Part 1: Sustainability in the Electricity Sector

Franz Trieb

MBA Energy Management, Vienna, September 12-13, 2012
EUMENA Scenario for Sustainable Electricity and Water
Trans-Mediterranean High Voltage Direct Current Electricity Grid: Interstate Highways for Renewable Electricity in EUMENA

www.desertec.org

EUMENA:
Europe
Middle East
North Africa

Solar (CSP)
Solar (PV)
Wind
Hydro
Biomass
Geothermal
Studies:

Assessment of the renewable energy potential for the sustainable supply of electricity and water in 50 countries of Europe, the Middle East and North Africa taking into consideration the option of Concentrating Solar Thermal Power Plants (CSP).

www.dlr.de/tt/med-csp
www.dlr.de/tt/trans-csp
www.dlr.de/tt/aqua-csp
50 Countries in EUMENA analysed

Europe (EU)
- Scandinavia
- Western Europe
- Eastern Europe
- South-Eastern Europe
- Western Asia
- North Africa
- Arabian Peninsula

Middle East & North Africa (MENA)
Electricity Demand in Europe

Population x 1
Economy x 2
Efficiency x 1.5
Demand x 1.1

Gross Electricity Consumption [TWh/y]

Year


Difference to Trend
Norway
Sweden
Finland
Iceland
Denmark
United Kingdom
Ireland
Germany
Switzerland
France
Netherlands
Luxembourg
Belgium
Austria
Portugal
Spain
Italy
Greece
Bosnia-Herzegovina
Serbia & Montenegro
Croatia
Macedonia
Slovenia
Turkey
Romania
Hungary
Bulgaria
Slovak Republic
Czech Republic
Poland

www.dlr.de/tt/trans-csp
Electricity Demand in MENA

Gross Electricity Consumption [TWh/y]

- Population x 2
- Economy x 5
- Efficiency x 1.1
- Demand x 5

Year

www.dlr.de/tt/med-csp
Water Demand in MENA

Freshwater Demand [billion m³/y]

- Demand x 1.8
- Deficit x 3

Year


www.dlr.de/tt/aqua-csp
Criteria for Sustainable Electricity Supply:

✓ 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
Renewable Energy Technologies

Hydropower

Concentrating Solar Power

Tides

Biomass

Waves

Wind Power

Photovoltaic

Geothermal

http://www.erneuerbare-energien.de/inhalt/36983/35338/
High Voltage Direct Current Transmission

Voltage: ± 800,000 Volt
Power: 6400 Megawatt
Length: 2070 km
Source: Hydropower
Losses: 7-8%
Construction: 2 years
Cost: 2.5 bn €
Principle of a Concentrating Solar Thermal Power Plant

- concentrated, easily storable solar thermal energy as fuel saver
- spinning reserve
- firm capacity, power on demand
- combined generation of process heat for cooling, industry, desalination, etc.

**Concentrating Solar Collector Field (Mirrors)**

**Thermal Power Cycle (e.g. Steam Turbine)**

**Thermal Energy Storage**

**Solar Heat**

**Fuel**

**Electricity**

**Process Heat**
Portfolio of Energy Sources for Electricity:

- Coal, Lignite
- Oil, Gas
- Nuclear Fission, Fusion
- 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
Renewable Electricity Potential in Europe, Middle East & North Africa

- Biomass (0-1)
- Geothermal (0-1)
- Solar (10-250)
- Wind Energy (5-50)
- Hydropower (0-50)

Electricity Yield in GWh/km²/y

Max

Min

DLR
Economic Renewable Electricity Potentials vs. Demand in EUMENA

How Does a Sustainable Mix Look Like?
Installed Capacity vs. Peak Load in EUMENA

- Photovoltaic
- Wind Power
- Geothermal
- Hydropower
- Biomass
- Tidal/Wave
- CSP
- Oil & Gas
- Coal
- Nuclear
- Firm Capacity
- Peak Load

⇒ 100% availability plus 25% reserve capacity

www.dlr.de/tt/trans-csp
Electricity Supply in Europe (TRANS-CSP Scenario)

- Import Solar
- Photovoltaics
- Wind
- Geothermal
- Hydropower
- Biomass
- Wave / Tidal
- CSP Plants
- Oil
- Gas
- Coal
- Nuclear

www.dlr.de/tt/trans-csp
33 new additional energy supply corridors for Europe

Background: m. a. s. l.

