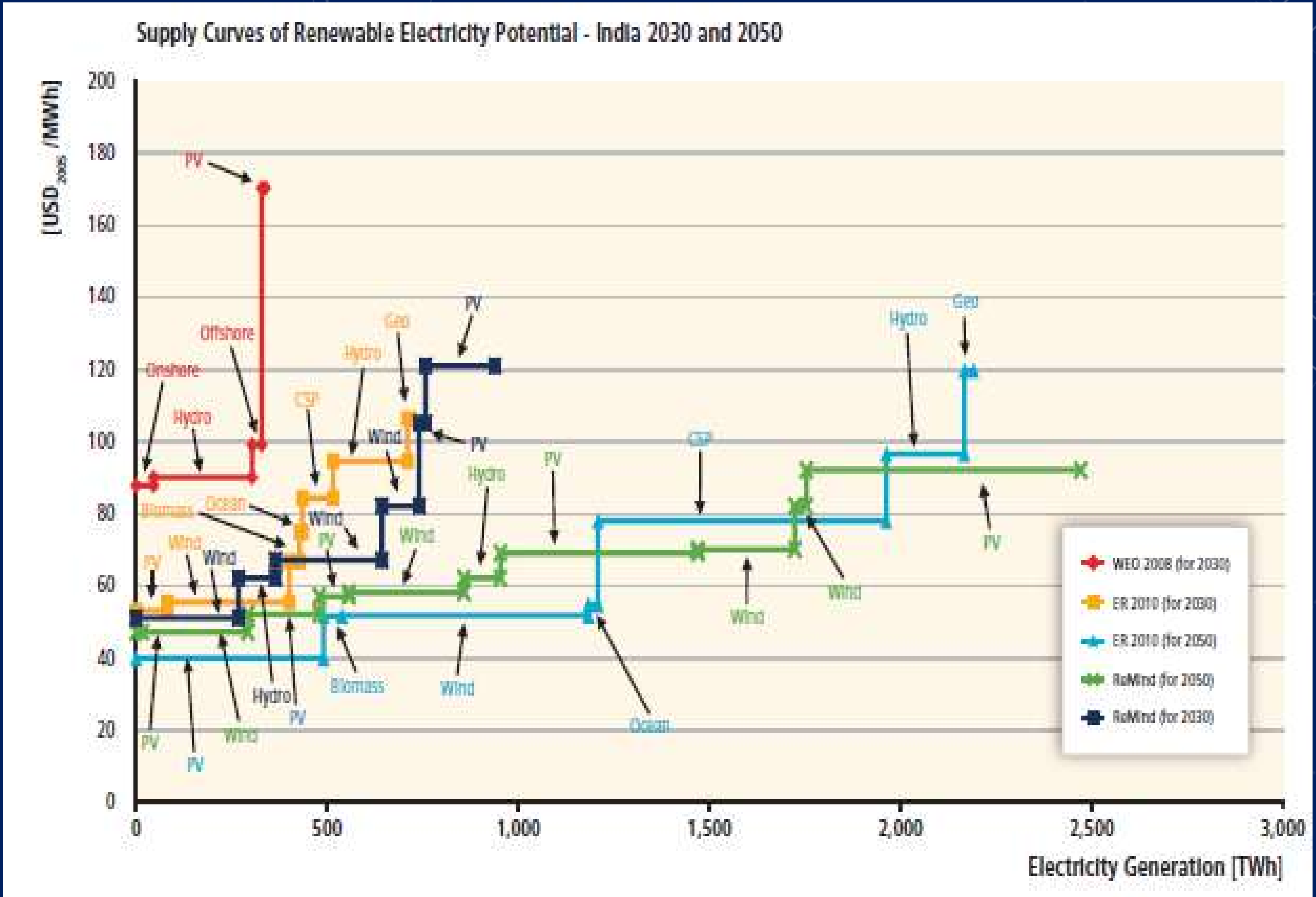
	Geothermal Energy (Electricity)	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy (Heat)	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

Source: SRREN , IPCC

Large Scale Storage Options



Source: SRREN , IPCC



Source: SRREN , IPCC

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- SRREN, IPCC: Renewable Energy Sources and Climate Change Mitigation, Special Report of the Intergovernmental Panel on Climate Change, 2012, available online: http://www.ipcc-wg3.de/report/IPCC_SRREN_Full_Report.pdf

Lecture – 8C

Energy Resources, Economics and Environment

Materials

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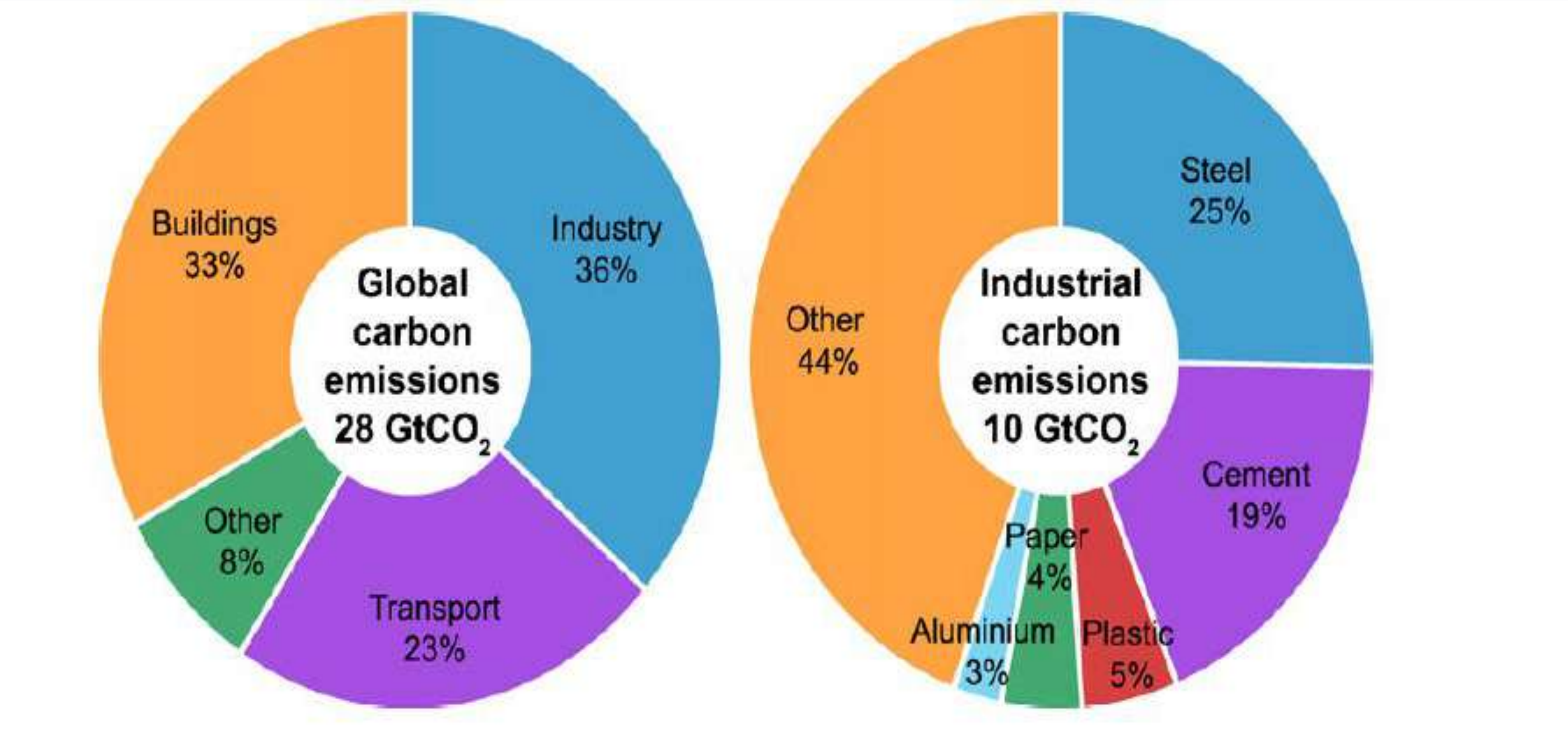
Issues

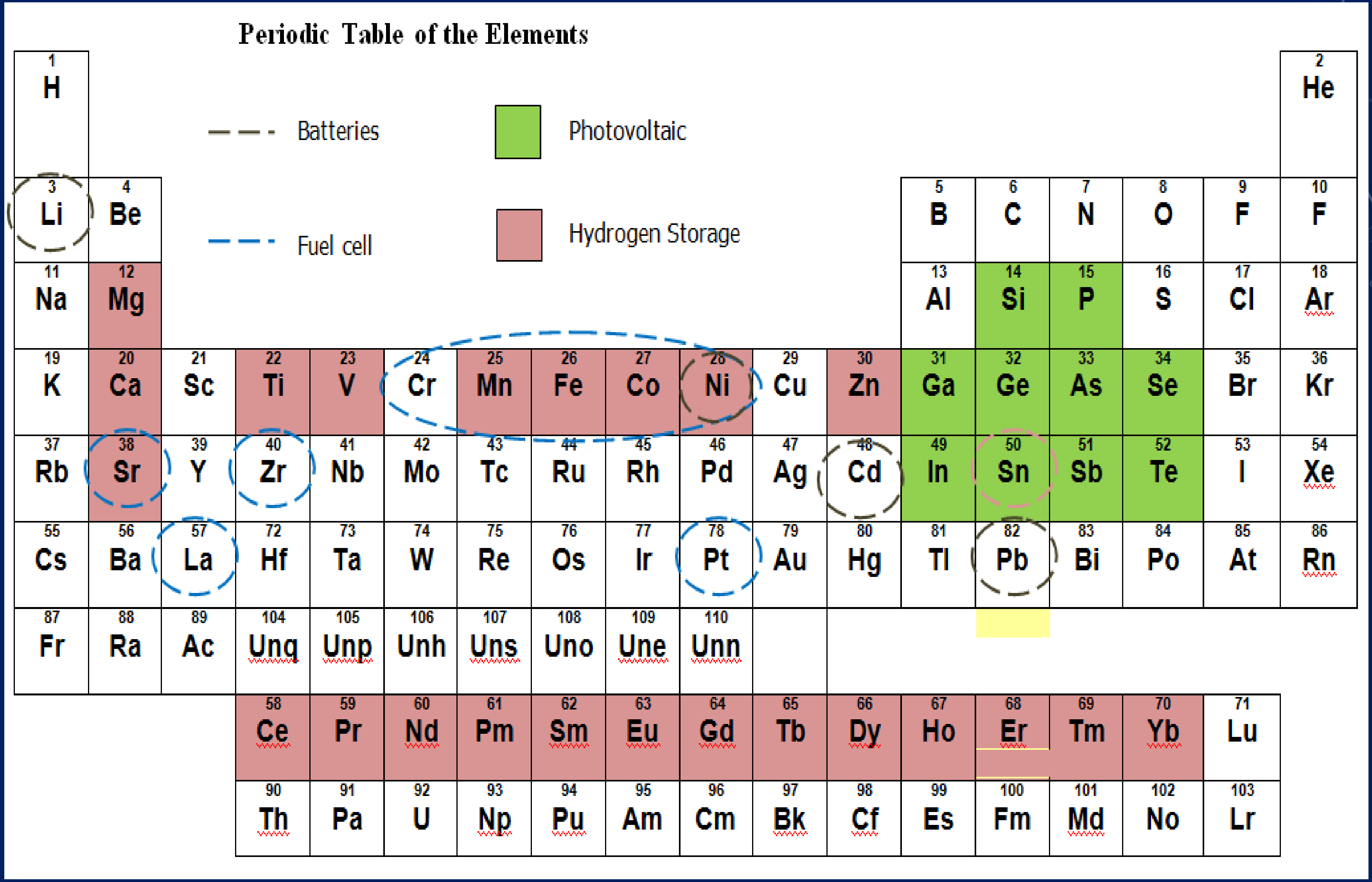
- Will we run out of materials?
- Can we create a closed loop materials system?
- Which renewable energy materials will be constrained and what will be the impact?

