Choosing a tempo to power Sub-Saharan Africa in 2050: Jazz and Symphony scenarios of the World Energy Council

IEW 2014, Beijing
Contents

- Current Situation in Sub-Saharan Africa and Challenges
- Modelling Framework
- Definition and Quantification of WEC‘s Scenarios* for Sub-Saharan Africa
- Results and Conclusions

* World Energy Council: World Energy Scenarios – Composing energy futures to 2050
Project partner Paul Scherrer Institut (PSI) Switzerland
### The Sub-Saharan Africa in 2010 – some facts

<table>
<thead>
<tr>
<th>POPULATION</th>
<th>ELECTRICITY GENERATION CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>857 million</strong> (12% of world)</td>
<td><strong>92 GW</strong> (UK: 94 GW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ANNUAL INCOME (per capita in MER)</th>
<th>ANNUAL ELECTRICITY CONSUMPTION IN RESID.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$1,350</strong> (world: $9,160)</td>
<td><strong>195 KWh/capita</strong> (China: 810) (EU-27: 3,440)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>POVERTY (pop. with &lt;$2 in PPP per day)</th>
<th>ACCESS TO ELECTRICITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>603 million</strong> (25% of world)</td>
<td><strong>589 million</strong> without access to electricity (46% of world)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>URBANISATION RATE (% of population)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>36% (world: 52%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>POLICY &amp; INSTITUTION INDEX (1 low, 6 high)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3.18</strong> (Developing Europe &amp; Central Asia: 3.71)</td>
</tr>
</tbody>
</table>
Interfacing PSI’s **Global** Multiregional MARKAL (GMM) model with a reduced-form econometric model
Overview of the GMM Model

Global Multi-regional MARKAL:

- Cost optimisation of the energy system; perfect foresight; bottom-up model with a detailed representation of resources, technologies, energy flows and technological change
- Non-cost, policy and behavioural assumptions are modelled with side-constraints
Reduced-form econometric model. Time-series estimation (1970-2010) using Polynomial Distribution Lags

\[
\ln \left( \frac{\text{poverty}_t}{\text{poverty}_{t-1}} \right) = \beta_0 + \beta_1 \cdot \sum_{k=0}^{10} \gamma_k \cdot \ln \left( \frac{\text{income}_{t-k}}{\text{income}_{t-k-1}} \right) + AR(1) + \epsilon_t
\]

\[
\ln \left( \frac{\text{rural migration}_t}{1 - \text{rural migration}_t} \right) = \beta_0 + \beta_1 \cdot \text{income}_{t-1} + \epsilon_t
\]

\[
\ln \left( \frac{\text{cpi}_t}{6 - \text{cpi}_t} \right) = \beta_0 + \beta_1 \cdot \ln(\text{gdp}_{t-1}) + \epsilon_t
\]

\[
\ln \left( \frac{\text{elc access}_t}{1 - \text{elc access}_t} \right) = \beta_0 + \beta_1 \cdot \sum_{k=0}^{7} \gamma_{1k} \cdot \text{poverty}_{t-k-1} +
\beta_2 \cdot \sum_{k=0}^{3} \gamma_{2k} \cdot \text{elcdem}_{t-k-1} + \beta_3 \cdot \sum_{k=0}^{10} \gamma_{3k} \cdot \text{urbanisation}_{t-k-2} +
\beta_4 \cdot \sum_{k=0}^{1} \gamma_{4k} \cdot \text{cpi}_{t-k-2} + \beta_5 \cdot \sum_{k=0}^{4} \gamma_{5k} \cdot \text{elccap}_{t-k} + AR(1) + \epsilon_t
\]

Correlations between model's variables:

<table>
<thead>
<tr>
<th>Income per capita</th>
<th>Urbanisation Rate</th>
<th>Poverty Rate</th>
<th>Institutional development</th>
<th>Electricity per capita</th>
<th>Electrification of demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urbanisation Rate</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poverty Rate</td>
<td>-1.00</td>
<td>-0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institutional development</td>
<td>0.33</td>
<td>0.32</td>
<td>-0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity per capita</td>
<td>0.76</td>
<td>0.85</td>
<td>-0.73</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Electrification of demand</td>
<td>0.66</td>
<td>0.79</td>
<td>-0.63</td>
<td>0.37</td>
<td>0.99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poverty</th>
<th>( \beta_0 )</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( \beta_3 )</th>
<th>( \beta_4 )</th>
<th>( \beta_5 )</th>
<th>S.E</th>
<th>adj R²</th>
<th>Akaike</th>
<th>Schwarz</th>
</tr>
</thead>
<tbody>
<tr>
<td>estimates</td>
<td>-0.421</td>
<td>0.522</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.044</td>
<td>0.743</td>
<td>-8.072</td>
<td>-7.930</td>
</tr>
<tr>
<td>p-values</td>
<td>0.001</td>
<td>0.008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Urbanisation</th>
<th>( \beta_0 )</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( \beta_3 )</th>
<th>( \beta_4 )</th>
<th>( \beta_5 )</th>
<th>S.E</th>
<th>adj R²</th>
<th>Akaike</th>
<th>Schwarz</th>
</tr>
</thead>
<tbody>
<tr>
<td>estimates</td>
<td>-5.493</td>
<td>0.216</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.008</td>
<td>0.944</td>
<td>-6.620</td>
<td>-6.576</td>
</tr>
<tr>
<td>p-values</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Institutional development</th>
<th>( \beta_0 )</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( \beta_3 )</th>
<th>( \beta_4 )</th>
<th>( \beta_5 )</th>
<th>S.E</th>
<th>adj R²</th>
<th>Akaike</th>
<th>Schwarz</th>
</tr>
</thead>
<tbody>
<tr>
<td>estimates</td>
<td>-0.352</td>
<td>0.063</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.004</td>
<td>0.718</td>
<td>-7.763</td>
<td>-7.867</td>
</tr>
<tr>
<td>p-values</td>
<td>0.078</td>
<td>0.040</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electricity access</th>
<th>( \beta_0 )</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( \beta_3 )</th>
<th>( \beta_4 )</th>
<th>( \beta_5 )</th>
<th>S.E</th>
<th>adj R²</th>
<th>Akaike</th>
<th>Schwarz</th>
</tr>
</thead>
<tbody>
<tr>
<td>estimates</td>
<td>-9.322</td>
<td>-0.020</td>
<td>3.610</td>
<td>7.843</td>
<td>1.916</td>
<td>0.224</td>
<td>0.464</td>
<td>0.005</td>
<td>0.999</td>
<td>-7.461</td>
</tr>
<tr>
<td>p-values</td>
<td>0.001</td>
<td>0.001</td>
<td>0.013</td>
<td>0.000</td>
<td>0.003</td>
<td>0.006</td>
<td>0.044</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## The “Jazz” and “Symphony” Scenarios of WEC

### WEC – PSI On-going partnership in “Composing Energy Future to 2050”

- **WEC**: Scenarios definition with the participation of over 3000 organisations from more than 95 countries
- **PSI Energy Economics Group**: Quantification of the scenarios with the GMM model for 15 world regions

### JAZZ

- Focus on economic growth via low cost energy and using the best available resources
  - Economy liberalisation, opening of upstream energy markets, increased FDI, high economic growth
  - Lower fertility driven by higher incomes and education
  - Technology choice based on energy markets => limited support for nuclear, CCS, large hydro
  - Efficiency is market driven
  - Delayed climate policy action

### SYMPHONY

- Focus on environmental sustainability and energy security
  - Market regulation with policies set by governments, regulatory hurdles, limited FDI, lower economic growth than “Jazz”
  - Medium fertility inline with UN Population Division
  - Government support for low-carbon technologies => CCS, nuclear, hydro, solar, wind
  - Efficiency measures by governments
  - Strong climate policy with global convergence
Quantification of Key Scenario Assumptions

**GDP per capita in USD 2010 (MER)**
- Jazz: 4600, 7300, 5500
- Symphony: 1350, 5500, 7300
- China (2010): 4600, 7300, 5500

**Population in million**
- Jazz: 857, 1650, 1960
- Symphony: 33, 1960, 1650

**CO₂ price in $/tn CO₂**
- Jazz: 5, 23, 70
- Symphony: 23, 70

**Cars per thousand capita**
- Jazz: 19, 33, 31
- Symphony: 19, 33, 31
- China (2010): 44

*Exceeding China’s population for first time in 2040*
Economic – Demographic Developments

**URBANISATION RATE (% of population)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Jazz 2050</th>
<th>Symphony 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>36%</td>
<td>53%</td>
</tr>
<tr>
<td>2050</td>
<td>58%</td>
<td>58%</td>
</tr>
</tbody>
</table>

