

A Model Coupling Optimisation Method for Long-Term Adequacy Constrained Investment and Operation Planning

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Introduction

- Energy transition transforms the system variability and uncertainty [1]
- Requires higher spatio-temporal resolution, increased planning horizon, stochastic modelling (e.g. Monte-Carlo) to consider it adequately [1]
- Loss of Load Expectation (LOLE) must be constrained to comply with the resource adequacy criterion
- Give rise to large-scale complex optimisation problems (i.e. tractability issues)
- Literature incentivize to look for new optimisation methods such as model-coupling [1]

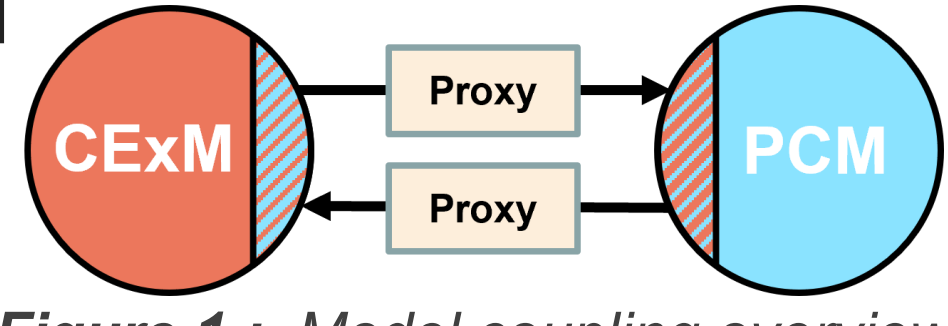


Figure 1 : Model coupling overview

Adequacy Constrained Investment and Operation Planning Problem (ACIOP)

$$\begin{aligned}
 (1) \quad ACIOP = \min_{\mathbf{x}_y} \quad & \sum_{y \in Y} \gamma_y [c_y^T \mathbf{x}_y + \Psi_y(\mathbf{x}_y)] \quad (1.1) \text{ Actualised expected TOTEX} \\
 \text{s.t.} \quad & A\mathbf{x} \leq a \quad (1.2) \text{ Investment constraints} \\
 & \Gamma_{y,n}(\mathbf{x}_y) \leq \alpha \quad (1.3) \text{ Adequacy constraint} \\
 & \mathbf{x}_y \geq 0
 \end{aligned}$$

$\forall n \in N, y \in Y$
 $\forall y \in Y$

$\mathbf{x}_y$ Investment decision variable
 $\Psi_y(\mathbf{x}_y)$ Optimal expected OPEX under operational constraints
 $\Gamma_{y,n}(\mathbf{x}_y)$ LOLE

Large scale bi-level problem

Model Coupling Methodology

To make the ACIOP problem tractable, we consider an **approximated $\widehat{ACIOP}^{(k)}$** which is **iteratively refined through model coupling** [2,3] (see fig. 1). $\widehat{ACIOP}^{(k)}$ is solved within a CExM (2) involving **approximated operational problems** (3) and **approximated adequacy constraints** (4).

$$\begin{aligned}
 (2) \quad \widehat{ACIOP}^{(k)} = \min_{\mathbf{x}_y^{(k)}} \quad & \sum_{y \in Y} \gamma_y [c_y^T \mathbf{x}_y^{(k)} + \tilde{\Psi}_y(\mathbf{x}_y^{(k)})] \quad (2.1) \text{ Approximated actualised expected TOTEX} \\
 \text{s.t.} \quad & A\mathbf{x}^{(k)} \leq a \quad (2.2) \text{ Investment constraints} \\
 & \tilde{\Gamma}_{y,n}^{(k)}(\mathbf{x}_y^{(k)}) \geq \tilde{\alpha}_{y,n}^{(k)} \quad (2.3) \text{ Approximated adequacy constraint} \\
 & \mathbf{x}_y \geq 0
 \end{aligned}$$