Critical Materials

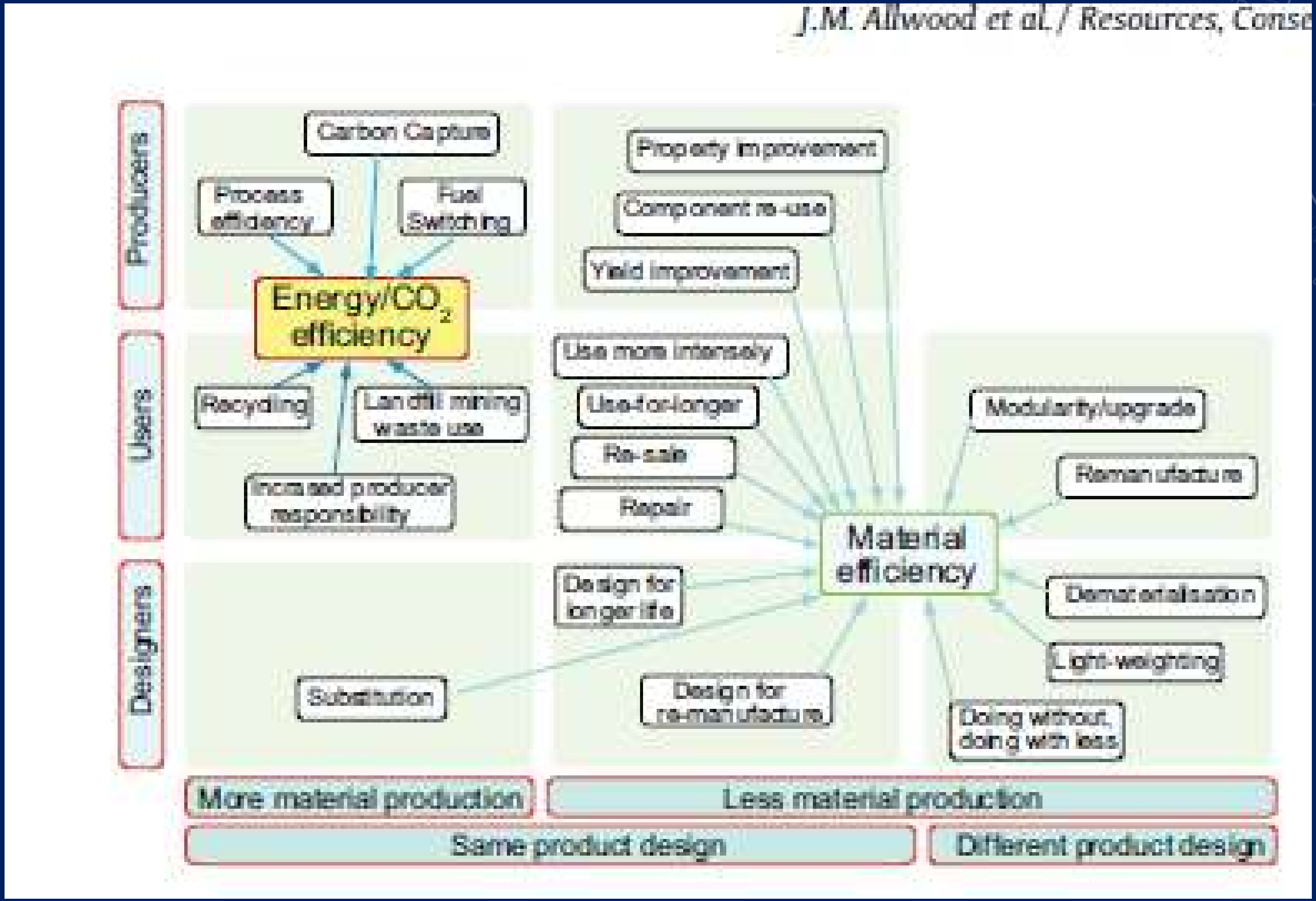


Source: Allwood et al, 2011

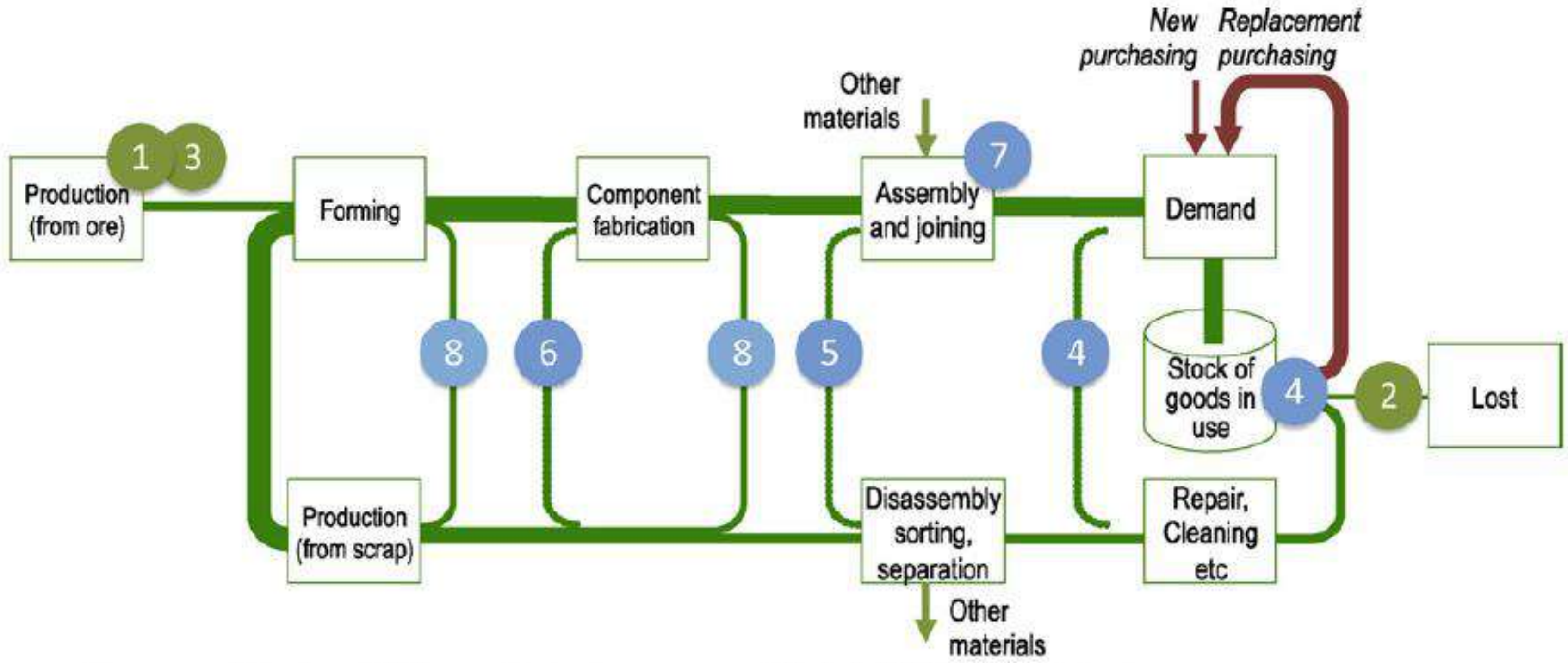
Examples of Energy Materials



Material Efficiency



Materials Strategies



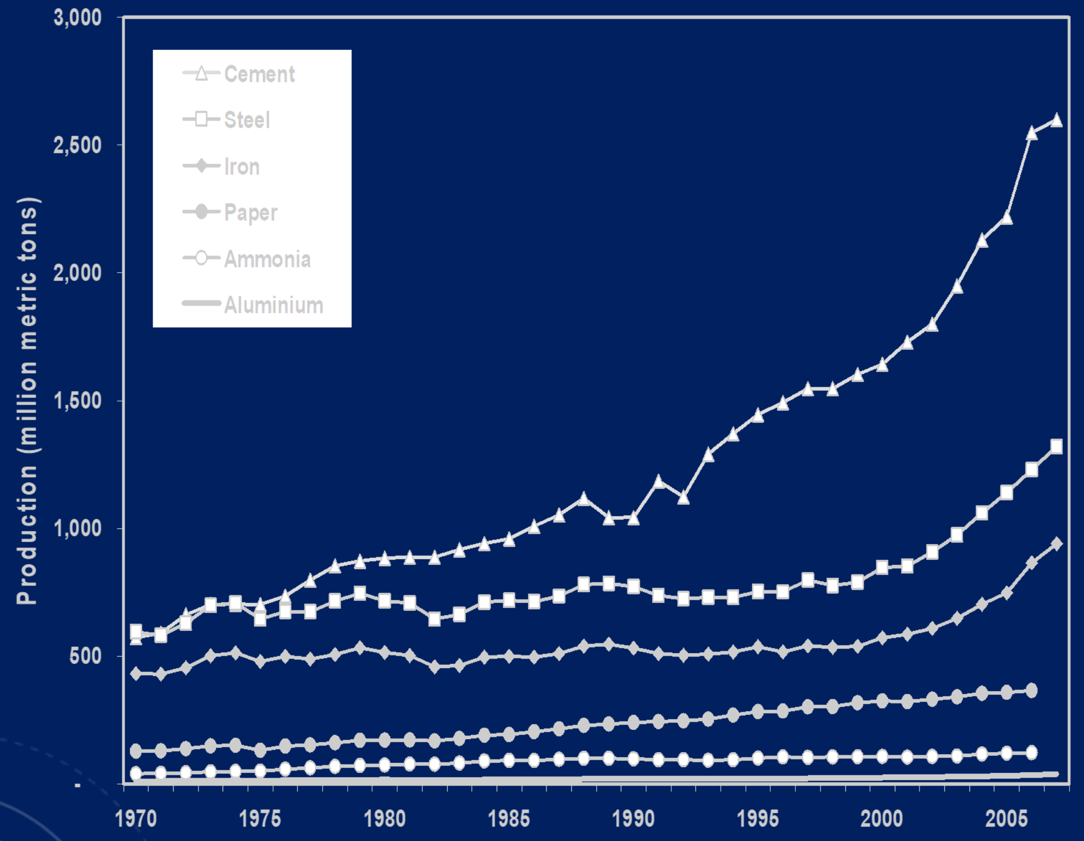
Energy and Carbon Efficiency strategies:

1. Energy efficiency
2. More recycling
3. Carbon Capture – process or energy

Material Efficiency strategies:

4. Longer life, more use, repair and re-sale
5. Product upgrade, modularity, remanufacturing
6. Component re-use
7. Less metal, same service
8. Yield improvements

Global Material Usage



GEA, Chapter 8

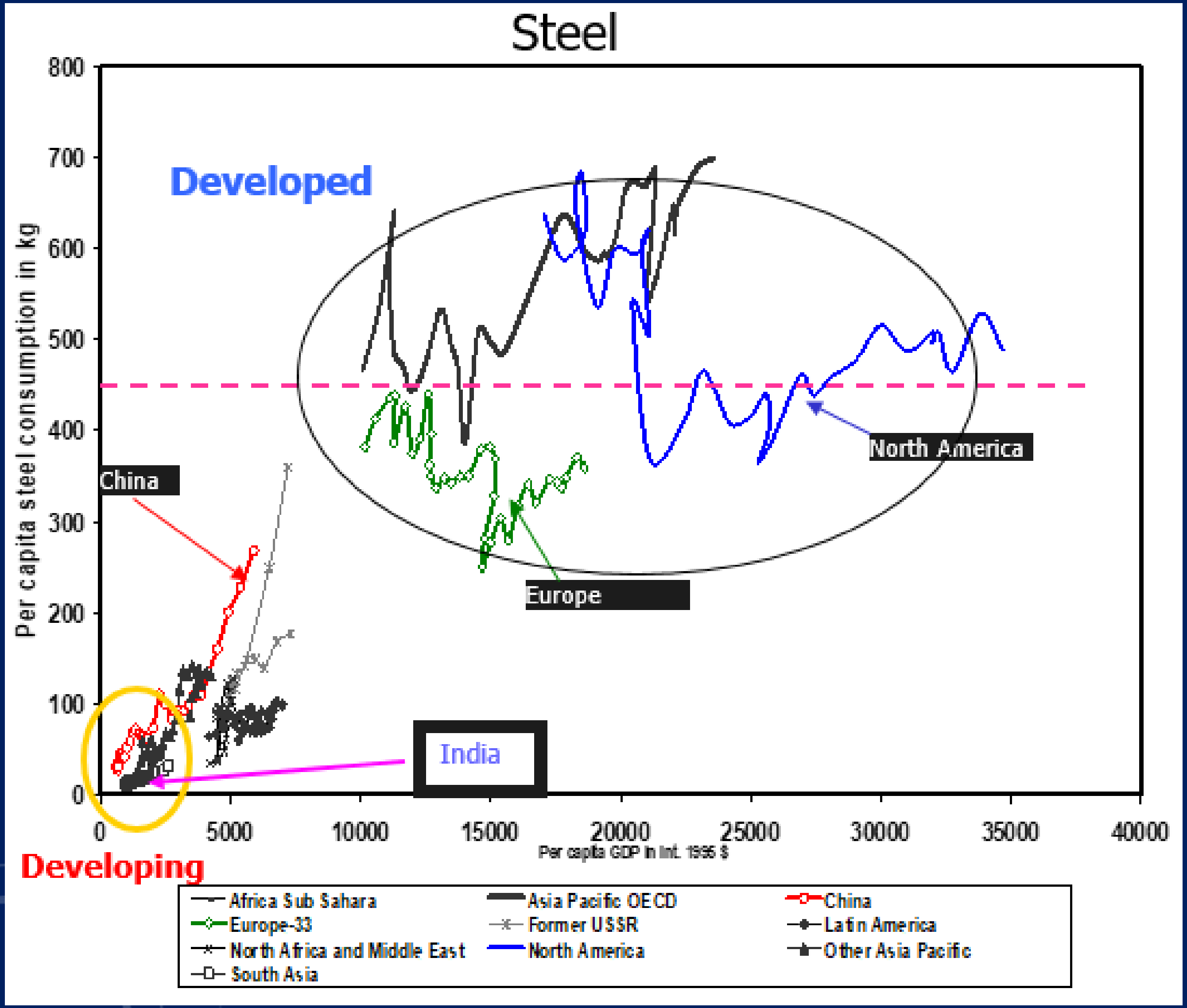
Energy intensive materials 50% of industrial energy use

Cement, Steel, Paper, Chemicals and fertilisers etc.

Substitution

Higher growth rate in developing countries

Understanding Material Usage Trends



Kuznetz curve- Apparent consumption as a function of income

High growth rates for developing countries

Saturation

Implications on global energy use

GEA, Chapter 8

Cement Consumption

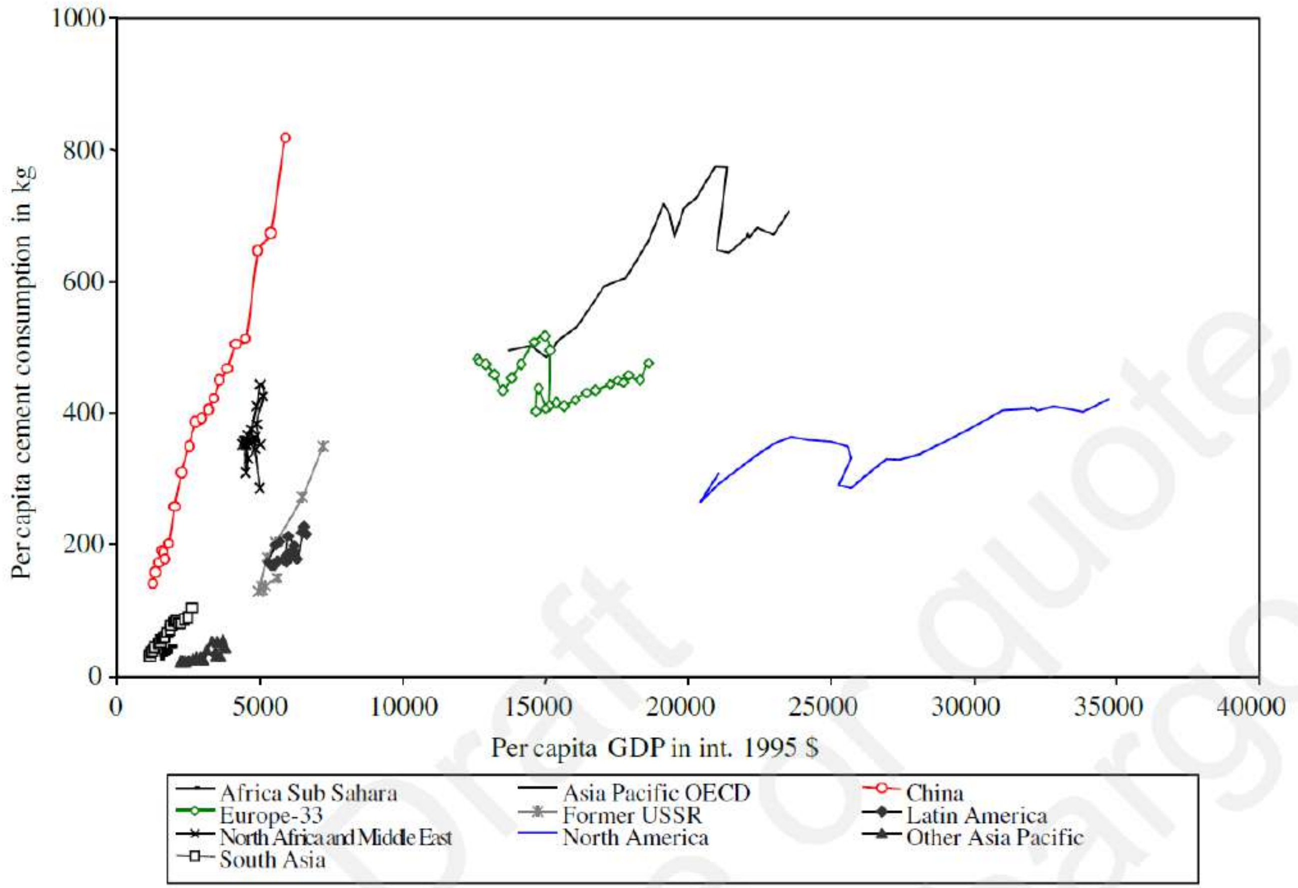
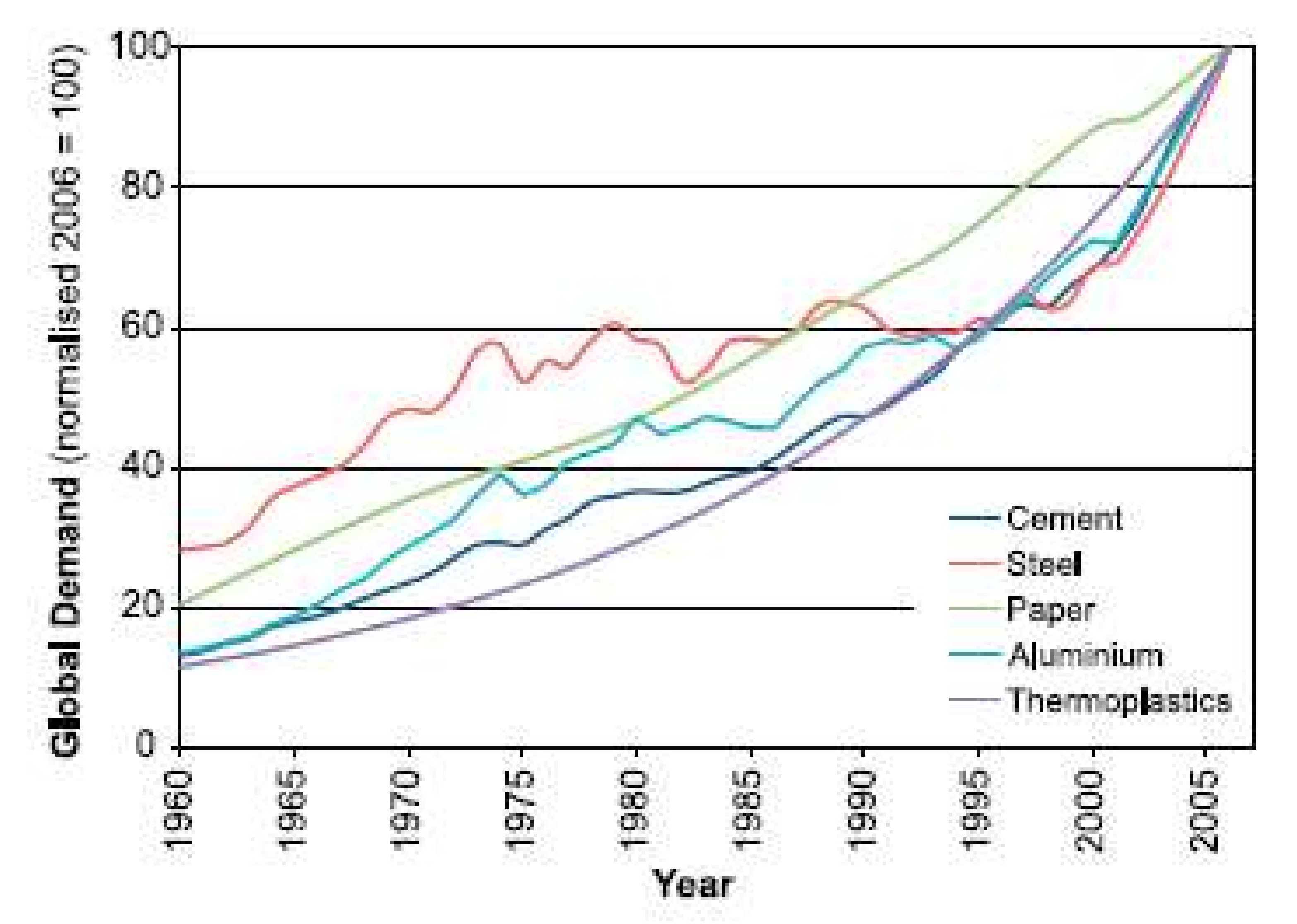
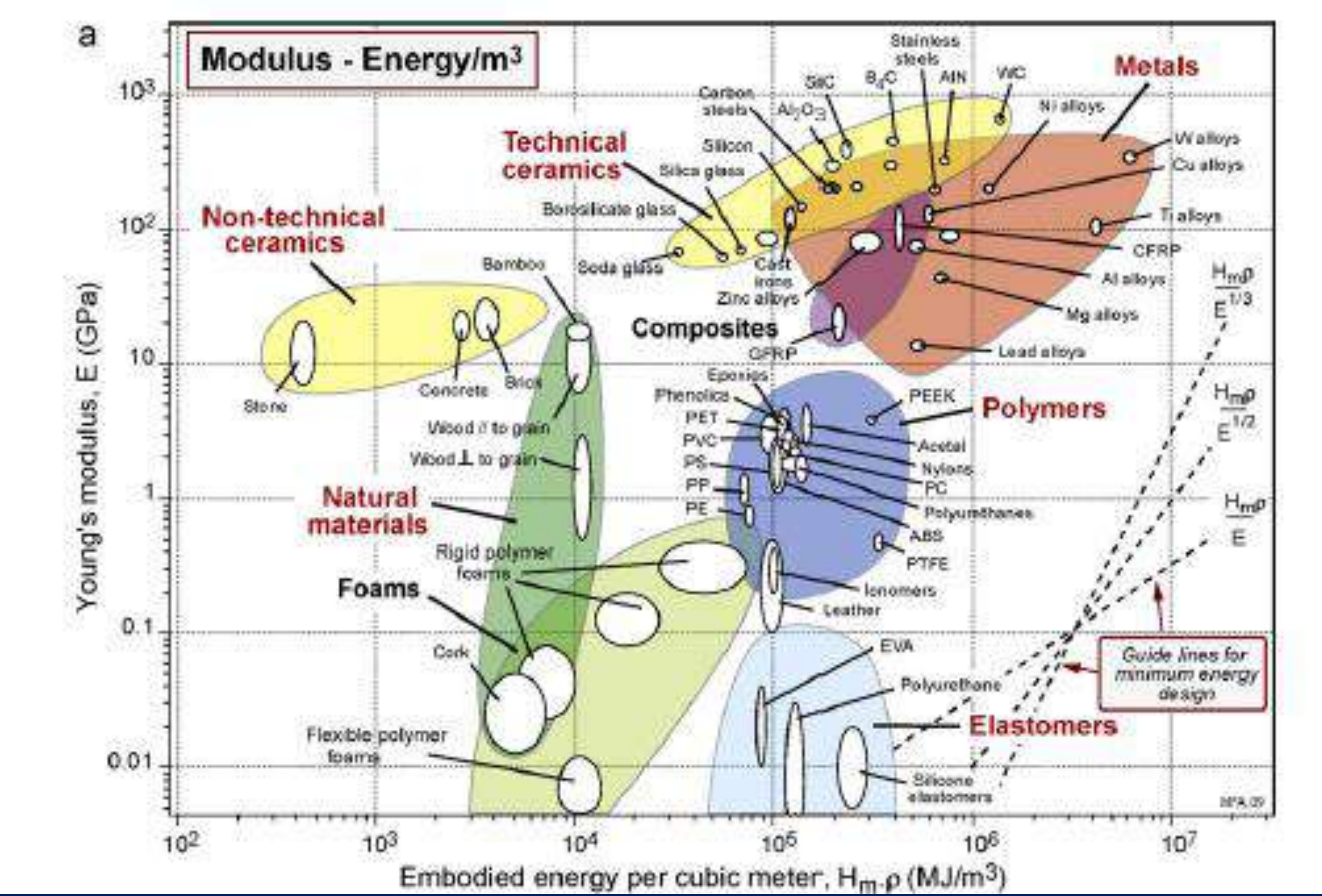


