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Efficient Energy Use

LNG Port Interconnection with the Natural Gas Distribution Network in Finland

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Finnish Natural gas network

2014

- **29 TWh NG** sold
- **34 GWh biogas** injected into network
- **3.9 TWh LNG** sold in Nordic countries

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What happens if:

- New larger consumers emerge ?
- The energy demand increases ?
- There is a NG supply shortage ?
- Regasified LNG is injected into the network ?

Modelling and Optimisation Approach

- Steady- state
- Known energy demands (Gasum)
- Mass and energy balances
- Pressure drop equation
- Network constraints (Gasum)

- Multi period formulation
- MINLP (mixed integer non-linear programming)

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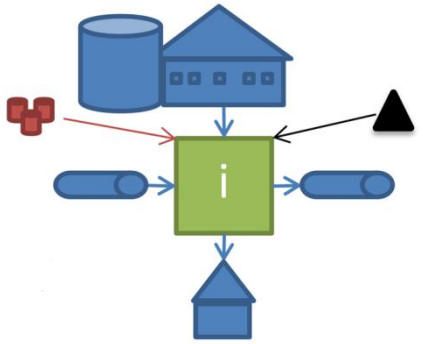
Balances



- Mass Balance

$$\sum_j m_{i,j,e} + O_{i,e} = \sum_j m_{j,i,e} + S_{i,e} \qquad \forall\, i \;, \forall\, j \;\; i \neq j$$

- Energy balance

$$O_{i,e} \cdot H_{\mathrm{NG}} + \sum_{ft \in FT} m_{i,ft,e} \cdot H_{ft} \geq D_{i,e} \qquad \forall\, i \in I \,, \forall\, e \in E \,, \forall\, ft$$

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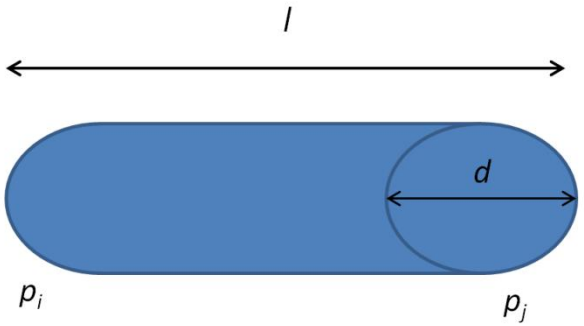
Pressure Drop



$$p_{j,e}^2 \leq p_{i,e}^2 - p_{i,e} \cdot \zeta \cdot \frac{l_{i,j}}{d_r} \cdot \rho_{i,e} \cdot \left(\frac{m_{i,j,r,e}}{\frac{1}{4} \cdot \rho_{i,e} \cdot \pi \cdot d_r^2} \right)^2 + \left(1 - a_{i,j,r}\right) \cdot M$$

$$p_{j,e}^2 \leq p_{i,e}^2 - p_{i,e} \cdot \zeta \cdot \frac{l_{i,j}}{d_r} \cdot \rho_{i,e} \cdot \left(\frac{m_{i,j,r,e}}{\frac{1}{4} \cdot \rho_{i,e} \cdot \pi \cdot d_r^2} \right)^2 - \left(1 - a_{i,j,r}\right) \cdot M$$

$$p_{i,e}^2 \leq p_{j,e}^2 - p_{j,e} \cdot \zeta \cdot \frac{l_{j,i}}{d_r} \cdot \rho_{j,e} \cdot \left(\frac{m_{j,i,r,e}}{\frac{1}{4} \cdot \rho_{j,e} \cdot \pi \cdot d_r^2} \right)^2 + \left(1 - b_{i,j,r}\right) \cdot M$$

$$p_{i,e}^2 \leq p_{j,e}^2 - p_{j,e} \cdot \zeta \cdot \frac{l_{j,i}}{d_r} \cdot \rho_{j,e} \cdot \left(\frac{m_{j,i,r,e}}{\frac{1}{4} \cdot \rho_{j,e} \cdot \pi \cdot d_r^2} \right)^2 - \left(1 - b_{i,j,r}\right) \cdot M$$

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Case study

- Existing pipeline
- Potential extensions specified
- Multi-period: winter, summer, autumn + spring
- Set of possible LNG terminals with regasification
- Price for NG and alternative fuel fixed
- Price of regasified LNG varied

