



Part 4: Renewable Electricity Output and Integration Modelling

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Demand Side Modelling

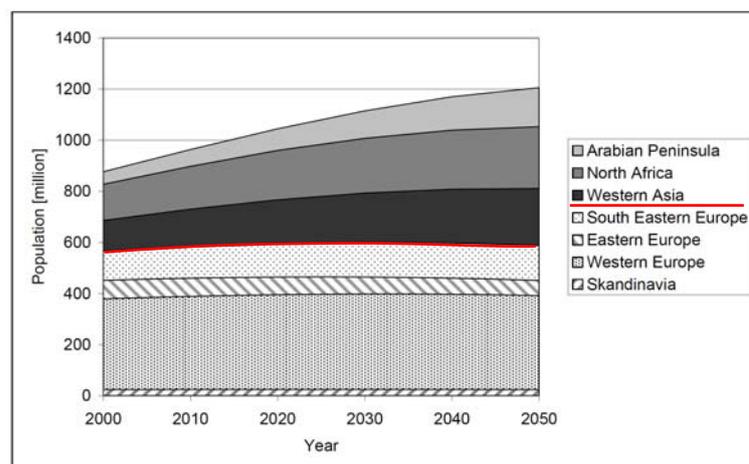
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Mounting an Electricity Demand Scenario

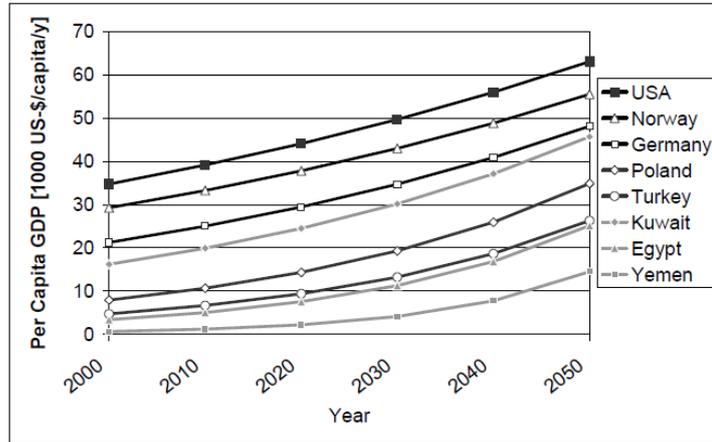
1. Present Annual Demand and Peak Load from National Power Statistics
2. Defining and Quantifying Electricity Demand Drivers
3. Future Annual Demand and Peak Load Perspectives
4. Required Security Margin for Power Capacity

1st Driver for Power Demand: Population



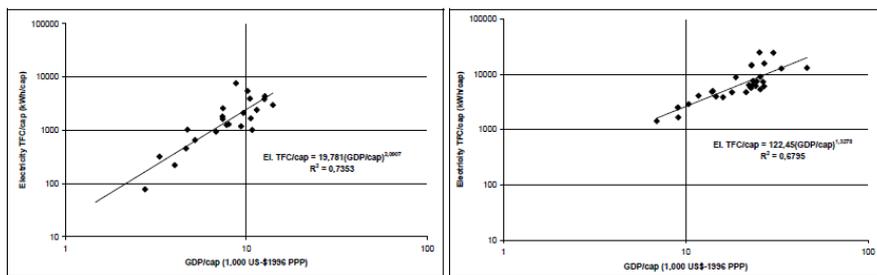
from United Nations World Population Prospects

2nd Driver for Power Demand: Economic Growth



from own estimates or other outlook studies

3rd Driver for Power Demand: Efficiency Gains

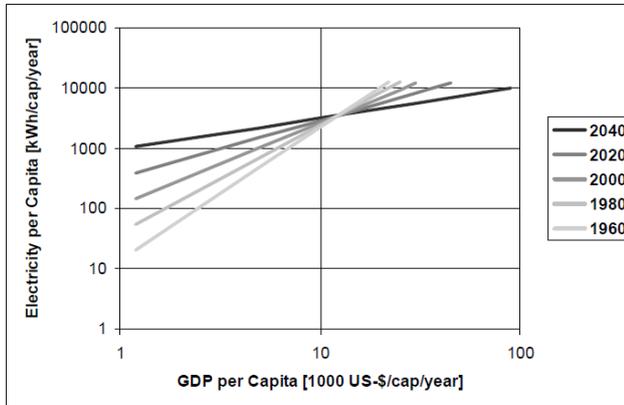


a) In the year 1960

b) In the year 2000

Figure 4: Examples for correlation between total final consumption per capita and GDP per capita. Data sources: (Heston et al. 2002), (IEA 2003-1,2), (Statistisches Bundesamt 2003)

