A risk-based evaluation of European natural gas supply security

The case of Nordstream 2 (PRELIMINARY WORK)

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Contents of our project

- Optimal flows
- Market influence and costs (see Balázs Sziklai's talk)
- Supply security

A description of the European gas network

Large, complex network – parallel edges, smaller/larger nodes

Our model of the network

Gas network as a graph

- Vertices = countries idealised as points
  - occasionally countries are combined
  - all demand is at this locus
  - produces or consumers,
  - produced and consumed gas quantities
  - (alternative) energy source to cover shortages
    - at a fixed replacement cost
  - net demands
- Edges = transnational pipelines
  - known transportation capacities and costs (i.e. lengths)
  - ... between idealised vertices.
- LNG
  - artificial vertex
  - edges connected to terminals; special costs

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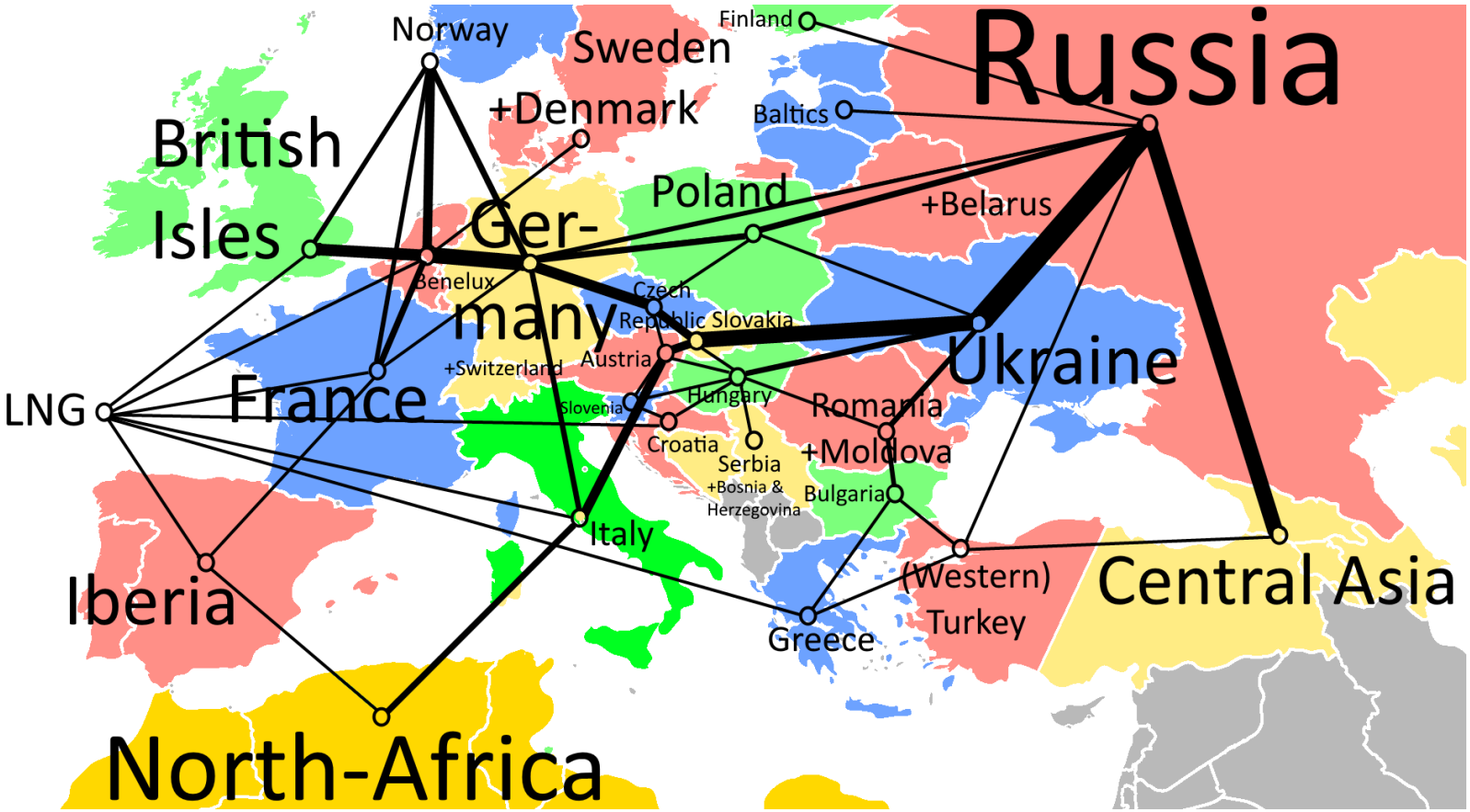
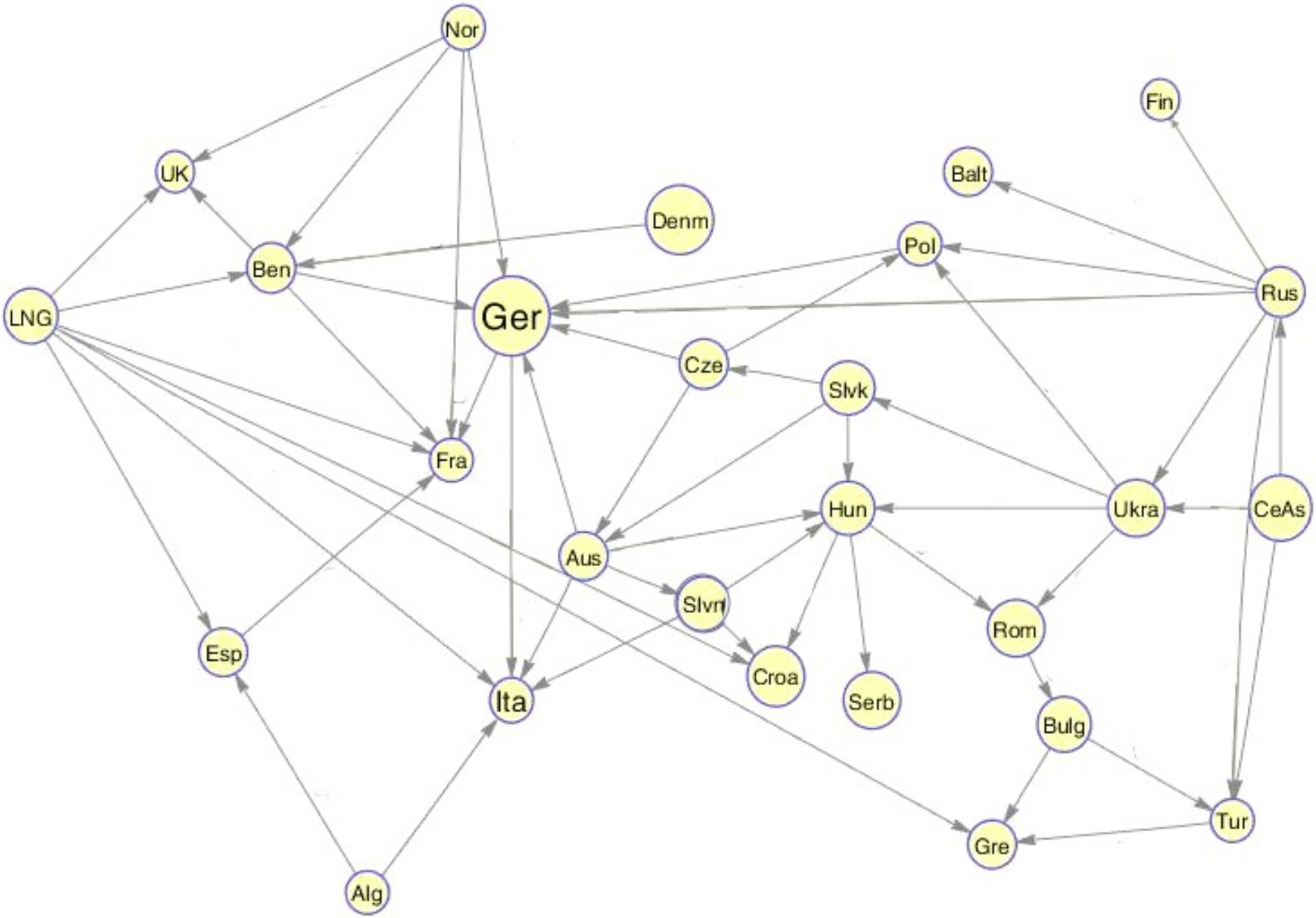
A simplified model



Simplification: pointlike countries, idealised pipelines

An abstract model



Optimal flows

Minimalise the total supply cost of member countries!

Assuming that

- all demand is satisfied (perhaps from own source)
- no resources from outside the coalition
- resources within the coaition only up to thei capacities
- flows are bounded by transportation capacities
- flows are nonnegative .

