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Network reduction methods for integrated energy systems using power grids and gas pipelines

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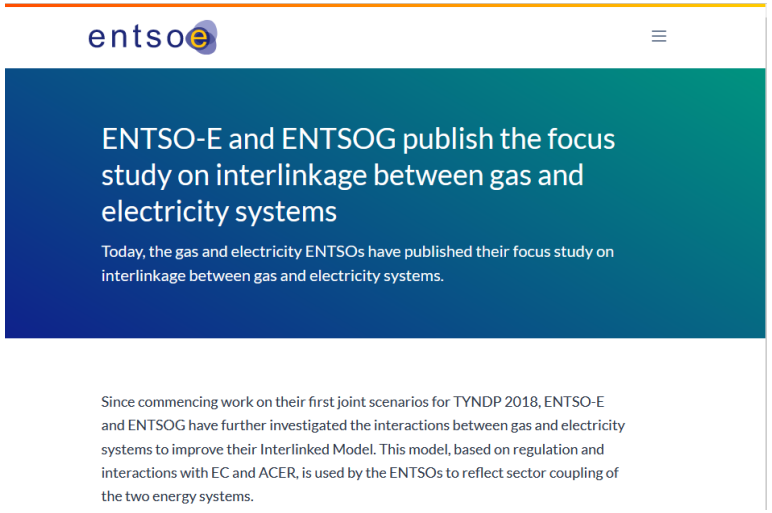
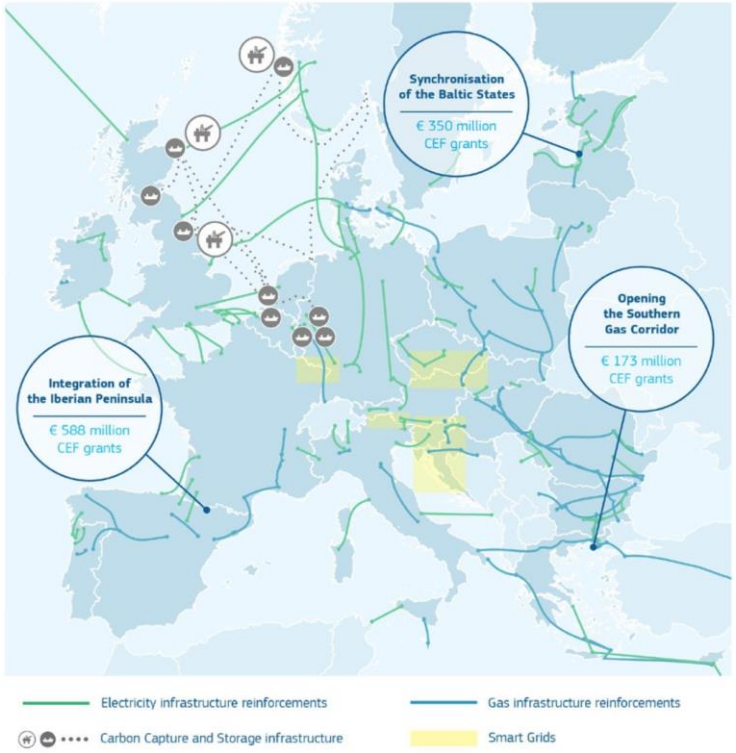
Institute of Networked Energy Systems
Energy Systems Analysis

European network expansion

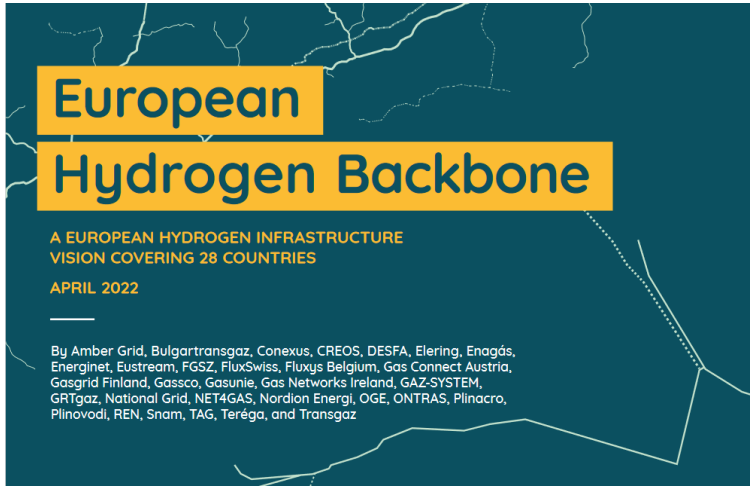
Joint planning of electricity and gas networks is becoming the status quo



Study commissioned by ENTSO-E / -G, Nov 2019



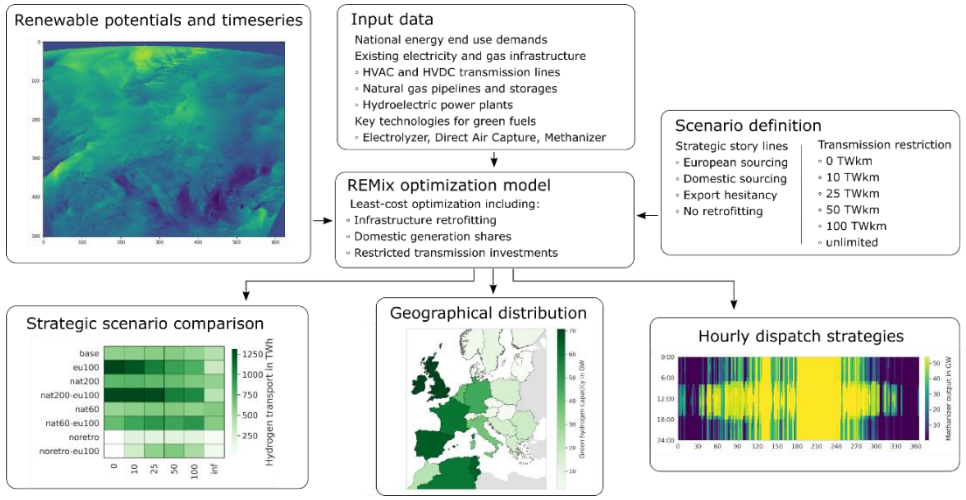
Study commissioned by EC: Clean Energy for all Europeans



Study commissioned by European Hydrogen Backbone

The role of green hydrogen and methane

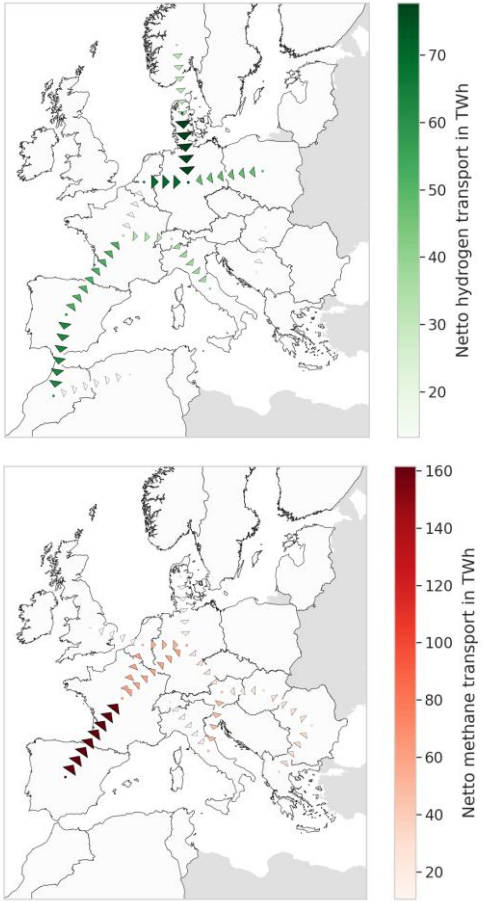
- Climate neutral energy system in 2050
- Scenarios on energy partnerships, domestic sourcing, network expansion limits