3rd Driver for Power Demand: Efficiency Gains



empirical uncoupling of power demand and gross domestic product (GDP)

$$\hat{y}_{i,t} = a_t \cdot x_{i,t}^{b_t}$$

t = time variable
 i = country
 x = GDP per capita
 y = electricity per capita

$$a(t) = 13.65 \cdot \exp(0,0531 \cdot (t - t_0))$$

$$b(t) = 2.2131 - 0.0212 \cdot (t - t_0)$$

Electricity Demand Scenario

$$\tilde{y}(t) = \hat{y}(t) \cdot (1 + \delta(t)) + \varphi(t)$$

correction function

$$\delta(t) = \delta(t_E) \cdot \varepsilon(t) + \delta(t_S) \cdot (1 - \varepsilon(t))$$

electricity distribution losses

$$\varphi(t) = \varphi(t_E) \cdot \varepsilon(t) + \varphi(t_S) \cdot (1 - \varepsilon(t))$$

change of demand pattern

$$\varepsilon = \frac{t - t_S}{t_E - t_S}$$

2001 ≤ t ≤ 2050 weighting factor

$$y(t) = y(t_S) \cdot (1 - \varepsilon(t)) + \tilde{y}(t) \cdot \varepsilon(t)$$

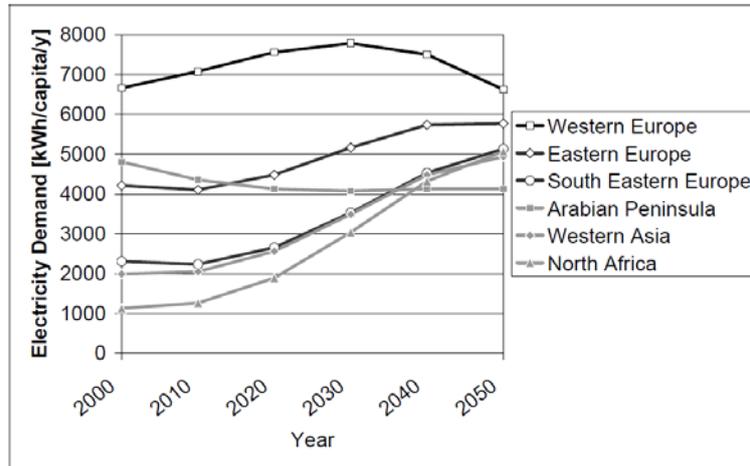
demand function

t_S = start time

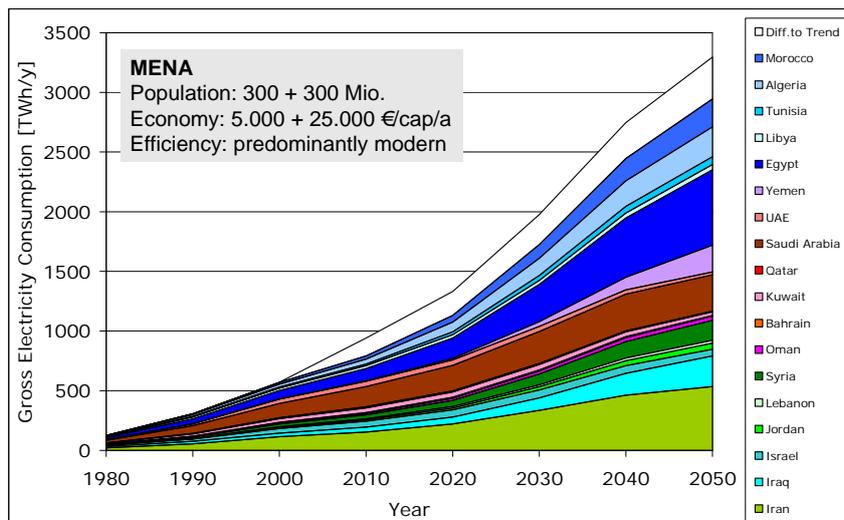
t_E = end time

use for own estimates or use other outlook studies

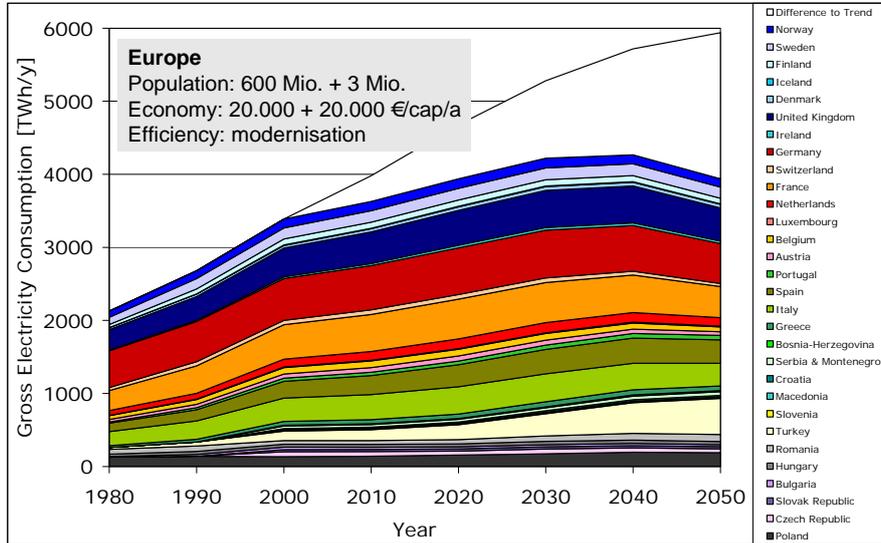
Per Capita Electricity Demand Scenario



Annual Electricity Demand Scenario MENA



Annual Electricity Demand Scenario Europe



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Demand Scenario Assumptions

Peak load assumed to grow proportional to consumption.
Minimum firm capacity reserve kept constant 25% over peak load.
Time pattern of load assumed to stay constant.

| | Peak Load [GW] | Electricity [TWh/y] | Full Load [h/y] |
|----------|----------------|---------------------|-----------------|
| Spain | 34,7 | 228,2 | 6576 |
| Germany | 83,4 | 571,5 | 6853 |
| France | 75,3 | 471,1 | 6256 |
| Italy | 52,4 | 319,6 | 6100 |
| Greece | 8,6 | 53,8 | 6253 |
| Slovakia | 4,0 | 28,1 | 7114 |
| Poland | 21,0 | 138,8 | 6611 |
| Sweden | 27,0 | 150,1 | 5559 |
| Turkey | 19,6 | 128,4 | 6551 |

Start values 2000

➔ minimum availability of power = 125% of peak load



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Supply Side Modelling

Portfolio of Supply Options:

- ✓ Coal, Lignite
 - ✓ Oil, Gas
 - ✓ Nuclear Fission
 - ✓ Concentrating Solar Power (CSP)
 - ✓ Geothermal Power (Hot Dry Rock)
 - ✓ Biomass
 - ✓ Hydropower