**POVERTY (% of population)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Jazz 2050</th>
<th>Symphony 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>70%</td>
<td>21%</td>
</tr>
<tr>
<td>2050</td>
<td>19%</td>
<td>21%</td>
</tr>
</tbody>
</table>

**Urban population (million)**

- **Jazz**: 310 (2010), 950 (2050), 1044 (2050)
- **Symphony**: 310 (2010), 950 (2050), 1044 (2050)

**Population living with <$2 in PPP per day (million)**

- **Jazz**: 603 (2010), 409 (2050)
- **Symphony**: 307 (2010), 307 (2050)

**POLICY & INSTITUTIONAL ASSESSMENT INDEX**

<table>
<thead>
<tr>
<th>Year</th>
<th>Jazz 2050</th>
<th>Symphony 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>3.18</td>
<td>3.39</td>
</tr>
<tr>
<td>2050</td>
<td>3.41</td>
<td>3.39</td>
</tr>
</tbody>
</table>
TOTAL FINAL ENERGY CONSUMPTION (EJ)

MODERN ENERGY CARRIERS IN RESIDENTIAL/COMMERCIAL (%)

ELECTRICITY per CAPITA in RESIDENTIAL/COMMERCIAL

195 KWh in 2010
703 KWh “Jazz” 2050
539 KWh “Symphony” 2050
Electricity Generation Sector

ELECTRICITY PRODUCTION (TWh)

NEW CAPACITY INVESTMENTS:  
more than 20 GW annually

- **JAZZ**: 980 GW “Jazz” in 2011-50
- **Symphony**: 930 GW “Symphony” in 2011-50

ELECTRICITY GRID EXPANSION:  
more than $20 billion annually

- **JAZZ**: $1,264 billion “Jazz” in 2011-50
- **Symphony**: $964 billion “Symphony” in 2011-50
Emissions, Energy intensity, Costs & Electricity Access

**CO₂ emissions (Mtn)**
- Jazz: 661, 871, 1749
- Symphony: 2010, 2050

**Energy System cost (% of GDP)**
- Jazz: 16.8%, 10.2%, 7.6%
- Symphony: 2010, 2050

**Final Energy Intensity (MJ/$GDP) vs Income per capita**
- Jazz: 14.68, 2010, 2050
- Symphony: 2.93, 2.97

**Percentage of population with access to electricity**
- 2050: 266 million w/o access in “Jazz”
- 400 million w/o access in “Symphony”
- 1993: 80% electrification in China
- 1970, 9%
- 2010, 31%
- IEA WEO 2013
- PIDA outlook 2040
- Symphony (WEC published)
Both scenarios suggest that:

- **Enormous investments** in power infrastructure are required: more than **$50 billion annually**
- **Access** to electricity **improves** but the problem is **not solved** by 2050
- **Biomass** remains an important **low cost energy source** during the projection period
- **Hydropower** potential is **large but not enough** to supply the electricity demand alone
- **Solar PV and gas turbines** are among the **key options** for electricity production
- **Wind** faces strong **competition** from solar PV in gaining market share in the power generation sector
- **Nuclear** is **unlikely** to be a game changer in the region (lack of institutional capacity, significant financial resources)

**In a “Jazz” world:**
- Electrification of demand increases due to high incomes and industrialisation
- Gas penetration in final consumption is constrained mainly by the rate of infrastructure expansion
- Increased urbanisation and access to electricity
- Coal and gas supply half of the electricity in 2050
- CO2 emissions are almost tripled in 2050 compared to 2010 levels

**In a “Symphony” world:**
- Electricity is important for achieving efficiency
- Lower incomes and lower urbanisation result in lower access to electricity than “Jazz”
- CCS and hydropower supply half of the electricity in 2050
- CO2 emissions remain close to a sustainable path
- Increased system costs due to capital intensive investments and financing of efficiency measures

Some methodological issues:

- **More modelling** is needed for electricity access to capture the complexity of its drivers, including coupling with CGE models
- **Possible deep dives** in SSA, by splitting the region into four power pools and developing specific to the different power pools scenarios, will enhance the analysis
Thank you very much for your attention!!

Any Questions?

Paul Scherrer Institut (PSI)
Laboratory for Energy Systems Analysis (LEA)
Energy Economics Group (EEG)

Evangelos Panos, +41563102675, evangelos.panos@psi.ch
Hal Turton, +41563102631, hal.turton@psi.ch
Martin Densing, +41563102598, martin.densing@psi.ch
Kathrin Volkart, +41563105779, kathrin.volkart@psi.ch