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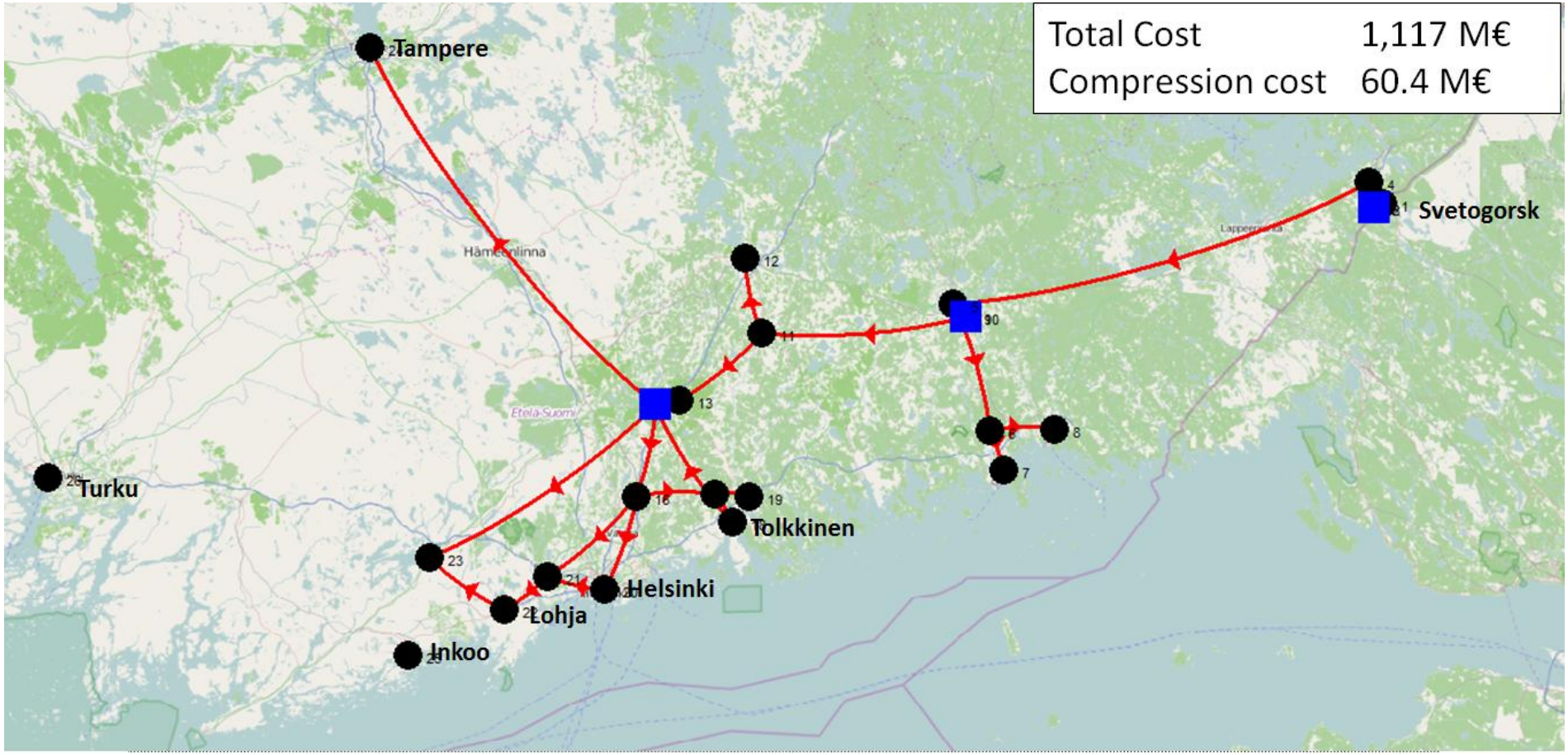
LNG price higher