 - ✓ Wind Power
 - ✓ Photovoltaic
 - ✓ Wave / Tidal
- } ideally stored primary energy
- } storable primary energy
- } fluctuating primary energy

Portfolio of Supply Options

| | Unit Capacity | Capacity Credit * | Capacity Factor ** | Resource | Applications | Comment |
|-----------------------------------|----------------|--|--------------------|--|----------------------|---|
| Wind Power | 1 kW – 5 MW | 0 – 30 % | 15 – 50 % | kinetic energy of the wind | electricity | fluctuating, supply defined by resource |
| Photovoltaic | 1 W – 5 MW | 0 % | 5 – 25 % | direct and diffuse irradiance on a tilted surface | electricity | fluctuating, supply defined by resource |
| Biomass | 1 kW – 25 MW | 50 - 90 % | 40 – 60 % | biogas from the decomposition of organic residues, solid residues and wood | electricity and heat | seasonal fluctuations but good storability, power on demand |
| Geothermal (Hot Dry Rock) | 25 – 50 MW | 90 % | 40 – 90 % | heat of hot dry rocks in several 1000 meters depth | electricity and heat | no fluctuations, power on demand |
| Hydropower | 1 kW – 1000 MW | 50 - 90 % | 10 – 90 % | kinetic energy and pressure of water streams | electricity | seasonal fluctuation, good storability in dams, used also as pump storage for other sources |
| Solar Updraft | 100 – 200 MW | 10 to 70 % depending on storage | 20 to 70 % | direct and diffuse irradiance on a horizontal surface | electricity | seasonal fluctuations, good storability, base load power |
| Concentrating Solar Thermal Power | 10 kW – 200 MW | 0 to 90 % depending on storage and hybridisation | 20 to 90 % | direct irradiance on a surface tracking the sun | electricity and heat | fluctuations are compensated by thermal storage and (bio)fuel, power on demand |
| Gas Turbine | 0.5 – 100 MW | 90 % | 10 – 90 % | natural gas, fuel oil | electricity and heat | power on demand |
| Steam Cycle | 5 – 500 MW | 90 % | 40 – 90 % | coal, lignite, fuel oil, natural gas | electricity and heat | power on demand |
| Nuclear | > 500 MW | 90 % | 90 % | uranium | electricity and heat | base load power |

Table 2: Some characteristics of contemporary power technologies. * Contribution to firm power and reserve capacity. ** Average annual utilisation.