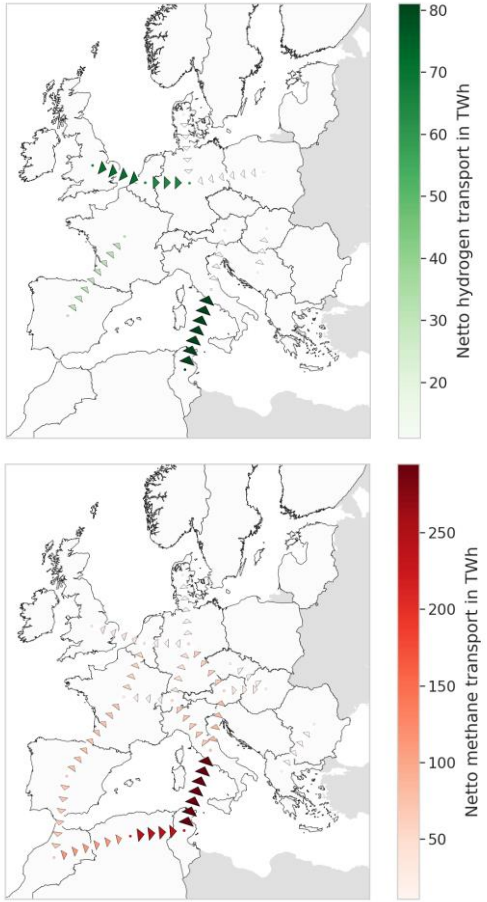
Main limitations:

- One node per country approach
- Connection to LNG terminals not modelled explicitly

Continental Europe

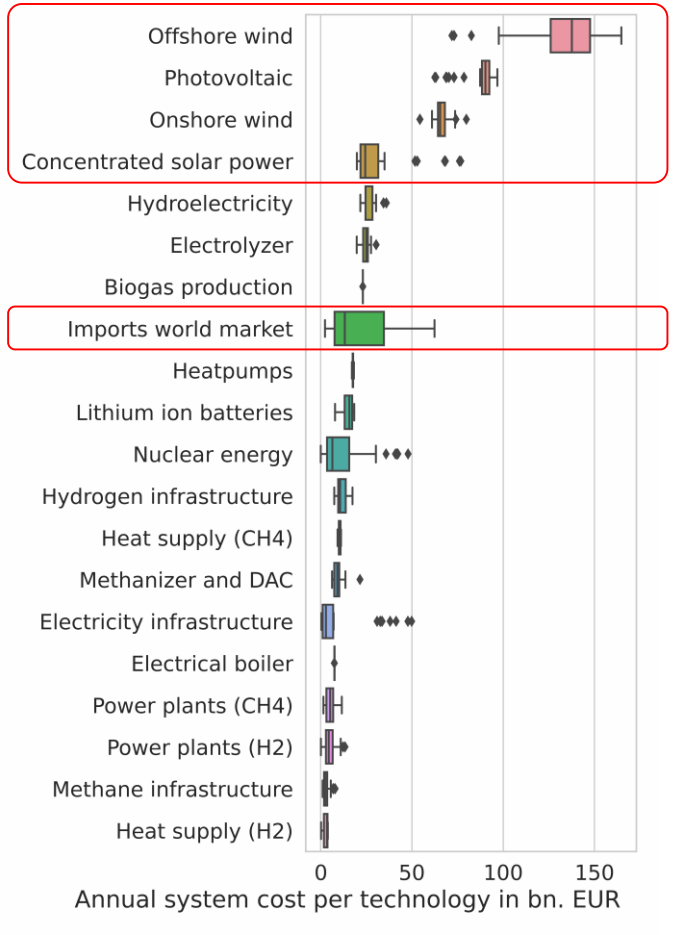


Energy Partnerships



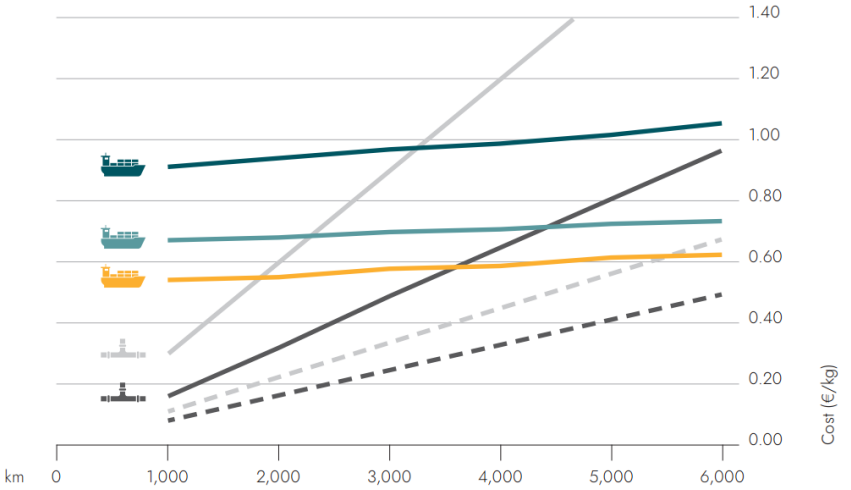
Wetzel, M., Gils, H.C., Bertsch, V., 2022, Green energy carriers and energy sovereignty in a climate neutral European energy system, Renewable Energy, under review

