1. Scope of Research

For decades, traditional long-term power generation expansion planning (GEP) models are based on simplifications with regard to operational costs and issues ignoring technical details such as start-up and shut-down related decisions, ramp rates and operating reserves. However, due to the intermittency of the rapidly penetrating renewable energy technologies (RES) (e.g., wind and solar), the net load required to be met by the hydrothermal power plants is characterized by higher uncertainty and has faster time dynamics. As a result, the incorporation of short-term decisions (unit commitment problem) into the long-term planning framework (GEP problem) can enhance the accuracy of the decisions to be made and guarantees power network’s stability.

A generic mixed integer linear programming (MILP) model has been developed in this work integrating the unit commitment problem (UCP) within the long-term GEP framework. Typical daily constraints at an hourly level such as start-up and shut-down related decisions, ramping limits, system reserves requirements are combined with representative hourly constraints such as power capacity additions, power generation bounds of each unit, peak reserve requirements, and energy policy issues (RES penetration limits, CO₂ emission cap). For modeling purposes, a representative day (24 hours) of each month over a number of years has been employed to obtain the optimal capacity additions, system marginal prices (SNP), and daily operational planning of the studied system. The model has been tested on an illustrative case study of the Greek power system. Our approach aims to provide useful insights into the strategic and challenging decisions to be determined by investors and/or policy makers at a national and/or regional level.

2. Problem Description - Mathematical Formulation

The modeling framework is based on the MILP and is integrated with the medium-term model (UCP) with the main focus on the optimal long-term development and operation of the power system. The main objective is to minimize the total cost of the system's development and operation, subject to various operational and technical constraints.

**Problem statement**:
- Power system: number of sectors s ∈ S and zones m ∈ M
- Planning horizon: sets of years y ∈ Y, months m ∈ M, and hours h ∈ T
- Power generation units: existing, new, candidate, Thermal, Renewables, Hydroelectric
- Power plants’ start-up and shut-down types: set α ∈ A (hot, warm, and cold start-up)
- Available interconnections: imports nc ∈ NC,m,m′ and exports nco ∈ NC,o,o′
- Operational blocks k ∈ BL, bids, offers, technical characteristics (e.g., efficiency, CO₂ emission factor)
- Power generation and consumption: at each zone and sector, over the planning horizon

**Objective Function**:
- Minimization of the total cost for the optimal long-term development and operation of the power system

**Key model decisions**:
- Daily operational planning (UCP):
  - Start-up decision
  - Synchronization phase
  - Soak phase
  - Dispatching period
  - Desynchronization phase
  - Shut-down decision
- Long-term energy planning (GEP problem):
  - New and existing technology type of power capacity additions
  - Annual power generation mix
  - CO₂ emissions evolution
  - Energy policy issues
  - Environmental issues
  - Annual fuel consumption

3. Case Study Description - Results

**Figure 6: Hourly solar availability factor (%) in each representative day of each month in Zone 5 (input data)**

**Table 1: Assumptions of each examined scenario (input data)**

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emission price</td>
<td>CO₂ emission cap</td>
<td>Renewable penetration target</td>
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<td></td>
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<tr>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Low</td>
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</tr>
<tr>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**Implementation in GAMS 24.1.3 software, using GAMS/CPLEX 12.6.0.0 solver**

**Figure 7: System marginal price evolution (weighted annual average values) in all scenarios (€/MWh) (optimal results)**

**Figure 8: Power generation mix evolution in Scenario 3 (MW) (optimal results)**

**Figure 9: Contribution to secondary reserve requirements per technology type during a representative day in Scenario 1 (MW) (optimal results)**

4. Conclusions

- Analytical and detailed representation of the day-ahead energy and wholesale markets inside the long-term planning horizon (short-term-based strategic investment decisions).
- Integration between energy policy targets (CO₂ emissions cap, RES penetration target) and daily production scheduling.
- Positive correlation of significant RES penetration with high natural gas production and electricity trade, offering more flexibility to the power demand satisfaction.
- Lignite and coal units: main technologies in the absence of environmental policy or in a high CO₂ emission price scenario.
- SNP: highly sensitive to the unit types utilized for power generation - at low levels in the absence of environmental policy.

5. References


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