Mounting an Electricity Supply Scenario

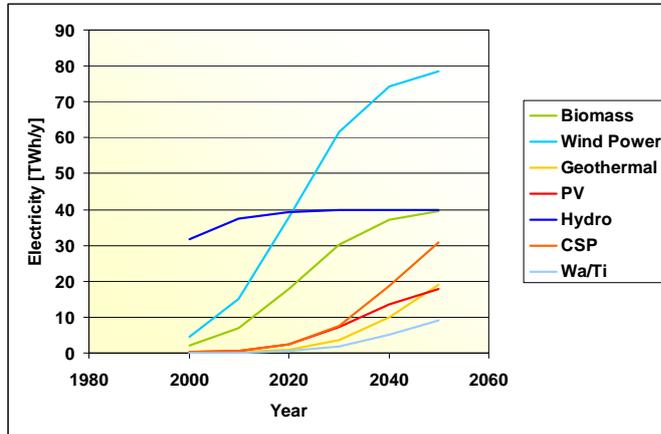
1. Integrated renewable shares cannot be larger than resource potentials
2. Technology growth rates must be achievable and sustainable
3. New capacity will equal demand minus existing capacity
4. Sustainability criteria must be satisfied
5. Annual electricity consumption must equal annual electricity generation
6. Firm capacity must equal 125% of peak load
7. Scenario results should match hourly power balance modeling

Growth Function:

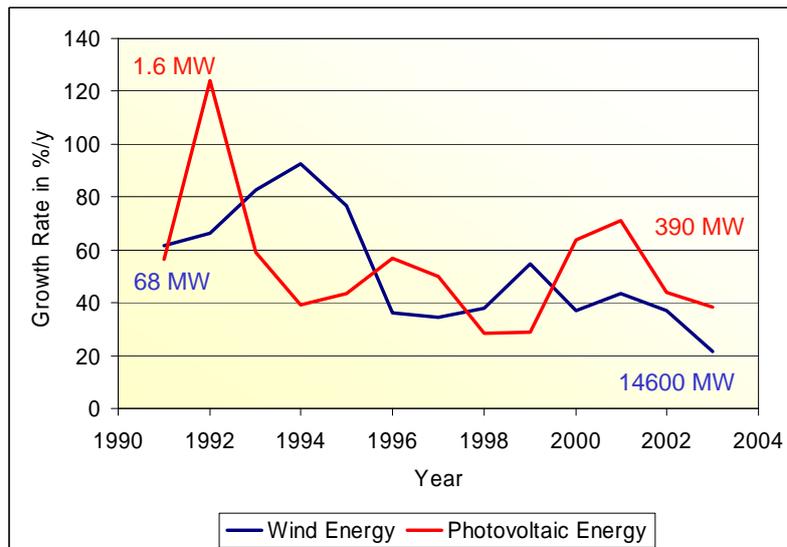
$$f(t) = G \cdot \frac{1}{1 + e^{-k \cdot G \cdot t} \left(\frac{G}{f(0)} - 1 \right)}$$