The uncertainty of future energy imports

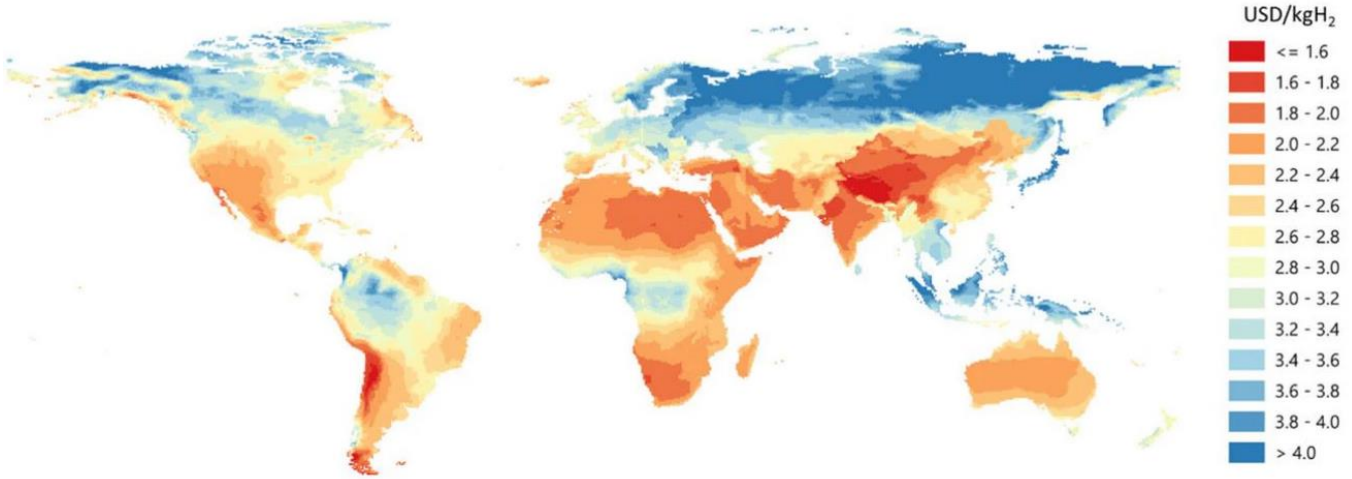


Investments into renewable energy becomes main driver of system costs

Large uncertainty about imports from global energy markets



Guidehouse 2021, Future demand, supply and transport of hydrogen



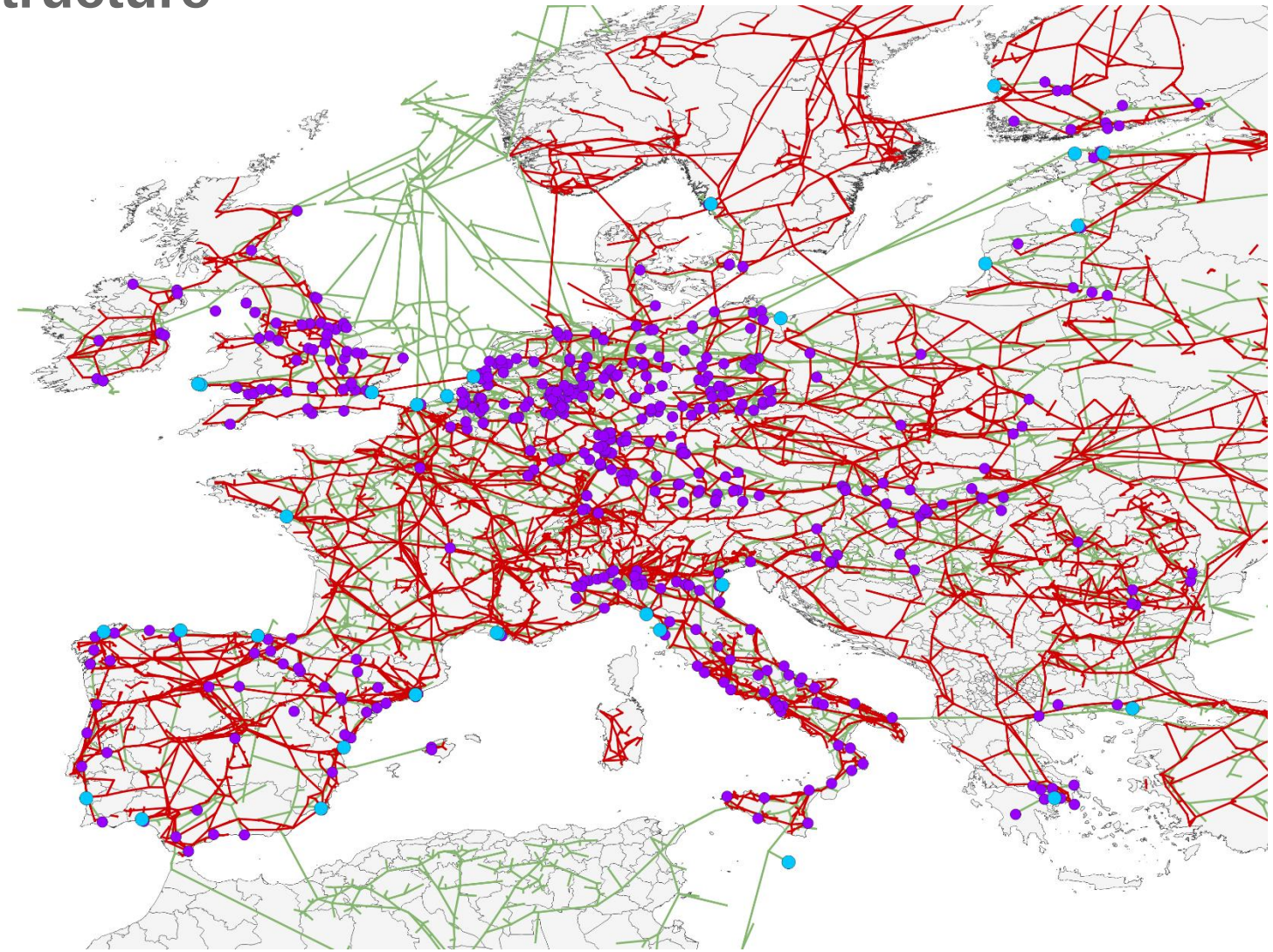
IEA 2020, The Future of Hydrogen

Wetzel et al. 2022, Green energy carriers and energy sovereignty in a climate neutral European energy system, submitted to Renewable Energy

European power and gas infrastructure

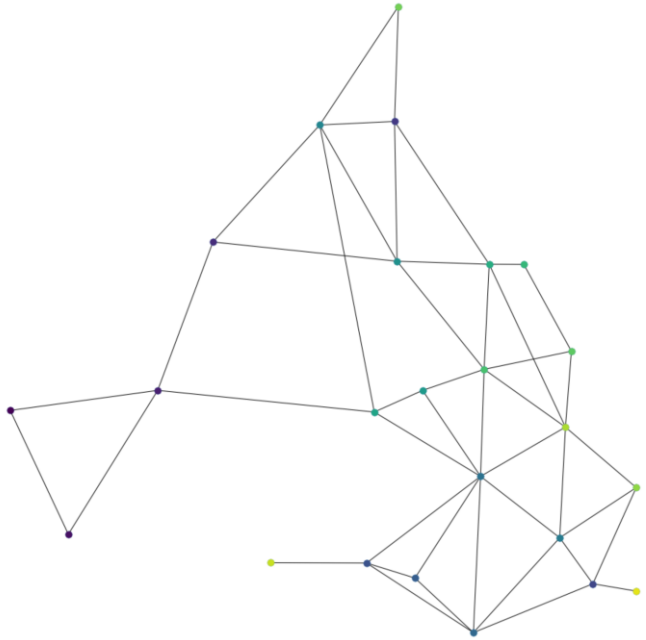
- One model region per country
- Increased spatial resolution
- Integration of high res power grid
- Integration of high res gas network
- Integration of LNG terminals
- Power and gas network with LNG terminals and gas power plants