Centres of demand in Europe

CSP sites in MENA

http://www.dlr.de/tt/csp-resources
## 33 new additional energy supply corridors for Europe

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**Case study Germany 2050**

The role of variable and flexible renewable power sources in a 90% renewable electricity scenario for the year 2050 for Germany.

**Installed Capacities:**
- Photovoltaics: 45 GW
- Wind Onshore: 40 GW
- Wind Offshore: 27 GW
- Runoff Hydropower: 6 GW
- Import CSP: 16 GW
- Import Hydro: 4 GW
- Geothermal: 4 GW
- Biomass: 9 GW
- Biomass Waste: 4 GW
- Natural Gas: 63 GW

50% var. RE
40% flex. RE
10% flex. Fuel
Why CSP imports from MENA?

Higher availability than in EU $\rightarrow$ flexible renewable power

CSP with large solar field and storage (SM4) at three sites:

**MENA advantages:**
- more sunny days
- lower latitude
- lower seasonal variation of electricity yield

www.dlr.de/tt/trans-csp
Availability and Redundancy

- Power on demand by a mix of fluctuating and balancing sources
- Increased number of non-correlated energy sources
- Increased number and reduced average size of power plants
- Increased number of supply regions
- Additional HVDC grid infrastructure for long-distance transfer
- Domestic sources dominate the electricity mix
- Non-depletable sources dominate the electricity mix
- Strategy is based on proven technologies
Life Cycle Carbon Emissions

Life Cycle Land Use


CSP Fresnel
CSP Trough
CSP Tower
Carbon emissions of EUMENA power sector are reduced to 38% until 2050 in spite of a quickly growing demand.
Environmental Security

- Reduced life cycle greenhouse gas emissions from power generation
- Reduced risks of nuclear contamination and proliferation
- Reduced local pollution by combustion products
- Optimal land use (1%) through diversified mix
- Technology based on recyclable materials
Equipment Cost Learning Curves

Nuclear Decommissioning Cost
National Audit Office UK
Nuclear Decommissioning Authority UK
11 GW Capacity
61 £ Billion of 2007
= 6000 - 9000 €/kW

WETO 2003, NAO 2008
Fuel Prices 2001 - 2011

Natural Gas
Russia

Crude Oil

Coal (thermal)
Australia

www.indexmundi.com
Electricity Cost Learning Curves (example Spain)
Electricity Cost (Example Spain)

Electricity Cost [c/kWh]

Year

Investment Phase  Profit Phase

TRANS-CSP Mix  BaU Mix 2000

Economic Security

- Economic risk hedged by increased portfolio
- Intrinsic trend to lower cost and lower price volatility
- Energy cost stabilization through investment in new sources
- Prevention of cost escalation due to environmental constraints
- Prevention of cost escalation due to scarcity
- Prevention of cost explosion due to nuclear decommissioning
- Reduction of energy subsidies in Europe and MENA
Electricity Supply in the Middle East & North Africa

- Desalination
- Export Solar
- Photovoltaics
- Wind
- Geothermal
- Hydropower
- Biomass
- Wave / Tidal
- CSP Plants
- Oil / Gas
- Coal
- Nuclear

www.dlr.de/tt/med-csp
Prospects for RES-E expansion in North Africa
ReMix-MENA cost optimization model for capacity expansion

- Example: Case study for Jordan
- Jordan’s situation:
  - Strongly increasing electricity demand
  - High dependency on fossil fuel imports
  - Peak- and upper mid-merit load by expensive H.F.O. and L.F.O

Source: Fichter (DLR) 2012, ReMix-MENA optimization tool
**Business case NA**

**Strongly required firm and flexible renewable power capacity**

- CSP competitive in the peak and upper-mid merit segment in the short-term.
- CSP providing strongly required firm and flexible power capacity.
- First CSP plants with rather small solar field and storage.
- Very limited availability of electricity storage and of other flexible and firm RES-E.
- PV as “fuel saver” in the peak load segment (noon-peak).
- Wind as “fuel saver” in the base load segment.
- In the medium-term CSP competitive in mid-merit and base load segment. SM and storage capacity is increased.
- CSP in long-term as back-bone of electricity supply.