G potential
 f(0) start value
 t time
 k shape factor

potential G
 from
 resource
 mapping

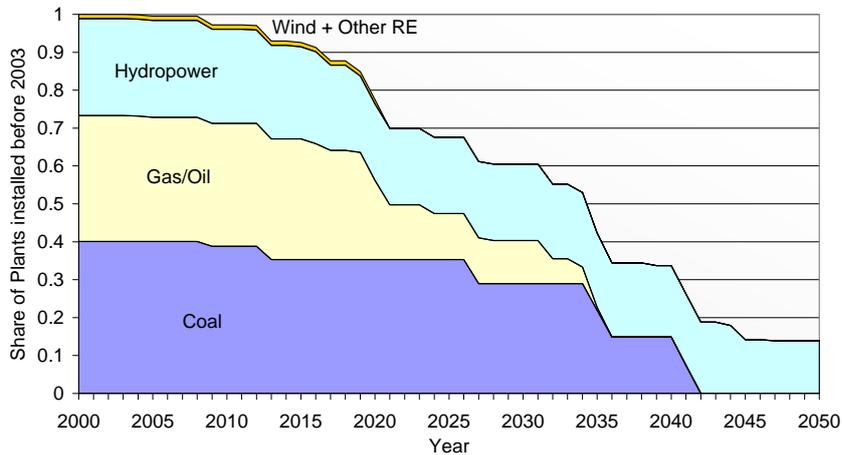


Growth Rates of PV and Wind Power in Germany



Life curve of power plants in Morocco installed before 2003

Old Power Plants in Morocco
Total Capacity 2003 = 4 700 MW



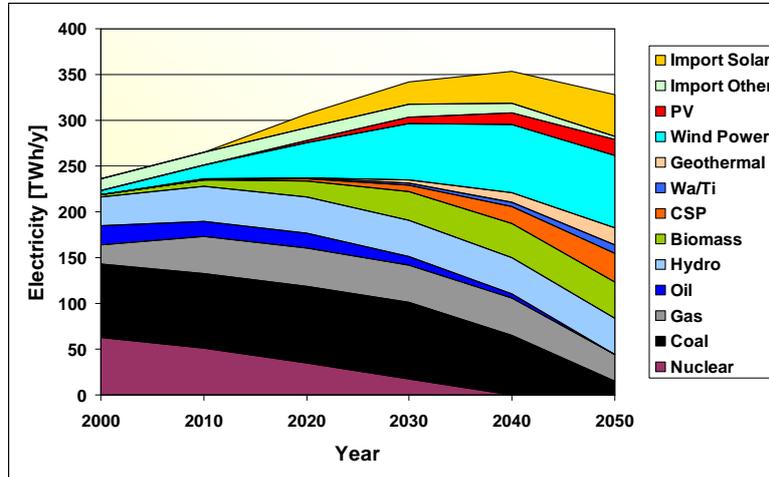
Criteria for Sustainable Electricity Supply Target:

- ✓ **Inexpensive**
 - low electricity cost
 - no long term subsidies

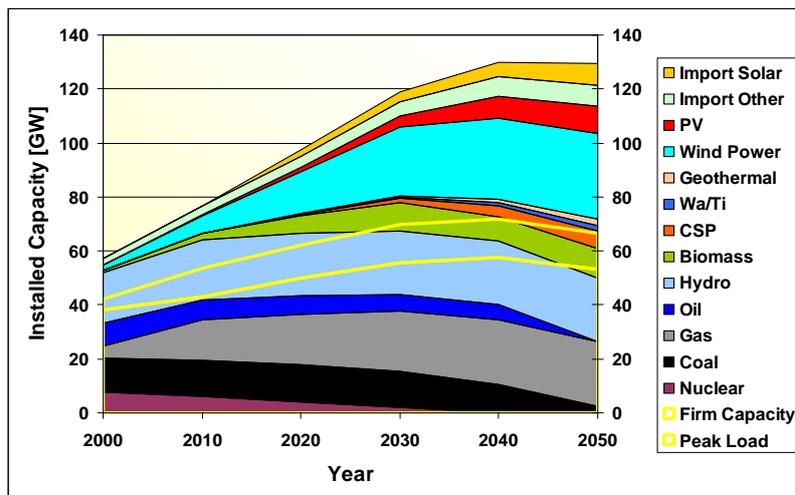
- ✓ **Secure**
 - diversified and redundant supply
 - power on demand
 - based on inexhaustible resources
 - available or at least visible technology
 - capacities expandable in time

- ✓ **Compatible**
 - low pollution
 - climate protection
 - low risks for health and environment
 - fair access

Energy Balance: Supply = Demand



Power Balance: Firm Capacity = Peak Load x 125%



Electricity generation according to availability and needs

| Electricity in TWh/a | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|----------------------|-------|-------|-------|-------|-------|-------|
| Consumption | 228,2 | 257,7 | 299,1 | 334,6 | 345,8 | 320,1 |
| Wind | 4,7 | 15,2 | 37,6 | 61,7 | 74,2 | 78,4 |
| Photovoltaics | 0,2 | 0,7 | 2,5 | 7,1 | 13,5 | 17,8 |
| Geothermal | 0,1 | 0,3 | 1,0 | 3,6 | 10,0 | 19,1 |
| Biomass | 2,1 | 7,0 | 17,8 | 30,3 | 37,1 | 39,5 |
| CSP Plants | 0,2 | 0,6 | 2,3 | 7,6 | 18,8 | 30,8 |
| Wave / Tidal | 0,0 | 0,1 | 0,5 | 1,9 | 5,0 | 9,2 |
| Hydropower | 31,8 | 37,5 | 39,3 | 39,8 | 40,0 | 40,0 |
| Oil / Gas | 41,6 | 57,4 | 57,7 | 50,6 | 44,9 | 29,2 |
| Oil | 20,6 | 16,5 | 16,5 | 9,4 | 3,8 | 0,0 |
| Gas | 21,0 | 40,9 | 41,2 | 41,2 | 41,2 | 29,2 |
| Coal | 80,0 | 82,0 | 84,0 | 84,0 | 65,0 | 15,0 |
| Nuclear | 63,0 | 50,7 | 35,0 | 16,9 | 0,0 | 0,0 |
| Import Other | 12,3 | 14,0 | 14,0 | 14,0 | 10,0 | 4,0 |
| Import Solar | 0 | 0 | 15 | 25 | 35 | 45 |