Optimal flows

Minimalise the total supply cost of member countries!

$$\min_x \begin{pmatrix} 1_n^T C & 1_n^T C & p^T \end{pmatrix} x \quad \text{where } x = \begin{pmatrix} f^+ \\ f^- \\ I \end{pmatrix}$$

Assuming that

- all demand is satisfied (perhaps from own source): $\begin{bmatrix} A & A & I^{n\times n} \end{bmatrix} x = d_i e^i$
- no resources from outside the coalition: $I_k = 0$, if $k \notin S$
- resources within the coaition only up to thei capacities: $I_j \leq S_j$
- flows are bounded by transportation capacities:

$$\begin{pmatrix} I^{2m\times 2m} & 0^{2m\times n} \\ 0^{n\times 2m} & 0^{n\times n} \end{pmatrix} x \leq q$$

- flows are nonnegative: $x \geq 0$.

Flow-optimisation

Optimum = optimum for the grand coalition
How to determine sources and thus costs for individual countries?
Countries

- near sources
- that are large

have an advantage. Cannot be solved in general.

Second best:

- Fixed order of countries
- Large countries near sources are listed first
- The first country is served optimally; the corresponding supply and transfer capacities are removed from the network
- The next country is served using the remaining resources.
- Note: For consistency, the order is not updated

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Supply security

What is supply security?

Literature focuses on efficiency. — What if something goes wrong?
What happens if a pipeline is closed due to:

- accident
- sabotage
- natural disaster
- terrorism.

- Will countries still get all its demanded gas supply?
- If yes, is the price (including transit) the same?
- If the price is higher, how much more?
- ... and how can we measure this??

"The cost increase induced by the closure of a single pipeline*"

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"The cost increase induced by the closure of a single pipeline*"

Supply security

- Each pipeline, with the same probability is closed down
- We recalculate the (constraint) optimum
- This results in a list of possible costs for each closure
- We look at the 5% *expected shortfall* (worst 5% of cases' avg)
  - Focuses on bad scenarios (i.e. conservative)
  - Looks beyond the worst case
  - ES is a *spectral risk measure* widely used in finance.

Limitations

- We do not model incident risk: may depend on length, age, politics
- We use idealised pipelines: no multiedges, etc.
  - Note: the largest capacity edges consist of single pipelines

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Some design considerations

(feedback needed!)

Model A **“Winter crisis”**

- remaining network must deliver
- shortage covered from (expensive) alternative source

Model B **“Summer crisis”**

- shortage is supplied from reserves
- network must resupply reserves in 3 months

$\therefore$ Extra demand over the network

- Any *remaining* shortage is supplied from (expensive) alternative source

Reality Somewhere in between...

Scenarios

- Baseline: Current network setup
- Nordstream: NS2 added to the current network.
  - Probably the most important current development
  - Drastic influence on the power balance in the European natural gas network (see our other paper)
  - Unlike other projects, NS2 has received permits and construction is in progress
- Ukraine: NS2 is added and the Ukrainian pipeline is closed down.
  - The maintenance of excess capacities is costly: Nordstream only makes sense as a replacement of Brotherhood
  - Gazprom hinted that the renovation is too costly
  - Ukraine repeatedly demanded the stop of NS2 construction
  - Past tensions, current conflicts make further cooperation difficult
- *Presentation compares 1st and 3rd scenarios.*

Data and calculations

Data

- 2016 network, production, price and consumption data (ENTSOG; BP Statistical Yearbook)
- Pipeline lengths from various sources; including estimations
- The cost of alternative source is 600 M USD/bcm.

