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WP3.4

Probabilistic Coupled Model for Electricity and Natural Gas Infrastructures

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Objectives & Context

Objectives

- Assessment of investments in Natural Gas and Electricity (NG&E) transport and storage infrastructure
  - D3.4.2: Development a probabilistic combined NG&E operational model
  - D3.4.1: Application of the model to identify weak points in existing EU27+ and Balkan Countries NG&E systems

Context

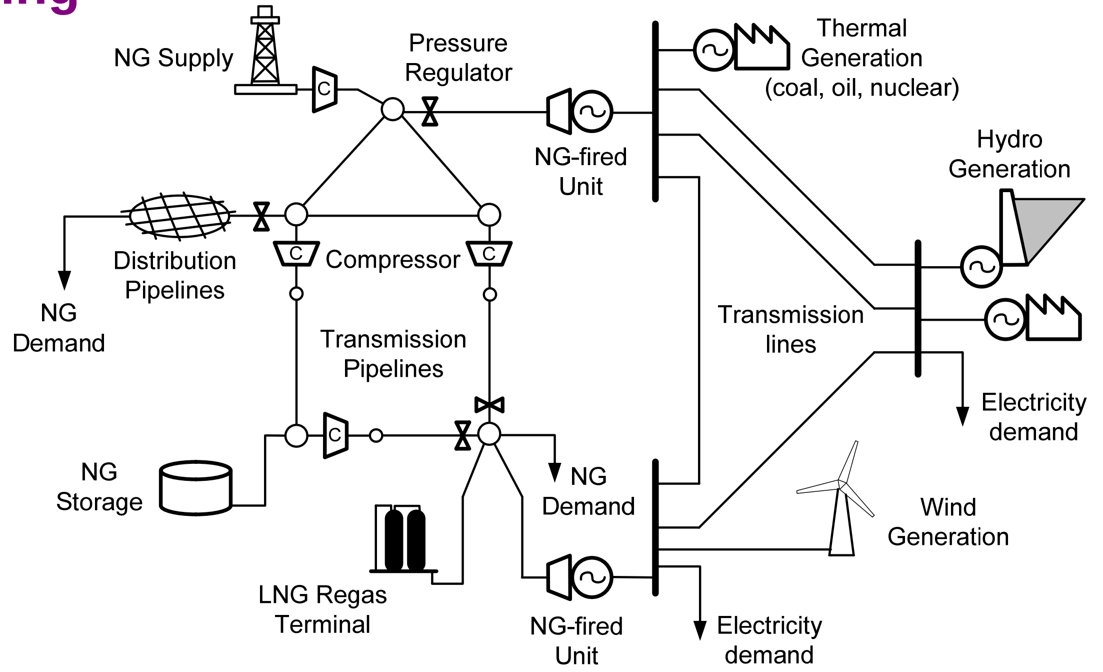
- Focus on electric power transmission
- Gas infrastructure assumed to be given
- Value-based expansion
- Combined NG&E systems operation
- Integrated NG&E markets with perfect competition

Framework

- Increasing interactions between NG&E $\Rightarrow$ combined NG&E optimization
- New step in the hierarchical planning procedure
- Pan-EU TIMES (PET) provides the long-term scenarios based on the assumed key drivers $\Rightarrow$ framework for the assessment of investments
- “Adapted systems”: PET input and result data for each milestone year
- Investments in NG&E network infrastructures: Centralized perspective

