Global Energy Assessment
Towards a Sustainable Future

Some remarks on GEA
with a focus on renewable energy

Wim C. Turkenburg
CLA ‘Renewable Energy’ of the Global Energy Assessment
&
Copernicus Institute – Utrecht University
w.c.turkenburg@uu.nl

Launch of GEA in the Netherlands
The Hague – The Netherlands
27 September 2012
Main GEA chapters dealing with renewable energy:

- Chapter 7: Energy Resources and Potentials - CLA: Hans Holger Rogner
- Chapter 11: Renewable Energy - CLA: Wim Turkenburg
- Chapter 17: Energy Pathways for Sustainable Development – CLA: Keywan Riahi
- Chapter 20: Land and Water: Linkages to Bioenergy - CLA: Suani T. Coelho

Lead Authors of GEA chapter 11 ‘Renewable Energy’:

- Doug Arent (USA)
- Ruggero Bertani (Italy)
- Andre Faaij (the Netherlands)
- Maureen Hand (USA)
- Wolfram Krewitt (Germany)
- Eric Larson (USA)
- John Lund (USA)
- Mark Mehos (USA)
- Tim Merrigan (USA)
- Catherine Mitchell (UK)
- José Roberto Moreira (Brazil)
- Wim Sinke (the Netherlands)
- Virginia Sonntag-O’Brien (France)
- Bob Thresher (USA)
- Wim Turkenburg (the Netherlands)
- Wilfried van Sark (the Netherlands)
- Eric Usher (France)
Present Status

(based mainly on GEA chapter 11)
## World Primary Energy Supply in 2009

(Using GEA substitution method to calculate contribution from renewables)

<table>
<thead>
<tr>
<th>Fossil fuels:</th>
<th>412 EJ (78%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- oil</td>
<td>167 EJ</td>
</tr>
<tr>
<td>- gas</td>
<td>106 EJ</td>
</tr>
<tr>
<td>- coal</td>
<td>139 EJ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Renewables:</th>
<th>89 EJ (17%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- large hydro</td>
<td>30 EJ *)</td>
</tr>
<tr>
<td>- traditional biomass</td>
<td>39 EJ</td>
</tr>
<tr>
<td>- ‘new’ renewables</td>
<td>20 EJ *)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuclear:</th>
<th>27 EJ (5%)</th>
</tr>
</thead>
</table>

### Total: 528 EJ (100%)

*) Assuming for hydro, wind, solar and geothermal electricity: 1 EJ(el) = 2.85 EJ savings on fossil fuels, and for solar and geothermal heat: 1 EJ(th) = 1.17 EJ savings on fossil fuels.

### Contribution ‘modern renewables’ to World Primary Energy Supply in 2009 *)

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>EJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydropower:</td>
<td>32</td>
</tr>
<tr>
<td>Modern biomass energy:</td>
<td>12.1</td>
</tr>
<tr>
<td>Wind electricity:</td>
<td>3.7</td>
</tr>
<tr>
<td>Geothermal energy:</td>
<td>1.2</td>
</tr>
<tr>
<td>Low temp. solar thermal energy:</td>
<td>0.5</td>
</tr>
<tr>
<td>Solar PV electricity:</td>
<td>0.33</td>
</tr>
<tr>
<td>Solar thermal electricity (CSP):</td>
<td>0.02</td>
</tr>
<tr>
<td>Ocean energy:</td>
<td>0.005</td>
</tr>
</tbody>
</table>

**Total:** 49.9 EJ

*) Assuming for hydro, wind, solar, geothermal, and ocean electricity: 1 EJ(el) = 2.85 EJ savings on fossil fuels, and for solar and geothermal heat: 1 EJ(th) = 1.17 EJ savings on fossil fuels

## Contribution ‘modern renewables’ in 2009 using different calculation methods

<table>
<thead>
<tr>
<th>Technology</th>
<th>Primary Supply using the substitution method</th>
<th>Primary Supply using the physical content method</th>
<th>Primary Supply using the direct equivalent method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydropower</td>
<td>32</td>
<td>11.2</td>
<td>11.2</td>
</tr>
<tr>
<td>Modern biomass energy</td>
<td>12.1</td>
<td>12.1</td>
<td>12.1</td>
</tr>
<tr>
<td>Wind electricity</td>
<td>3.7</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Geothermal energy</td>
<td>1.2</td>
<td>3.3</td>
<td>0.67</td>
</tr>
<tr>
<td>Low temp. solar thermal energy</td>
<td>0.5</td>
<td>0.43</td>
<td>0.43</td>
</tr>
<tr>
<td>Solar PV electricity</td>
<td>0.33</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Solar thermal electricity (CSP)</td>
<td>0.02</td>
<td>0.05</td>
<td>0.007</td>
</tr>
<tr>
<td>Ocean energy</td>
<td>0.005</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>TOTAL SUPPLY</strong></td>
<td><strong>49.9 EJ</strong></td>
<td><strong>28.5 EJ</strong></td>
<td><strong>25.9 EJ</strong></td>
</tr>
</tbody>
</table>

Some general results and some trends

- The renewable resource based is sufficient to meet several times the present world primary energy demand, and potentially even more than 10 times this demand.