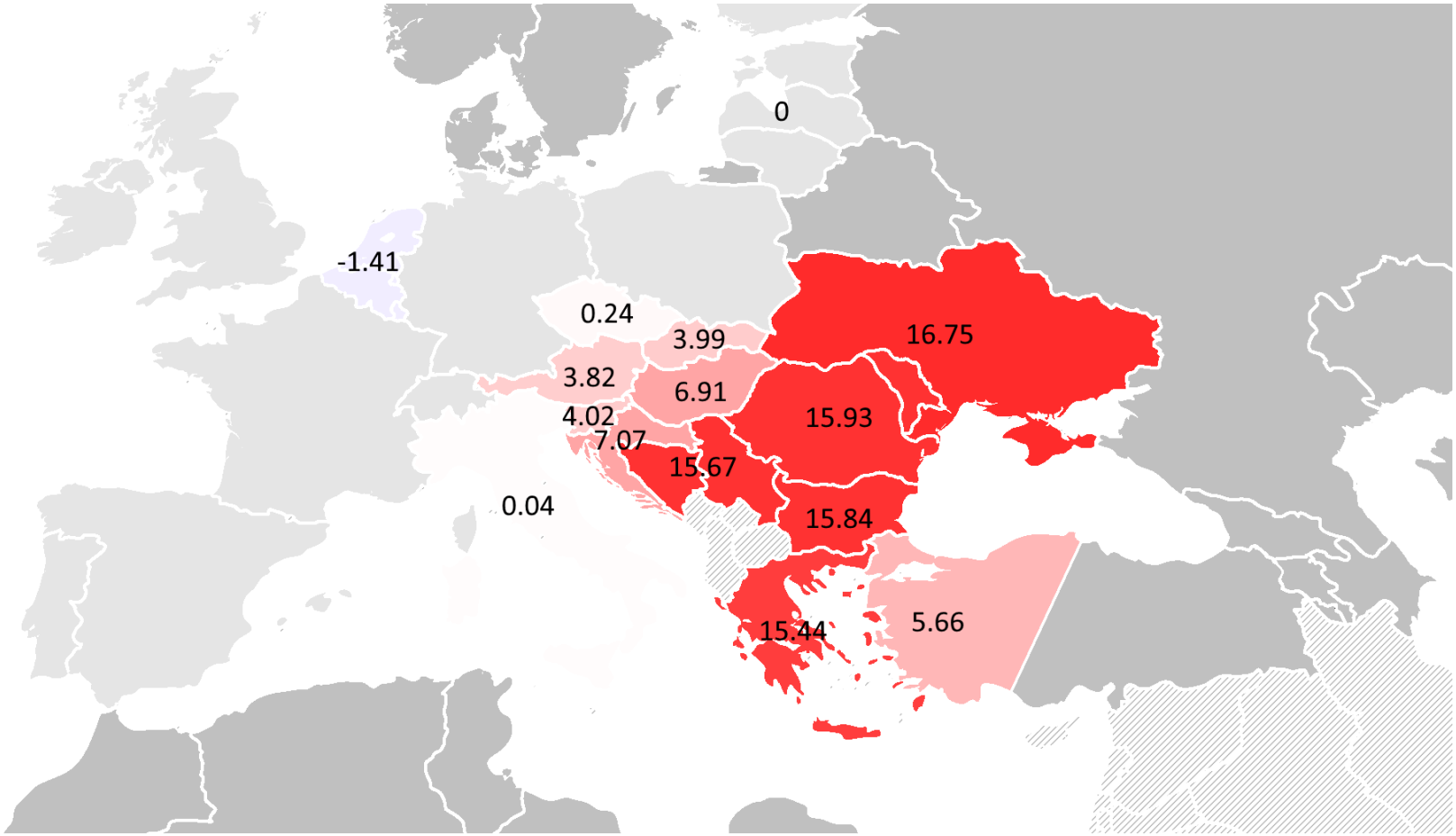
Limitations

- Idealized network; prices not directly observable
- Uniform gas quality; bidirectional pipelines, etc.
- Uniform incident probabilities

Calculations

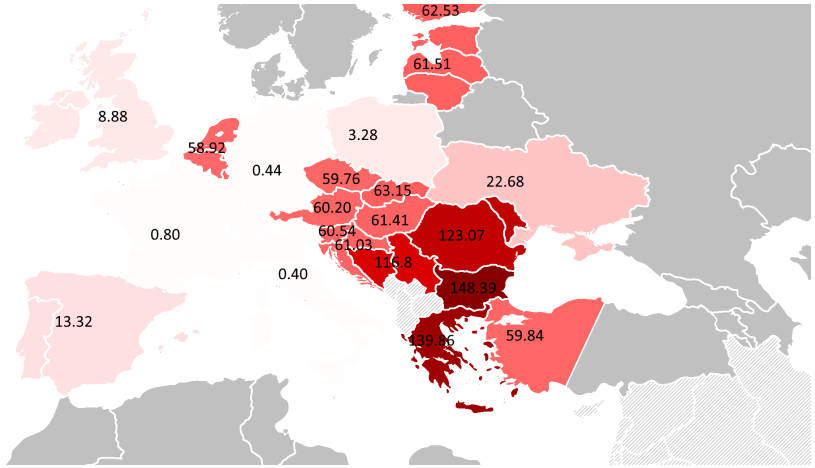
- Implemented in Java by research assistant Attila Nás.