$\forall n \in N, y \in Y$
 $\forall y \in Y$

$$\begin{aligned}
 (3) \quad \tilde{\Psi}_y(\mathbf{x}_y) = \min_{\tilde{\mathbf{y}}_{tl}, \tilde{\mathbf{u}}_{tl}} \quad & \sum_{tl \in Tl} \tau_{tl} [d_{tl}^T \tilde{\mathbf{y}}_{tl} + \kappa \cdot e^T \tilde{\mathbf{u}}_{tl}] \quad (3.1) \text{ Approximated OPEX} \\
 \text{s.t.} \quad & \tilde{B}_{tl} \tilde{\mathbf{y}}_{tl} + \tilde{C}_{tl} \tilde{\mathbf{u}}_{tl} \leq \tilde{b}_{tl} - \tilde{E}_{tl} \mathbf{x}_y \quad (3.2) \text{ Approximated operational constraints} \\
 & \tilde{\mathbf{y}}_{tl}, \tilde{\mathbf{u}}_{tl} \geq 0
 \end{aligned}$$

$\forall tl \in Tl_y$
 $\forall tl \in Tl_y$

$\tilde{\mathbf{y}}_{tl}$ Assets' operational decision variables
 $\tilde{\mathbf{u}}_{tl}$ Unserved energy decision variables

$$\begin{aligned}
 (4) \quad \tilde{\Gamma}_{y,n}^{(k)}(\mathbf{x}_y^{(k)}) = \sum_{tech} f_{p_{y,n,fr,tech}}^{(k)} \cdot \mathbf{x}_{y,n,tech}^{(k)} \geq \tilde{\alpha}_{y,n}^{(k)} \quad & \text{Approximated adequacy constraint} \\
 & f_{p_{y,n,fr,tech}}^{(k)} \text{ Flexibility provision proxy} \\
 & \tilde{\alpha}_{y,n}^{(k)} \text{ Flexibility need proxy}
 \end{aligned}$$

$\forall y \in Y, n \in N, fr \in FR$

Flexibility needs, and provision are iteratively updated based on a PCM (5) outputs ($\tilde{\mathbf{y}}_{tl}, \tilde{\mathbf{u}}_{tl}$) the decision variables respectively associated to the assets operations and unserved energy) that solves a **high-resolution operational problem** associated to an investment decision $\mathbf{x}_y^{(k)}$.

$$\begin{aligned}
 (5) \quad \Psi_y(\mathbf{x}_y^{(k)}) = \min_{\mathbf{y}_s^{(k)}, \mathbf{u}_s^{(k)}} \quad & \sum_{s \in S_y} \omega_s [d_s^T \mathbf{y}_s^{(k)} + \kappa \cdot e^T \mathbf{u}_s^{(k)}] \quad (5.1) \text{ Expected OPEX} \\
 \text{s.t.} \quad & B_s \mathbf{y}_s^{(k)} + C_s \mathbf{u}_s^{(k)} \leq b_s - E_s \mathbf{x}_y^{(k)} \quad (5.2) \text{ Detailed operational constraints} \\
 & \mathbf{y}_s^{(k)}, \mathbf{u}_s^{(k)} \geq 0
 \end{aligned}$$

$\forall s \in S_y, y \in Y$
 $\forall s \in S_y, y \in Y$

$\mathbf{y}_{tl}$ Assets' operational decision variables
 $\mathbf{u}_{tl}$ Unserved energy decision variables

By using **Fourier transform**, **filtering** and back Fourier transform on the $\mathbf{y}_s^{(k)}, \mathbf{u}_s^{(k)}$ provide low, mid and high frequency range (fr) **modulation** $mod_{fr}(\mathbf{y}_{s,tech})$ of the system's assets [3]. **Statistical aggregation** is then used to construct **flexibility provision proxies** $f_{p_{y,n,fr,tech}}^{(k)}$ (6). I is a term of inertia.