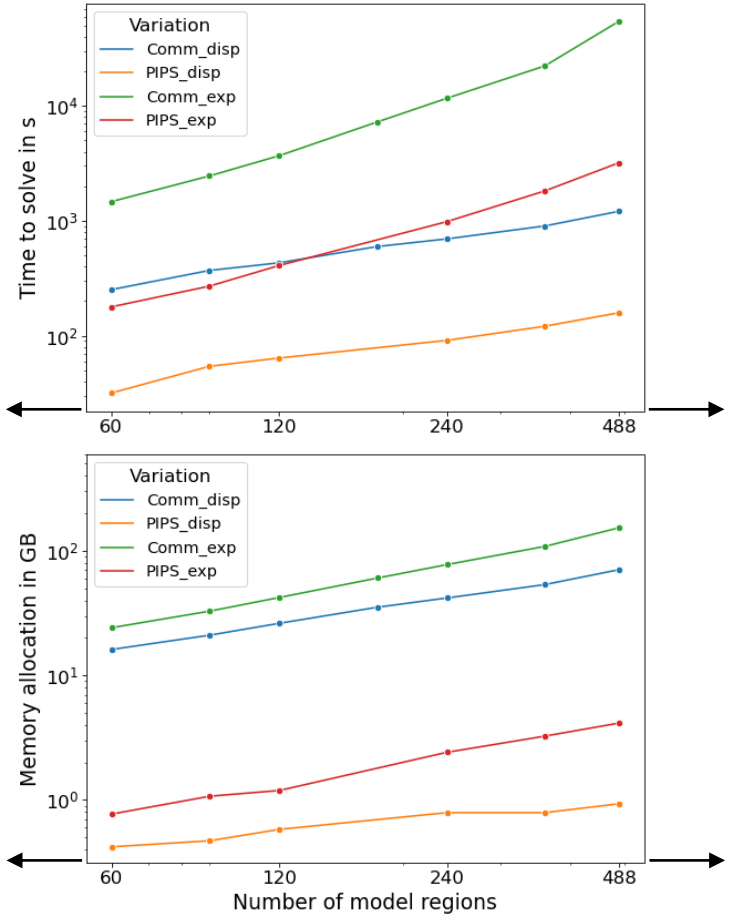
↳ Method for network topology reduction while preserving shared intersections

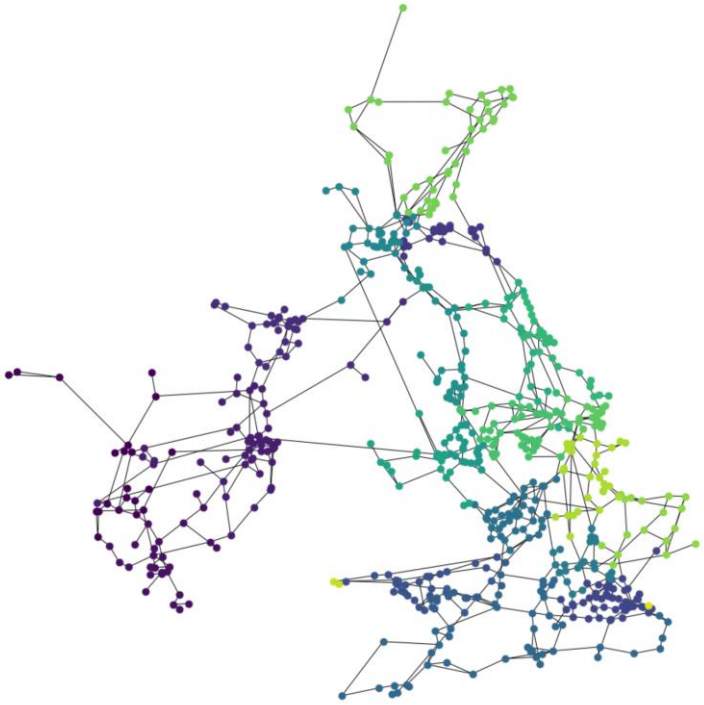


Own depiction based on ENTSO-E GridKit and SciGrid_gas IGGIELGN

Computational complexity, solving time and memory demand





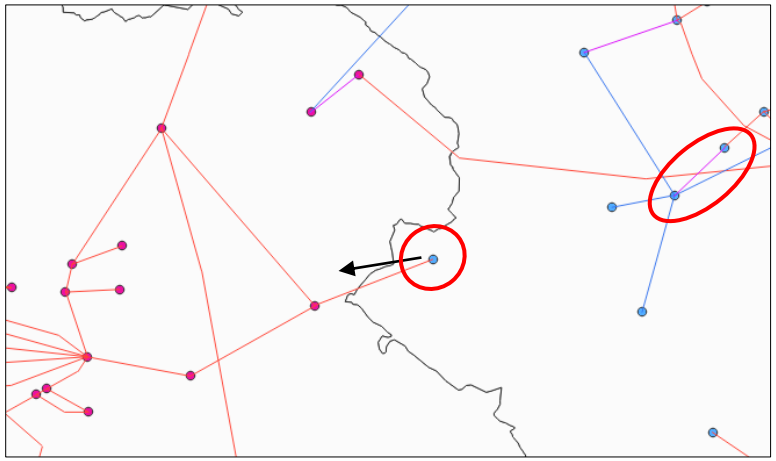


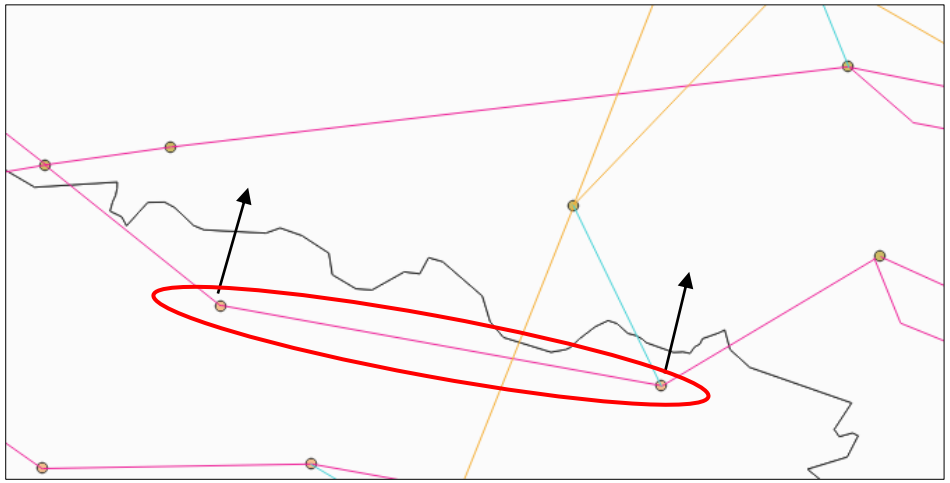
Goal: Adequately capture the network bottlenecks while allowing for faster solving times

