Paul Scherrer Institut
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Achieving universal electricity access by 2030 in a sustainable way
IEW 2015, Abou Dhabi
Presentation structure

- Population without access to electricity and the SE4All objective

- Methodology used to address the SE4All objective
  - The modelling framework
  - The World Energy Council/PSI global energy scenarios “Jazz” and “Symphony”

- Electricity access in the original WEC/PSI scenarios and its drivers

- Universal electricity access in the WEC/PSI scenarios

- Conclusions
Population w/o access to electricity

- Electricity access (IEA definition): initial connection to a household and then increasing consumption to reach country’s average
- UN SE4ALL initiative (launched in 2011) aims at universal electricity access by 2030
- Goal of the study: Assessment of the effort required in the two WEC energy scenarios: 
  a) “Jazz”: focus on low cost energy ; b) “Symphony”: focus on sustainability
Modelling framework for electricity access

Coupling an energy system model with an electricity access model:

- Common economic & demographic assumptions between them
- The interface is established at electricity consumption

Update of useful energy demands in universal electricity access case

Demographic & Economic Development

Useful energy demands

Energy policies

Electricity access model

GMM large scale energy system model

Urbanisation Poverty
Institutional development
Population electrification

Technology Mix
Energy balances
CO₂ emissions
Depletion of resources
Energy System costs
Marginal costs

Electricity consumption
The **Global Multi-regional MARKAL Model**

- Cost optimisation of the energy system
- Perfect foresight → takes the position of a central planner
- Bottom-up → 400 energy supply & demand technologies
- Non-cost, policy & behavioural assumptions modelled as constraints
The electricity access model

- Reduced-form econometric model
- Based on time series 1970-2012 from IEA and World Bank
- Takes into account key drivers affecting access
- Polynomial distribution lag estimation

### Correlations of electricity access and its main drivers, 1970-2012

<table>
<thead>
<tr>
<th>Region</th>
<th>Poverty</th>
<th>Urbanisation</th>
<th>CPIA Index</th>
<th>Electricity per capita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Asia</td>
<td>-0.96</td>
<td>0.99</td>
<td>0.89</td>
<td>0.98</td>
</tr>
<tr>
<td>Central Asia</td>
<td>-0.97</td>
<td>0.97</td>
<td>0.34</td>
<td>0.58</td>
</tr>
<tr>
<td>India</td>
<td>-0.97</td>
<td>0.99</td>
<td>0.98</td>
<td>0.96</td>
</tr>
<tr>
<td>Latin America</td>
<td>-0.41</td>
<td>0.99</td>
<td>0.76</td>
<td>0.96</td>
</tr>
<tr>
<td>M. East &amp; N. Africa</td>
<td>-0.68</td>
<td>0.83</td>
<td>0.74</td>
<td>0.77</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>-0.82</td>
<td>1.00</td>
<td>0.45</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Legend:
- Scenario Assumption
- GMM result
- Econ. Model result
- Average electricity consumption per capita

Key drivers affecting access:
- GDP
- Population
- Income per Capita
- Inst. Devel.
- Poverty
- Urbanisation

% population with access to electricity
# The Jazz and Symphony scenarios

**Jazz: Focus on economic growth via low cost energy**
- Economy liberalisation, increased FDI, high economic growth
- Lower population fertility
- Technology choice driven by energy markets
- Delayed climate policy action (adaptation)

**Symphony: Focus on environmental sustainability and energy security**
- Market regulation, energy policy set by governments, limited FDI
- Medium population fertility
- Technology choice driven by government support to low-carbon options
- Strong climate policy with global convergence (mitigation)
Jazz & Symphony: GDP & population

In 2010:
- 3.9 billion people
- 2.5 k$ per capita

Jazz in 2030:
- +1 billion people
- 5.7 k$ per capita
  (+4.2% p.a.)
- $5/t CO₂ price

Symphony in 2030:
- +1.2 billion people
- 4.9 k$ per capita
  (+3.4% p.a.)
- $32/t CO₂ price
Urbanisation rate: in 2010 40%, in 2030 49% in Jazz, 48% in Symphony

Internal migration contributes to >50% in urban population increase
Poverty: in 2010 51%, in 2030 21% in Jazz, 23% in Symphony

