Reliability standards and generation adequacy assessments for interconnected electricity systems

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Power outages are one of the main sources of public and political attention to the electricity sector
Heavy-handed policies that aim at ensuring *generation adequacy* are often implemented.

Source: ACER based on ENTSO-E’s 2019 MAF.
Reliability standards

Generation adequacy assessments consist in determining how much electricity generation capacity should be installed to meet a national reliability standard (or whether a prospective generation fleet meets the standard).

If we define:

\[
\text{Loss of load expectation (LOLE)} \equiv \Pr[\text{load} > \text{available capacity}]
\]

then, a reliability standard is generally specified as:

\[
\text{LOLE} \leq \hat{\alpha} = 2.4/3/4/8 \text{ hours/year}
\]
The microeconomic foundation for reliability standards has been established for a given power system *in isolation*.
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\[ \text{LOLE}^* = \alpha \equiv \frac{\text{CONE}_{\text{fixed}}}{\text{VoLL} - \text{CONE}_{\text{var}}} \]
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Turvey (1968)
Research question

Does/can the enforcement of a national reliability standard still make sense in an interconnected power system?

In particular:

- Should we update/replace the national reliability standard?
- How should countries coordinate their adequacy assessments?
We show theoretically that the social optimum may still be reached with national reliability standards under **two conditions**: 

1. Optimal installed generation capacity for each country should be determined **jointly**, while considering the full power system; 

2. LOLE calculations in generation adequacy assessments should fully **internalize external adequacy benefits** occurring throughout the full power system.

We run a numerical application for Europe that suggests that **regional coordination** matters the most.
Generation adequacy assessments approaches

- **Current approach**: each country determines how much it will install, making assumptions on available imports from neighbors in times of scarcity.

- **Optimal approach**: determine jointly how much capacity to install in every sub-region, taking into account the full power system.

However, national decision makers may be reluctant to transfer this responsibility to a supra-national level, because of the high economic, social, and political stakes.
Following the adoption of the Clean Energy Package (Regulation (EU) 2019/943), a regional adequacy assessment has to be implemented by the European Network of Transmission System Operators by the end of 2023.

This single assessment will determine the need for generation capacity investments in the different countries simultaneously, based on national LOLE targets provided by Member States.

Does/can such a hybrid approach remain consistent with social welfare maximization?

In the European context, can ACER’s current proposal for generation adequacy assessments be improved?
Framework

**Demand:**

\[ D_i \equiv \text{hourly electricity demand in country } i. \]

\[ V \equiv \text{value of lost load (VoLL).} \]

**Assumptions:** inelastic with a known distribution. Symmetric VoLL.
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**Interconnection:**
\[ L_{ij} \equiv \text{interconnection capacity from country } i \text{ to } j \text{ (can vary across hours).} \]
**Assumption:** NTC model (no power flow modeling), lossless exchanges.
Autarky reliability standard

We define:

\[ \alpha \equiv \frac{CONE_{\text{fixed}}}{VoLL - CONE_{\text{var}}} \]

For a power system in **autarky**, welfare maximization/cost minimization is achieved when:

\[ LOLE = \alpha \]

\[ \Rightarrow \text{We refer to } \alpha \text{ as the autarky reliability standard.} \]
Lost-load region
How should one assess LOLE in country 1?

**Domestic priority**

- $D_2$ vs. $D_1$
- $K_2$
- $0$ vs. $K_1$

**Neighbor first**

- $D_2$ vs. $D_1$
- $K_2$
- $0$ vs. $K_1$
First-order condition w.r.t. $K_1$ for optimality
First-order condition w.r.t. $K_1$ for optimality

**Take away 1:** Regional coordination

\[ K_2^* \]

\[ 0 \]

\[ D_1 \]

\[ D_2 \]

\[ K_1^* \]
First-order condition w.r.t. $K_1$ for optimality

Take away 2: Need to internalize external adequacy benefits
First-order condition w.r.t. $K_1$ for optimality

Take away 3: Autarky reliability standard need not be removed
We compare 4 approaches to generation adequacy assessments in an interconnected power system:

<table>
<thead>
<tr>
<th></th>
<th>Neighbor contribution considered</th>
<th>Capacity determined jointly</th>
<th>Internalize external adeq. benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autarky National</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Optimal</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Data - Load (1/2)

Hourly load and NTC data for 2015-2018 is retrieved from ENTSO-E Transparency Platform.

