THE ENERGY LADDER

A model for projecting energy demand

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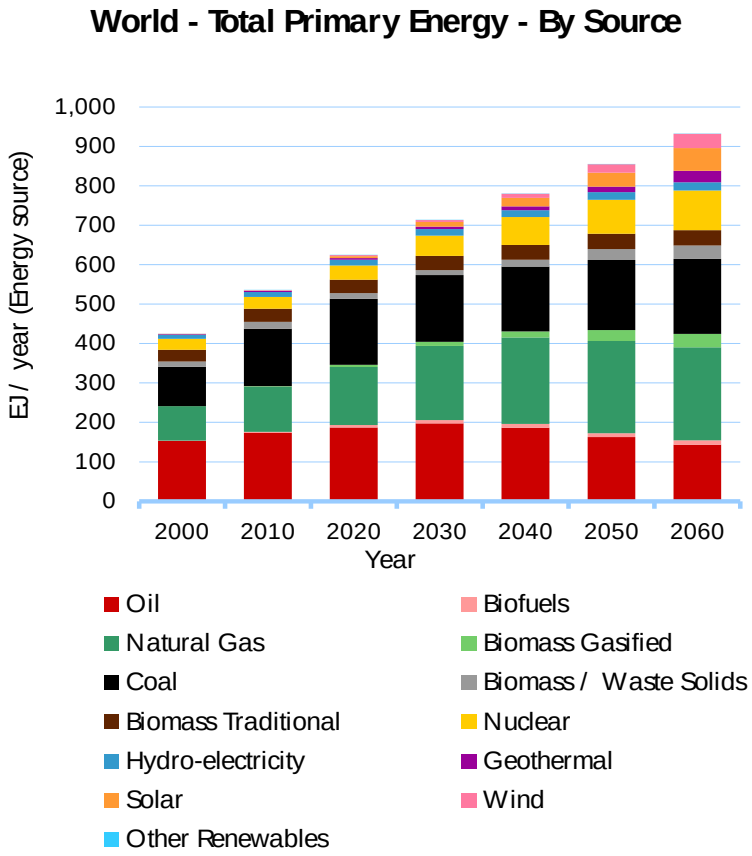
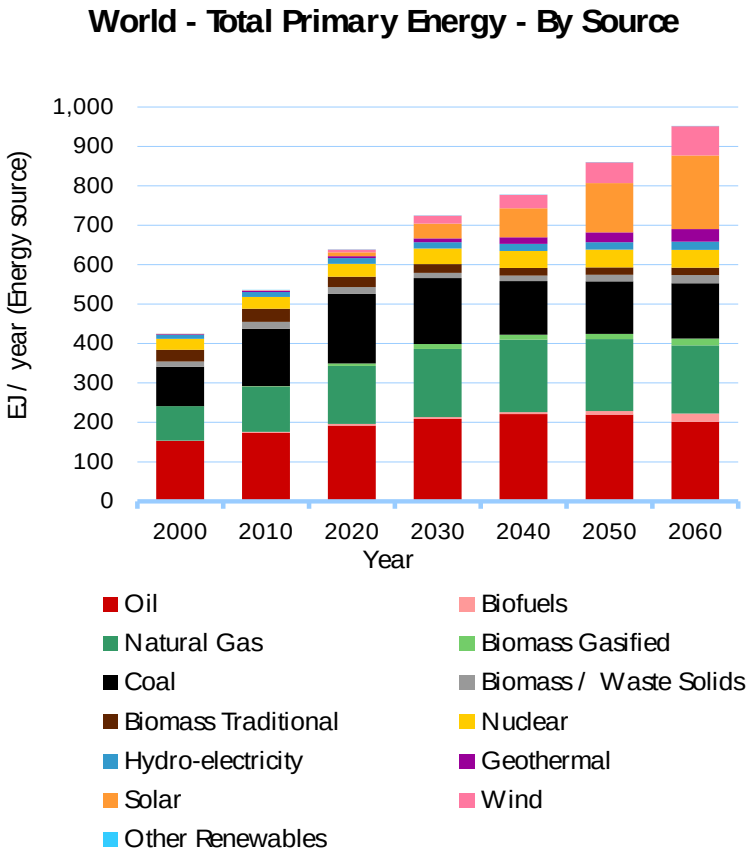
Shell's New Lens Scenarios

Mountains



Source: FSB Energy - Shell WEM v2.5.20 - Mountains - Balanced

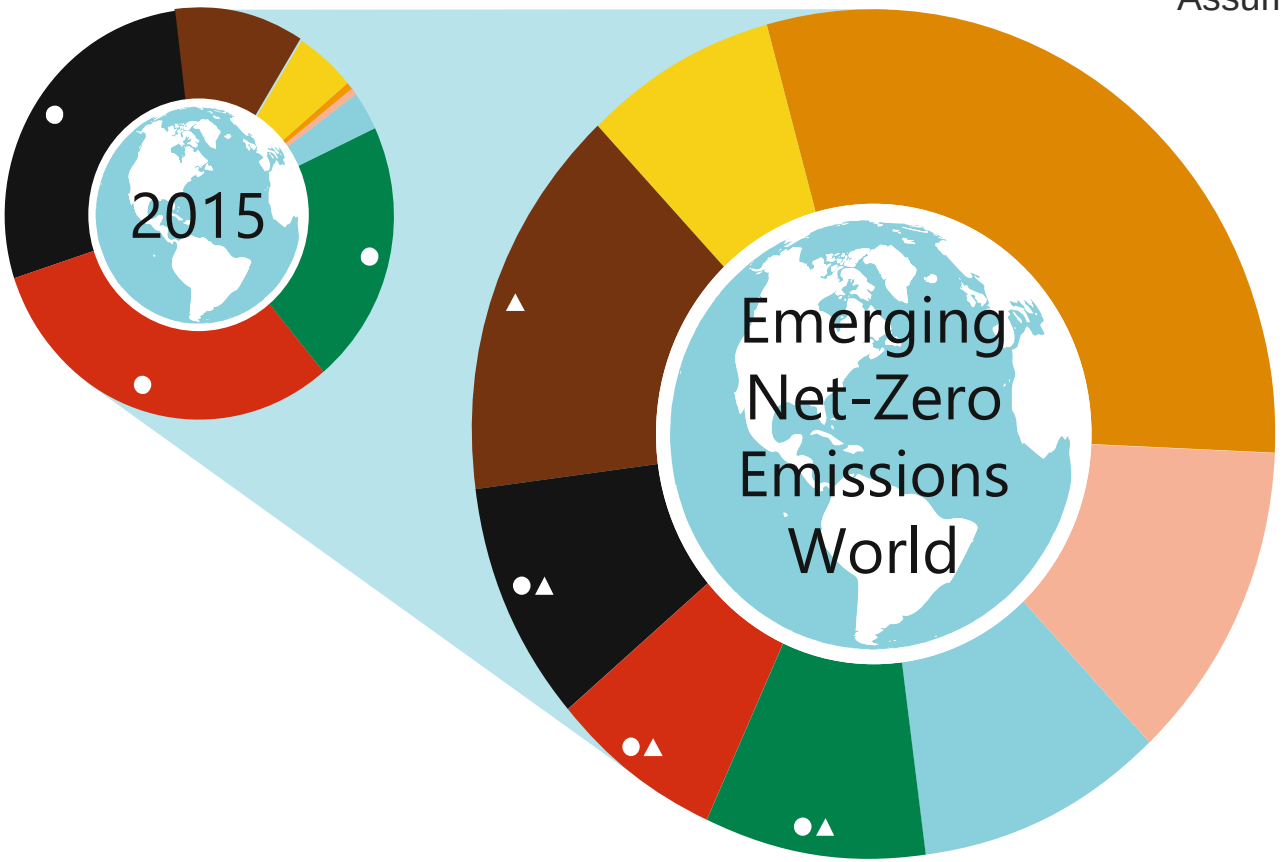
Oceans



FSB Energy - Shell WEM v2.5.20 - Oceans - Balanced

Net-zero emissions world, towards the end of the century

Assumes 50% electrification of end use.



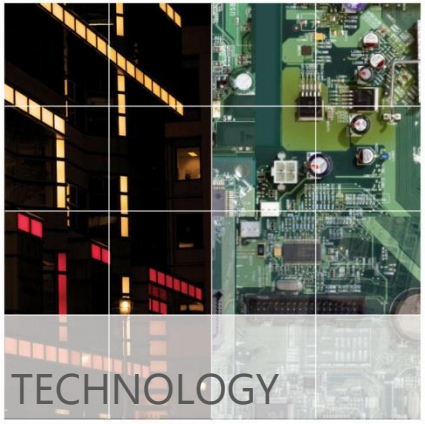
ENERGY SOURCE:
GAS
OIL
COAL
BIOENERGY
NUCLEAR
SOLAR
WIND
OTHER

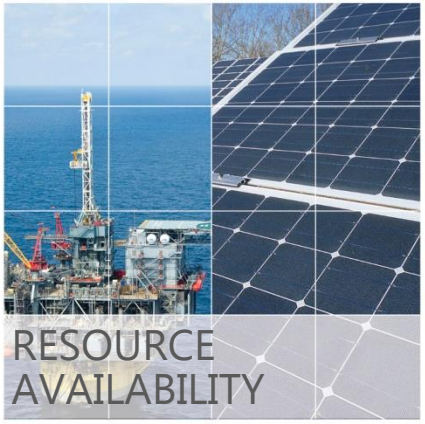
Source: Shell analysis

▲ With Carbon Capture and Storage

● Fossil

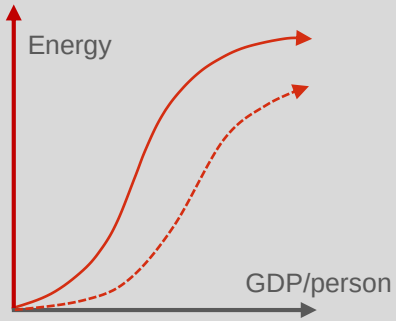
Six key drivers of the energy system





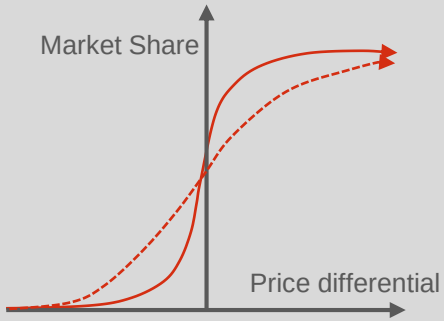
Three core models form the heart of the World Energy Model