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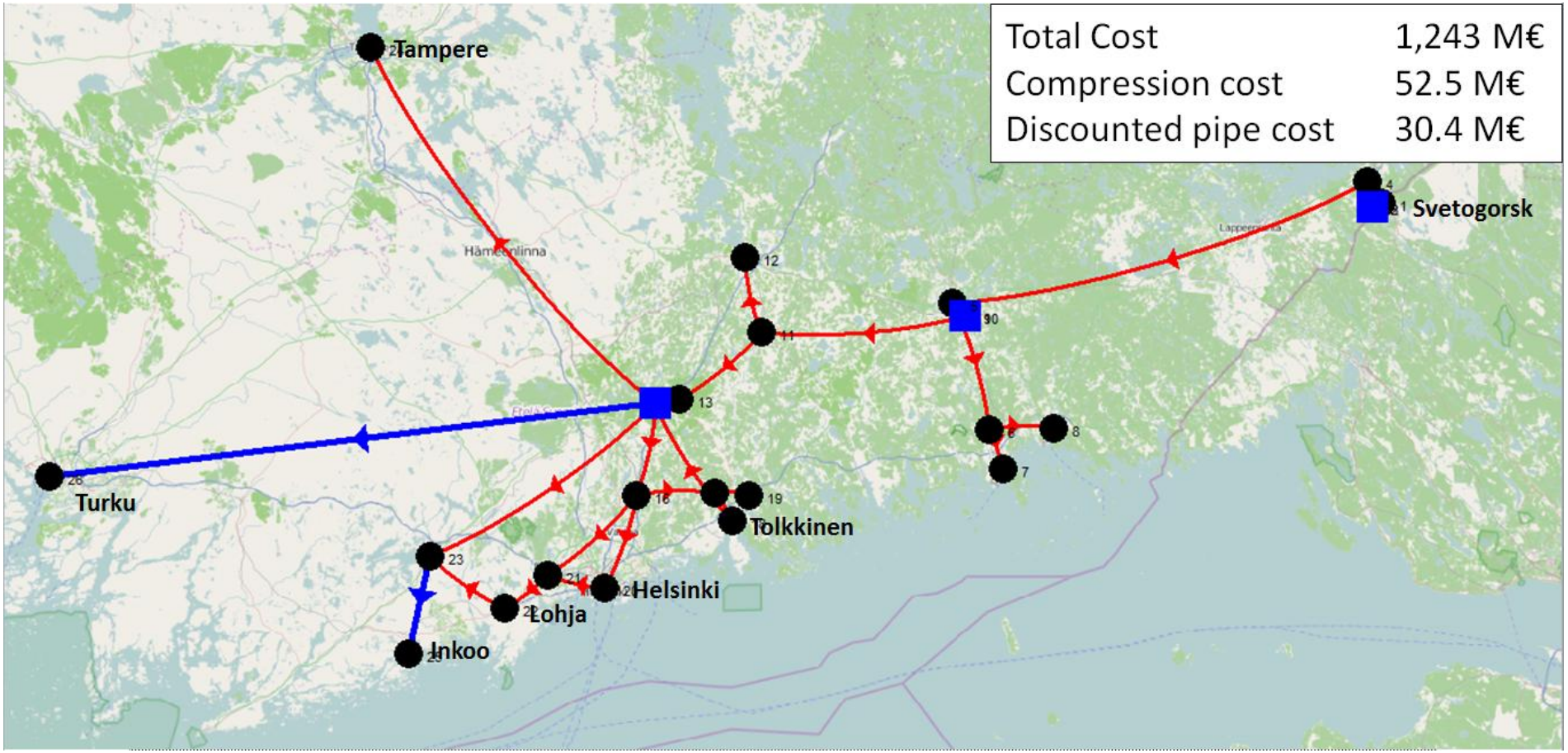
LNG price lower



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Mass flows (kg/s)

NG Supply (kg/s)	Period 1		Period 2		Period 3	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Svetogorsk (Russia)	107.1	98.9	97.2	77.8	66.6	25.5
Tolkkinen (LNG terminal)	14.0	0	3.8	0	0	0
Inkoo (LNG terminal)	0	20.0	0	20.0	0	20.0
Turku (LNG terminal)	8.8	20.0	7.1	7.1	2.5	2.5