Results 1: Prices

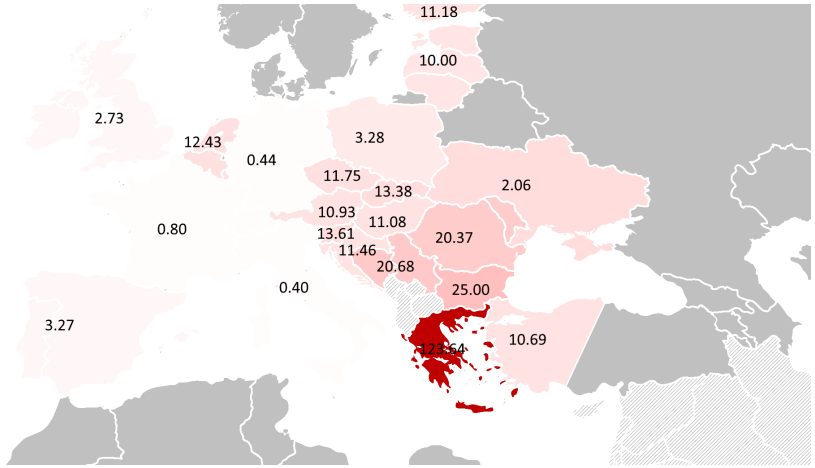


The % change in supply *costs* (without transit fees, etc.)