*Source: Fichter (DLR) 2012, ReMix-MENA optimization tool*
AQUA-CSP Scenario for Middle East & North Africa

![Water Consumption Graph](https://www.dlr.de/tt/aqua-csp)

- Natural Water Used
- Wastewater reused
- Fossil Fuel Desalination
- Groundwater Over-Use
- CSP Desalination
- Efficiency Gains
Solar Power & Desalination Plants

Energy, Water, Food, Labor and Income

for further 300 Million People in MENA?

(artist view created with Google Earth)
Political Security

- Conflict prevention between EU and MENA reducing pressure on fuels
- Conflict prevention in MENA solving energy and water scarcity
- Conflict prevention in Europe increasing energy diversity
- Reduction of European energy import dependency
- Addition of energy corridors for European supply
- Initiating EU-MENA (Energy) Partnership
Challenges

- Requires new structures and new thinking (change of paradigm)
- Requires long-term financing schemes due to long-term investments
- Based on international cooperation and interdependencies
- Higher complexity than using ideally stored fossil energy sources
- More stakeholders involved due to decentralized generation
- Cultural and political differences in EUMENA
- Lobby groups acting against each other
- Speed of environmental change and conflict potentials
Global Achievements
Renewable Share of Global Final Energy Consumption in 2010

- Modern Renewables: 8.2%
- Traditional biomass: 8.5%
- Nuclear: 2.7%
- Fossil fuels: 80.6%

Other categories:
- Biomass/solar/geothermal hot water/heating: 3.3%
- Hydropower: 3.3%
- Wind/solar/biomass/geothermal power generation: 0.9%
- Biofuels: 0.7%
Renewable Energy Share of Global Electricity Production, 2011

- Fossil fuels and nuclear: 79.7%
- Hydro-power: 15.3%
- Other renewables (non-hydro): 5.0%

Note: Based on renewable generating capacity in operation at year-end 2011.
Average Annual Growth Rates of Renewable Energy Capacity and Biofuels Production, 2006–2011

- Solar PV: 74% growth
- Wind power: 58% growth
- Concentrating Solar Thermal Power (CSP): 35% growth
- Geothermal power: 1% growth
- Hydropower: 3% growth
- Solar hot water/heating: 27% growth
- Ethanol production: 17% growth
- Biodiesel production: 16% growth
FIGURE 4. RENEWABLE POWER CAPACITIES¹, EU 27, BRICS, AND TOP SEVEN COUNTRIES, 2011

World total
EU-27
BRICS

Wind power
Biomass power
Solar PV
Geothermal power
Others

Gigawatts
0 50 100 150 200 250 300 350 400

China
United States
Germany
Spain
Italy
India
Japan

0 10 20 30 40 50 60 70

¹ - excluding hydropower

www.ren21.net
TABLE R2. RENEWABLE ELECTRIC POWER CAPACITY, WORLD AND TOP REGIONS/COUNTRIES, TOTAL YEAR-END 2011

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>World Total</th>
<th>EU-27</th>
<th>BMUS</th>
<th>China</th>
<th>United States</th>
<th>Germany</th>
<th>Spain</th>
<th>Italy</th>
<th>India</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(GW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass power</td>
<td>72</td>
<td>26</td>
<td>17.5</td>
<td>4.4</td>
<td>13.7</td>
<td>7.2</td>
<td>0.8</td>
<td>2.1</td>
<td>3.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>11.2</td>
<td>0.9</td>
<td>0.1</td>
<td>~0</td>
<td>3.1</td>
<td>~0</td>
<td>0</td>
<td>0.8</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Ocean (tidal) power</td>
<td>0.5</td>
<td>0.2</td>
<td>~0</td>
<td>~0</td>
<td>0</td>
<td>~0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Solar PV</td>
<td>70</td>
<td>51</td>
<td>3.7</td>
<td>3.1</td>
<td>4</td>
<td>25</td>
<td>4.5</td>
<td>13</td>
<td>0.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Concentrating solar thermal power (CSP)</td>
<td>1.8</td>
<td>1.1</td>
<td>~0</td>
<td>~0</td>
<td>0</td>
<td>0.5</td>
<td>1.1</td>
<td>~0</td>
<td>~0</td>
<td>0</td>
</tr>
<tr>
<td>Wind power</td>
<td>238</td>
<td>94</td>
<td>80</td>
<td>62</td>
<td>47</td>
<td>29</td>
<td>22</td>
<td>6.7</td>
<td>16</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Total renewable power capacity</strong> (not including hydropower)</td>
<td>390</td>
<td>174</td>
<td>101</td>
<td>70</td>
<td>68</td>
<td>61</td>
<td>28</td>
<td>22</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>Per capita capacity (kW/inhabitant, not including hydropower)</td>
<td>0.06</td>
<td>0.35</td>
<td>0.03</td>
<td>0.05</td>
<td>0.22</td>
<td>0.75</td>
<td>0.60</td>
<td>0.37</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td>Hydropower</td>
<td>970</td>
<td>120</td>
<td>383</td>
<td>212</td>
<td>79</td>
<td>4.4</td>
<td>20</td>
<td>18</td>
<td>42</td>
<td>28</td>
</tr>
<tr>
<td><strong>Total renewable power capacity</strong> (including hydropower)</td>
<td>1,360</td>
<td>294</td>
<td>484</td>
<td>282</td>
<td>147</td>
<td>65</td>
<td>48</td>
<td>40</td>
<td>62</td>
<td>39</td>
</tr>
</tbody>
</table>
In 2011, 40GW of wind power capacity was installed, increasing the total to 238GW.

