THE ENERGY LADDER
A model for projecting energy demand

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Shell’s New Lens Scenarios

Mountains

World - Total Primary Energy - By Source

- Oil
- Natural Gas
- Coal
- Biomass Traditional
- Hydro-electricity
- Solar
- Other Renewables
- Biofuels
- Biomass Gasified
- Biomass / Waste Solids
- Nuclear
- Geothermal
- Wind

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

Oceans

World - Total Primary Energy - By Source

- Oil
- Natural Gas
- Coal
- Biomass Traditional
- Hydro-electricity
- Solar
- Other Renewables
- Biofuels
- Biomass Gasified
- Biomass / Waste Solids
- Nuclear
- Geothermal
- Wind

Source: FSB Energy - Shell WBM v2.5.20 - Oceans - Balanced
Net-zero emissions world, towards the end of the century

Assumes 50% electrification of end use.

Source: Shell analysis
Six key drivers of the energy system

- Population
- Economic Growth
- Environmental Pressures
- Technology
- Resource Availability
- People’s Choices
Three core models form the heart of the World Energy Model

**TOTAL DEMAND**
- Energy vs. GDP/person
- Residential, Industry & Transport

**ENERGY CHOICE**
- Market Share vs. Price differential
- End User & Energy Producers

**ENERGY SUPPLY**
- Production/year vs. Time
- Fossil, Nuclear & Renewables
Energy Ladder – the relationship between energy demand and incomes is non-linear and partially country-specific

The Energy Ladder, 1960 - 2015 *


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

Copyright of Shell International BV
The inexorable link: economic growth and energy demand

The Energy Ladder, 1960 - 2012 *

Primary energy (GJ / capita / year)

GDP (PPP) / capita (2010 USD) [log scale]

USA, CAN

FRA, DEU, GBR

JPN

300-350 North America

130-160 W Europe, Japan

* 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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The inexorable link: economic growth and energy demand

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The inexorable link: economic growth and energy demand

The Energy Ladder, 1960 - 2012 *

North America

Scandinavia, Australia, Asian Tigers

W Europe, Japan

* 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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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)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Unit of Energy service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Industry</td>
<td>Tonne of steel</td>
</tr>
<tr>
<td>Other Industry</td>
<td>Heating requirement in buildings</td>
</tr>
<tr>
<td>Services</td>
<td>Heating requirement in buildings</td>
</tr>
<tr>
<td>Passenger Transport</td>
<td>Passenger kilometre</td>
</tr>
<tr>
<td>Freight Transport</td>
<td>Tonne kilometre</td>
</tr>
<tr>
<td>Residential Heating</td>
<td>Heating requirement in buildings</td>
</tr>
<tr>
<td>Lighting Cooking</td>
<td>Heating requirement in buildings</td>
</tr>
<tr>
<td>Residential Appliances</td>
<td>Electricity need (benchmark = fridge)</td>
</tr>
<tr>
<td>Non energy</td>
<td>Oil equivalent for output</td>
</tr>
</tbody>
</table>
... 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:

  \[ ES_{cap_{it}} = c_i + a \cdot GDP_{cap_{it}} + b \cdot Price_{it} + \epsilon_{it} \]

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

  \[ ES_{cap_{i,maturity}} = c + a \cdot X_i + \epsilon_i \]

- **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.

Energy service per capita (GDP/cap = $30k)

\[
ES\text{cap}_{i,\text{mat}} = cpatter_{n} - 0.003 \cdot ES\text{Price}_{i,\text{mat}}
\]

R-squared = 92.4%

Percentage of variation in demand explained by this model.

Source: Shell analysis

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

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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)

Energy service per capita (GDP/cap > $30k)

\[ E_{\text{Scap}}_{it} = c_i + \alpha_p \cdot GDP_{\text{capit}} + b \cdot Price_{it} + \epsilon_{it} \]

Price Elasticity = \( b \cdot \frac{E_{\text{Scap}}}{Price} \)

Coefficients:

<table>
<thead>
<tr>
<th>Coefficient/P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDPcap</td>
</tr>
<tr>
<td>-1.2358e-05 0.03561</td>
</tr>
<tr>
<td>GDPcap2</td>
</tr>
<tr>
<td>7.3795e-05 &lt; 2.2e-16</td>
</tr>
<tr>
<td>GDPcap3</td>
</tr>
<tr>
<td>5.5433e-05 1.449e-07</td>
</tr>
<tr>
<td>Price</td>
</tr>
<tr>
<td>-4.7291e-04 0.03194</td>
</tr>
</tbody>
</table>

Effects statistically significant if P-value < 0.05

*Countries removed:
- Oil & gas countries
- Small countries

Source: Shell analysis

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Energy Ladder example: Heavy Industry in India

Energy ladder selected sector

Source: Shell analysis

Note: dashed line is predicted
Energy Ladder example: Heavy Industry in China

Energy ladder selected sector

Source: Shell analysis

Note: dashed line is predicted
Heavy Industry: what if China’s demand is flat?

**Base case**

World - Energy Service Ladder - Heavy Industry - (1960 - 2060)

- USA
- India
- Germany
- Canada
- Brazil
- China
- Japan
- France
- United Kingdom
- South Korea

**‘China flat’ scenario**

World - Energy Service Ladder - Heavy Industry - (1960 - 2060)

- USA
- India
- Germany
- Canada
- Brazil
- China
- Japan
- France
- United Kingdom
- South Korea

Source: FSB Energy - Shell WEM v2.8.6
‘China flat’ leads to slowdown in global Heavy Industry

**Base case**

World - Energy Service Ladder - Heavy Industry - (1960 - 2060)

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

**‘China flat’ scenario**

World - Energy Service Ladder - Heavy Industry - (1960 - 2060)

Source:
FSB Energy - Shell WEM v2.8.7

FSB Energy - Shell WEM v2.8.6 - China Flat HI
China’s share of world **Heavy Industry** (tonnes of steel equivalent) declines from 38% in 2015 to 23% in 2060

**Base case**

World - Energy Service - Heavy Industry

World - Energy Service Ladder - Heavy Industry - (1960 - 2060)

World - Total Final Consumption - Heavy Industry

World - Energy Ladder TFC - Heavy Industry - (1960 - 2060)

Source: FSB Energy - Shell WEM v2.8.6
Energy demand may double in the first half of this century

Mountains

Oceans

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