Preprocessing and data cleanup

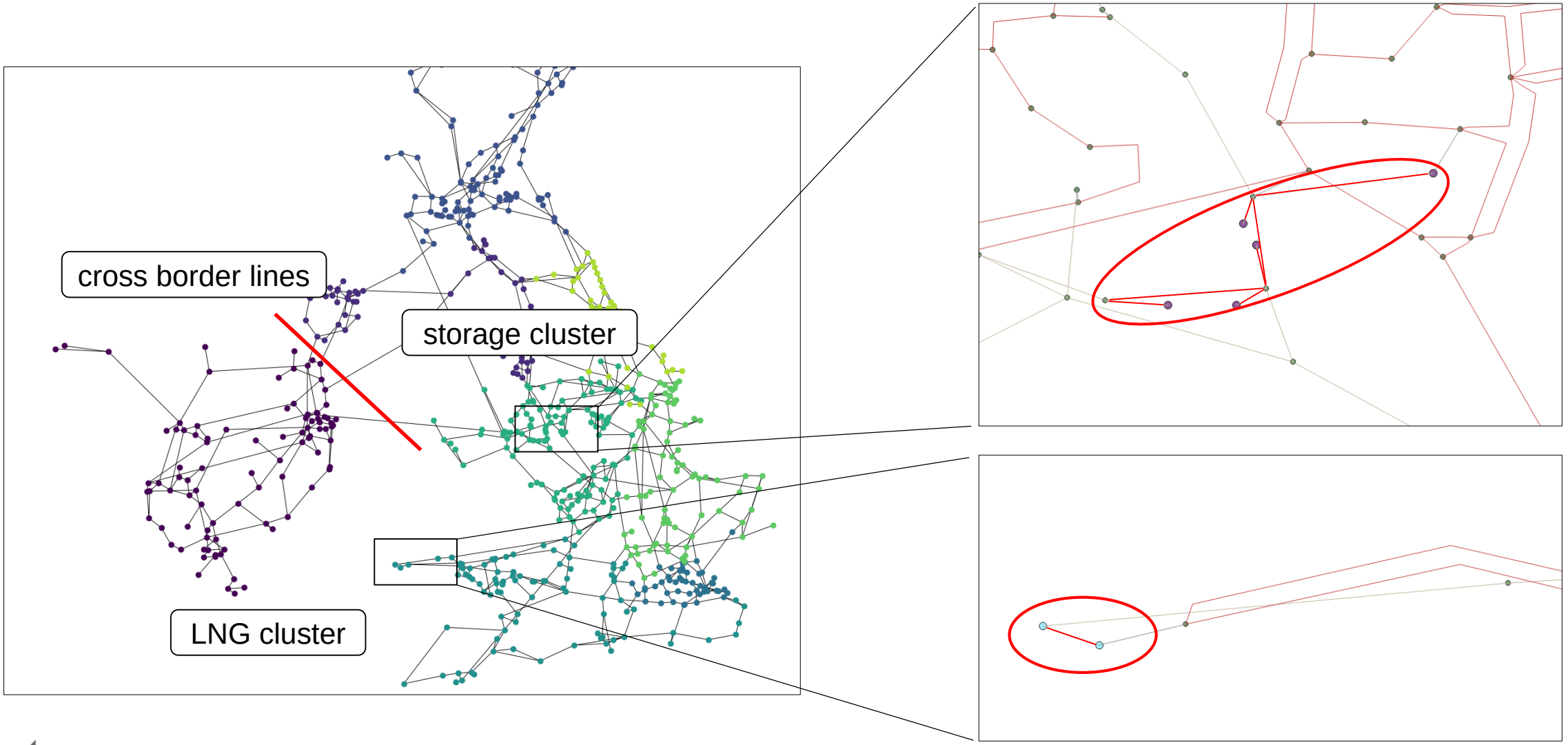
Incomplete networks resulting from web scraps, digitalization, heterogenous datasets

- Re-align overlaying nodes
- Assign initial region mapping
- Add cross-sectoral links
- Re-assign dangling clusters / pass through lines
- Identify LNG and storage clusters
- Separate and preserve feature clusters



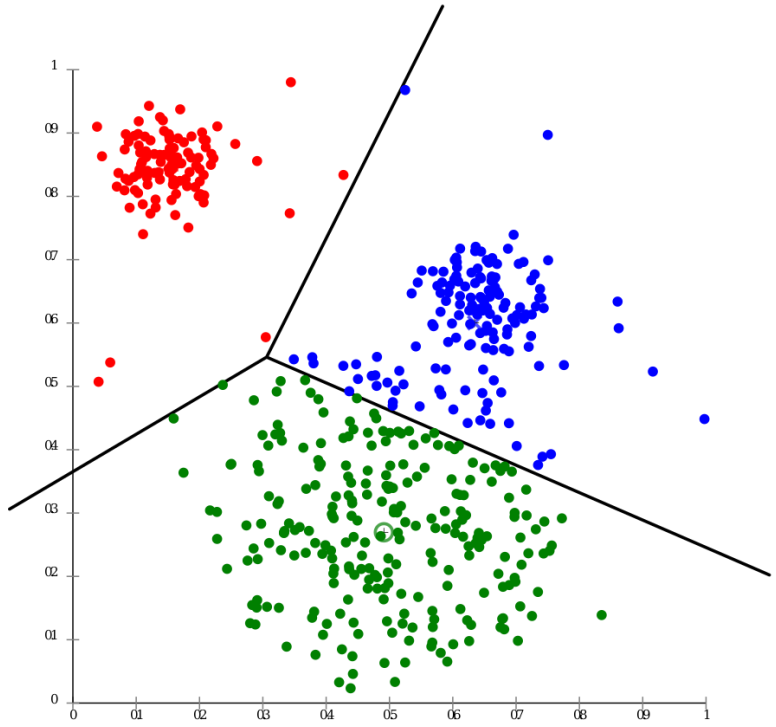


Feature identification and preservation



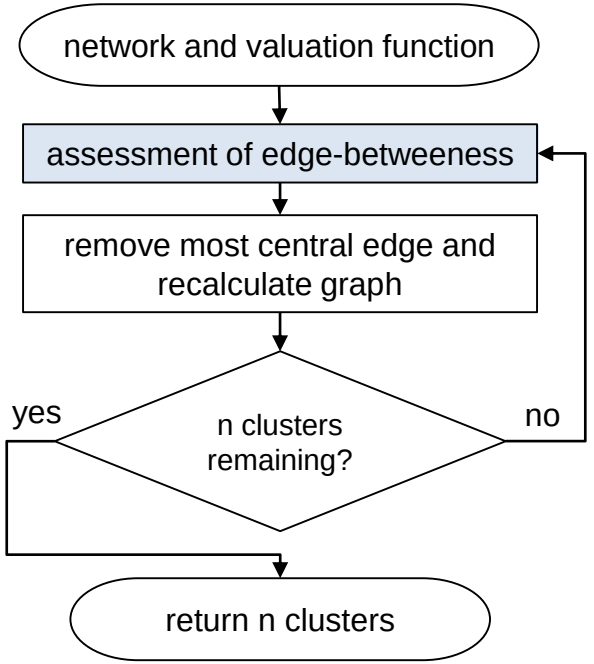
Clustering methods

K-means clustering



- Clustering based on location
- Connectivity information can be added

Girvan-Newman graph partitioning



Modified assessment

Always remove:
- cross-border edges
- edges to LNG clusters
- edges to storage clusters

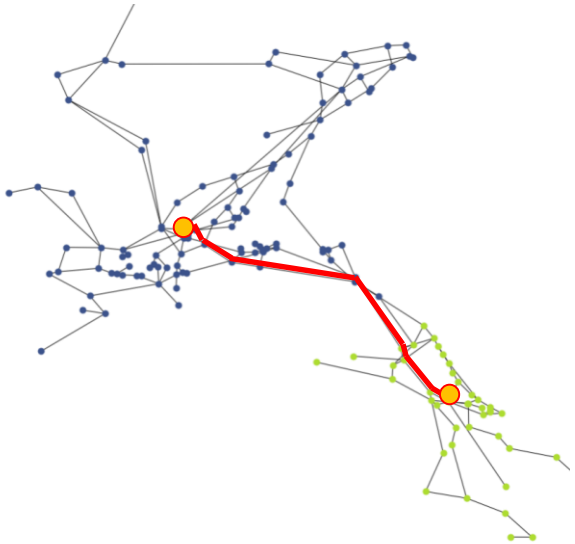
Never remove:
- cross-sector edges
- edges linking LNG clusters
- edges linking storage clusters