Poverty is reduced in Asia, remains a problem in Sub-Saharan Africa
Jazz: flexible projects with short construction times, coal & gas dominate
Symphony: lower-carbon pathway driven by climate policy and subsidies
Jazz & Symphony: Electricity access

Population without access to electricity in millions and as % of total

- **Middle East & North Africa**
  - 20 (5%)
  - 1 (0%)
  - 2 (0%)

- **Central Asia**
  - 169 (36%)
  - 99 (17%)
  - 111 (18%)

- **Pacific Asia**
  - 135 (22%)
  - 49 (7%)
  - 74 (10%)

- **Latin America**
  - 27 (10%)
  - 1 (0%)
  - 3 (1%)

- **Sub-Saharan Africa**
  - 589 (69%)
  - 455 (36%)
  - 542 (40%)

- **India**
  - 301 (25%)
  - 127 (9%)
  - 153 (10%)

- **Assumption:** no additional policies are enacted over the projection period
- **Population w/o electricity access:** Jazz 733 million, Symphony 885 million
Investment for electricity access in 2009 was $9 billion (IEA)

Connection cost per capita: Jazz $370, Symphony $440
**Universal electricity access by 2030**

Initial annual consumption of 120 kWh per person
- Reaching the regional average levels after 5 years

<table>
<thead>
<tr>
<th>Electricity demand</th>
<th>Jazz (in TWh)</th>
<th>Symphony (in TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base Case</td>
<td>Additional</td>
</tr>
<tr>
<td>Pacific Asia</td>
<td>922</td>
<td>69</td>
</tr>
<tr>
<td>Central Asia</td>
<td>301</td>
<td>59</td>
</tr>
<tr>
<td>India</td>
<td>942</td>
<td>88</td>
</tr>
<tr>
<td>Latin America</td>
<td>543</td>
<td>2</td>
</tr>
<tr>
<td>M. East &amp; N. Africa</td>
<td>1109</td>
<td>3</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>387</td>
<td>285</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4203</td>
<td>507</td>
</tr>
</tbody>
</table>
Universal electricity access by 2030

Cumulative electricity generation capacity investment:

- Additional electricity capacity: Jazz +133 GW, Symphony +192 GW
- Solar and hydro for rural electrification, fossil for on-grid urban electrification
Universal electricity access by 2030

Annual investment expenditure over the period 2011-30, USD2010

- Total annual investment 2011-30: Jazz $36 billion, Symphony $45 billion
- Less than 4% of the global investment in the power sector in the WEC/PSI scenarios
Universal electricity access by 2030

Impacts on primary energy supply in 2030 (left) & cumulative CO₂ emissions 2010-30 (right)

- Low levels of consumption by people gaining access → minor impacts on TPES
- High proportion of renewable solutions adopted → minor impacts on CO₂
- Symphony vs Jazz: -13% energy consumption, -25% cum. CO₂ emissions
Universal electricity access by 2030

Sensitivity analysis on GDP and population assumptions

- **Annual investment expenditure over the period 2011-30:**
  - In a Jazz-like world $34 – 37 billion
  - In a Symphony-like world $45 – 48 billion
  - For reference: IEA $45 billion, IIASA $33 – 38 billion
Establishing universal electricity access in the WEC scenarios requires annual investment of $34 to $48 billion over the period 2011-30. This is 4% of the global investment in the electricity sector over the same period. Solar and hydro power are key options for increasing the electrification of the population (especially in rural areas). Establishing universal electricity access results in minor impacts on energy demand and CO$_2$ emissions. A lower-carbon pathway is about 27% more expensive, but it requires 13% less energy consumption and produces 25% less cumulative CO$_2$ emissions.

Methodological issues:
- The diversity of the regions is not fully captured.
- Coupling with CGE models could provide more insights regarding the socio-economic drivers of electricity access.
- Sensitivity analyses on scenario assumptions other than GDP and population could provide additional insights.
Thank you for the attention!