TOTAL DEMAND



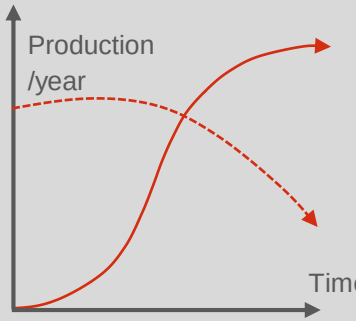
RESIDENTIAL, INDUSTRY & TRANSPORT

ENERGY CHOICE



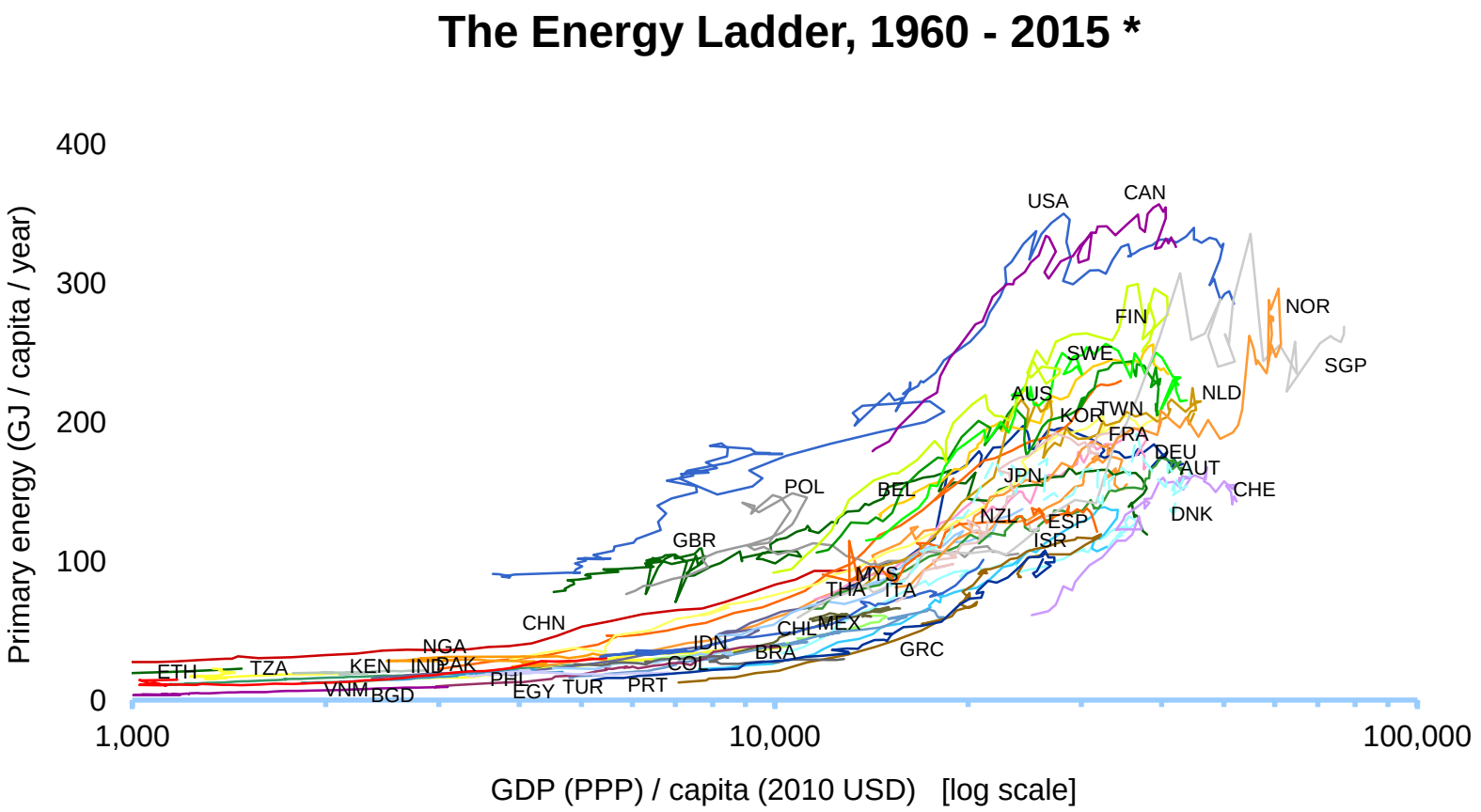
END USER & ENERGY PRODUCERS

ENERGY SUPPLY



FOSSIL, NUCLEAR & RENEWABLES

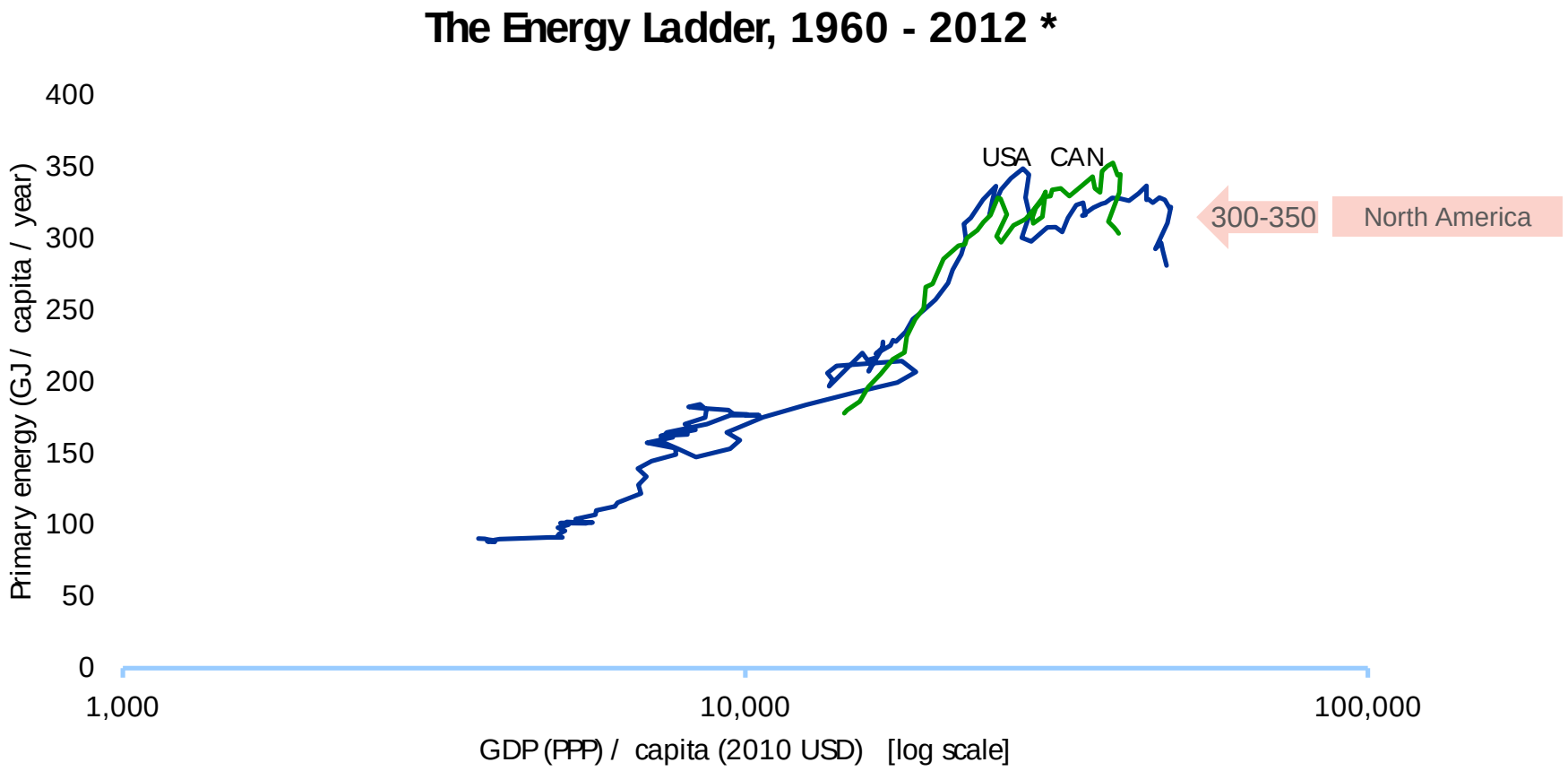
Energy Ladder – the relationship between energy demand and incomes is non-linear and partially country-specific



* UK and USA 1870 - 2015; Japan 1953 - 2015; Non-OECD 1971 - 2015

Sources: IEA 2015 energy balances and Shell Scenarios Team estimates; World Bank 2015; UN Population Division 2015 revision. For 1870 – 1960 data for UK and USA: US EIA, UK DECC, Angus Maddison (www.ggdc.net/maddison). Japan national statistics.

The inexorable link: economic growth and energy demand



* USA and UK from 1870.

