Representing Cross-border Trade in Long-term Power System Planning Models with Limited Geographical Scope

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Planning models with a limited geographical scope

Recent studies regarding long-term planning have focused on the impact of:

- the temporal/spatial resolution
- the level of technical detail

However, less attention has been drawn to the impact of the model’s **geographical scope**.
Planning models with a limited geographical scope

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Often long-term planning models are designed for a specific country or region, e.g., TIMES-Belgium, which requires a proper representation of cross-border trade with neighbouring regions.

- **Extend the geographical scope** beyond the focus region, e.g. NREL’s RPM
- **Define exogenous import and export functions/processes**
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• Define exogenous import and export functions/processes

How to properly design and use these import and export functions?
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• Methodology

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Methodology

Make assumptions regarding the *capacity mix* and *electricity demand* in the neighbouring countries.

- Existing studies/scenario analyses
- Communicated policy targets
- ...

The methodology adopted for representing cross-border trade can be summarized in the following three steps.

1. Construct *import/export functions*.
2. Include the obtained functions from ① in the *optimization model* (and solve the optimization model).
3. Perform an *ex-post cost reallocation*. 
1. Construct import/export functions

Construct import and export functions that:

- Reflects the potential of other countries to facilitate electricity imports (import curve)
- Reflects the willingness-to-pay of other countries for electricity exports (export curve)
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Due to varying demand and intermittent RES, the process is repeated for every time step.
2. Planning model formulation

\[
\text{Min} \quad \text{Investment cost} + \text{Generation cost} + \text{Import cost} - \text{Export revenue}
\]

Subject to:

- System constraints (e.g., supply-demand balance)
- Policy constraints (e.g., RES targets, emission prices)
- Technical constraints (e.g., generation limits)
- Cross-border trade constraints

\[
\text{Import cost} = \sum_{i \in I} \sum_{t \in T} P_{i}^{\text{imp}} \cdot \text{import}_{i,t}
\]

\[
\text{Export revenue} = \sum_{e \in E} \sum_{t \in T} P_{e}^{\text{exp}} \cdot \text{export}_{e,t}
\]
Export revenue in objective function

\[ D_A \]

\[ D_B \]
Export revenue in objective function
Export revenue in objective function
Export revenue in objective function
Import cost in objective function
3. Ex-post cost reallocation
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The Import/export curves trigger the correct investment decisions, however the objective function does not represent the true cost for the modeled country.

- **Objective function**
  - Import cost is underestimated while the export revenue is overestimated
  - Total welfare increase due to cross-border trade is allocated to the modeled country.

- **Ex-post cost reallocation**
  - Traded electricity is valued at the locational electricity price (pay-as-cleared/marginal pricing)
  - Total welfare\(^1\) due to cross-border trade are split up in (i) profits for exporting country, (ii) avoided costs for importing country and (iii) a congestion rent.

\(^1\)not including cost reductions due to more efficient investment decisions
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2-country example

Static greenfield optimization for different RES shares

Three cases

- A+B (co-optimized case)
- A (isolated)
- A + import/export curves
Performance of methodology

<table>
<thead>
<tr>
<th>RES 50</th>
<th>A + B</th>
<th>A (isolated)</th>
<th>A + Import/Export curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost for country A (no congestion rents included) [billion EUR]</td>
<td>5.854</td>
<td>5.917</td>
<td>5.854</td>
</tr>
<tr>
<td>Error [%]</td>
<td>-</td>
<td>+ 1.06</td>
<td>+ 0.0</td>
</tr>
<tr>
<td>Computation time [s]</td>
<td>22.23</td>
<td>2.25</td>
<td>4.31</td>
</tr>
</tbody>
</table>

If the import/export curves are constructed based on the optimal capacity mix for country B.

- We get the same solution for country A as would be obtained in the multi-country optimization.

- The computation time can be reduced substantially

This method reduces the cross-border trade issue to making accurate exogenous assumptions about the power system in the neighbouring countries (without the need for co-optimization).
Ex-post cost reallocation

The objective function overestimates the cost reductions due to cross-border trade.

We need to compensate the objective value for:

1. The congestion rent in case of congested transmission line.
2. Profits and avoided costs that are actually contributing to welfare increases in neighbouring countries.

![Graph showing total cost reduction and market-based cost allocation against RES share]
Wrap-up

Limiting the geographical scope of long-term planning models requires correctly representing cross-border trade.

The proposed methodology has the benefit of:

1. Reducing the cross-border trade issue to **making (accurate) assumptions** about the surrounding power systems.

2. Correctly exogenizing the countries excluded from the scope of the model, hereby **improving computational tractability**.

There is a need to **reallocate country-specific costs**.

Future work:

- Perform a proper case study focusing on CWE-system
- Perform sensitivity analyses with Belgian TIMES model.
- Include stochasticity in current approach
References


Total welfare increase due to cross-border trade

Welfare gains due to CBT increase for increasing RES shares:

- More efficient RES investments - RES potential varies geographically
- Smoothing of variability - correlation effect of generation profiles and demand profiles

Total welfare gains are split between:

- Welfare increase for country A
- Welfare increase for country B
- Congestion rent