- Since 1990 energy provided by renewables has risen with 2% a year, but in recent years with 5% a year.

- In last 5 years: many renewable technologies have experienced a high annual growth rate – some (biofuels, wind, solar electricity, solar thermal, and geothermal heat) even experiencing two-digit growth (up to 50% a year).


- Contribution to primary energy supply in 2009: 17% (89 EJ); contribution to electricity supply: 19% (3800 TWh).

- Renewable power capacity additions in 2010 represented more than one-third of all global power capacity additions.

► Renewables are beginning to change the energy paradigm!
Major developments in 2011

• Renewables continued to grow strongly in all end-use sectors (power; heating and cooling; transport).

• Global investments in renewables increased by 17%, compared with 2010.

• Net investments in renewable power capacity (including larger-scale hydropower) exceeded that of fossil fuels.

• About half of the new electricity capacity installed worldwide was renewable based.

• European Union installed more renewable energy capacity during 2011 than ever before.

• Globally, an estimated 5 million people work directly or indirectly in renewable energy industries.

• At least 118 countries now have renewable energy targets in place, and 109 countries have policies to support renewables in the power sector.

EU renewables shares of final energy, in 2005 and 2010, with targets for 2020

NL is far behind other countries; it is unlikely the 2020 target will be reached.

Source:
Towards a Sustainable Future

(based mainly on GEA chapter 17)
Objectives GEA Sustainable Development energy back-casting scenario for 2050

- Support economic growth at recent historic rates (2% a year increase of per capita income, on average).
- Almost universal access to electricity and cleaner cooking by 2030 (diffusion of clean technology; extension of grids).
- Reduce air pollution impacts on health, adhering to WHO guidelines (reduced 5 million premature death due to air pollution by 50% by 2030).
- Avoid dangerous climate change; stay below + 2 °C above pre-industrial global mean temperature with more than 50% likelihood (CO2 emission peak by 2020; 30-70% reduction in 2050; negative emissions later).
- Improve energy security through enhanced diversity, limited energy trade and resilience of energy supply by 2050 (reduce share oil import in primary energy by 30-80%; decrease energy intensity; increase local energy supply options; infrastructure expansion; storage and back-up capacity).
- And in the process: address issues like peak oil and nuclear proliferation challenges.
Allowable \( \text{CO}_2 \) emission budget, and required \( \text{CO}_2 \) price in GEA

- In the period 2010-2100: 940-1460 Gt\( \text{CO}_2 \) in total.

  Note: This budget is achieved in 30-45 years if we stay at present level of \( \text{CO}_2 \) emissions!

- \( \text{CO}_2 \) price in GEA: at least 15-45 $/t\( \text{CO}_2 \) at present; up to 110 $/t\( \text{CO}_2 \) or above in later years.

  Note: In July 2012, the \( \text{CO}_2 \) price on the spot market was about 7 Euro per tonne \( \text{CO}_2 \).
Global population projections
(stabilization at about 9 billion in GEA)

- Urban population in 2050: 6.4 billion people.
- Rural population: will peak in 2030 at 3.5 billion people and decline thereafter.
Economic development projections

(In GEA: developing countries 3.5% a year, on average; developed countries 1.2% a year)

In GEA pathways:
Global real per capita income grows at an annual average of 2% over the next 50 years
Branching points and GEA pathways

• **Branching point 1:**  
  *What is level of energy demand?*  
  (GEA-Efficiency; GEA-Supply; GEA-Mix - range reduction energy intensity: 1.5% - 2.2% a year).

• **Branching point 2:**  
  *What are the dominant transportation fuels and technologies?* (Conventional; Advanced).

• **Branching point 3:**  
  *How divers is the portfolio of supply-side options?*  
  (Full portfolio – all options available; Restricted portfolio – excludes or limits particular options).