Annual growth rate of cumulative wind power capacity between 2006-2010 averaged at 26%

Latin America saw the most significant growth in wind power. Brazil, Argentina, Chile, Dominican Republic, Honduras and Mexico; all added capacity during 2011.
Global Wind Power Expansion Perspectives until 2015
Global Photovoltaic Power Capacity Expansion 1995 to 2011

30 GW of new solar PV capacity in 2011, increasing total to 70 GW

size of global PV industry exceeds USD 100 billion per year
EPIA scenarios for global annual new installed pv capacity until 2015

www.irena.org
Spain is the leading CSP country but recently has stopped its FIT system due to financial crisis.
Global Concentrating Solar Thermal Power Outlook 2011

[Bar chart showing estimated MW operation, construction, promotion, and GW estimation by 2050 for different regions like North America, South Europe, China, India, South Africa, Australia, and South America.]
Global Cumulated Wind, PV and CSP Capacity in 2011


$257 billion invested in RE in 2011 (up 16% from 2010)

To this adds:

- estimated $10 billion (unreported) invested in solar hot water
- $25 billion invested in large hydropower (>50 MW)
Global New Investment in Renewable Energy in 2011

- USA: 48 billion $
- China: 51 billion $
- Germany: 31 billion $
- Italy: 29 billion $
- India: 12 billion $
Renewable Energy Targets and Achievements in the EU27
FIT payments for renewable energy technologies, selected countries, 2011/2012

- Small wind (<100 kW) [14]
  - Lowest: 10.9 US cents/kWh
  - Highest: 42.1 US cents/kWh
  - 5th highest: 73.5 US cents/kWh

- Wind onshore [19]
  - Lowest: 8.7 US cents/kWh
  - Highest: 29.4 US cents/kWh

- Wind offshore [7]
  - Lowest: 11 US cents/kWh
  - Highest: 25 US cents/kWh

- Geothermal [12]
  - Lowest: 7.7 US cents/kWh
  - Highest: 36.5 US cents/kWh

- Biomass [18]
  - Lowest: 9.5 US cents/kWh
  - Highest: 28.9 US cents/kWh

- Biogas [20]
  - Lowest: 9.9 US cents/kWh
  - Highest: 52.1 US cents/kWh

- Hydropower [20]
  - Lowest: 7.2 US cents/kWh
  - Highest: 32.1 US cents/kWh

- Ocean power [4]
  - Lowest: 16 US cents/kWh
  - Highest: 66 US cents/kWh

- Solar PV (<30 kW or non-differentiated) [21]
  - Lowest: 14.2 US cents/kWh
  - Highest: 50.3 US cents/kWh

- Solar PV (>30 kW) [9]
  - Lowest: 14.2 US cents/kWh
  - Highest: 53.4 US cents/kWh
## Jobs in Renewable Energy Industry in 2011 (up 1.5 million from 2010)