Figure 8.4. Apparent cement consumption (expressed as kg/capita/year) as a function of income (expressed as $US\$_{1995}$/capita) for different regions in the world.

Demand Growth - Materials

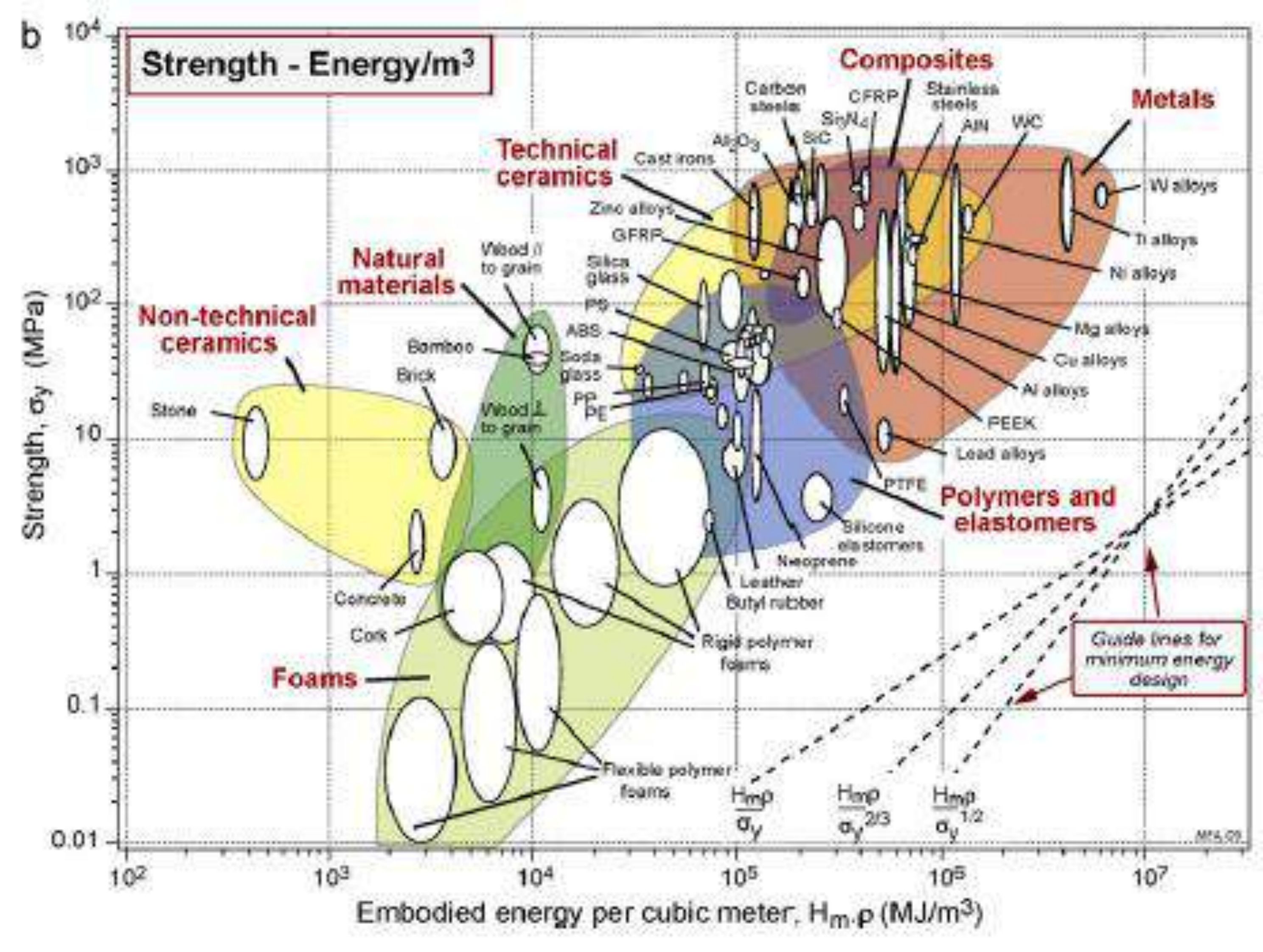


Material Choice



Allwood et al, 2011

Material Choice



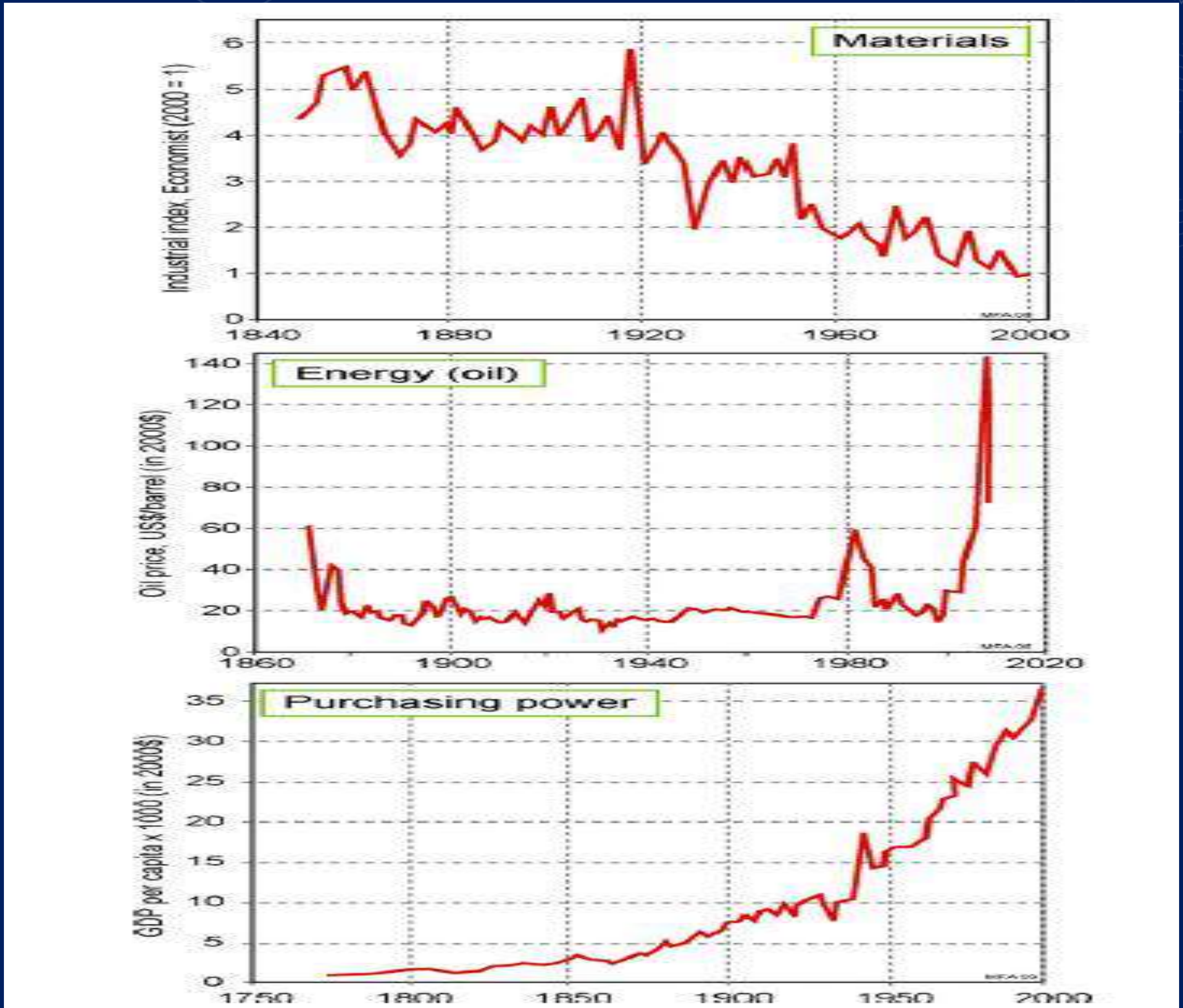
Allwood et al, 2011

Embodied Energy of Elements

Element	Standard chemical exergy[a]		Estimated embodied energy (MJ/kg)	Apparent efficiency (%)
	kJ/mol	MJ/kg		
Al	795.7	29.5	190–230	14
Cu	134.2	2.1	60–150	2
Fe	374.3	6.7	20–25	30
Mg	626.1	25.8	356–394	7
Ni	232.7	4.0	135–150	3
Pb	232.8	1.1	30–50	3
Sn	558.7	4.71	40	12
Ti	907.2	18.9	600–1000	2
Zn	339.2	5.2	70–75	7

[a] Standard chemical exergy is the minimum reversible work required to produce a pure material from its reference composition at standard temperature and pressure. As an illustration, iron (Fe) is produced from Fe_2O_3 at its crustal composition.

Allwood et al, 2011



Allwood et al, 2011

Betting on the Planet

Cornucopians

Prof Julian Simon, Professor Business Administration, Univ of Maryland 1932-1998

Article in Science 1980

Resources, Population, Environment: An Oversupply of False Bad News

Julian L. Simon

incredible as it may seem at first," he wrote in his 1980 article -- the planet's resources are actually not finite.

Betting on the Planet

Malthusians

Paul Ehrlich

Ecologist , Professor Of Stanford University

The Population Bomb , !968

John Harte, John Holdren, UC Berkeley
– Professors of Energy and Resources

Simon’s Challenge

- 1980
- If scarcity due to population growth –prices of natural resource grain, oil, timber, metals – should rise – at future date
- Willing to bet anyone that prices would decline at a future date (offer – pick any natural resource and any future date)

The Bet

- Ehrlich, John Holdren, John Harte accepted challenge – October 1980
- Chose – Chrome

  - Copper
  - Nickel
  - Tin
  - Tungsten

US $ 200 each at 1980 prices

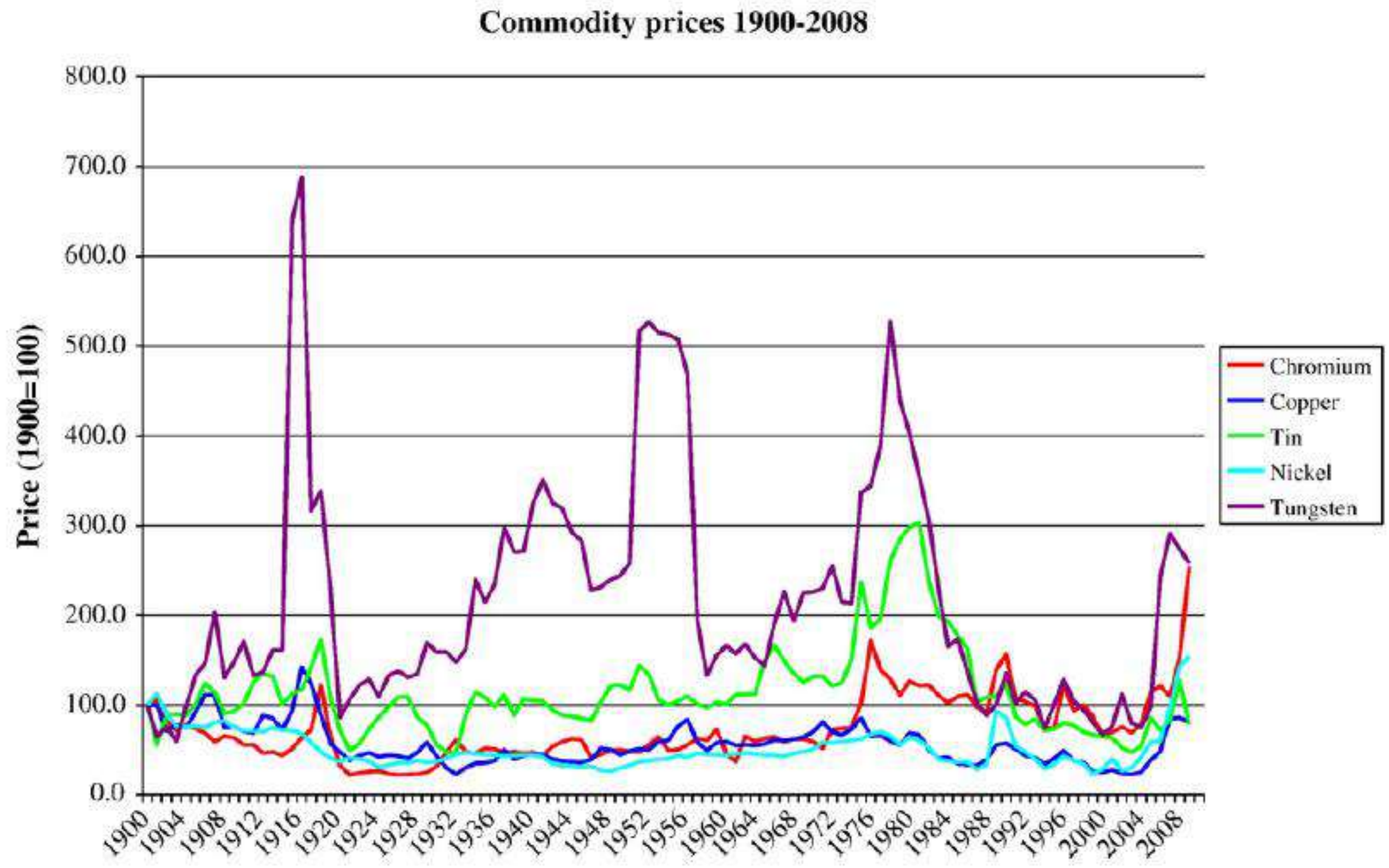


Fig. 1. Commodity prices 1900–2008.