Sources: IEA 2013; World Bank 2013; UN Population Division 2012; US EIA; UK DECC; Angus Maddison; Japan national statistics; Shell New Lens Scenarios

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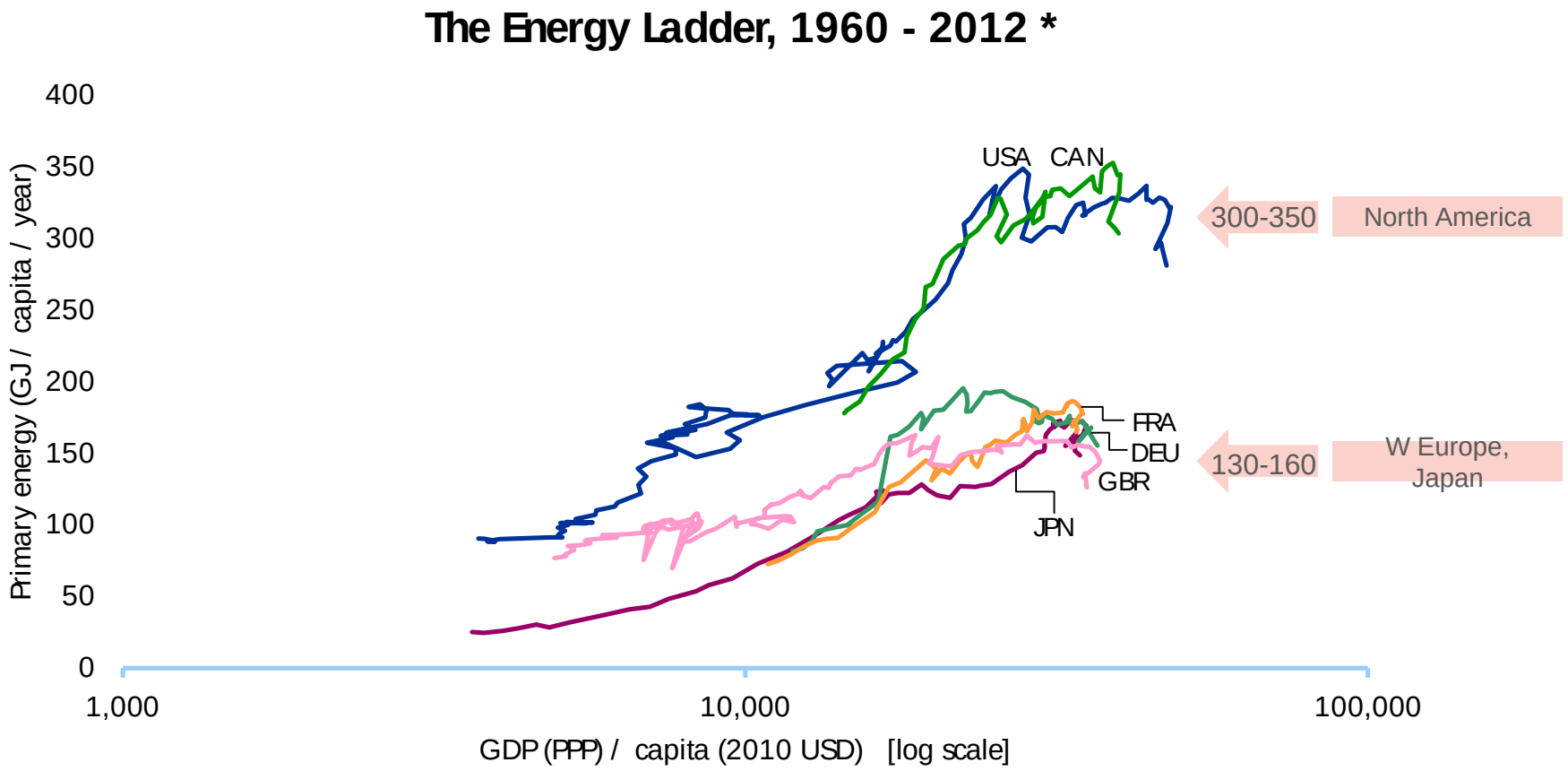

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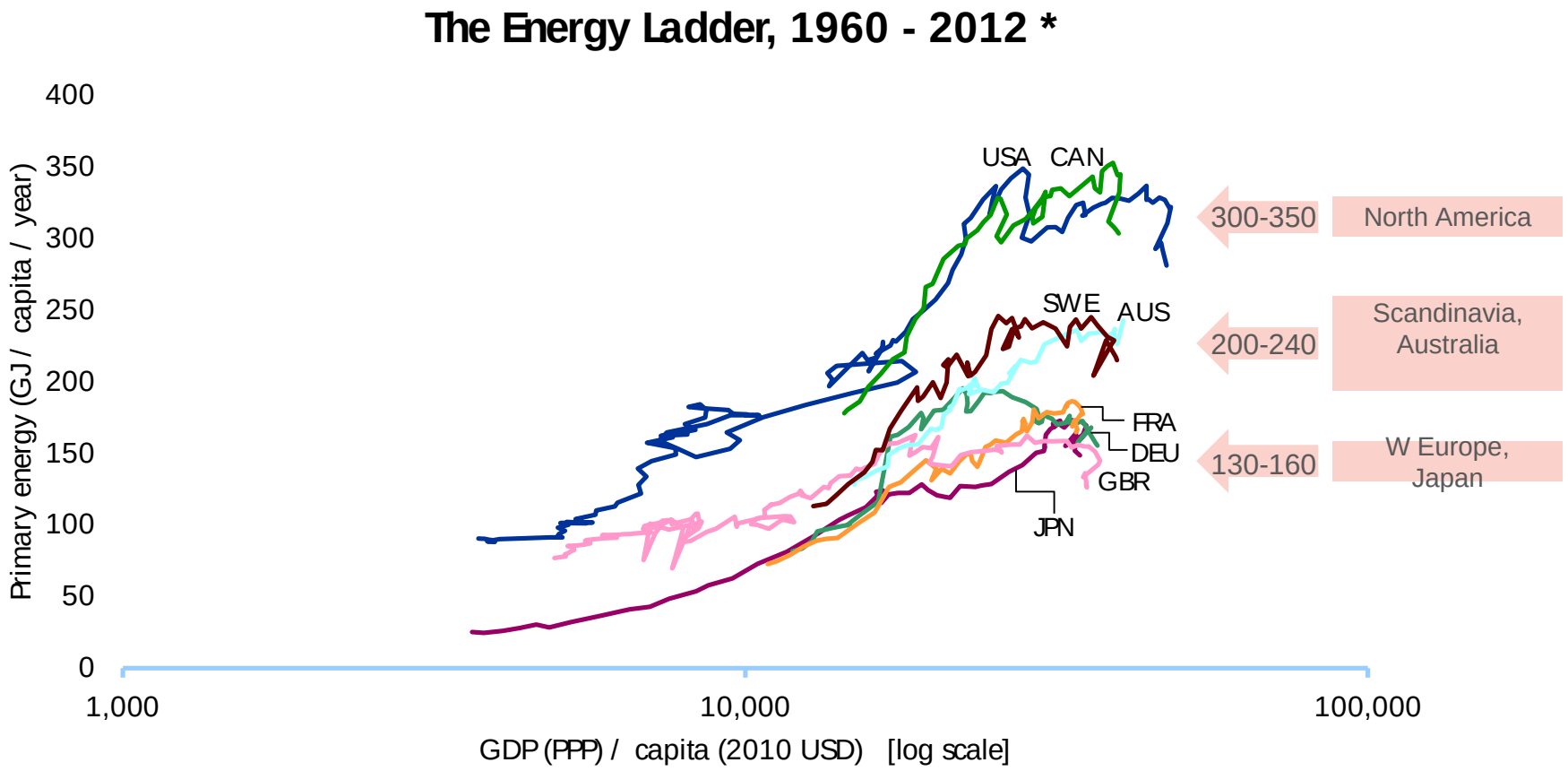

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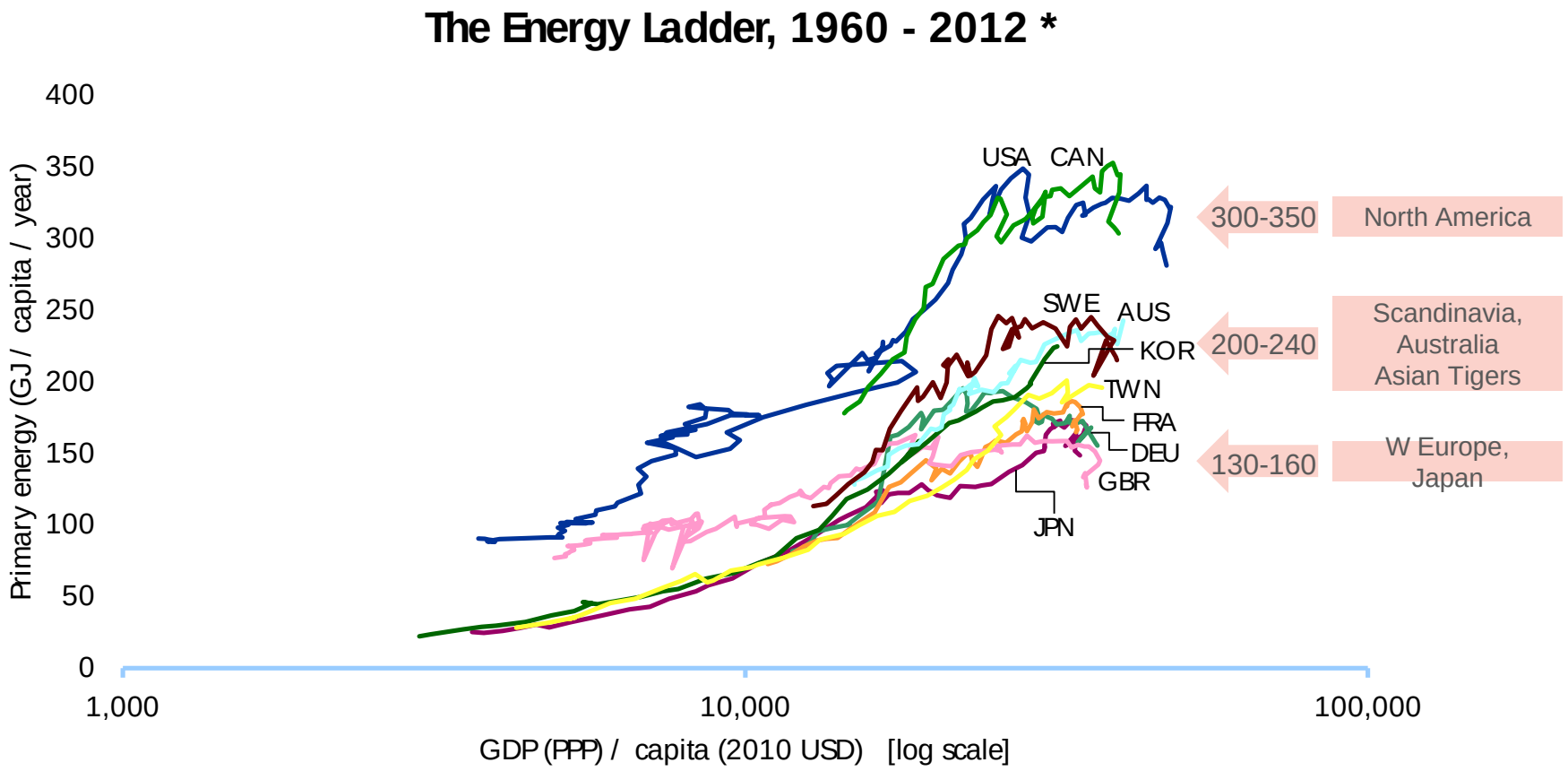