TIMES - The Integrated Markal Efom System

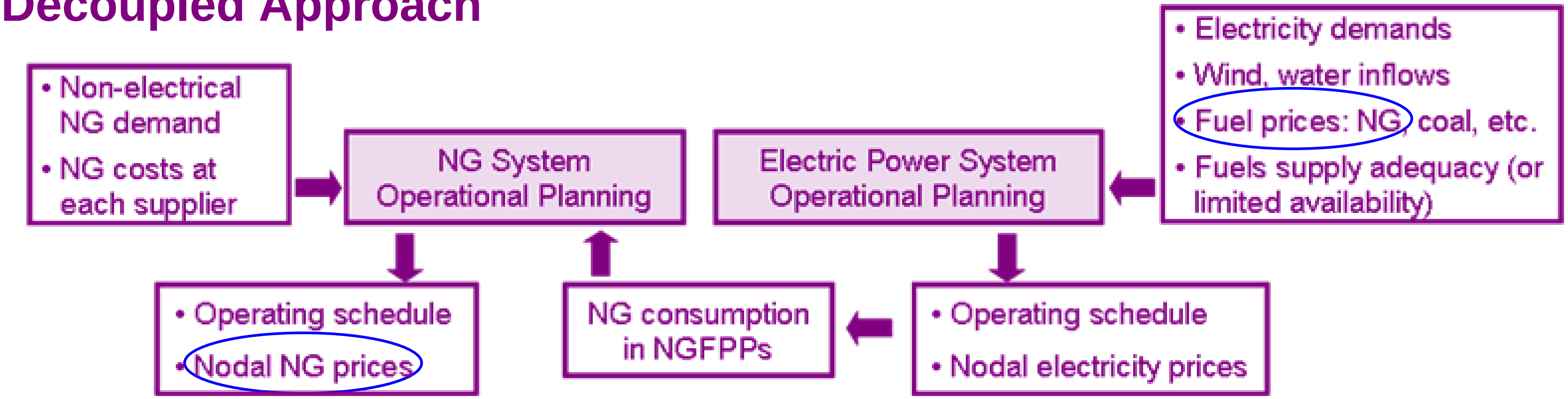
Modelling



- DC electric power flows
- Compressors and regulators provide NG flow controllability ⇒ nodal NG balances
- Energy storage: different NG storage facilities, NG line-pack and hydro storage