- Identification of bottlenecks in transfer capacity
- Computationally more expensive

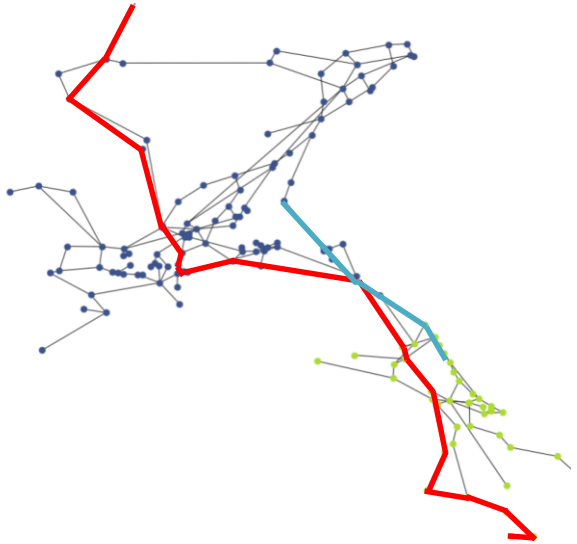
Girvan and Newman, 2002, Community structure in social and biological networks, Applied Mathematics

Calculation of distances and capacities

Distance between clusters



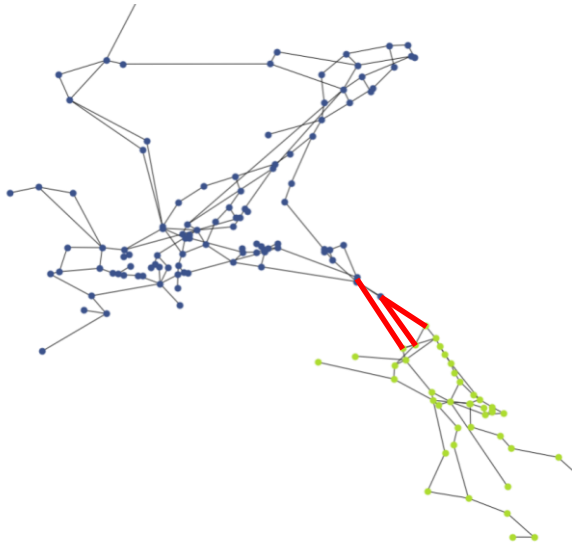
Shortest path between nodes with highest betweenness centrality



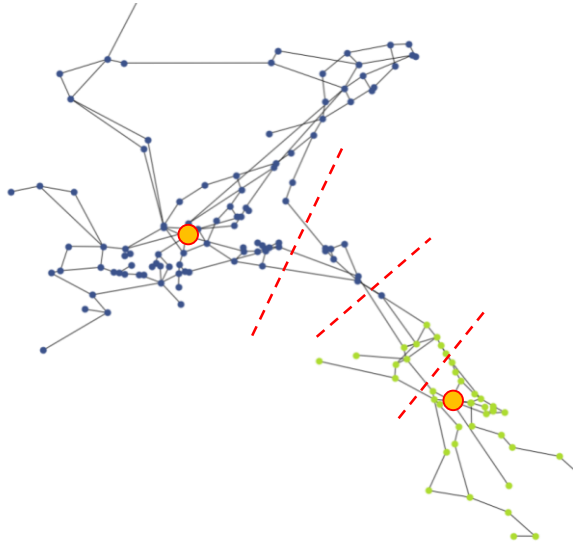
Shortest paths between all nodes in cluster 1 to all nodes in cluster 2