Capacity x Full Load Hours = Electricity Supply

Full load hours according to availability and needs

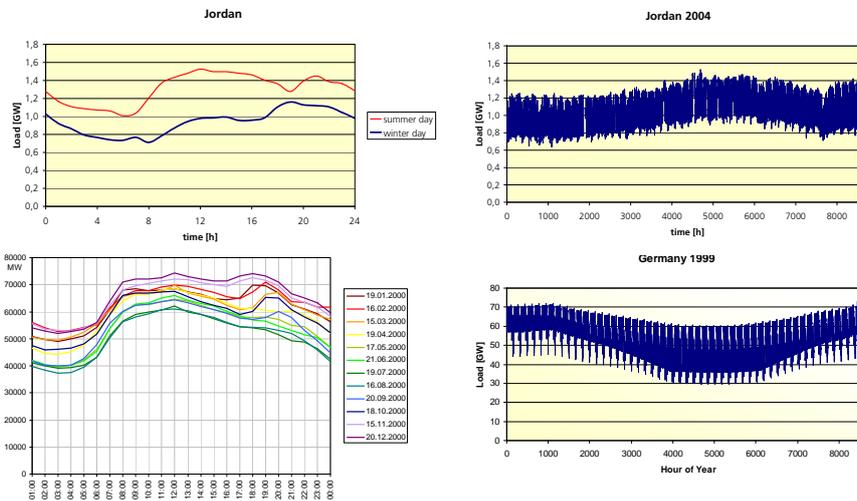
| Full Load Hours h/a | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|--------------------------|------|------|------|------|------|------|
| Load | 6005 | 6005 | 6005 | 6005 | 6005 | 6005 |
| Wind | 2325 | 2359 | 2393 | 2427 | 2460 | 2494 |
| Photovoltaics | 1353 | 1515 | 1677 | 1697 | 1707 | 1717 |
| Geothermal | 7500 | 7500 | 7500 | 7500 | 7500 | 7500 |
| Biomass | 2800 | 2800 | 2800 | 2800 | 4000 | 3500 |
| CSP Plants | 1900 | 3500 | 4500 | 5000 | 5000 | 5000 |
| Wave / Tidal | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 |
| Hydropower | 1705 | 1705 | 1705 | 1705 | 1705 | 1705 |
| Oil / Gas | 3261 | 2533 | 2240 | 1787 | 1517 | 1225 |
| Oil | 2458 | 2185 | 2427 | 1537 | 686 | 686 |
| Gas | 4805 | 2707 | 2173 | 1856 | 1707 | 1225 |
| Coal | 6202 | 6202 | 6202 | 6202 | 6202 | 6202 |
| Nuclear | 8367 | 8367 | 8367 | 8367 | 8367 | 8367 |
| Import Other (incl. Sol: | 4920 | 4667 | 3500 | 2800 | 1333 | 533 |
| Import Solar HVDC) | 0 | 0 | 6000 | 6250 | 7000 | 5625 |

Installed capacity according to availability and needs

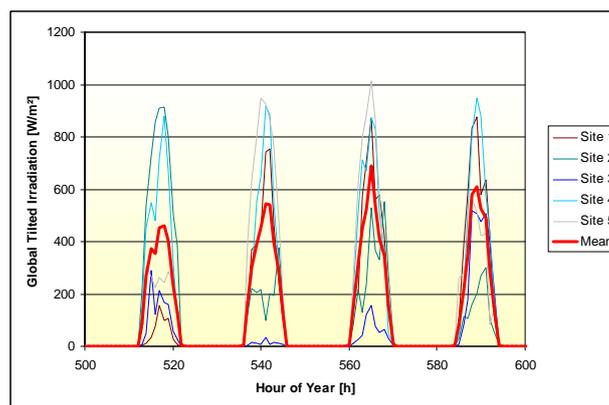
| Capacity in GW | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|------------------|-------------|------------|------------|------------|------------|------------|
| Peak Load | 38,0 | 42,91 | 49,80 | 55,72 | 57,58 | 53,31 |
| Wind | 2,00 | 6,43 | 15,73 | 25,42 | 30,16 | 31,43 |
| Photovoltaics | 0,15 | 0,49 | 1,51 | 4,19 | 7,93 | 10,34 |
| Geothermal | 0,01 | 0,04 | 0,14 | 0,48 | 1,33 | 2,54 |
| Biomass | 0,75 | 2,48 | 6,36 | 10,82 | 9,28 | 11,28 |
| CSP Plants | 0,09 | 0,18 | 0,52 | 1,51 | 3,76 | 6,17 |
| Wave / Tidal | 0,01 | 0,04 | 0,14 | 0,46 | 1,26 | 2,29 |
| Hydropower | 18,65 | 21,97 | 23,05 | 23,35 | 23,43 | 23,45 |
| Oil / Gas | 12,77 | 22,67 | 25,75 | 28,30 | 29,63 | 23,87 |
| Oil | 8,4 | 7,56 | 6,80 | 6,12 | 5,51 | 0,00 |
| Gas | 4,4 | 15,11 | 18,94 | 22,18 | 24,11 | 23,87 |
| Coal | 12,9 | 13,22 | 13,55 | 13,55 | 10,48 | 2,42 |
| Nuclear | 7,5 | 6,06 | 4,18 | 2,02 | 0,00 | 0,00 |
| Import Other | 2,5 | 3,0 | 4,0 | 5,0 | 7,5 | 7,5 |
| Import Solar | 0,0 | 0,0 | 2,5 | 4,0 | 5,0 | 8,0 |