Table: Summary statistics of hourly load [MW] in the 11 studied countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Observations</th>
<th>Mean</th>
<th>P95</th>
<th>$K^*_{autarky}$</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>35,064</td>
<td>9,973</td>
<td>12,216</td>
<td>13,506</td>
<td>13,670</td>
</tr>
<tr>
<td>Denmark</td>
<td>35,057</td>
<td>3,740</td>
<td>4,997</td>
<td>5,638</td>
<td>5,819</td>
</tr>
<tr>
<td>France</td>
<td>35,040</td>
<td>54,040</td>
<td>75,280</td>
<td>92,433</td>
<td>94,492</td>
</tr>
<tr>
<td>Germany-Austria-Luxembourg</td>
<td>35,064</td>
<td>70,037</td>
<td>89,770</td>
<td>96,788</td>
<td>98,259</td>
</tr>
<tr>
<td>Great Britain</td>
<td>35,058</td>
<td>35,893</td>
<td>48,360</td>
<td>56,544</td>
<td>57,388</td>
</tr>
<tr>
<td>Ireland</td>
<td>34,899</td>
<td>3,132</td>
<td>4,077</td>
<td>4,798</td>
<td>4,901</td>
</tr>
<tr>
<td>Italy</td>
<td>35,064</td>
<td>33,096</td>
<td>45,077</td>
<td>53,212</td>
<td>55,157</td>
</tr>
<tr>
<td>Netherlands</td>
<td>35,064</td>
<td>12,557</td>
<td>16,686</td>
<td>18,692</td>
<td>19,272</td>
</tr>
<tr>
<td>Portugal</td>
<td>35,064</td>
<td>5,669</td>
<td>7,283</td>
<td>8,500</td>
<td>8,732</td>
</tr>
<tr>
<td>Spain</td>
<td>35,047</td>
<td>28,684</td>
<td>36,084</td>
<td>40,232</td>
<td>41,015</td>
</tr>
<tr>
<td>Switzerland</td>
<td>34,990</td>
<td>6,697</td>
<td>8,474</td>
<td>9,826</td>
<td>9,968</td>
</tr>
</tbody>
</table>

Note: Germany load is aggregated with Austria and Luxembourg. Some observations are missing or where ignored because they differed more than 50% from their day-ahead forecast.
### Table: Median NTC [MW] for each border between the 11 studied countries.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>BE</th>
<th>DK</th>
<th>FR</th>
<th>DE-AT-LU</th>
<th>GB</th>
<th>IE</th>
<th>IT</th>
<th>NL</th>
<th>PT</th>
<th>ES</th>
<th>CH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>DK</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>FR</td>
<td>885</td>
<td>1,300</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>France</td>
<td>GB</td>
<td>2,100</td>
<td>1,800</td>
<td>2,000</td>
<td>2,686</td>
<td>2,400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany-AT-LU</td>
<td>IE</td>
<td>1,400</td>
<td>2,000</td>
<td></td>
<td></td>
<td>780</td>
<td>1,468</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Britain</td>
<td>IT</td>
<td>2,090</td>
<td>1,400</td>
<td></td>
<td></td>
<td>750</td>
<td>1,016</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ireland</td>
<td>NL</td>
<td>800</td>
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<tr>
<td>Ireland</td>
<td>PT</td>
<td>995</td>
<td>100</td>
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<td>Ireland</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Ireland</td>
<td>CH</td>
<td>1,200</td>
<td>1,468</td>
<td>1,016</td>
<td>2,900</td>
<td></td>
<td>2,900</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ireland</td>
<td>CH</td>
<td>1,200</td>
<td>5,200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Note: missing observations were replaced by the median value of NTC for the corresponding interconnection.


**Results**

<table>
<thead>
<tr>
<th></th>
<th>Autarky</th>
<th>National</th>
<th>Regional</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs (M€/year)</td>
<td>23,395</td>
<td>24,590</td>
<td>22,446</td>
<td>22,436</td>
</tr>
<tr>
<td>Total installed capacity (GW)</td>
<td>389.9</td>
<td>361.3</td>
<td>372.2</td>
<td>372.3</td>
</tr>
<tr>
<td>Average realized LOLE</td>
<td>0.1</td>
<td>15</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

**Main take-aways:**

- In the absence of regional coordination, national adequacy assessments can backfire (i.e. yield a worse outcome than just installing autarky capacities);
- In terms of getting total system costs right, regional coordination appears to be more important than correctly internalizing external adequacy benefits in national LOLE computations.
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