K. Kiel et al. / Ecological Economics 69 (2010) 1365-1367

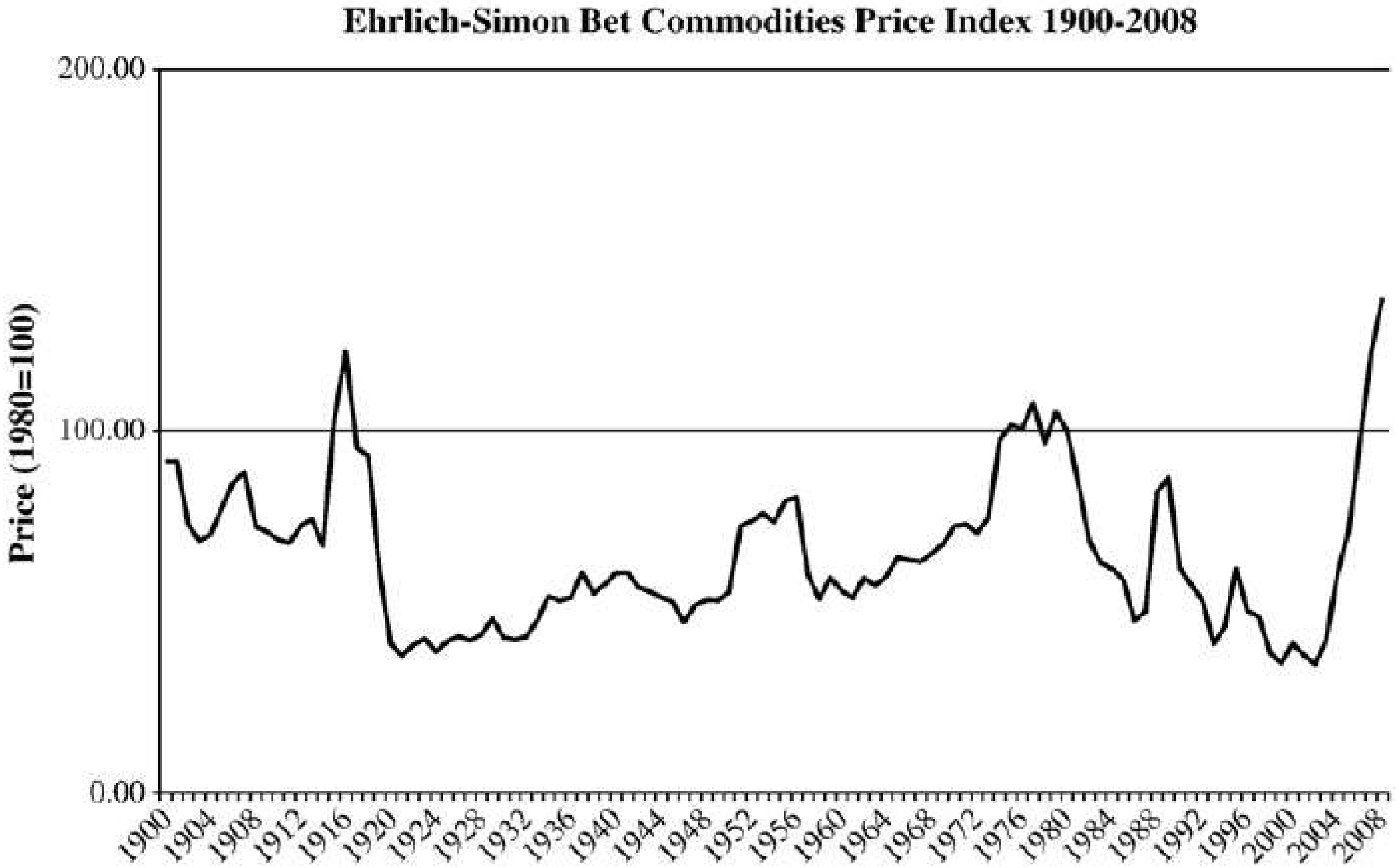
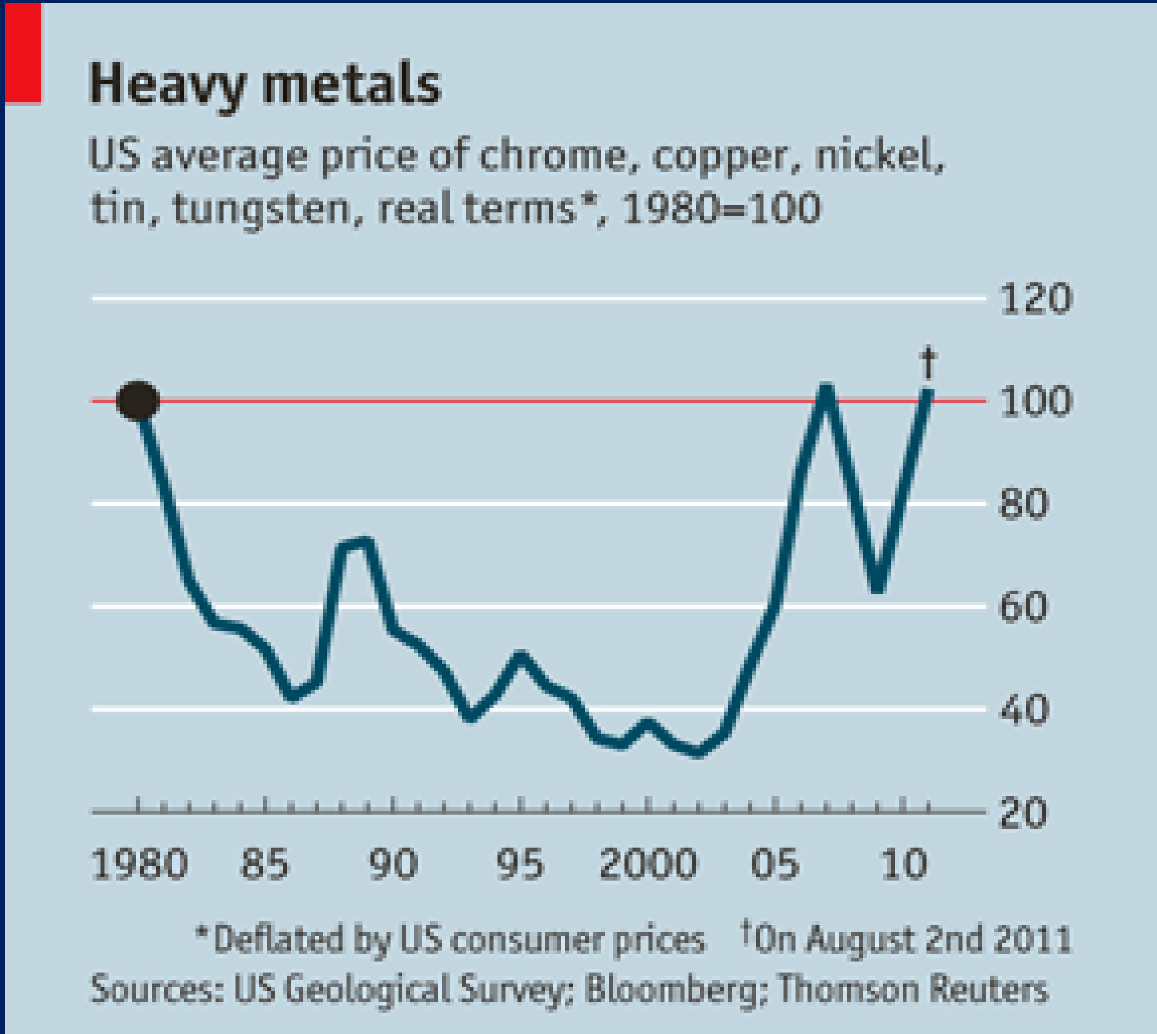


Fig. 2. Price Index for Ehrlich–Simon bet commodities 1900–2008.

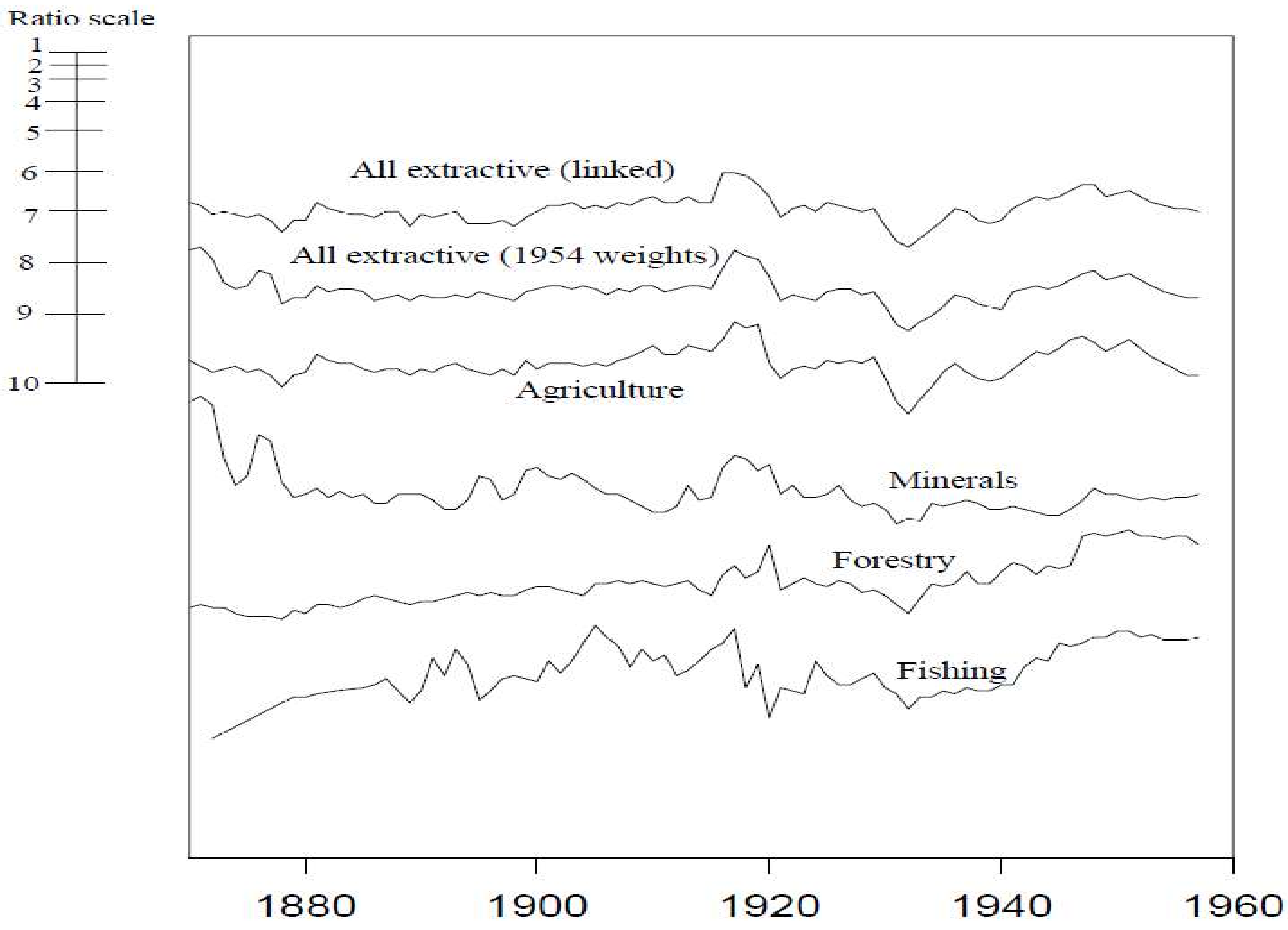
K. Kiel et al. / Ecological Economics 69 (2010) 1365-1367