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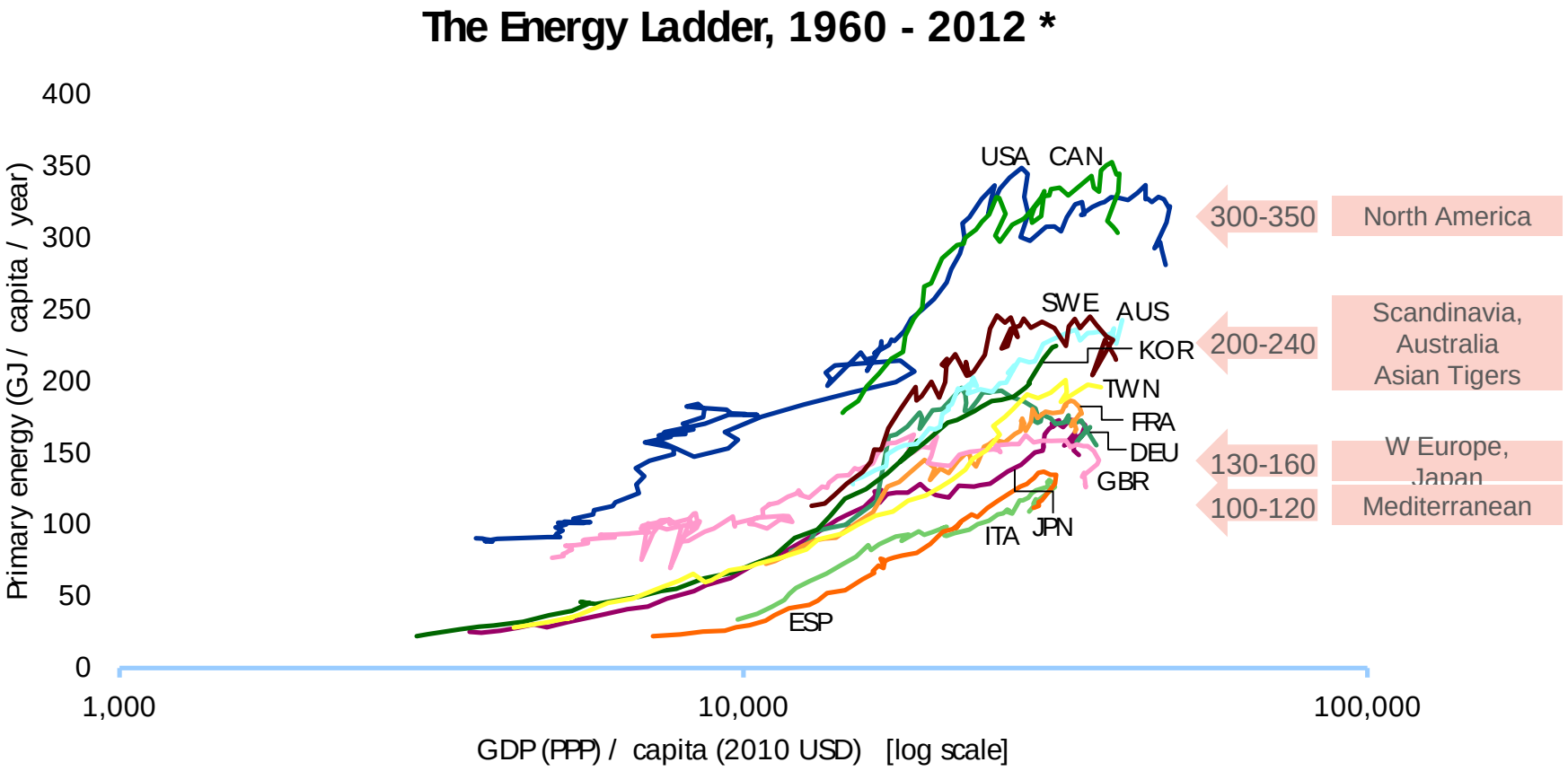

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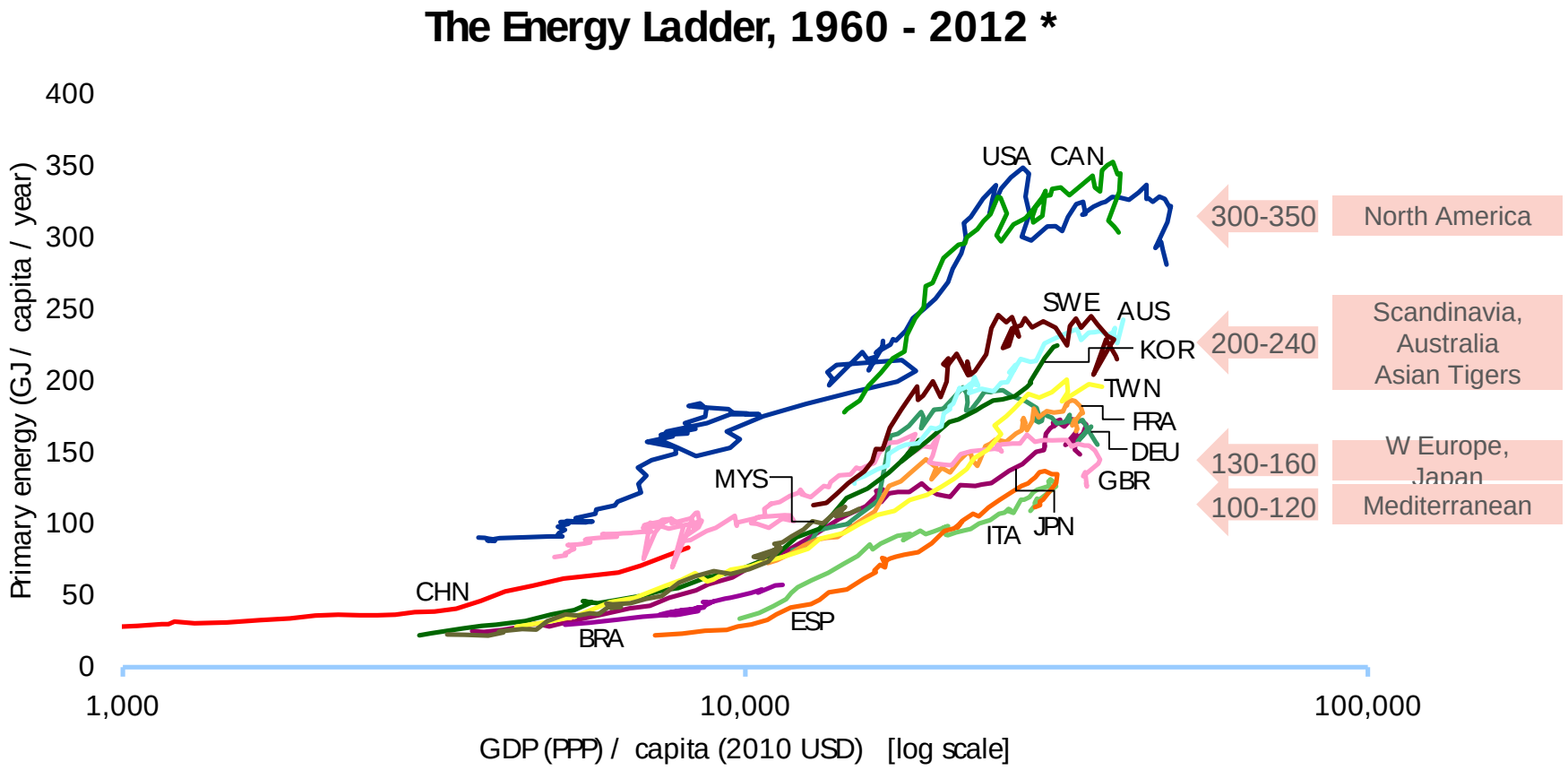
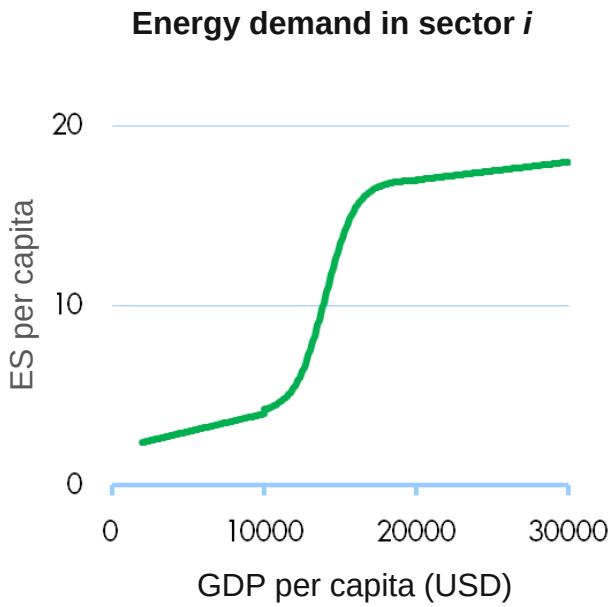


* USA and UK from 1870.

Sources: IEA 2013; World Bank 2013; UN Population Division 2012; US EIA; UK DECC; Angus Maddison; Japan national statistics; Shell New Lens Scenarios

WEM Energy Ladders track non-linear growth with GDP, specific to each sector ...