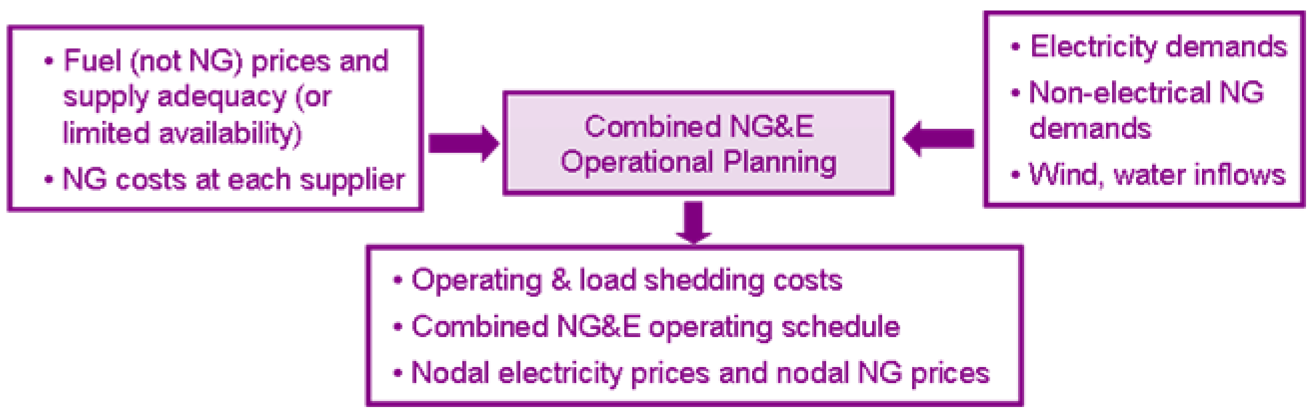
NG&E Operational Planning

Decoupled Approach



- Iterative procedure: slow & hard convergence

Proposed Combined Approach



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Mathematical Formulation

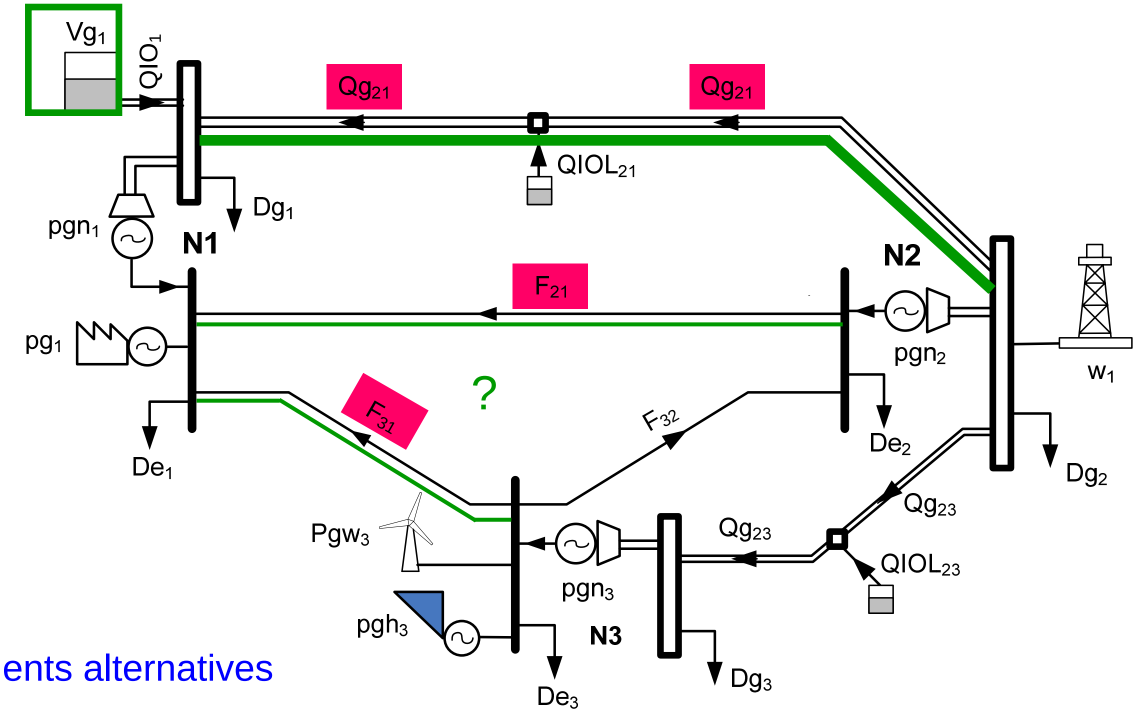
- Objective: Minimize NG&E supply and shortage costs

$$\min\left\{\sum_t \sum_k B^k \begin{pmatrix} \sum_i C_i\left(pg_i^{k,t}\right)+\sum_j CSE\left(ps_j^{k,t}\right)+CO\&M_i(pgn_i) \\ \sum_g C_g\left(w_g^{k,t}\right)+\sum_j CSG\left(ws_j^{k,t}\right) \end{pmatrix}\right\}$$

- Electric power system constraints
  - Global balance, transmission capacity limits, energy and capacity limits on thermal and hydro power plants
- NG system constraints
  - Nodal balances, production limits, pipelines capacity limits, storage injection and withdrawal limits
- Storage constraints
  - Inventory constraints, capacity limits, final volumes

Model Use

- Winter constraints: Qg_{21} binding at all *k;* F_{21}, F_{31} binding at peak
- High NG&E prices at node 1



- Investments alternatives
  - Pipeline expansion
  - Electric power transmission expansions
  - NG storage capacity expansion
  - Combinations: Enlarge F12 or F13 under a given pipeline expansion

Assessment Approach

- Value-based transmission expansions: reduction in operating and shortage costs vs. investment costs of predefined expansion projects

- Assessment based on adapted NG&E systems for each milestone year

- Probabilistic combined NG&E operational planning model
  - Monte Carlo simulation method
  - Uncertainties: NG&E demands, fuel prices and wind generation
  - Multivariate probability distribution of the errors on the forecasts