Computationally expensive

Capacity between clusters



Summation of capacities of all connecting edges

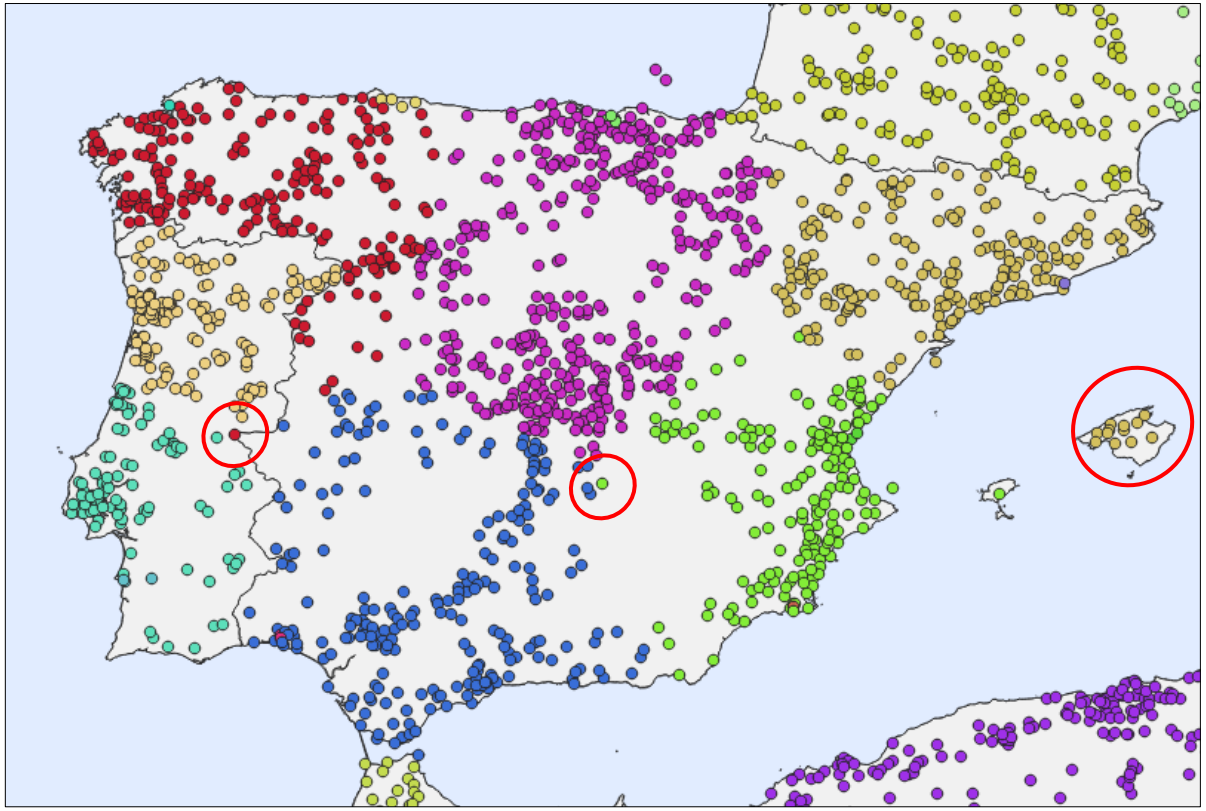


Compute max-flow from nodes with highest betweenness centrality

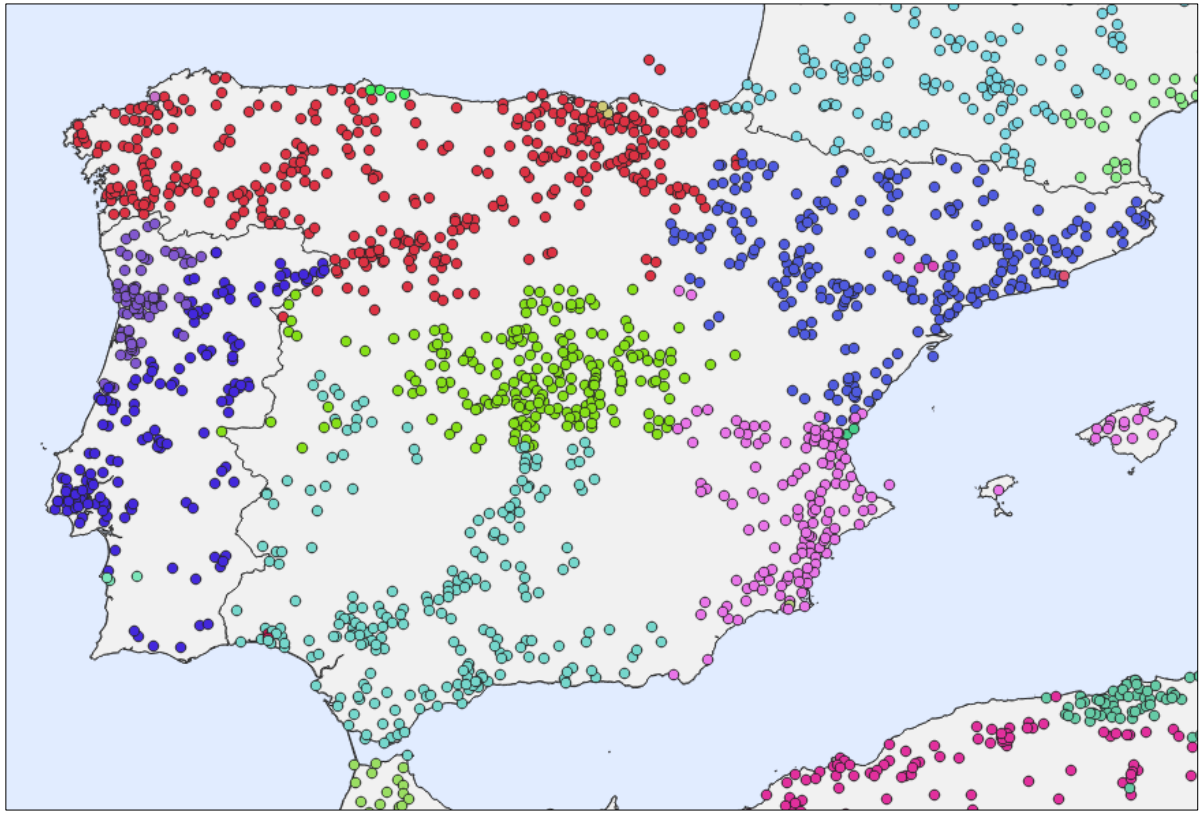
Computationally expensive

Clustering results: Iberia

K-means