<table>
<thead>
<tr>
<th>TECHNOLOGIES</th>
<th>Global</th>
<th>China</th>
<th>India</th>
<th>Brazil</th>
<th>USA</th>
<th>EU7</th>
<th>Germany</th>
<th>Spain</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thousand jobs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Biomass¹</td>
<td>750</td>
<td>266</td>
<td>58</td>
<td>152</td>
<td>273</td>
<td>51</td>
<td>14</td>
<td>2</td>
<td>2³</td>
</tr>
<tr>
<td>Biofuels</td>
<td>1,500</td>
<td></td>
<td></td>
<td>889⁶</td>
<td>47–160</td>
<td>151</td>
<td>23</td>
<td>2</td>
<td>194³</td>
</tr>
<tr>
<td>Biogas</td>
<td>230</td>
<td>90</td>
<td>85</td>
<td></td>
<td>53</td>
<td>51</td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geothermal¹</td>
<td>90</td>
<td></td>
<td></td>
<td>10</td>
<td>53</td>
<td>14</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydropower (Small²)</td>
<td>40</td>
<td>12</td>
<td></td>
<td>8</td>
<td>16</td>
<td>7</td>
<td>1.6</td>
<td>1³</td>
<td></td>
</tr>
<tr>
<td>Solar PV</td>
<td>820⁴</td>
<td>300⁵</td>
<td>112</td>
<td>82</td>
<td>268</td>
<td>111</td>
<td>28</td>
<td>60¹⁰</td>
<td></td>
</tr>
<tr>
<td>CSP</td>
<td>40</td>
<td></td>
<td></td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Heating/ Cooling</td>
<td>900⁴</td>
<td>800</td>
<td>41</td>
<td>9</td>
<td>50</td>
<td>12</td>
<td>10</td>
<td>1³</td>
<td></td>
</tr>
<tr>
<td>Wind Power</td>
<td>670⁴</td>
<td>150</td>
<td>42</td>
<td>14</td>
<td>75</td>
<td>253</td>
<td>101</td>
<td>55</td>
<td>33¹¹</td>
</tr>
<tr>
<td><strong>Total³</strong></td>
<td>5,000</td>
<td>1,606</td>
<td>350</td>
<td>889</td>
<td>392-505</td>
<td>1,117</td>
<td>372</td>
<td>137</td>
<td>291</td>
</tr>
</tbody>
</table>

¹ Data for 2010 for biomass only.
² Data for 2011 for hydropower (small) only.
³ Data for 2011 for others only.
⁴ Data for 2012 for solar PV only.
⁵ Data for 2013 for solar PV only.
⁶ Data for 2014 for hydropower (small) only.
⁷ Data for 2015 for EU7 only.
⁸ Data for 2016 for others only.
## Selected Renewable Energy Indicators 2009 - 2011