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### Data used in the econometric model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income per capita</td>
<td>USD2005 (PPP)</td>
<td>World Bank</td>
</tr>
<tr>
<td>Urbanisation</td>
<td>% of population</td>
<td>UNPD</td>
</tr>
<tr>
<td>Poverty</td>
<td>% of population living with less than $2 per day</td>
<td>World Bank</td>
</tr>
<tr>
<td>Institutional development</td>
<td>Average of CPIA indices</td>
<td>World Bank</td>
</tr>
<tr>
<td>Electricity per capita</td>
<td>kWh per capita in residential/commercial sectors</td>
<td>IEA energy balances</td>
</tr>
<tr>
<td>Electrification of demand</td>
<td>% of electricity in final energy consumption in residential/commercial</td>
<td>IEA energy balances</td>
</tr>
<tr>
<td>Electricity access</td>
<td>% of population with access to electricity</td>
<td>IEA WEO series</td>
</tr>
</tbody>
</table>
Mathematical specification of the econometric model

\[
\ln \left( \frac{\text{elcacc} s_{r,t}}{1-\text{elcacc} s_{r,t}} \right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} (\gamma_{r,k_r,1} \cdot \text{poverty}_{r,t-k_r}) + \beta_{r,2} \cdot \sum_{\lambda_r} (\gamma_{r,\lambda_r,2} \cdot \text{urbanisation}_{r,t-\lambda_r}) + \beta_{r,3} \cdot \\
\sum_{\nu_r} (\gamma_{r,\mu_r,3} \cdot \text{elccap}_{r,t-\mu_r}) + a_{r,t} + \epsilon_{r,t}
\]

\[
\ln \left( \frac{\text{poverty}_{r,t}}{\text{poverty}_{r,t-1}} \right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} (\gamma_{k_r} \cdot \ln \left( \frac{\text{incom } e_{r,t-k_r}}{\text{incom } e_{r,t-k_r-1}} \right)) + \beta_{r,2} \cdot \sum_{\lambda_r} (\gamma_{\lambda_r} \cdot \ln (\text{cpi}_{r,t-k_r})) + \epsilon_{r,t}
\]

\[
\ln \left( \frac{\text{cpi } a_{r,t}}{6-\text{cpi } a_{r,t}} \right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} (\gamma_{k_r} \cdot \text{gd}_{r,t-k_r}) + \epsilon_{r,t}
\]

\[
\ln \left( \frac{\text{migratio } n_{r,t}}{1-\text{migratio } n_{r,t}} \right) = \beta_{r,0} + \beta_{r,1} \cdot \sum_{k_r} (\gamma_{k_r} \cdot \text{income}_{r,t-k_r}) + \epsilon_{r,t}
\]

\[
\text{urbanisation}_{r,t} = \text{urbanisation}_{r,t-1} \cdot \frac{\text{pop}_{r,t}}{\text{pop}_{r,t-1}} + \text{migratio}_{r,t} \cdot \text{pop}_{r,t} \cdot \frac{\text{pop}_{r,t-1} - \text{urbanisation}_{n,t-1}}{\text{pop}_{r,t-1}}
\]
Example of estimation using PDLs

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Programme name</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>North &amp; South Latin America</td>
<td>Enabling Electricity - ENEL</td>
<td>Implementing more than 30 projects in 20 Latin America Countries to improve electricity access in isolated communities [57]</td>
</tr>
<tr>
<td>Brazil</td>
<td>Luz para Todos</td>
<td>Aiming at increasing rural electrification in Brazil (2003-2014) [58]</td>
</tr>
<tr>
<td>India</td>
<td>Rajiv Gandhi Grameen Vidyutikaran Programme</td>
<td>Electrification of more than 17 million rural households [59]</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>Master Plan for Electrification</td>
<td>Electricity for all by 2020 [60]</td>
</tr>
<tr>
<td>Nepal</td>
<td>Rural Electrification Programme</td>
<td>Electricity for all by 2027 [61]</td>
</tr>
<tr>
<td>Philippines</td>
<td>Philippines Energy Plan</td>
<td>Electrification of 90% of households by 2017 [62]</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Rural Electrification Programmes</td>
<td>Electricity access for 95% of the population by 2020 [63].</td>
</tr>
<tr>
<td>Vietnam</td>
<td>National energy development programme</td>
<td>Universal electrification by 2020 [64]</td>
</tr>
<tr>
<td>Ghana</td>
<td>National Electrification Scheme</td>
<td>100% electricity access by 2020 [65]</td>
</tr>
<tr>
<td>South Africa</td>
<td>Integrated National Electrification Programme</td>
<td>100% electricity access by 2020 [66]</td>
</tr>
<tr>
<td>Zambia</td>
<td>Rural Electrification Master Plan</td>
<td>Electricity access for 78% in urban and 15% in rural areas by 2015 [67]</td>
</tr>
</tbody>
</table>