$$f_{p_{y,n,fr,tech}}^{k+1} = I \cdot f_{p_{y,n,fr,tech}}^k + (1 - I) \cdot \left(\frac{qntl_{s \in S_y}^{(0.5)}(qntl_{s \in S_y}^{(0)} \left(\sum_{tech} \frac{mod_{fr}(\mathbf{y}_{s,tech})}{mod_{fr}(\mathbf{y}_{s,tech})} \right))}{\sum_{tech} \mathbf{x}_{y,tech}^{(k)}} \right) \cdot \mathbf{x}_{y,tech} \quad (6)$$

$(year) (frequency\ range) (tech) (node - implicit)$
 $(scenario) (timesteps)$

- Process
- Variables
- Parameters
- Linkage
- Harmonization

Hyperparameters



Figure 2 : Flowchart of the model-coupling framework for an iteration (k)

Figure 2.1 : Modulation

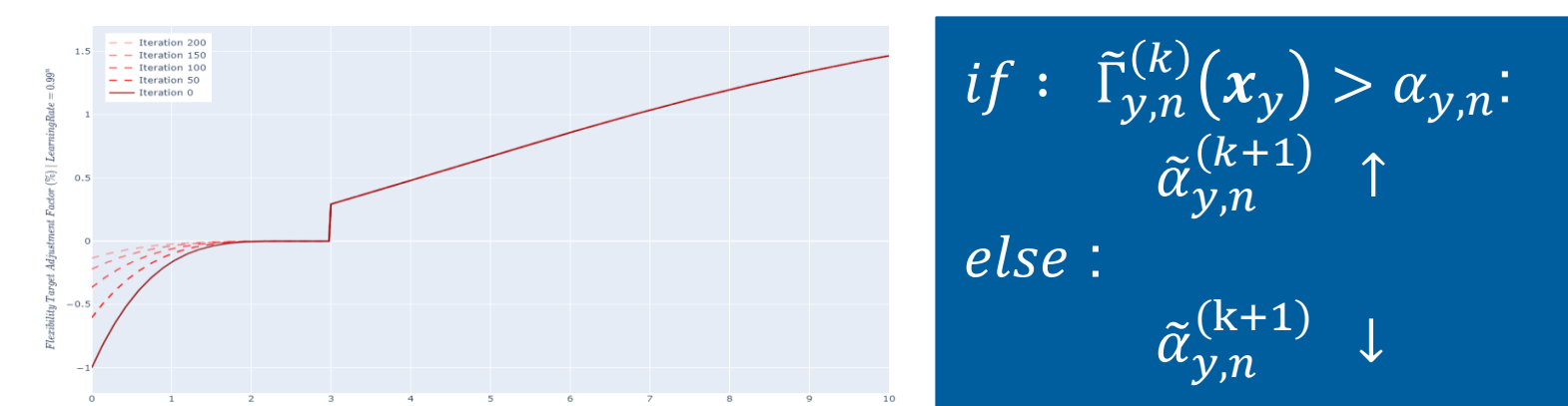


Figure 3 : Flexibility needs adjustment policy

The scale-specific flexibility needs $\tilde{\alpha}_{y,n}^{(k)}$ are updated according to the policy presented in fig. 3.

Model Coupling Results and Sensitivities

The coupling methodology is implemented on a **17 nodes** case study representing the **European electrical grid**. The investment planning horizon range on 2020-2025-...-2050; 11 hourly scenarios (PCM) and 24 time-slices (CExM) per year, a **Paris agreement compliant emission constraint**.

Data are taken from the **OSMOSE dataset** [4]. The CExM and the PCM used are respectively **OSemOSYS** [5] and **ANTARES** [6].