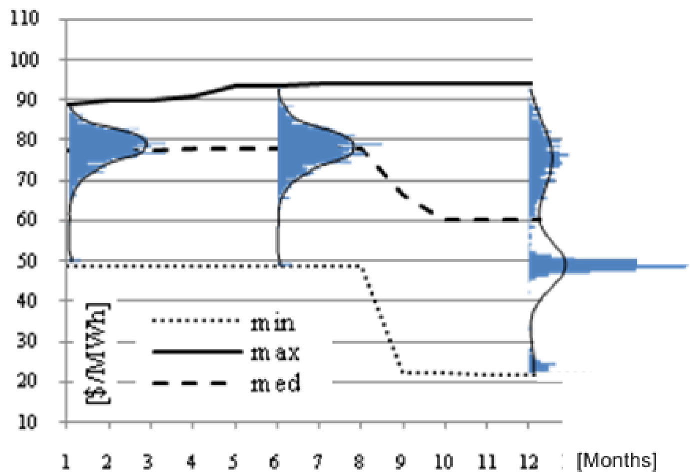
$$\left(\hat{\varepsilon}_{De_j}, \hat{\varepsilon}_{Dg_j}\right) \sim N\left(\mu_D, \Sigma_D\right) \qquad \left(\hat{\varepsilon}_{j,f}, \hat{\varepsilon}_{g}\right) \sim N\left(\mu_F, \Sigma_F\right) \qquad \hat{\varepsilon}^{t}_{Pgw_j} \sim N\left(\mu_W, \Sigma_W\right)$$

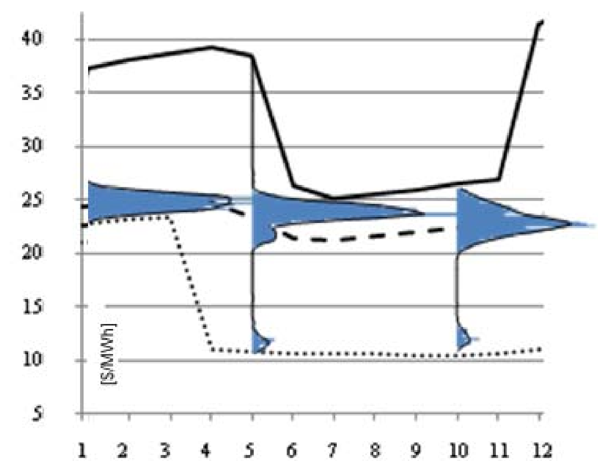
Results

Expected benefits of the investments alternatives

	Base Case	Pipeline Expansion	Line L21 Expansion	Line L31 Expansion	NG storage Expansion
Expected anunual Operating & Shortage cost [pu]	1	0.88	0.93	0.89	0.91
Expected Electricity Price N1 – Average [pu]	1	0.95	0.92	0.90	0.96
Expected NG Price N1 – Average [pu]	1	0.84	0.95	0.94	0.87

Electricity price N1- pdf **Base Case** NG price N1 - pdf





Assessments

- Identification of the weak points in the existing in the EU36 (EU27+ and Balkan countries) NG&E infrastructures

- Ranking of expansion alternatives: standard financial metrics NPV, IRR
  - Electric power transmission expansions
    - Based on an “adapted” NG system
    - For different sets of investments in NG transport and storage

- Analysis of the robustness of the ranking of the expansion alternatives under NG supply disruptions

Thank you for your attention!

Mathematical Formulation

- Objective: Minimize NG&E supply and shortage costs

$$\min\left\{\sum_t \sum_k B^k \left(\begin{array}{l}\sum_i C_i\left(pg_i^{k,t}\right)+\sum_j CSE\left(ps_j^{k,t}\right)+\\ \sum_g C_g\left(w_g^{k,t}\right)+\sum_j CSG\left(ws_j^{k,t}\right)\end{array}\right)\right\}$$

- Electric power system constraints

Global balance: $$\sum_i\left(pg_i^{k,t}+pgn_i^{k,t}+pgh_i^{k,t}\right)+\sum_j Pgw_j^{k,t}+\sum_j ps_j^{k,t}=\sum_j De_j^{k,t}$$

Transmission capacity limits: $$-F_m^{max}\le\sum_j\left[H_{mj}\left(\sum_{i\in G_j}\left(pg_i^{k,t}+pgn_i^{k,t}+pgh_i^{k,t}\right)+Pgw_j^{k,t}+ps_j^{k,t}-De_j^{k,t}\right)\right]\le F_m^{max}\quad\forall m$$

Production limits: $$0\le pg_i^{k,t},\, pgn_i^{k,t},\, pgh_i^{k,t}\le P_i^{dmax}\qquad\forall i$$