Betting the Planet Revisited



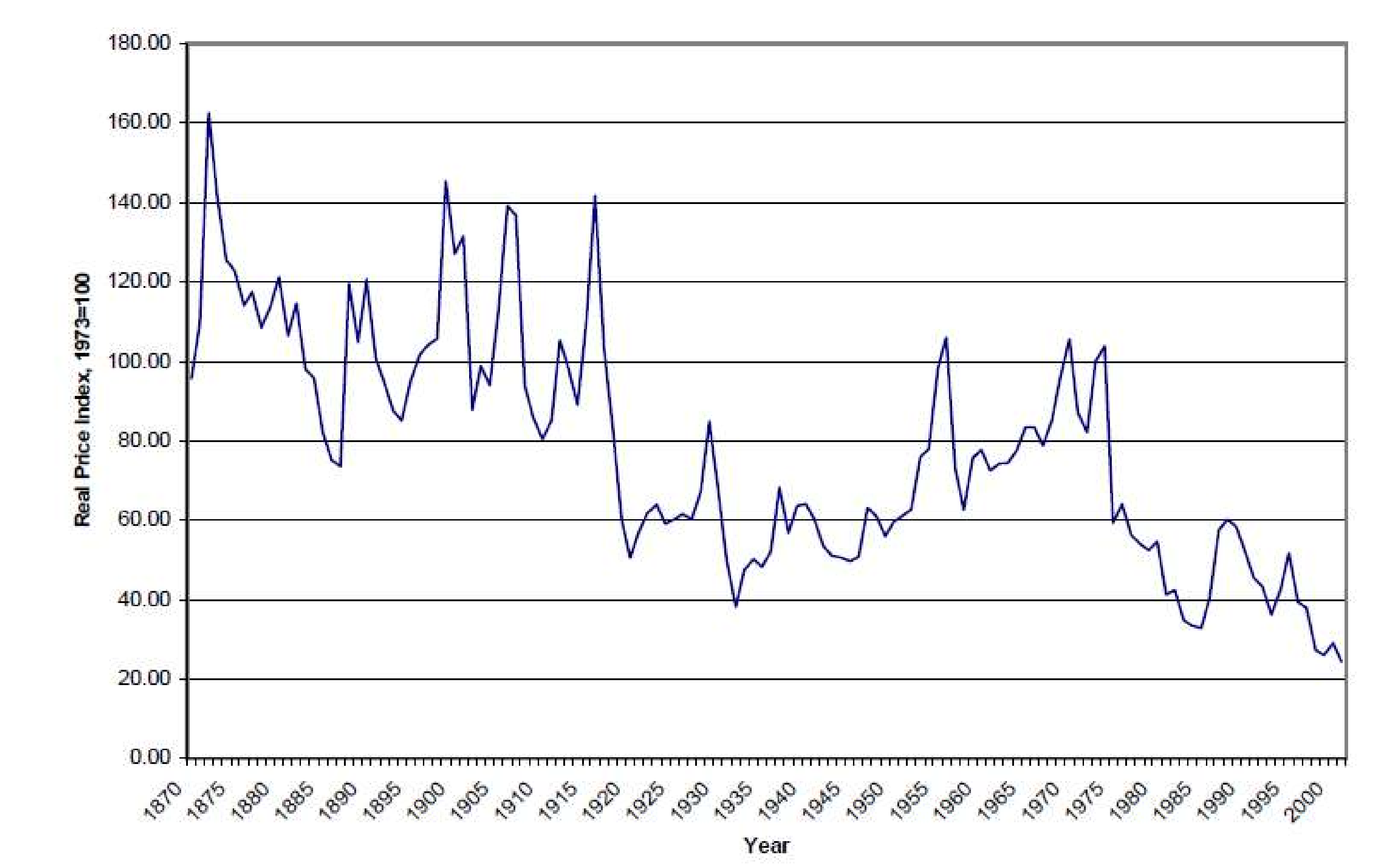
http://www.economist.com/node/21525472

Figure 1. Trends in natural resource prices relative to other prices in United States 1879-1957



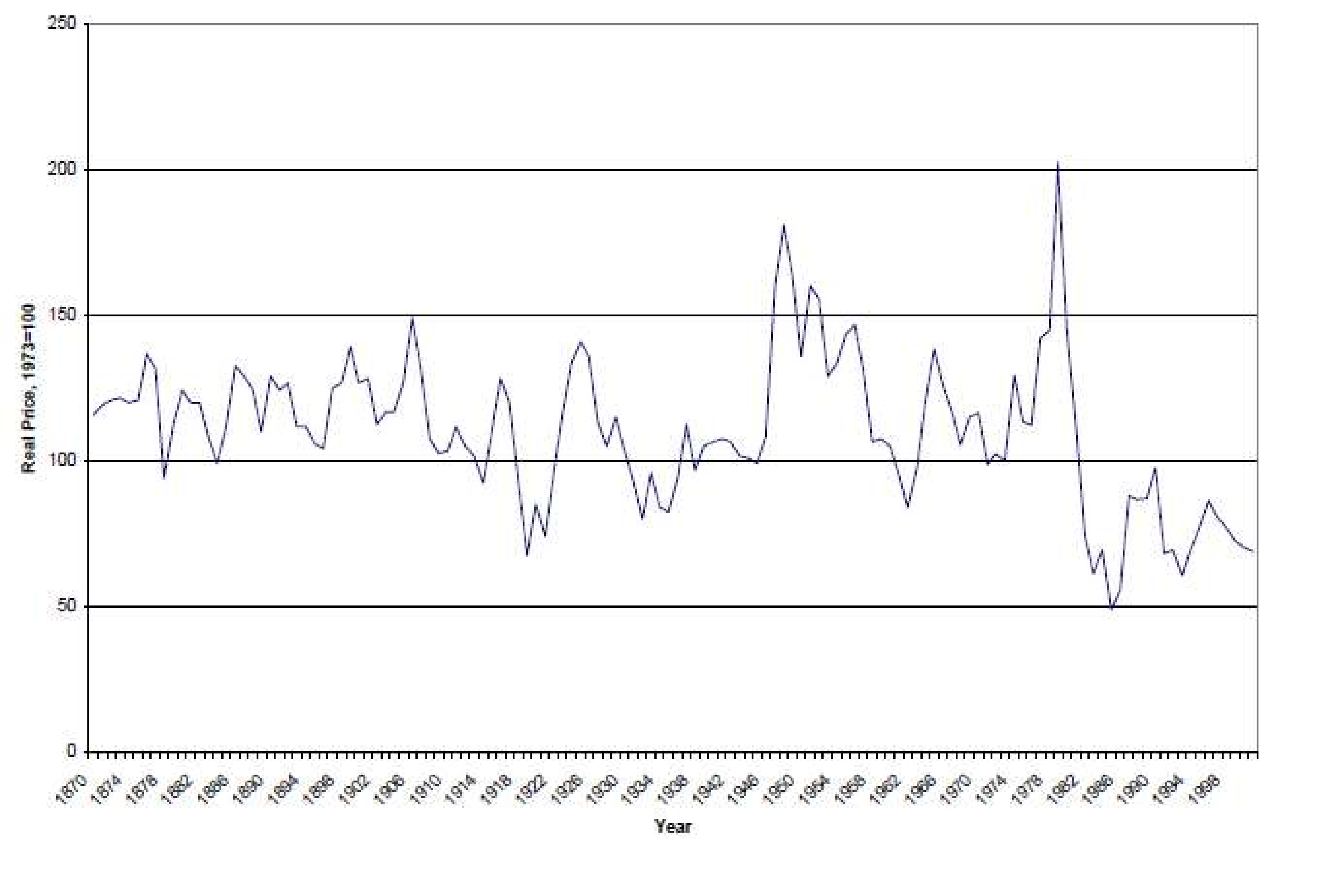
Source: Barnett and Morse (1963).