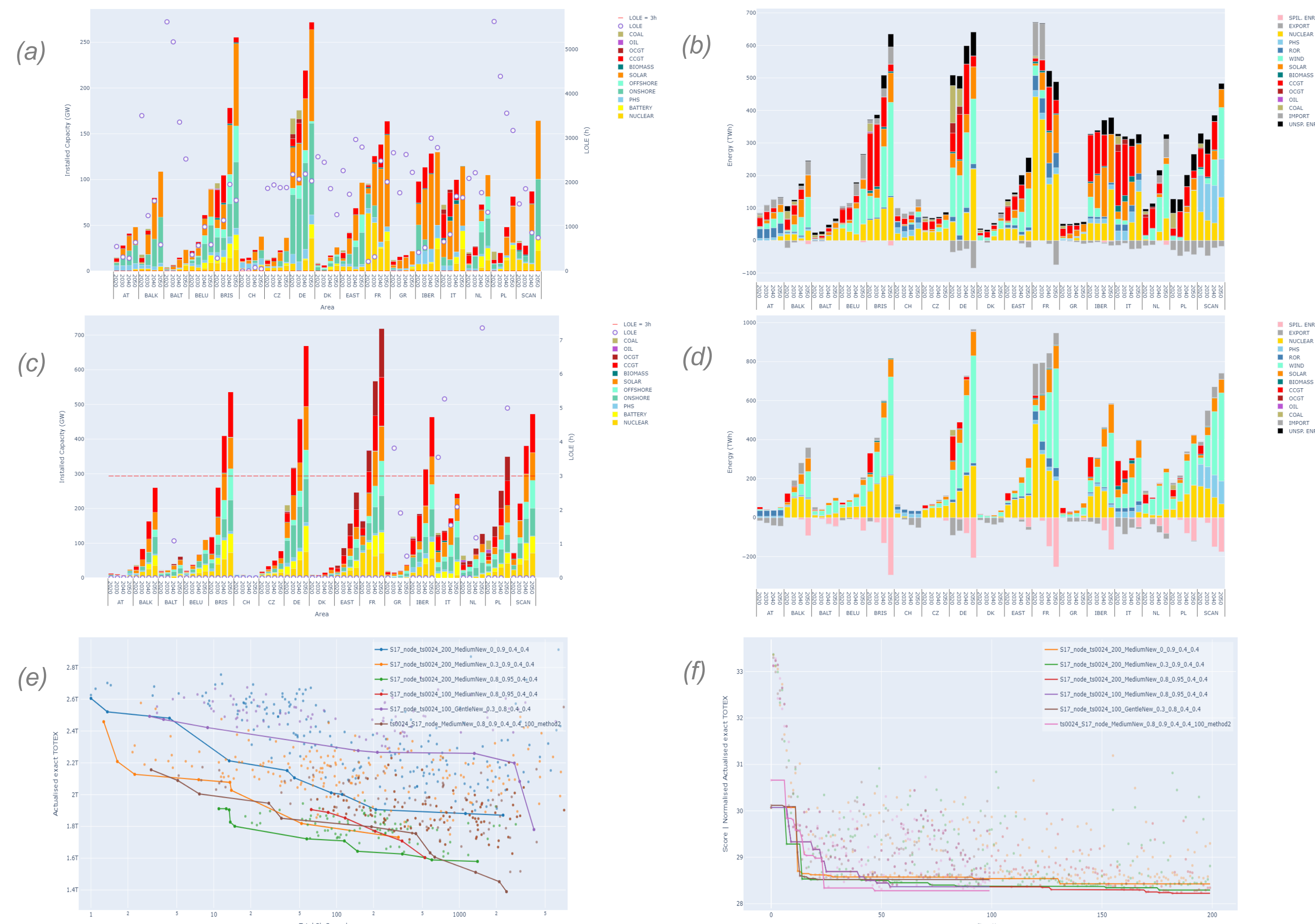


Figure 4: System and Mix Energy Mix without adequacy constraint (respectively (a) & (b)) and with a good approximated adequacy constraint (respectively (c) & (d)). Pareto optimum between adequacy and costs (e) and convergence curve (f) sensitivity for several hyperparameters combinations

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