Sector energy demand per capita versus GDP per capita



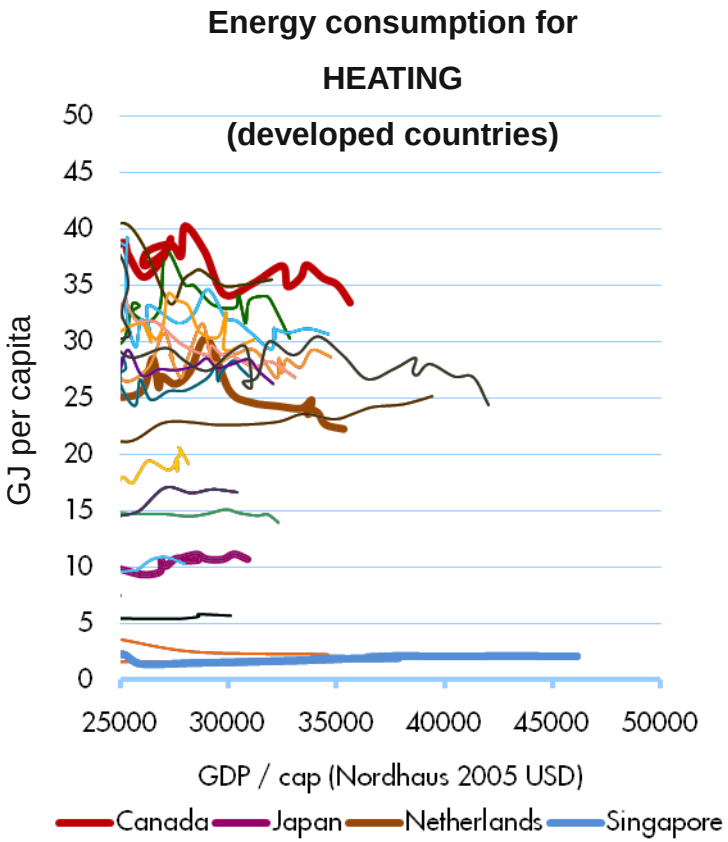
Sector energy demand in "Energy Service" (ES)

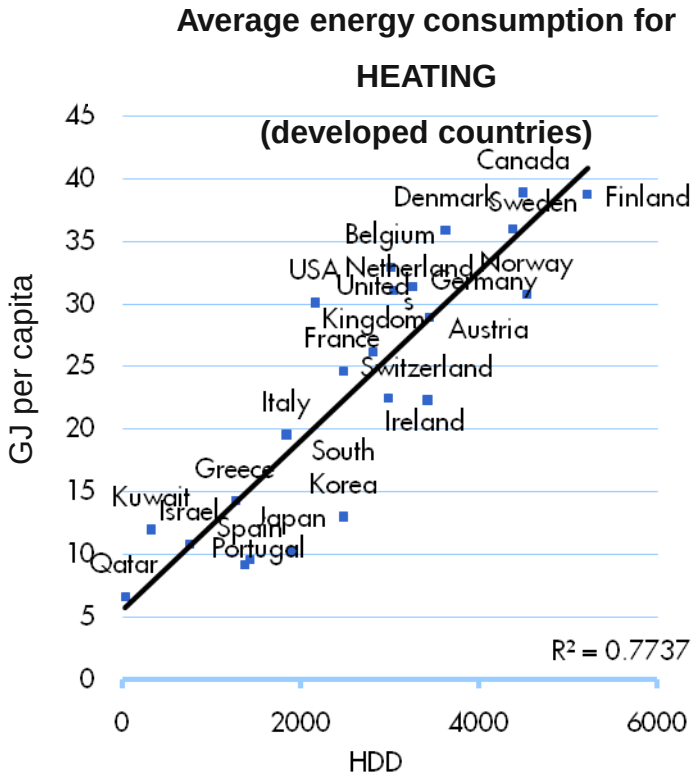
Sector	Unit of Energy service
Heavy Industry	Tonne of steel
Other Industry	Heating requirement in buildings
Services	Heating requirement in buildings
Passenger Transport	Passenger kilometre
Freight Transport	Tonne kilometre
Residential Heating Lighting Cooking	Heating requirement in buildings
Residential Appliances	Electricity need (benchmark = fridge)
Non energy	Oil equivalent for output

... and enable an evolution to “mature” at levels of demand, dependent on country-characteristics

Example:

Residential Heating needs depend on the heating-degree days





How are the energy ladders modelled?

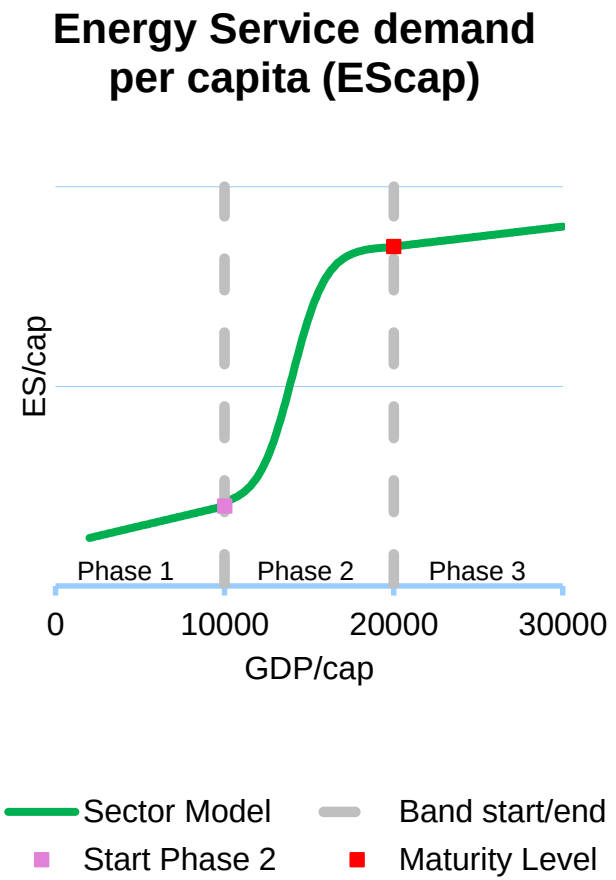
- Phase 1: **Linear**
  - Slope and Price Elasticity estimated from:

$$EScap_{it} = c_i + a \cdot GDPcap_{it} + b \cdot Price_{it} + \epsilon_{it}$$

- Phase 2: **S-Shape**
  - Logistic curve to maturity level
  - Maturity levels estimated from:

$$EScap_{i,maturity} = c + a \cdot X_i + \epsilon_i$$

- Phase 3: **Linear**, convergence to saturation level
  - Slope and Price Elasticity estimated as in Phase 1



Estimation of maturity level: linear regression

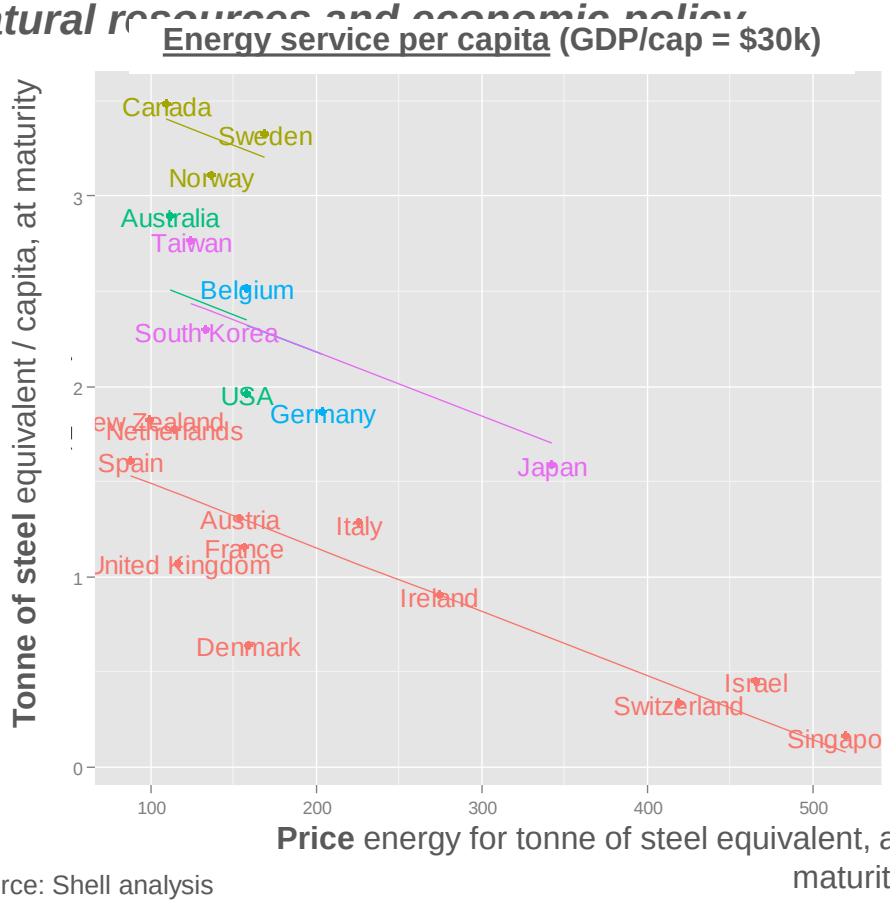
Example

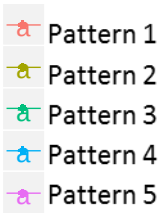
Energy service in Heavy Industry at maturity (GDP/cap = $30k) depends on price,
natural resources and economic policy

$$EScap_{i,mat} = cpatter_n - 0.003 \cdot ESPrice_{i,mat}$$

R-squared = **92.4%**

Percentage of variation in demand explained by this model.





Heavy Industry
Standard
Large forest
Natural resources
Manufacturing Policy while developing
Manufacturing Policy while developed

*Countries removed:
-Oil & gas countries
-Luxembourg, Finland

Source: Shell analysis

Estimation income and price elasticity: panel data regression

Example

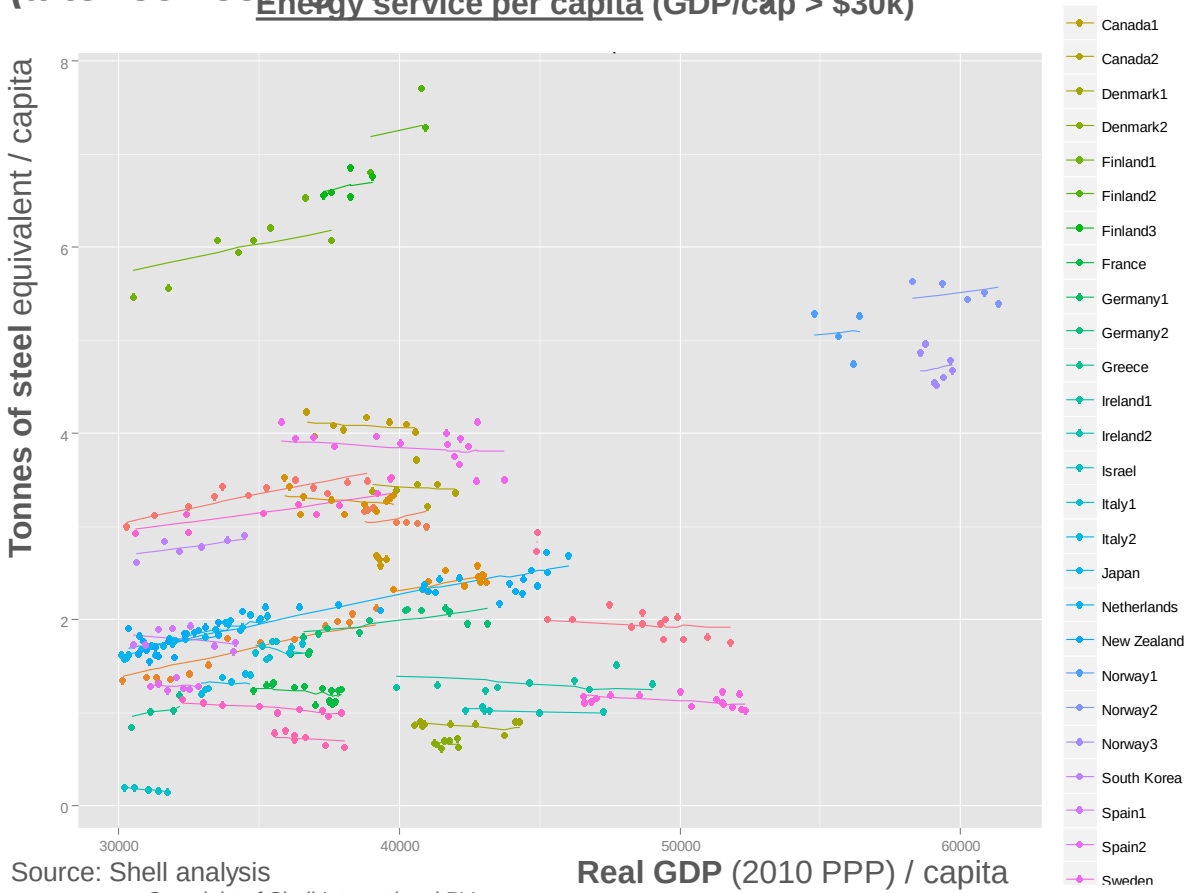
Energy demand in Heavy Industry has a statistically significant price elasticity of -0.045
(after correcting for the effect of GDP)