Real Price of Copper Variation



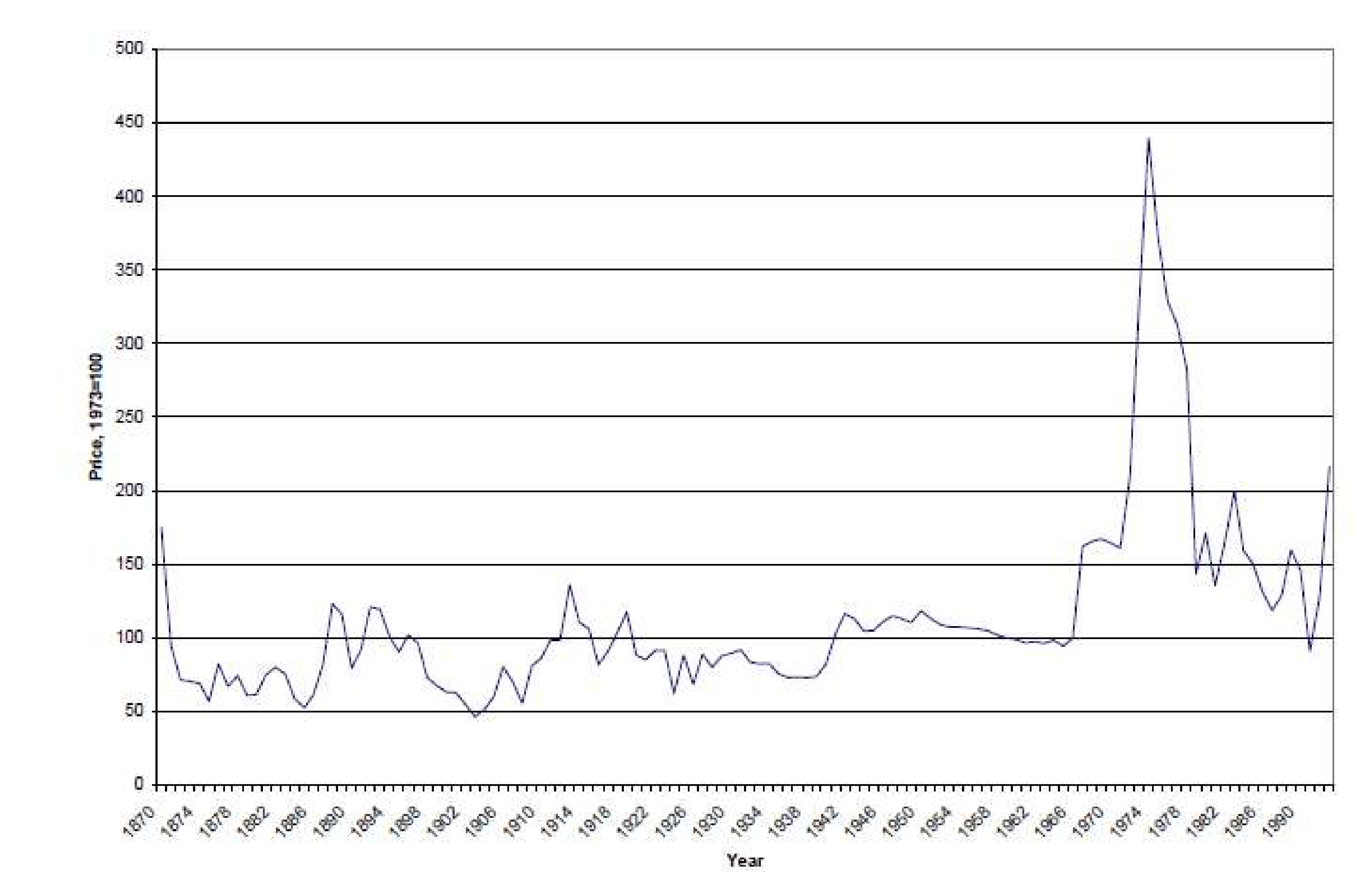
Krautkraemer, 2005

Real Price of Lead Variation



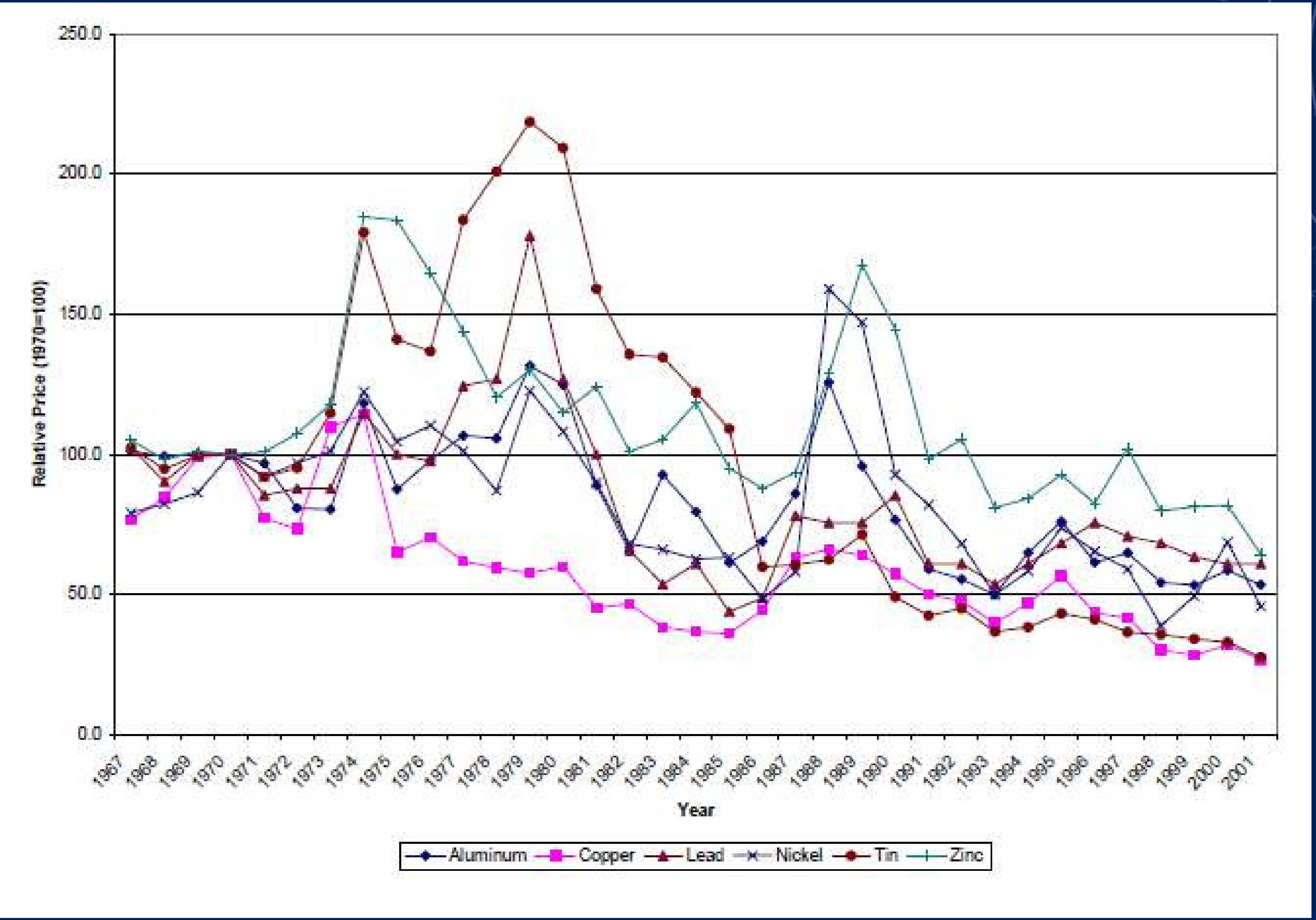
Krautkraemer, 2005

Real Price of Petroleum Variation

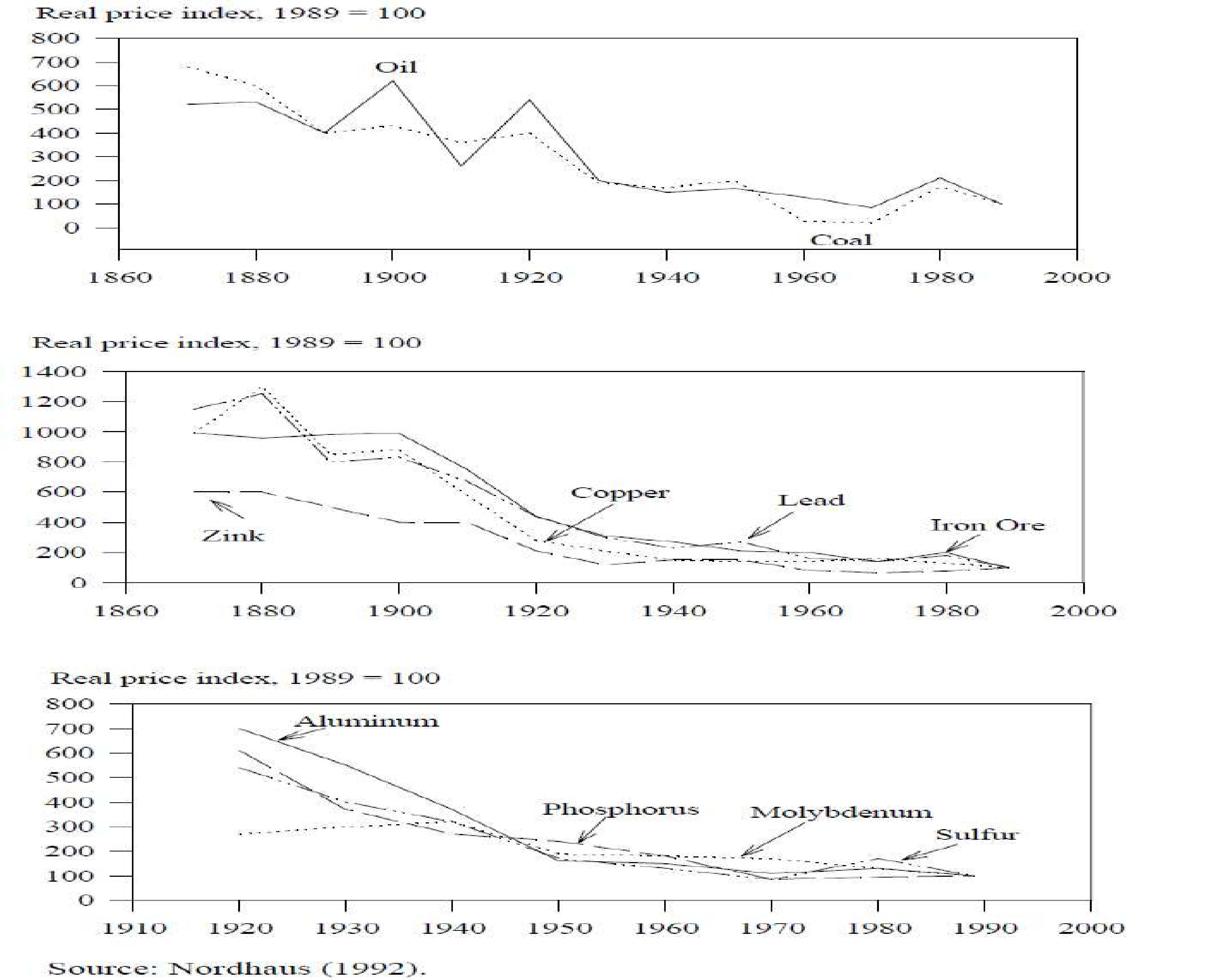


Krautkraemer, 2005

Price trend of metals

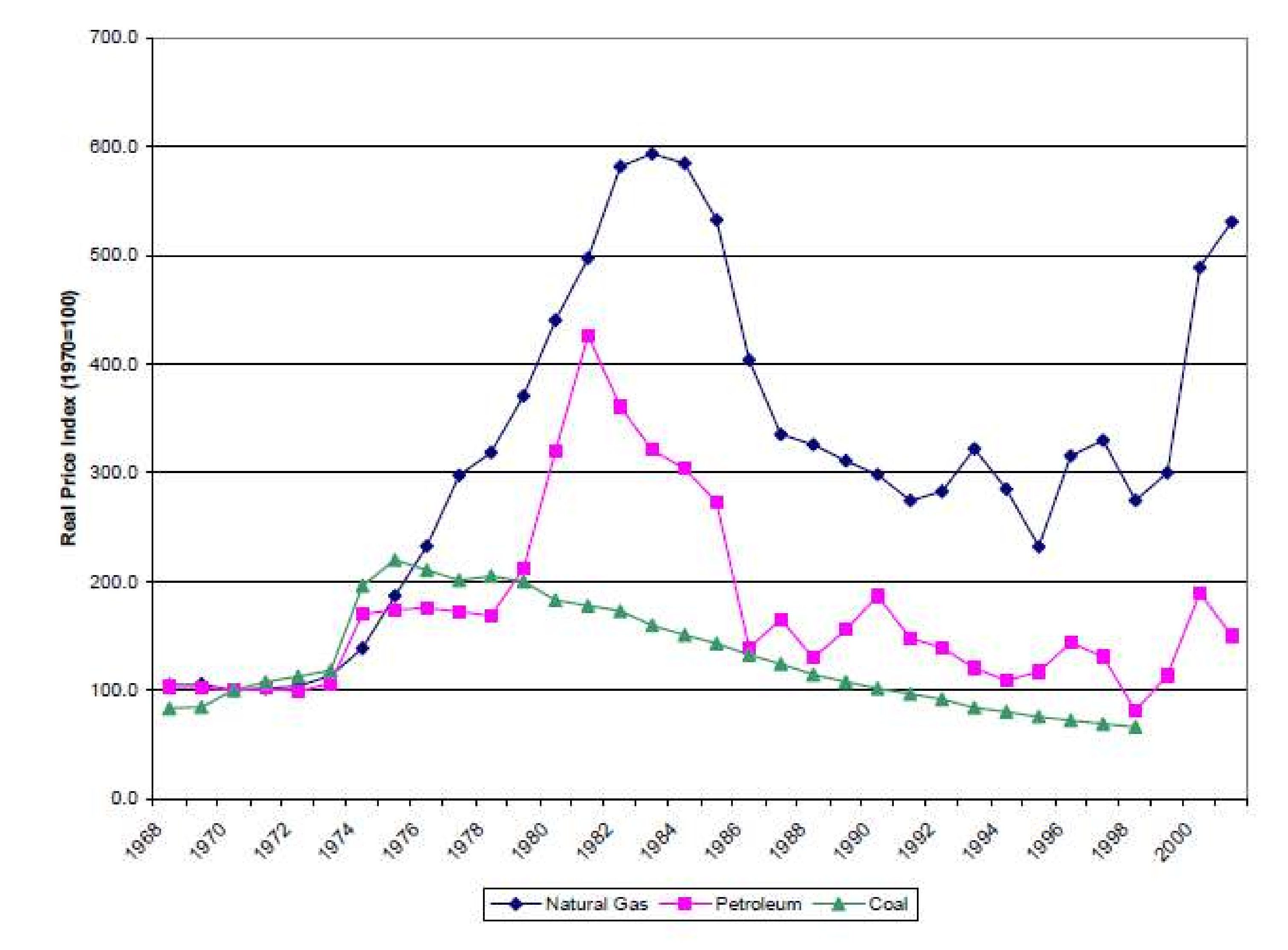


Krautkraemer, 2005



Tahvonen, 2000

Fossil Fuel Prices



Krautkraemer, 2005

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Katherine Kiel, Victor Matheson, Kevin Golembiewski (2010) Luck or skill? An examination of the Ehrlich–Simon bet , Ecological Economics 69 (2010) 1365–1367.

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