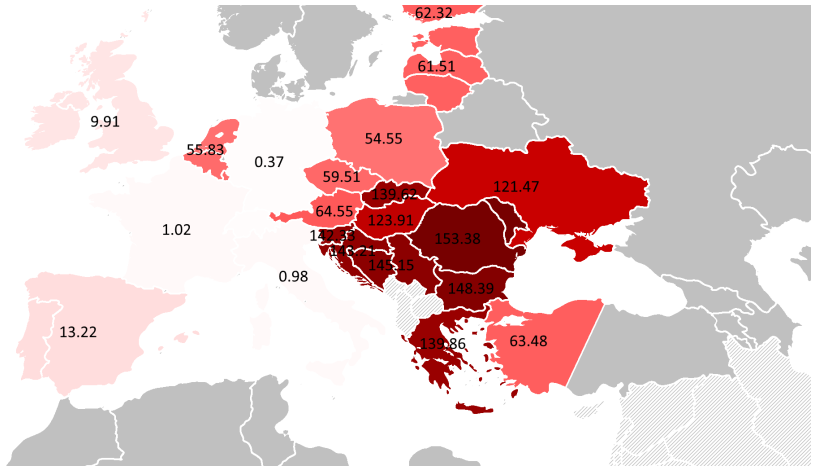
Results 2: Supply security



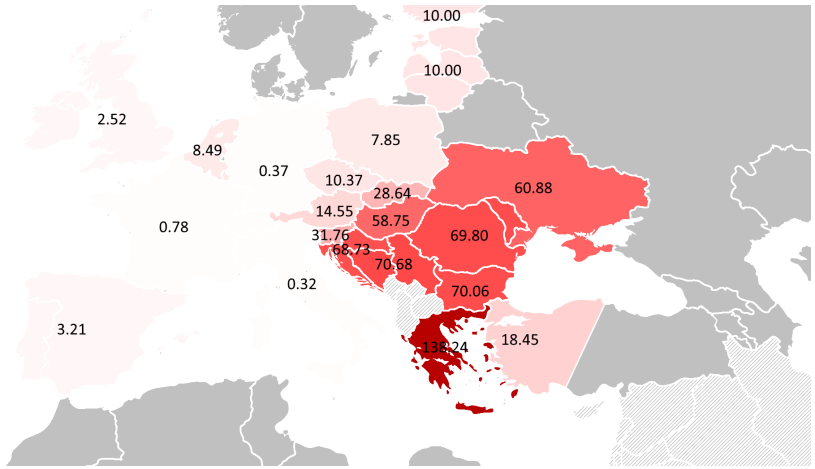
Baseline winter scenario



Baseline summer scenario

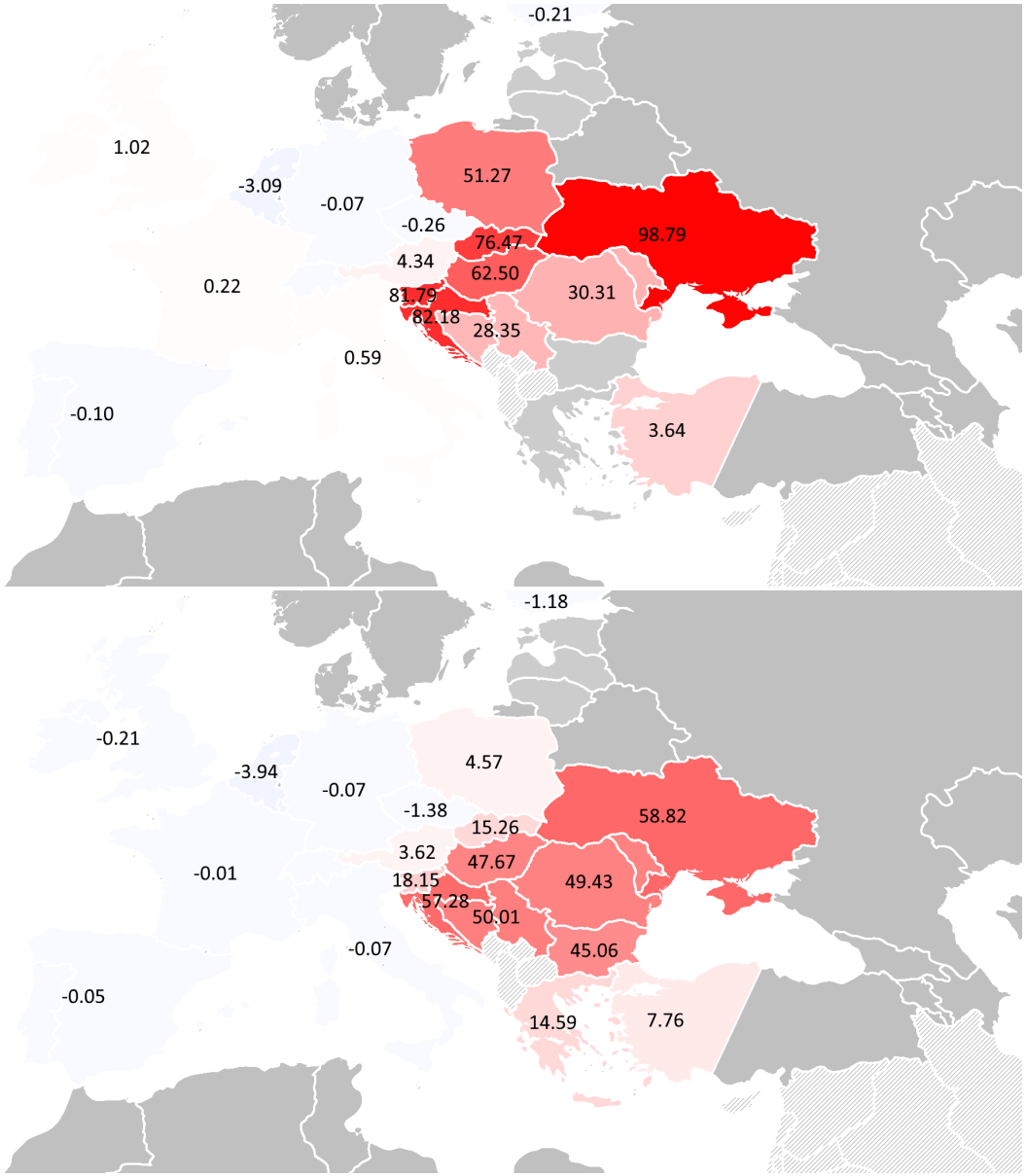


Target winter scenario



Target summer scenario

Results 2: Supply security: change (winter/summmer)



- West: closer source
- East (AT to UA): lasting damages; longer transit routes, smaller transit capacities.
- South-East: bottlenecks remain; Turkey gets its supply through countries with shortages
- We do *not* consider power changes, only costs.