Global Energy Assessment (GEA) Pathway Taxonomy

Branching point: Supply

High demand

Intermediate demand

Low demand

Branching point: Efficiency

GEA-Supply

GEA-Efficiency

GEA-Mix

Feasible supply-side transitions (primary energy by 2050)

Branching point: Supply

Development of Primary Energy in three sets of GEA pathways

(Three illustrative examples on the left, and all 60 pathways explored on the right)

Conclusion: 41 out of the 60 pathways reach the GEA normative goals.

Composition of global primary energy supply in 2005, 2030 and 2050
(across pathway groups, under unrestricted supply portfolio and Conventional Transportation set-up)

Development of primary energy
(In the GEA-Supply pathway, with a nuclear phaseout shortly after 2050)

Deployment of renewables in 2050, by region (in EJ)

<table>
<thead>
<tr>
<th>region</th>
<th>bio-energy</th>
<th>hydro power</th>
<th>wind</th>
<th>solar</th>
<th>geothermal</th>
<th>all renew.</th>
<th>renew. % of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan African</td>
<td>9 - 41</td>
<td>2 - 6</td>
<td>0.5 - 20</td>
<td>1 - 26</td>
<td>0 – 0.3</td>
<td>11-91</td>
<td>31 - 94</td>
</tr>
<tr>
<td>Centrally Planned Asia and China</td>
<td>7 - 25</td>
<td>10</td>
<td>4 - 9</td>
<td>1 - 40</td>
<td>0 – 0.3</td>
<td>21 - 84</td>
<td>24 - 50</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>1 - 3</td>
<td>1</td>
<td>1 - 5</td>
<td>0.2 - 6</td>
<td>0 - 0.3</td>
<td>3 - 15</td>
<td>23 - 85</td>
</tr>
<tr>
<td>Former Soviet Union</td>
<td>3 - 10</td>
<td>3 - 16</td>
<td>1 - 7</td>
<td>0.3 - 10</td>
<td>0 - 1</td>
<td>7 - 44</td>
<td>25 - 93</td>
</tr>
<tr>
<td>Latin America and Caribbean</td>
<td>11 - 23</td>
<td>11 - 18</td>
<td>4 - 12</td>
<td>0.5 - 22</td>
<td>0 - 2</td>
<td>25 - 76</td>
<td>40 - 100</td>
</tr>
<tr>
<td>Middle East and North Africa</td>
<td>1 - 5</td>
<td>1</td>
<td>1 - 9</td>
<td>0.5 - 16</td>
<td>0 – 0.3</td>
<td>4 - 31</td>
<td>17 - 40</td>
</tr>
<tr>
<td>North America</td>
<td>10 - 21</td>
<td>7 - 8</td>
<td>3 - 37</td>
<td>1 - 42</td>
<td>0 - 3</td>
<td>21 - 111</td>
<td>38 - 89</td>
</tr>
<tr>
<td>Pacific OECD</td>
<td>3 - 11</td>
<td>1 - 2</td>
<td>1 - 5</td>
<td>0.2 - 5</td>
<td>0.1 - 1</td>
<td>6 - 24</td>
<td>26 - 89</td>
</tr>
<tr>
<td>Pacific Asia</td>
<td>5 - 12</td>
<td>2 - 7</td>
<td>1 - 2</td>
<td>0.4 - 15</td>
<td>0.2 - 1</td>
<td>9 - 37</td>
<td>15 - 63</td>
</tr>
<tr>
<td>South Asia</td>
<td>5 - 21</td>
<td>4</td>
<td>1 - 7</td>
<td>1 - 79</td>
<td>0 – 0.2</td>
<td>11 - 111</td>
<td>21 - 65</td>
</tr>
<tr>
<td>Western Europe</td>
<td>4 - 11</td>
<td>6 - 8</td>
<td>3 - 30</td>
<td>0.7 - 29</td>
<td>0.1 - 2</td>
<td>13 - 80</td>
<td>34 - 83</td>
</tr>
<tr>
<td>WORLD</td>
<td>78 - 139</td>
<td>50 - 80</td>
<td>29 - 134</td>
<td>7 - 285</td>
<td>1 - 12</td>
<td>164 - 651</td>
<td>28 - 74</td>
</tr>
</tbody>
</table>

