Cost-optimal regional deployment of renewable energy in the Mexican electric power system

Anahi Molar Cruz, Beatriz Guillén, Thomas Hamacher

Technical University of Munich
Faculty of Electrical and Computer Engineering
Chair of Renewable and Sustainable Energy Systems

International Energy Workshop 2018
Gothenburg, 20.06.2018
1. Transformation of the Mexican power sector to a low-carbon system

2. Clean energy policy (2015)

3. Long-term auction prices of RE projects in 2017 (with financial incentives):
   - Solar: 21 USD/MWh (avg 27 USD/MWh)
   - Wind: 19 USD/MWh (avg 32 USD/MWh)

4. Massive national RE potential

5. High dependency on imported natural gas

6. Very few literature on the gradual transformation of the power system until 2050

*RE, nuclear, efficient cogeneration, waste-based generation
Methodology
Regional model in urbs

• Nine regions + interconnections
• 2016-2050 in four years: 2016, 2020, 2030, 2050
• Input data:
  Hourly time series of electricity demand
  Hourly time series of RES
  Power plant list
  Storage capacities
  Transmission capacities
  Restrictions for grid and generation capacity expansion
• Scenarios: BASE, CLEAN-ENERGY, COST-OPTIMAL
### Control regions and demand

<table>
<thead>
<tr>
<th></th>
<th>Annual average growth rate</th>
<th>Annual electricity consumption [TWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2016</td>
</tr>
<tr>
<td>BC</td>
<td>2.2%</td>
<td>13</td>
</tr>
<tr>
<td>BCS</td>
<td>3.0%</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>1.6%</td>
<td>59</td>
</tr>
<tr>
<td>E</td>
<td>2.1%</td>
<td>48</td>
</tr>
<tr>
<td>N</td>
<td>2.3%</td>
<td>25</td>
</tr>
<tr>
<td>NE</td>
<td>2.5%</td>
<td>52</td>
</tr>
<tr>
<td>NW</td>
<td>2.5%</td>
<td>23</td>
</tr>
<tr>
<td>P</td>
<td>3.0%</td>
<td>12</td>
</tr>
<tr>
<td>W</td>
<td>2.5%</td>
<td>63</td>
</tr>
<tr>
<td>Mexico</td>
<td>2.4%</td>
<td>299</td>
</tr>
</tbody>
</table>
The Mexican power system in 2016

Installed capacity by technology and region in GW

TOTAL: 70 GW
Untapped renewable potential

<table>
<thead>
<tr>
<th></th>
<th>Bio</th>
<th>CHP</th>
<th>Geo</th>
<th>Large Hydro</th>
<th>Small Hydro</th>
<th>Wind</th>
<th>PV</th>
<th>PSHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>0</td>
<td>0.1</td>
<td>0.8</td>
<td>0</td>
<td>0.2</td>
<td>0.8</td>
<td>2.9</td>
<td>0.3</td>
</tr>
<tr>
<td>BCS</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>6.4</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>0.3</td>
<td>0.9</td>
<td>0.4</td>
<td>0.2</td>
<td>0.7</td>
<td>1.3</td>
<td>7.0</td>
<td>2.8</td>
</tr>
<tr>
<td>E</td>
<td>0.4</td>
<td>3.2</td>
<td>0.1</td>
<td>1.0</td>
<td>1.8</td>
<td>8.0</td>
<td>13.0</td>
<td>0</td>
</tr>
<tr>
<td>N</td>
<td>0.5</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>10.6</td>
<td>47.4</td>
<td>0</td>
</tr>
<tr>
<td>NE</td>
<td>0.2</td>
<td>2.1</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
<td>8.4</td>
<td>21.8</td>
<td>0.2</td>
</tr>
<tr>
<td>NW</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>0</td>
<td>0.6</td>
<td>0.8</td>
<td>35.7</td>
<td>0</td>
</tr>
<tr>
<td>P</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.8</td>
<td>19.1</td>
<td>0</td>
</tr>
<tr>
<td>W</td>
<td>0.5</td>
<td>0.5</td>
<td>1.9</td>
<td>0</td>
<td>0.2</td>
<td>3.0</td>
<td>29.5</td>
<td>0</td>
</tr>
<tr>
<td>MEX</td>
<td>2.3</td>
<td>7.0</td>
<td>3.6</td>
<td>1.2</td>
<td>3.8</td>
<td>33.7</td>
<td>183</td>
<td>3.3</td>
</tr>
</tbody>
</table>

- Cogeneration in the industrial sector
- Hydro has been exploited already
- Geothermal potential with temperatures above 130°C
- Share of available considered:
  - Wind: 2.5%
  - PV: 1%
Average load factors for RE

National averages
- Solar: 21%
- Wind: 35%
- Large hydro: 27%
- Small hydro: 44%
Validation – Electricity generation mix

Real generation mix from PRODESEN 2017 vs BASE 2016

Anahi Molar-Cruz (TUM ENS) | IEW 2018 | 20.06.2018 Gothenburg
Evolution of installed capacity at the country level
2016-2050 (CLEAN-ENERGY)

Anahi Molar-Cruz (TUM ENS) | IEW 2018 | 20.06.2018 Gothenburg
Evolution of installed capacity at the regional level
2016-2050 (CLEAN-ENERGY)
Regional clean energy share
2016-2050 (CLEAN-ENERGY)

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Clean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2016</td>
<td>50%</td>
<td>0%</td>
</tr>
<tr>
<td>2050</td>
<td>50%</td>
<td>0%</td>
</tr>
</tbody>
</table>

The map shows the distribution of clean energy across different regions from 2016 to 2050.

Anahi Molar-Cruz (TUM ENS) | IEW 2018 | 20.06.2018 Gothenburg
Comparison with the national sector plan (PRODESESEN) 2030 (CLEAN-ENERGY vs BASE)

- Geothermal energy could play a major role
- CHP fraction is overestimated
- Storage allows the integration of PV
The cost of the clean energy targets

CLEAN-ENERGY vs COST-OPTIMAL

Additional
$2.4 USD billions per year
or 0.38 ¢/kWh
to reach the targets
Conclusions

• 50% share of clean energy by 2050 is an attainable goal

• In the scenarios analyzed:
  • Short term: geothermal
  • Medium term: wind + PHSP
  • Long term: solar + nuclear + battery + small hydro
  • The interconnection of regions is strengthened
  • Even with low costs of RES-based generation, an additional 0.38 c/kWh is required

• Results are highly sensible to the future demand and the costs of the technologies