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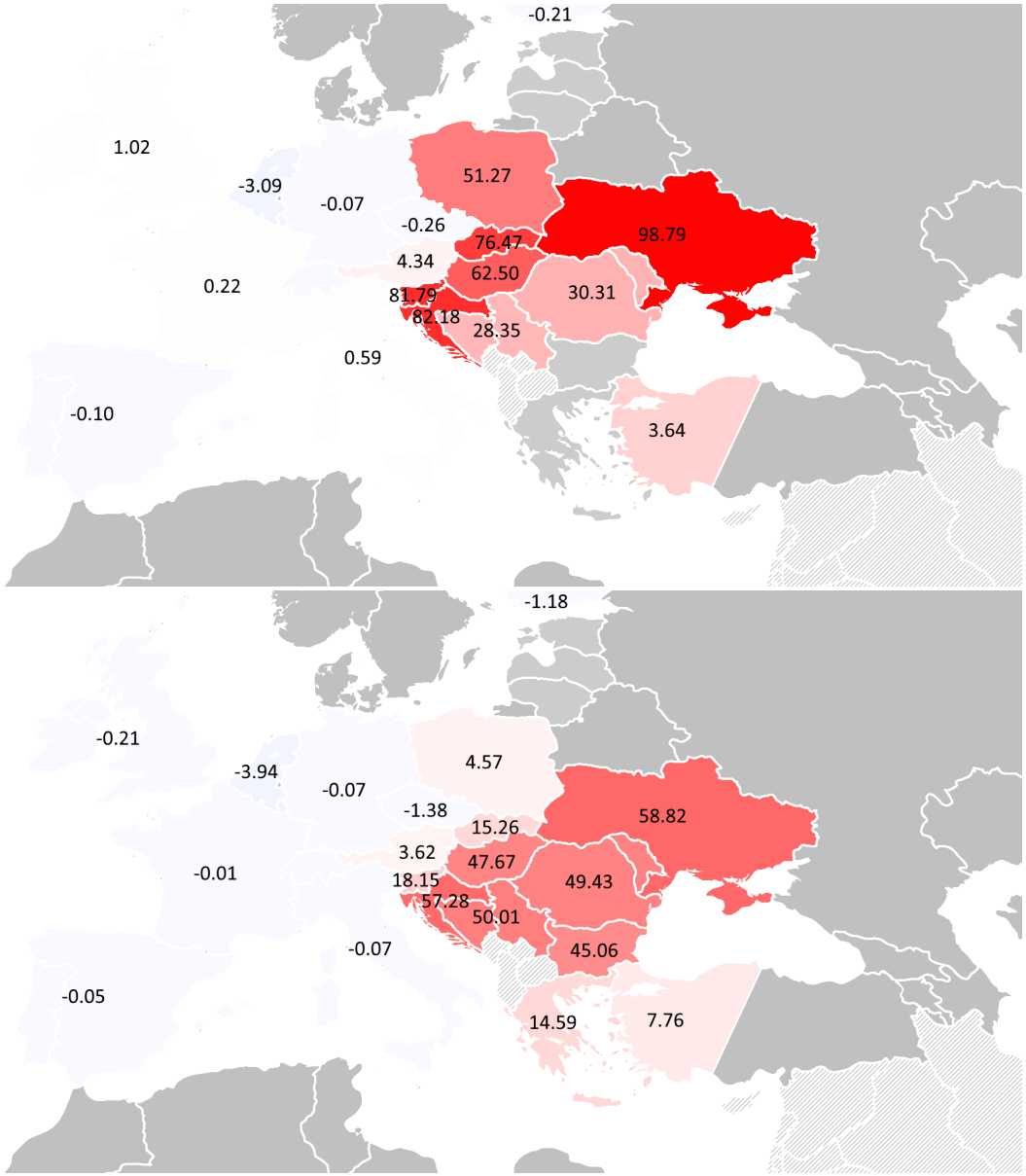

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Conclusion 1

- The supply of Easter Europe is already very fragile
- NS2 with the likely closing of the Brotherhood increases the costs, and makes supply *far more* risky
- (Shifts all the power to Germany)
- Goes against the principles of the Energy Union
- Other developments, such as TAP may mitigate the damage.

Further research

An alternative model with mixed inflows

- At each node inflows are mixed
- outflows at the same prices.
- optimal flows
- like an exchange-based model (as planned in the EU)

Preliminary findings for replacing Brotherhood with NS2

- Greater benefits to the West
- Turkey loses much
- Ambiguous results for CEE

And more

In a complementary paper we consider Third Party Access pipelines: free capacities can be used by anyone.

Nord Stream 2 may be the most controversial, but the model is not specific to Nord Stream 2. We plan to do a similar analysis for other pipelines under construction.