### Energy investments needed to achieve GEA sustainability objectives (billions of US$/year)

<table>
<thead>
<tr>
<th>Energy area</th>
<th>Investments in 2010</th>
<th>Investments per year in 2010-2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>(300)</td>
<td>290-800</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5-40</td>
<td>15-210</td>
</tr>
<tr>
<td><strong>Renewables</strong></td>
<td>190</td>
<td>260-1010</td>
</tr>
<tr>
<td>CCS</td>
<td>&lt;1</td>
<td>0-64</td>
</tr>
<tr>
<td>Infrastructure (grid, storage and back-up)</td>
<td>260</td>
<td>310-500</td>
</tr>
<tr>
<td>Energy access</td>
<td>n.a.</td>
<td>36-41</td>
</tr>
<tr>
<td><strong>Total investments</strong></td>
<td>~ 1300</td>
<td>1700-2200 *)</td>
</tr>
</tbody>
</table>

*) Continuing a business-as-usual (unsustainable) pathway, this figure might be ~ 1600 bln in 2050

Conclusions about a.o. the role of renewables in 2050 energy supplies

• At least the historical rate of improvement of the energy efficiency a year should be achieved, preferably more (decrease en. intens.: 1.5-2.2% a year).

• Low carbon energy shares in primary energy at least at 60-80% by 2050.

• Strong growth in renewable energy, beginning immediately and reaching 165-650 EJ a year by 2050 - about 30-75% of primary energy demand (and in some regions more than 90% of this demand in 2050).

• Increasing requirement for storage technologies, apart from other measures, to support system integration of intermittent renewable.

• Growth in bioenergy to 80-140 EJ a year by 2050. Strong growth of liquid biofuels in the short to medium term. Thereafter, the mix of liquid and gaseous fuels depends on transportation system choices.

• Nuclear energy may play an important role, but it is also possible to phase out nuclear, still meeting the GEA sustainability targets.

• Fossil CCS as an necessity or an optional bridge in the medium term; biomass plus CCS to achieve negative CO2 emission in longer term; cumulative storage of CO2 up to 250 GtCO2 by 2050.
6 essential technology-related requirements for radical energy transformation

GEA highlights the following essential requirements:

• Significantly larger investments in energy efficiency improvements, especially end-use, across all sectors;

• Rapid escalation of investments in renewable energies (hydropower, wind, solar energy, modern bioenergy, and geothermal) as well as the smart and super grids that enable renewable energies to become the dominant sources of energy;

• Reaching universal access to modern forms of energy and cleaner cooking through micro-financing and subsidies;

• Use of fossil fuels and bioenergy (with CCS) at the same facilities for efficient co-production of multiple energy carriers and chemicals;

• Full-scale deployment of CCS; and

• On one extreme nuclear energy could make a significant contribution to the global electricity, but in the other, it could be phased out.
Major challenges for renewables, both technical and economic

- Reducing costs through learning and scale-up;
- Creating a flexible (and predictable) investment environment that provides the basis for scale-up and diffusion;
- Integrating renewable energies into the energy system;
- Enhancing research and development to ensure technological advances; and
- Assuring the sustainability of the proposed renewable technologies.
<table>
<thead>
<tr>
<th>Energy area</th>
<th>Regulation, standards</th>
<th>Externality pricing</th>
<th>Carefully designed subsidies</th>
<th>Capacity building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Essential (elimination less efficient technology every few years)</td>
<td>Essential (prices should reflect full costs)</td>
<td>Complement (a basket of financing tools is needed)</td>
<td>Essential (expertise needed for new technologies)</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Essential (for waste disposal and to prevent proliferation)</td>
<td>Uncertain (GHG pricing helps, but pricing nuclear risks would hurt)</td>
<td>Uncertain (with GHG pricing perhaps not needed)</td>
<td>Desired (need to correct loss of expertise in recent decades)</td>
</tr>
<tr>
<td>Renewables</td>
<td>Complement (renew. port folio standards can complement GHG pricing)</td>
<td>Essential (GHG pricing is key to rapid development of renewables)</td>
<td>Complement (feed-in tariffs and tax credits can complement GHG pricing)</td>
<td>Essential (expertise needed for new technologies)</td>
</tr>
<tr>
<td>CCS</td>
<td>Essential (CCS requirement for all new coal plants and phase-in with existing)</td>
<td>Essential (GHG pricing is essential but prob. not enough in near term)</td>
<td>Complement (would help first plants while CHG pricing is still low)</td>
<td>Desired (expertise needed for new technologies)</td>
</tr>
<tr>
<td>Infrastructure (grid, storage and back-up)</td>
<td>Essential (security regulation critical for some aspects of reliability)</td>
<td>Uncertain (neutral effect)</td>
<td>Essential (customers must pay for reliability levels they value)</td>
<td>Essential (expertise needed for new technologies)</td>
</tr>
</tbody>
</table>
Thanks!

Wim Turkenburg
w.c.turkenburg@uu.nl

For more information:
www.globalenergyassessment.org