Mathematical Formulation

■ NG system constraints

Nodal balances:

$$\left(\begin{array}{l}\sum_{g\in W_j} w_g^{k,t} + ws_j^{k,t} + \sum_{m\in I_j} Qg_m^{k,t} - \sum_{m\in O_j} Qg_m^{k,t} + \\ \sum_{p\in P_j} QO_p^{k,t} - \sum_{p\in P_j} QI_p^{k,t} - \sum_{i\in G_j} HR_i\left(pgn_i\right)\end{array}\right) = Dg_j^{k,t} \qquad \forall j$$

Production limits:

$$W_g^{min} \le w_g^{k,t} \le W_g^{max} \qquad \forall g$$

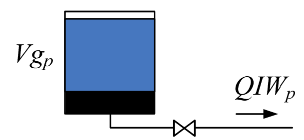
Pipelines capacity limits:

$$-Qg_m^{max} \le Qg_m^{k,t} \le Qg_m^{max} \qquad \forall m$$

■ Storage inventory constraints

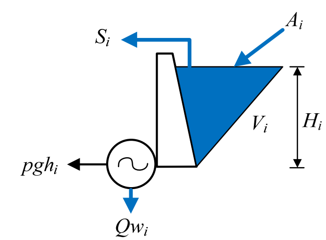
NG storages:

$$Vg_p^t = Vg_p^{t-1} - \sum_k B_k\, QIW_p^{k,t} \qquad \forall p$$



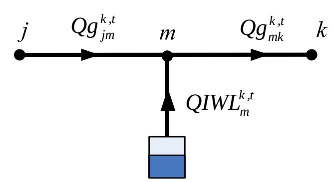
Water reservoirs:

$$V_i^t = V_i^{t-1} + A_i^t\, ST - \sum_k B_k\, Qw_i^{k,t} - S_i^t\, ST \qquad \forall i \in G_h$$



Pipelines line-pack:

$$\sum_k B_k\, QWIL_m^{k,t} = 0 \qquad \forall m \in M_{LP}$$



Mathematical Formulation

■ Storage capacity limits

NG storages: $Vg_p^{min} \le Vg_p^t \le Vg_p^{max} \quad \forall p$

Water reservoirs: $V_i^{min} \le V_i^t \le V_i^{max} \quad \forall i \in G_h$

■ Other storage constraints

Hydropower productions (reservoirs) : $pgh_i^{k,t} = \rho_i\left(Qw, H\right) Qw_i^{k,t} \quad \forall i \in G_h$

Equivalent hydro power plants: $\sum_k pgh_{i,o}^{k,t} = HE_i^t \; RF_i \quad \forall i \in G_{he}$

$$pgh_{i,b}^{k,t} = \frac{HE_i^t \left(1 - RF_i\right)}{ST} \quad \forall k, \forall i \in G_{he}$$

$$pgh_i^{k,t} = pgh_{i,b}^t + pgh_{i,o}^{k,t} \quad \forall i \in G_{he}$$

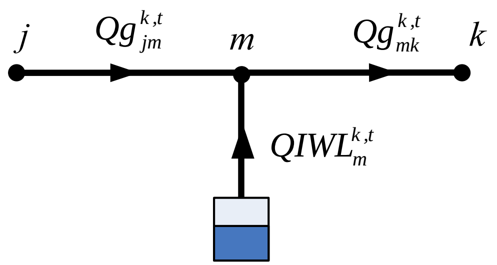
NG Storage injection and withdrawal limits: $-QI_p^{max} \le QIW_p^{k,t} \le QW_p^{max} \quad \forall p$

Mathematical Formulation

■ Line-pack limits

Equivalent Injection and withdrawal limits: $-QWIL_m^{max} \leq QWIL_m^{k,t} \leq QWIL_m^{max} \qquad \forall m \in M_{LP}$

Balance at the fictitious node: $Qg_{jm}^{k,t} + QWIL_m^{k,t} - Qg_{mk}^{k,t} = 0 \qquad \forall m \in M_{LP}$



$$Qg_{jm}^{max} = Qg_{mk}^{max} = Qg_m^{max} \qquad \forall m \in M_{LP}$$

■ Time horizon coupling constraints

NG storages: $Vg_p^{\text{ini}} = Vg_p^T \qquad \forall p$

Water reservoirs: $V_e^{\text{ini}} = V_e^T \qquad \forall e$