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>→</th>
<th>2010</th>
<th>→</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment in new renewable capacity (annual)¹</td>
<td>billion USD</td>
<td>161</td>
<td>→</td>
<td>220</td>
<td>→</td>
</tr>
<tr>
<td>Renewable power capacity (total, not including hydro)</td>
<td>GW</td>
<td>250</td>
<td>→</td>
<td>315</td>
<td>→</td>
</tr>
<tr>
<td>Renewable power capacity (total, including hydro)²</td>
<td>GW</td>
<td>1,170</td>
<td>→</td>
<td>1,260</td>
<td>→</td>
</tr>
<tr>
<td>Hydropower capacity (total)²</td>
<td>GW</td>
<td>915</td>
<td>→</td>
<td>945</td>
<td>→</td>
</tr>
<tr>
<td>Solar PV capacity (total)</td>
<td>GW</td>
<td>23</td>
<td>→</td>
<td>40</td>
<td>→</td>
</tr>
<tr>
<td>Concentrating solar thermal power (total)</td>
<td>GW</td>
<td>0.7</td>
<td>→</td>
<td>1.3</td>
<td>→</td>
</tr>
<tr>
<td>Wind power capacity (total)</td>
<td>GW</td>
<td>159</td>
<td>→</td>
<td>198</td>
<td>→</td>
</tr>
<tr>
<td>Solar hot water/heat capacity (total)³</td>
<td>GW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>153</td>
<td>→</td>
<td>182</td>
<td>→</td>
</tr>
<tr>
<td>Ethanol production (annual)</td>
<td>billion litres</td>
<td>73.1</td>
<td>→</td>
<td>86.5</td>
<td>→</td>
</tr>
<tr>
<td>Biodiesel production (annual)</td>
<td>billion litres</td>
<td>17.8</td>
<td>→</td>
<td>18.5</td>
<td>→</td>
</tr>
<tr>
<td>Countries with policy targets</td>
<td>#</td>
<td>89</td>
<td>→</td>
<td>109</td>
<td>→</td>
</tr>
<tr>
<td>States/provinces/countries with feed-in policies⁴</td>
<td>#</td>
<td>82</td>
<td>→</td>
<td>86</td>
<td>→</td>
</tr>
<tr>
<td>States/provinces/countries with RPS/quota policies⁴</td>
<td>#</td>
<td>66</td>
<td>→</td>
<td>69</td>
<td>→</td>
</tr>
<tr>
<td>States/provinces/countries with biofuels mandates⁵</td>
<td>#</td>
<td>57</td>
<td>→</td>
<td>71</td>
<td>→</td>
</tr>
<tr>
<td>POWER GENERATION</td>
<td>Typical Characteristics</td>
<td>Capital Costs (USD/kW)</td>
<td>Typical Energy Costs (US cents/kWh)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>-------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydropower (grid-based)</td>
<td>Plant size: 1 MW–18,000 MW; Plant type: reservoir, run-of-river; capacity factor: 30–60%</td>
<td>Projects &gt;300 MW: &lt;2.000; Projects &lt;300 MW: 2.000–4.000</td>
<td>5–10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydropower (off-grid/rural)</td>
<td>Plant capacity: 0.1–1,000 kW; Plant type: run-of-river, hydrokinetic, diurnal storage</td>
<td>1.175–3.500</td>
<td>5–40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean Power (tidal range)</td>
<td>Plant size: &lt;1 to &gt;250 MW; Capacity factor: 23–29%</td>
<td>5.290–5.870</td>
<td>21–28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar PV (rooftop)</td>
<td>Peak capacity: 3–5 kW (residential); 100 kW (commercial); 500 kW (industrial); conversion efficiency: 12–20%</td>
<td>2.480–3.270</td>
<td>22–44 (Europe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar PV (ground-mounted utility-scale)</td>
<td>Peak capacity: 2.5–100 MW; conversion efficiency: 15–27%</td>
<td>1.830–2.350</td>
<td>20–37 (Europe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrating Solar Thermal Power (CSP)</td>
<td>Types: trough, tower, dish; Plant size: 50–500 MW (trough), 50–300 MW (tower); Capacity factor: 20–25% (trough); 40–50% (trough with six hours storage); 40–80% (solar tower with 6–15 hours storage)</td>
<td>Trough without storage: 4.500; Trough with six hours storage: 7.100–9.000; Solar tower with 6–18 hours storage: 6.300–10.500</td>
<td>18.8–29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Power (onshore)</td>
<td>Turbine size: 1.5–3.5 MW; Rotor diameter: 60–110+ meters; Capacity factor: 20–40%</td>
<td>1.410–2.475</td>
<td>5.2–16.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Power (offshore)</td>
<td>Turbine size: 1.5–7.5 MW; Rotor diameter: 70–125 meters; Capacity factor: 35–45%</td>
<td>3.760–5.870</td>
<td>11.4–22.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Power (small-scale)</td>
<td>Turbine size: up to 100 kW</td>
<td>3.000–6.000 (USA); 1.500 (China)</td>
<td>15–20 (USA)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Greenpeace Energy (R)evolution Scenario 2012

**Figure 5.6:** Global electricity generation structure under the reference scenario and the energy [r]evolution scenario (including electricity for electromobility, heat pumps and hydrogen generation)

Literature

Greenpeace 2012  energy [r]evolution, A SUSTAINABLE WORLD ENERGY OUTLOOK,  

IRENA 2012  RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES (Biomass, Hydropower, PV, Wind, CSP)  http://www.irena.org


MED-CSP 2005  Concentrating Solar Power for the Mediterranean Region  www.dlr.de/tt/med-csp

TRANS-CSP 2006  Trans-Mediterranean Interconnection for Concentrating Solar Power  www.dlr.de/tt/trans-csp


BMU 2011  Renewable Energies - Perspectives for a Sustainable Energy Future  