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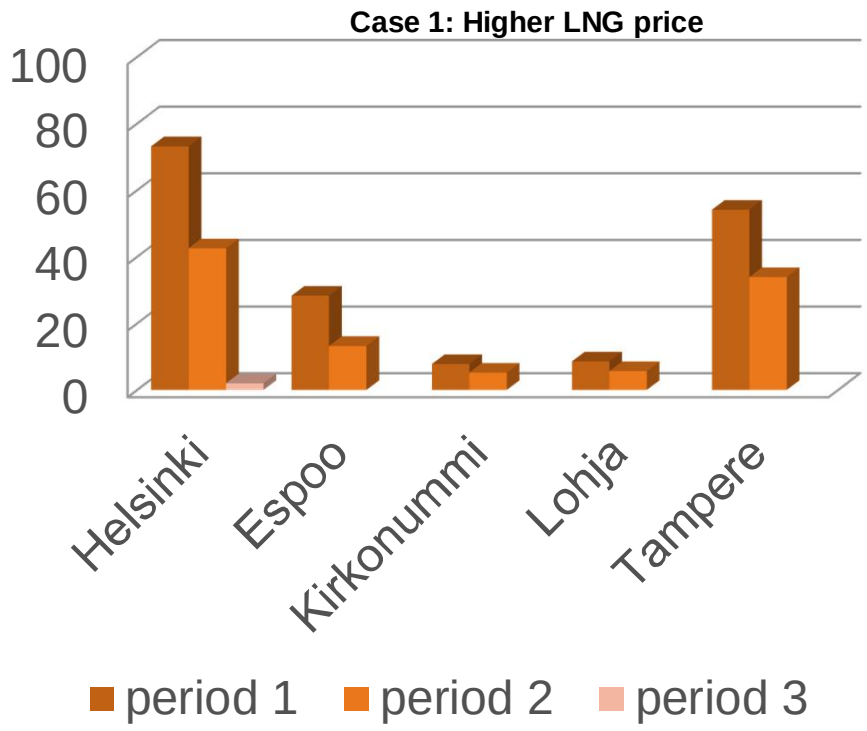
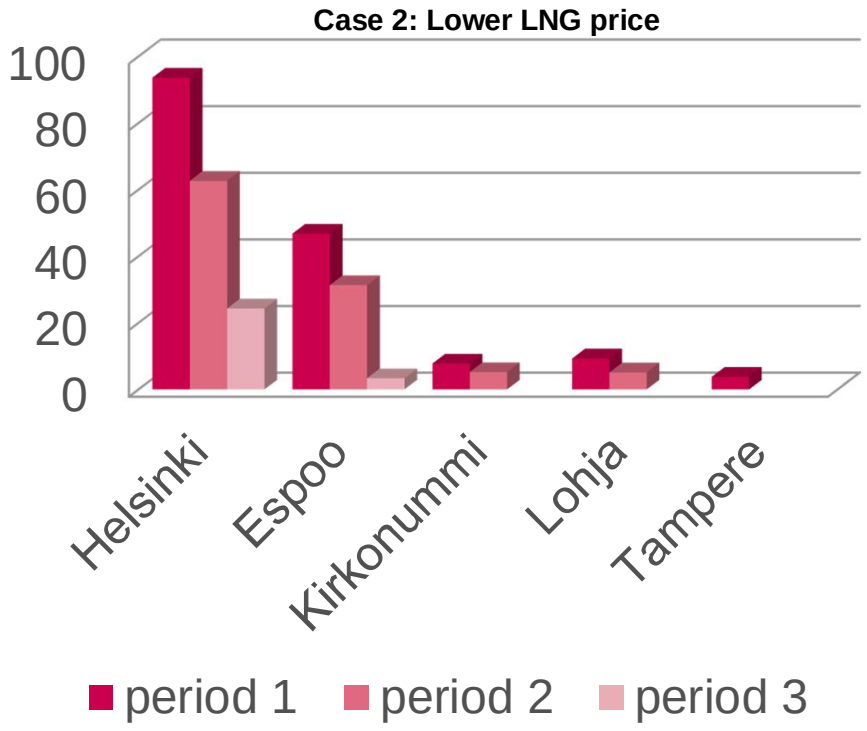
Alternative fuel use (kg/s)





Results and conclusions

The optimization gives information about

- pressures, mass flows and flow directions in network
- new supply and demand points
- investment and operation costs
- consumption of NG, LNG and alternative fuel during the periods
- threshold values at which structural changes occur: new concept becomes feasible
- sensitivity of the solution
- limits of the system

Future plans

- Expansion to a larger network
- Alternative or several objective functions:
  - Economics
  - Environmental issues
  - Primary energy use
  - Exergy use
- Sensitivity analysis
- Network in a larger supply chain scheme
- Sequential optimisation

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- Thank for your attention!