$$EScap_{it} = c_i + \boldsymbol{a_p} \cdot GDPcapit + \boldsymbol{b} \cdot Priceit + \epsilon_{it}$$
$$Price\ Elasicity = b \cdot \overline{EScap}/\overline{Price}$$

Coefficients :

	Coefficient	P-value
GDPcap	-1.2358e-05	0.03561
GDPcap2	7.3795e-05	< 2.2e-16
GDPcap3	5.5433e-05	1.449e-07
Price	-4.7291e-04	**0.03194**

Effects statistically significant if P-value < 0.05

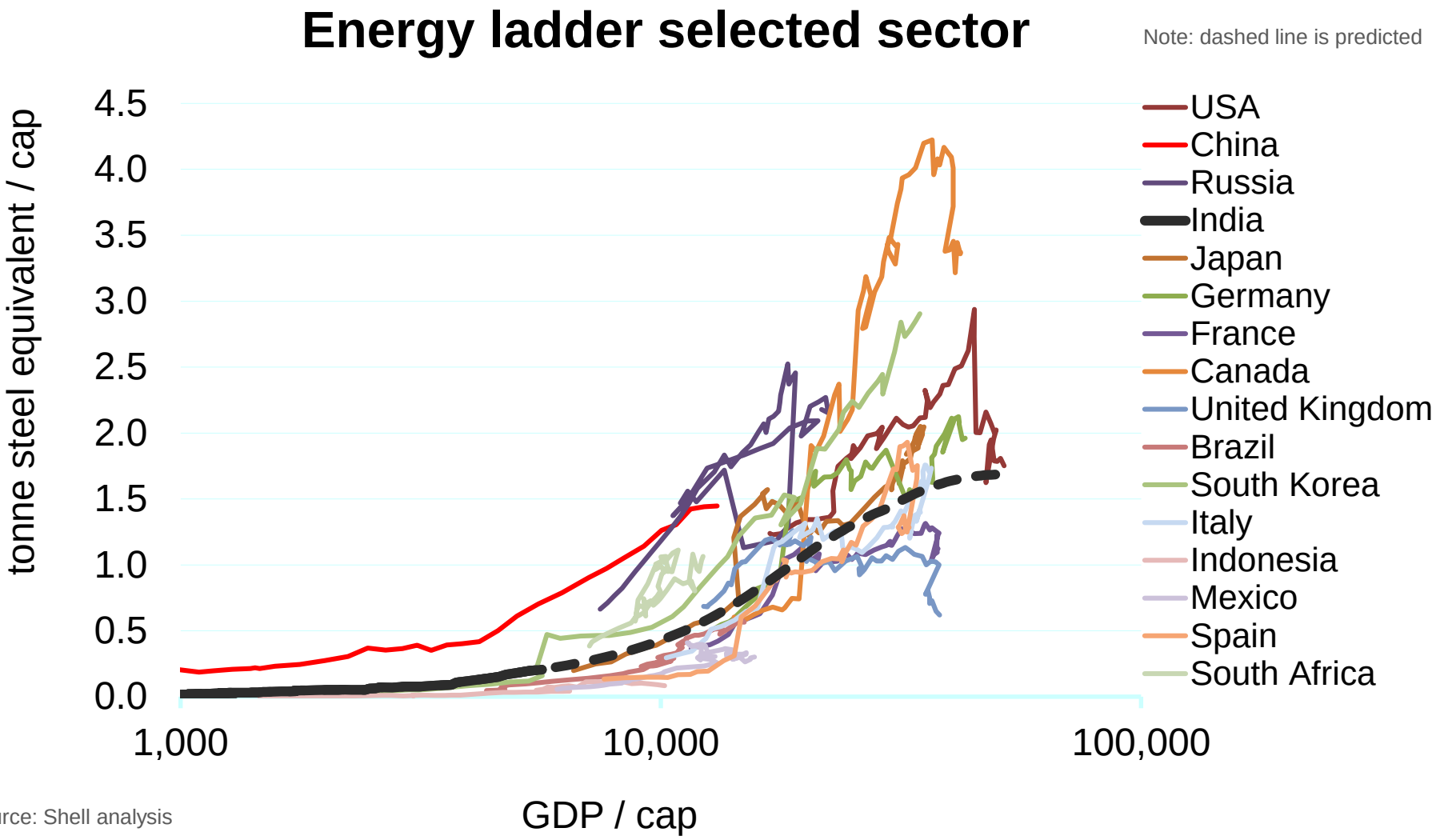


*Countries removed:

-Oil & gas countries
-Small countries

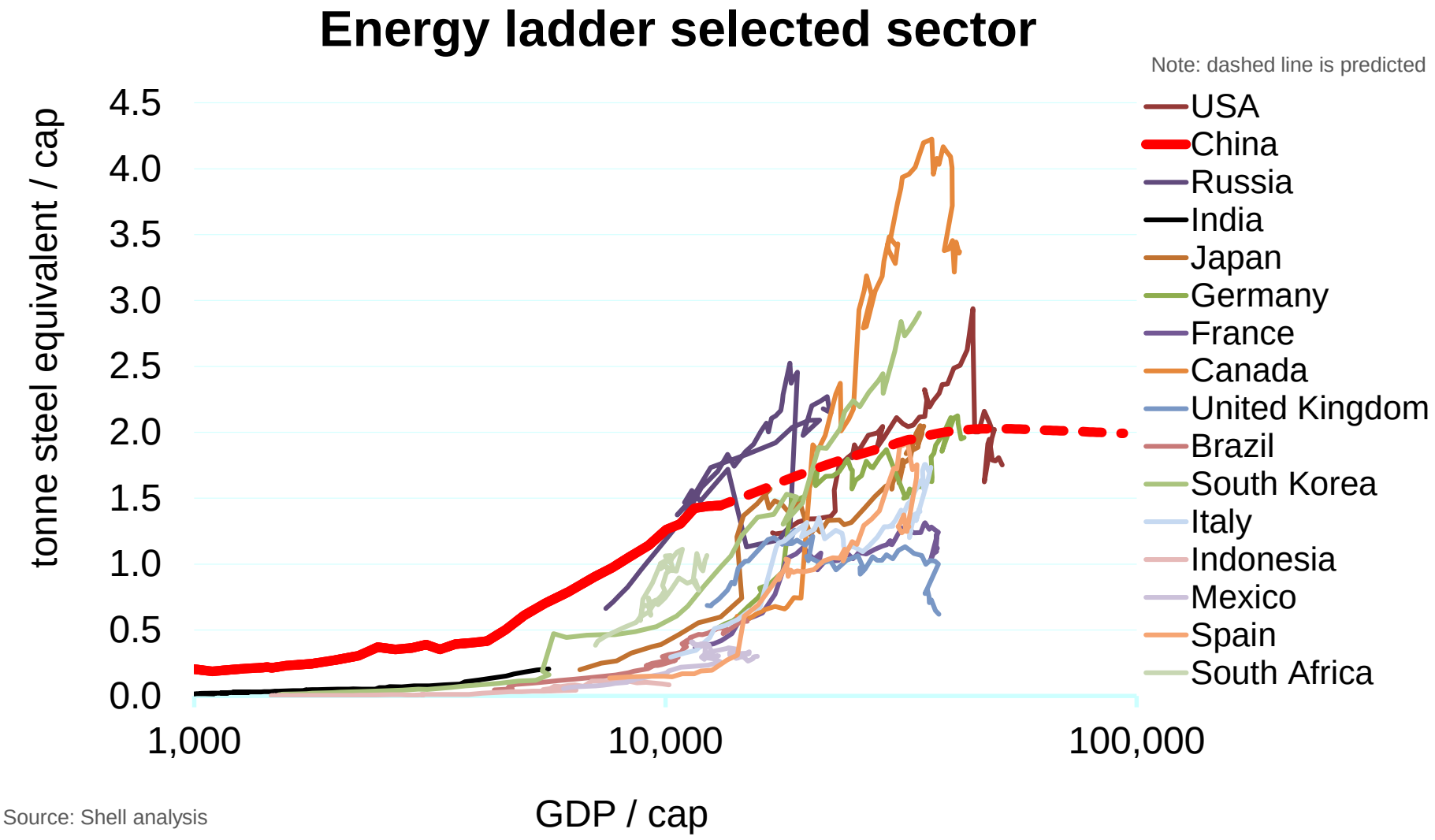
Source: Shell analysis

Energy Ladder example: Heavy Industry in India



Source: Shell analysis

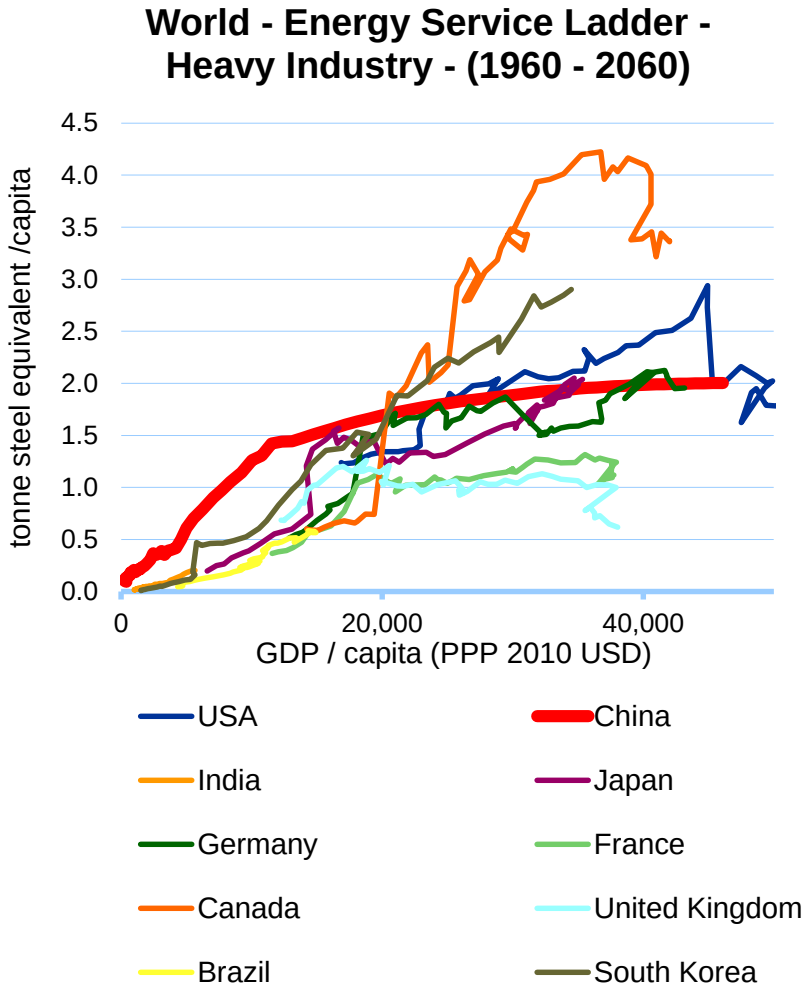
Energy Ladder example: Heavy Industry in China



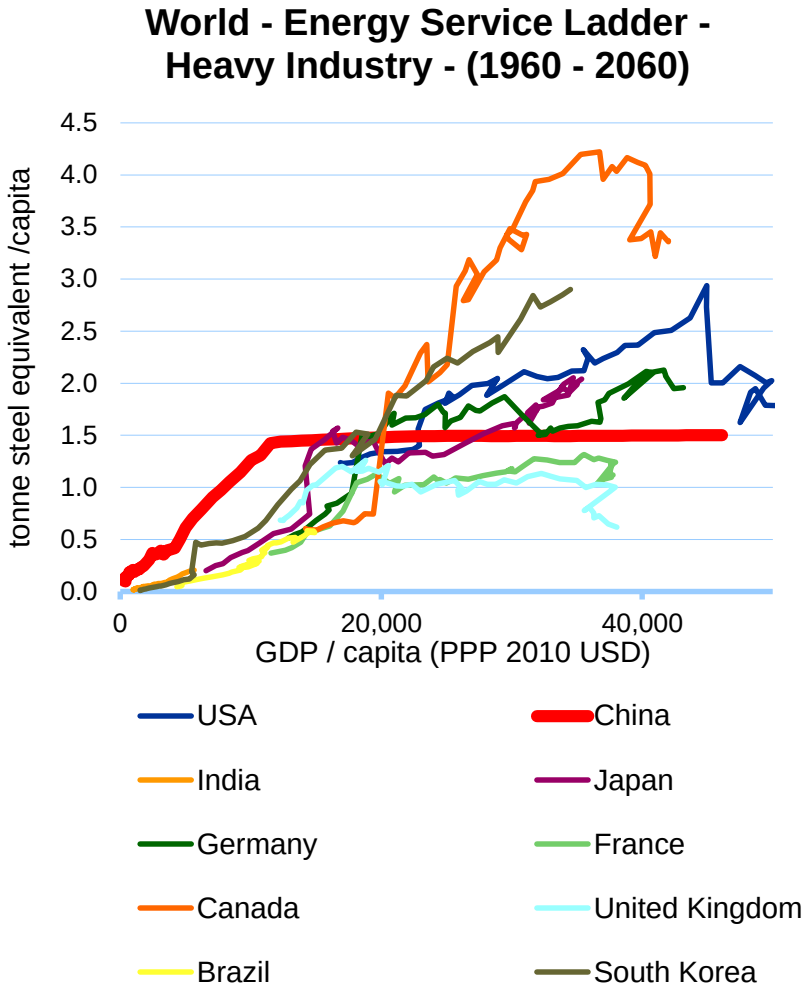
Source: Shell analysis

Heavy Industry: what if China's demand is flat?

Base case



'China flat' scenario

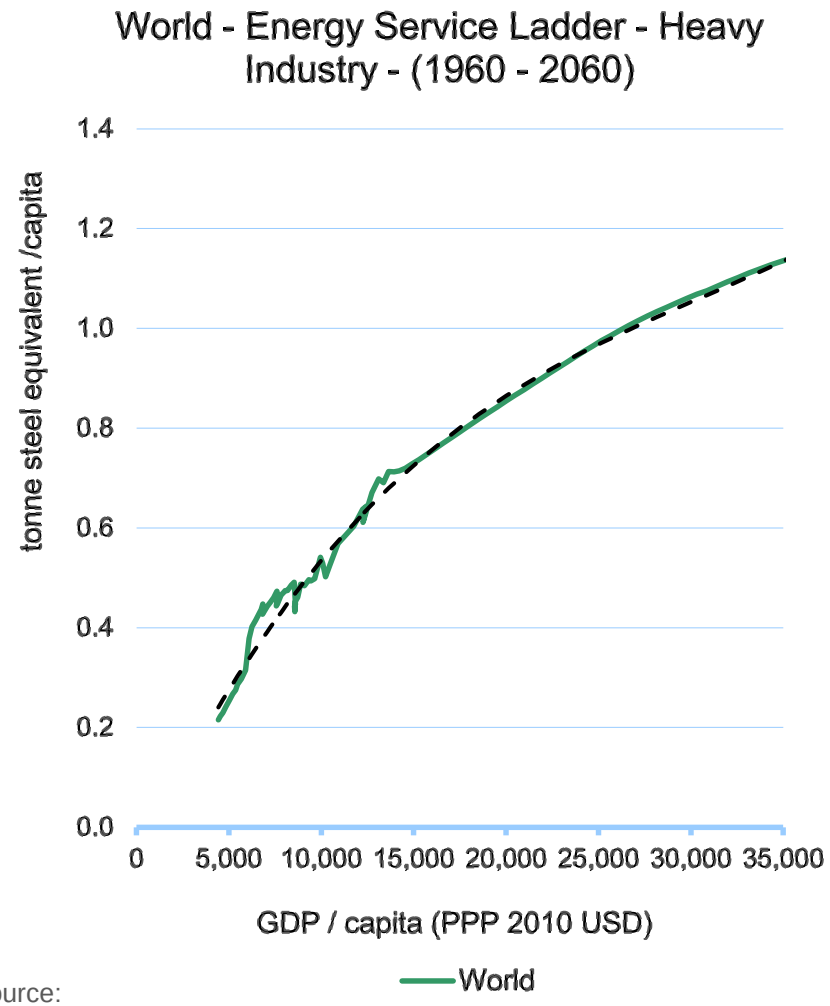


Source: FSB Energy - Shell WEM v2.8.6

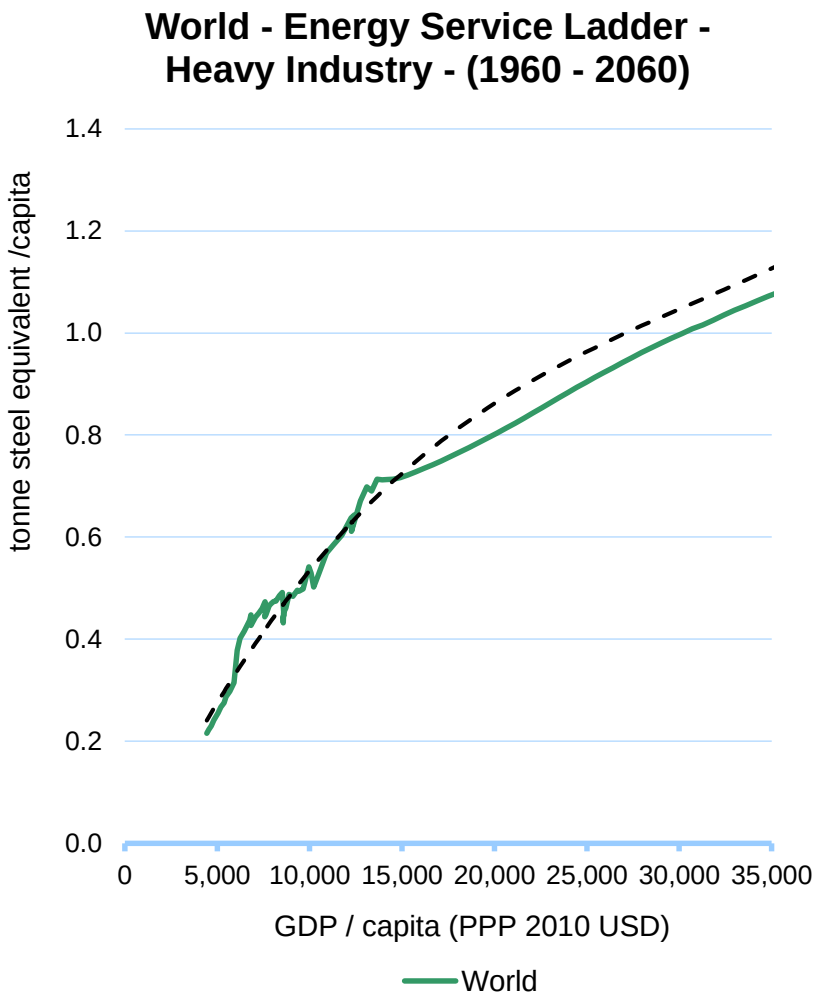
FSB Energy - Shell WEM v2.8.6 - China Flat HI