Hourly Time Series Modelling

National Daily and Annual Time Series of Demand

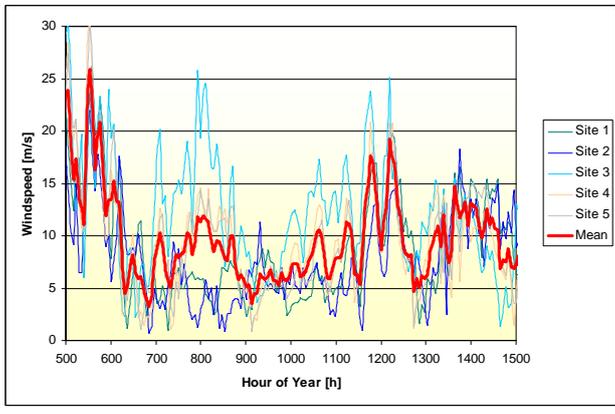


Photovoltaic Energy Resources



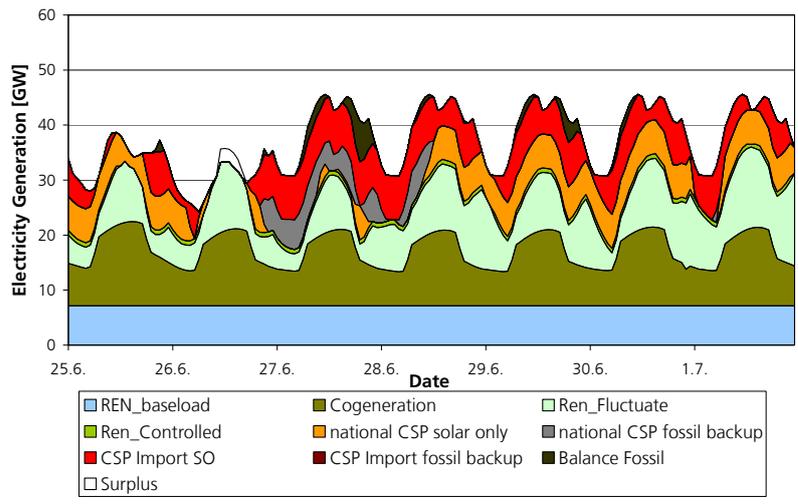
Example: GTI at 5 sites and mean value

Wind Energy Resources

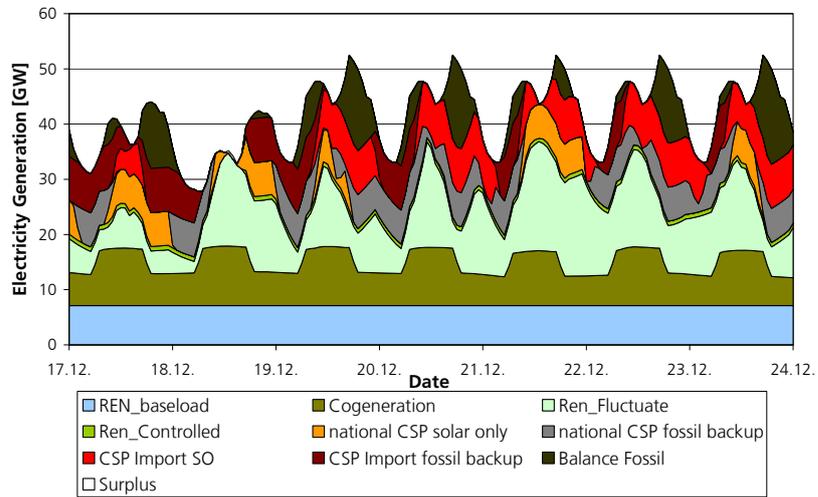


Example: Wind speed at 80 m for 5 sites and mean value

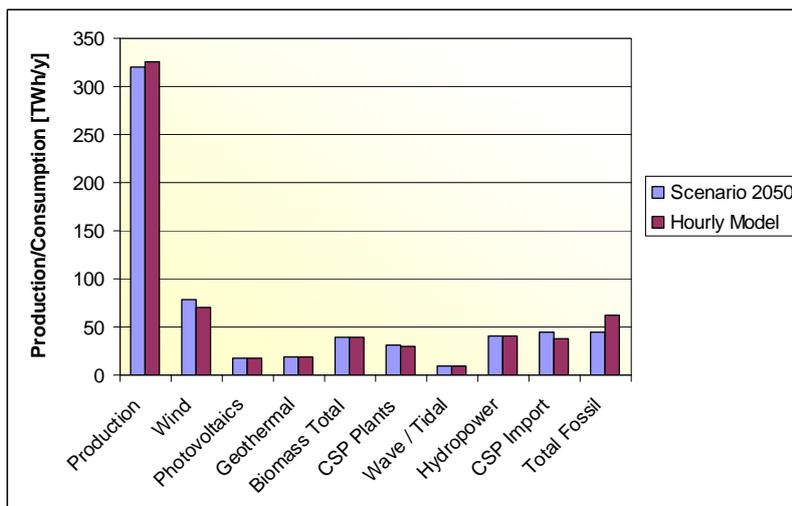
Hourly Model: Summer Week 2050

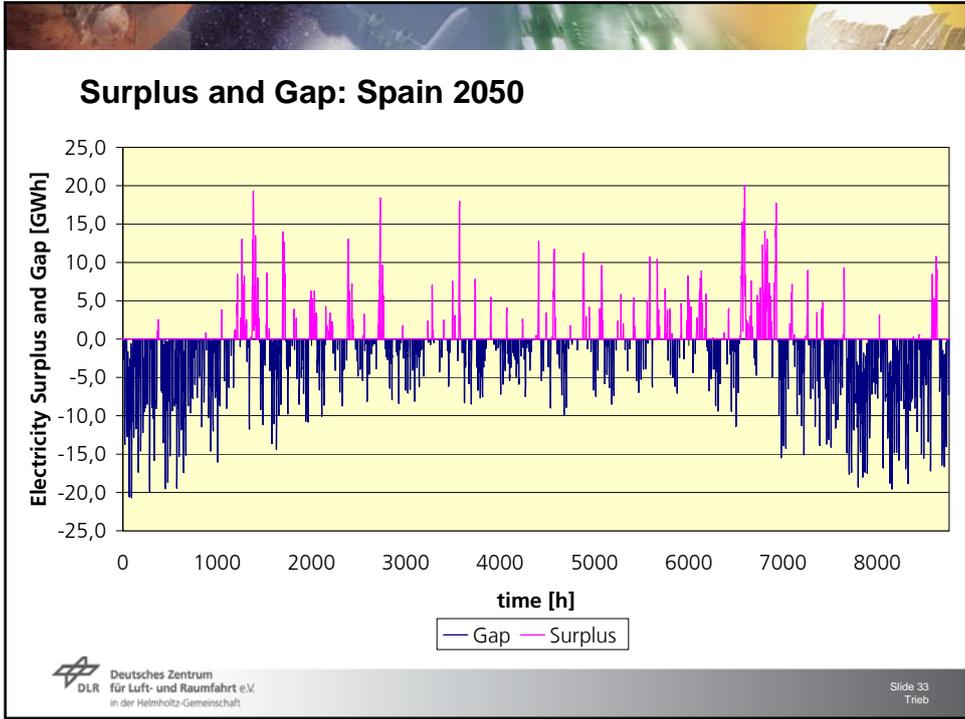


Hourly Model: Winter Week 2050



Scenario versus Hourly Model: Spain 2050





Conclusions

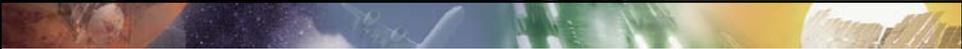
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The Old Paradigm

Renewable sources of electricity are widely dispersed, fluctuating and unpredictable. Therefore, they will never be able to cover base load.



What has been overlooked

- 1. Electric load is the statistic addition of widely dispersed, fluctuating and unpredictable consumers.**
- 2. „Base load plants“ can only operate at constant power. There is no use in itself for plants restricted to that operation mode.**



The New Paradigm

A well balanced mix of renewable and conventional sources of electricity can cover base load, medium load and peak load demand.

Conventional base load plants will disappear while conventional peaking and balancing power plants will remain.