‘China flat’ leads to slowdown in global Heavy Industry

Base case



‘China flat’ scenario



Source:

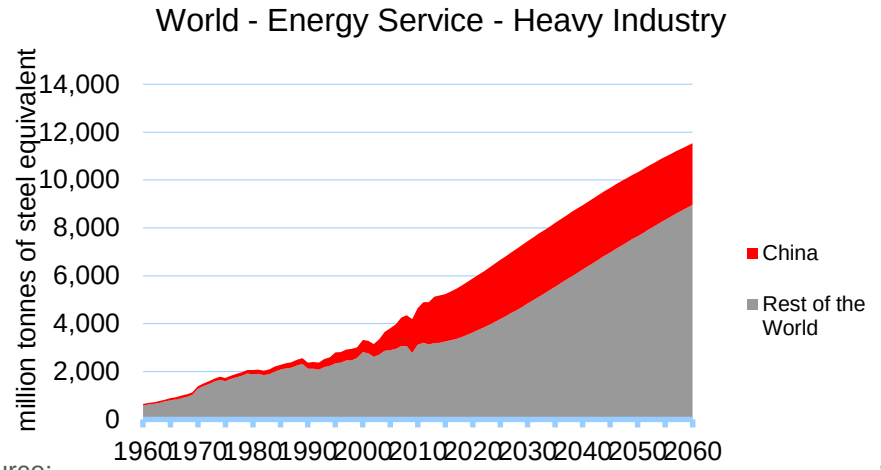
FSB Energy - Shell WEM v2.8.7

FSB Energy - Shell WEM v2.8.6 - China Flat HI

Note: dashed included to compare the ‘China flat’ scenario with the base case

China's share of world *Heavy Industry* (tonnes of steel equivalent) declines from 38% in 2015 to 23% in 2060

Base case



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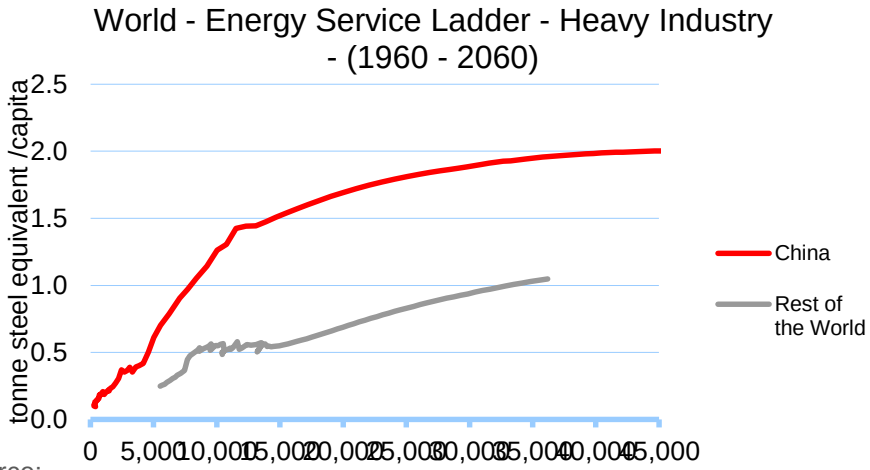

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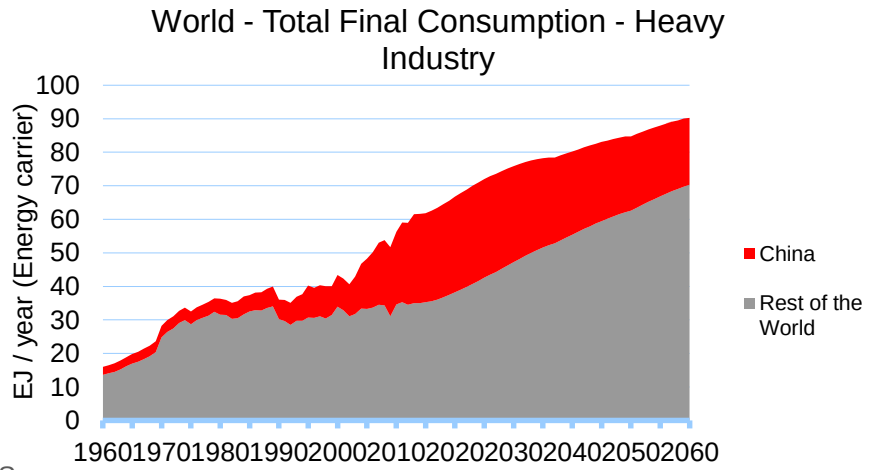

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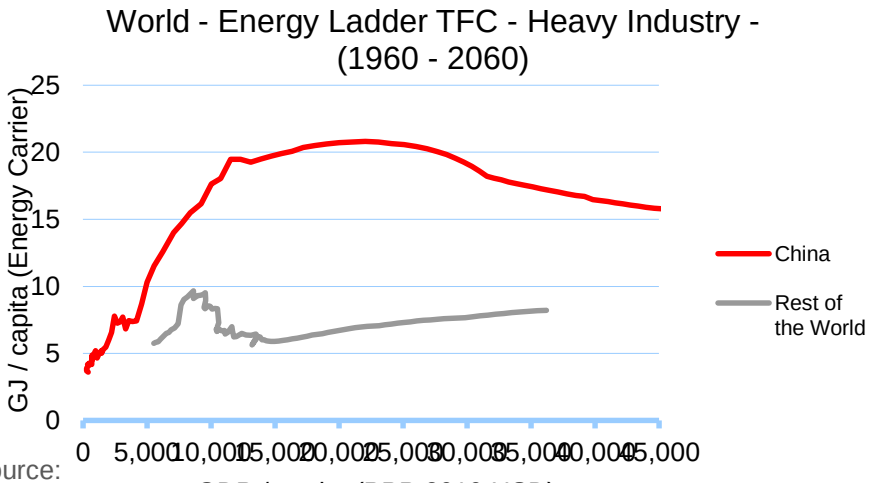

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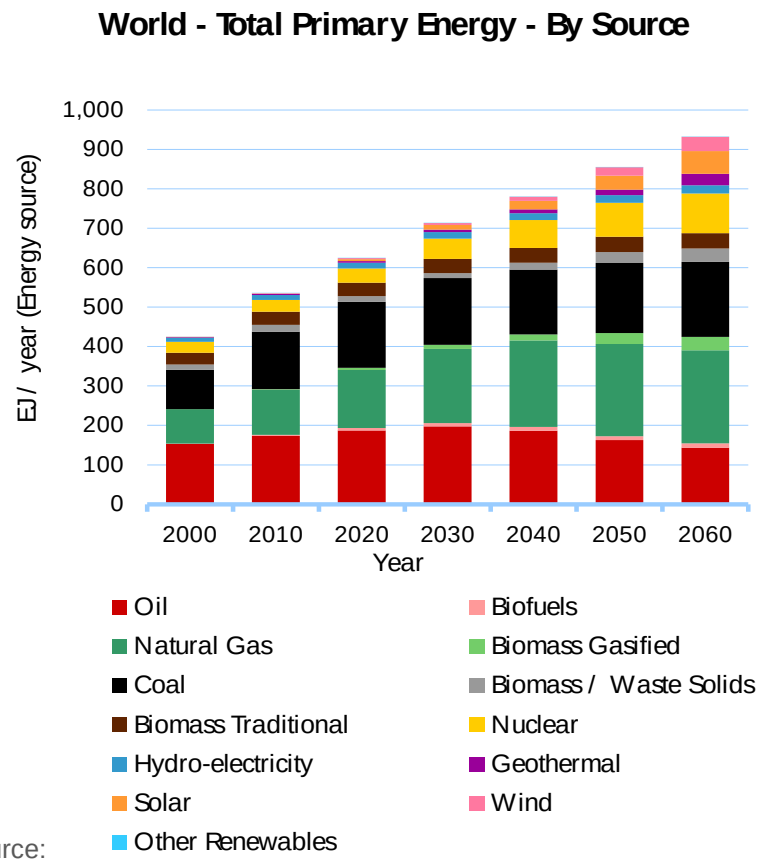
Energy demand may double in the first half of this century

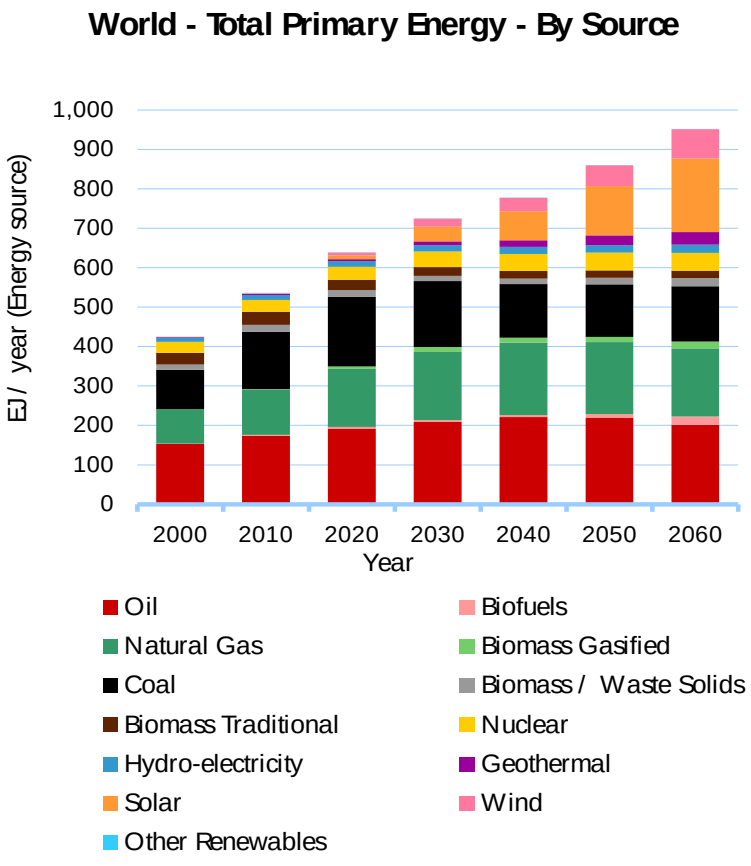
Mountains



Source:

FSB Energy - Shell WEM v2.5.20 - Mountains - Balanced

Oceans



FSB Energy - Shell WEM v2.5.20 - Oceans - Balanced