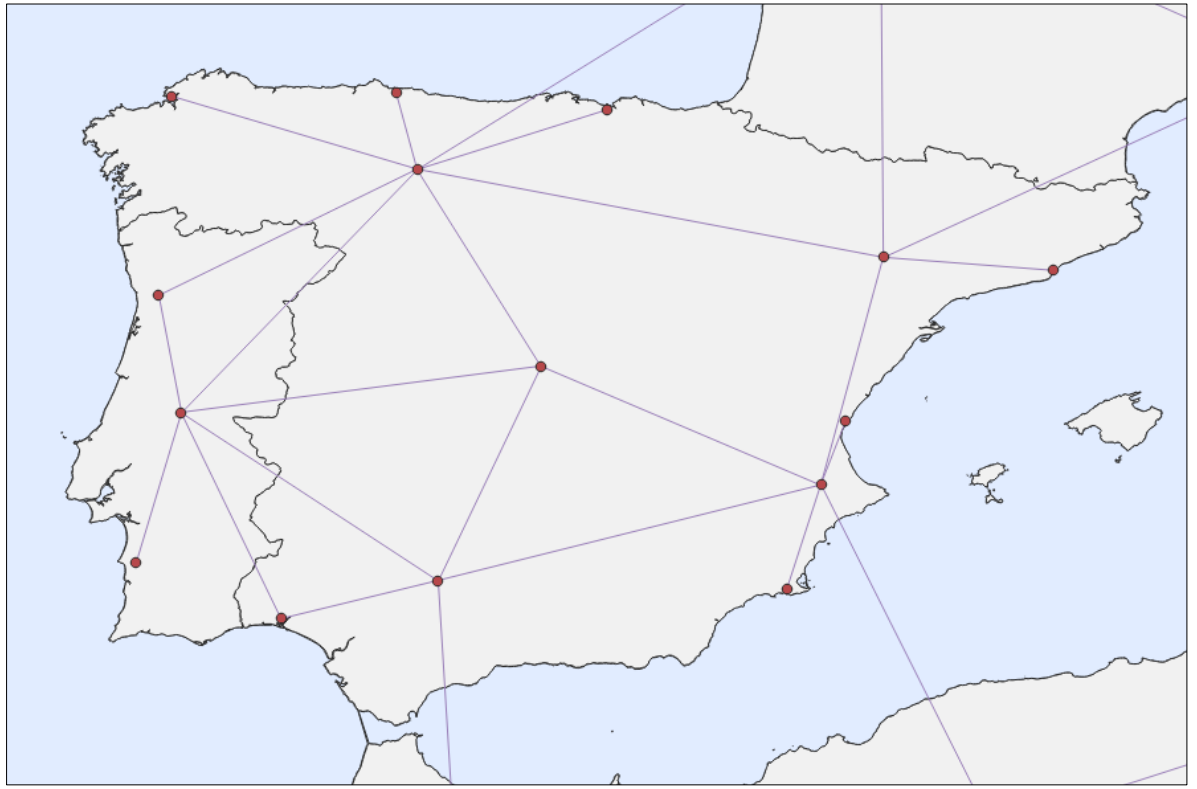
K-means + connectivity



Clustering results: Iberia

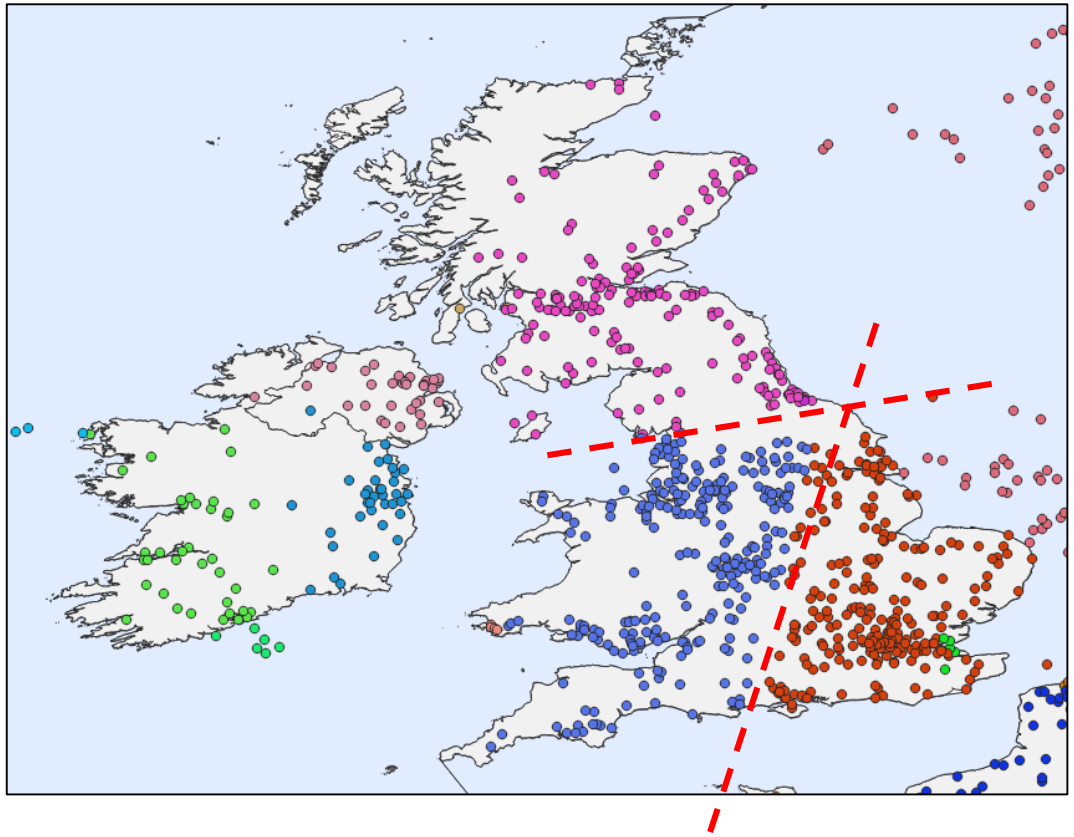
K-means

K-means + connectivity

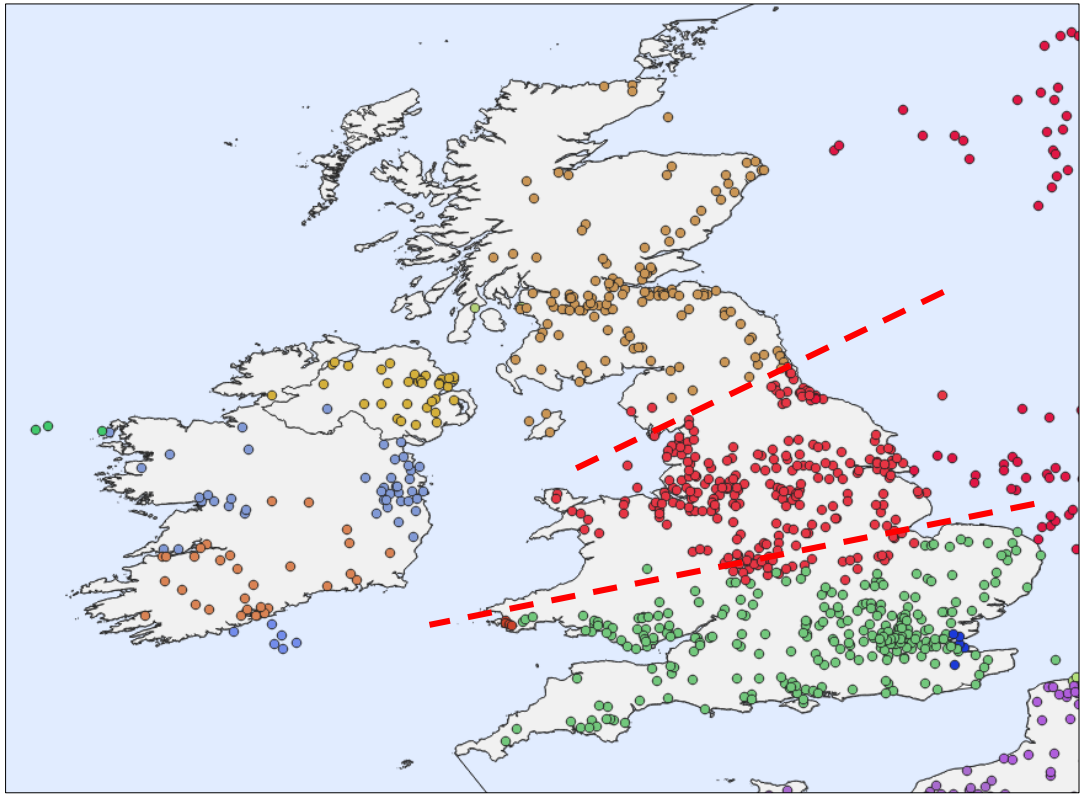


Clustering results: United Kingdom

K-means

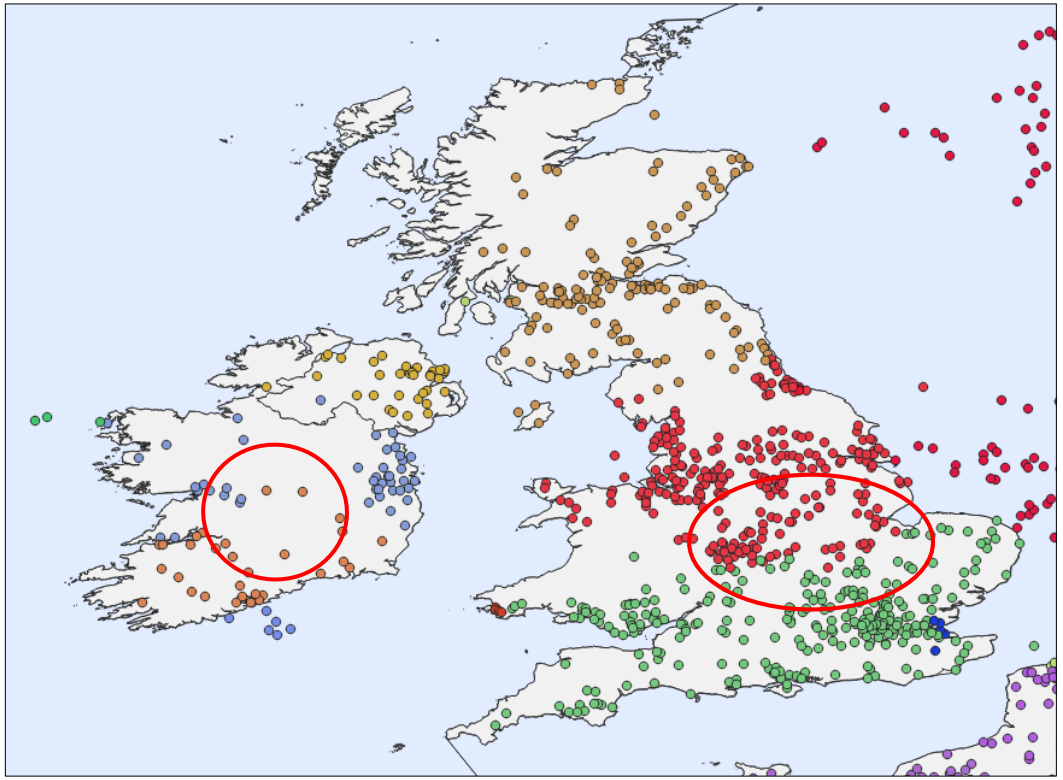


K-means + connectivity

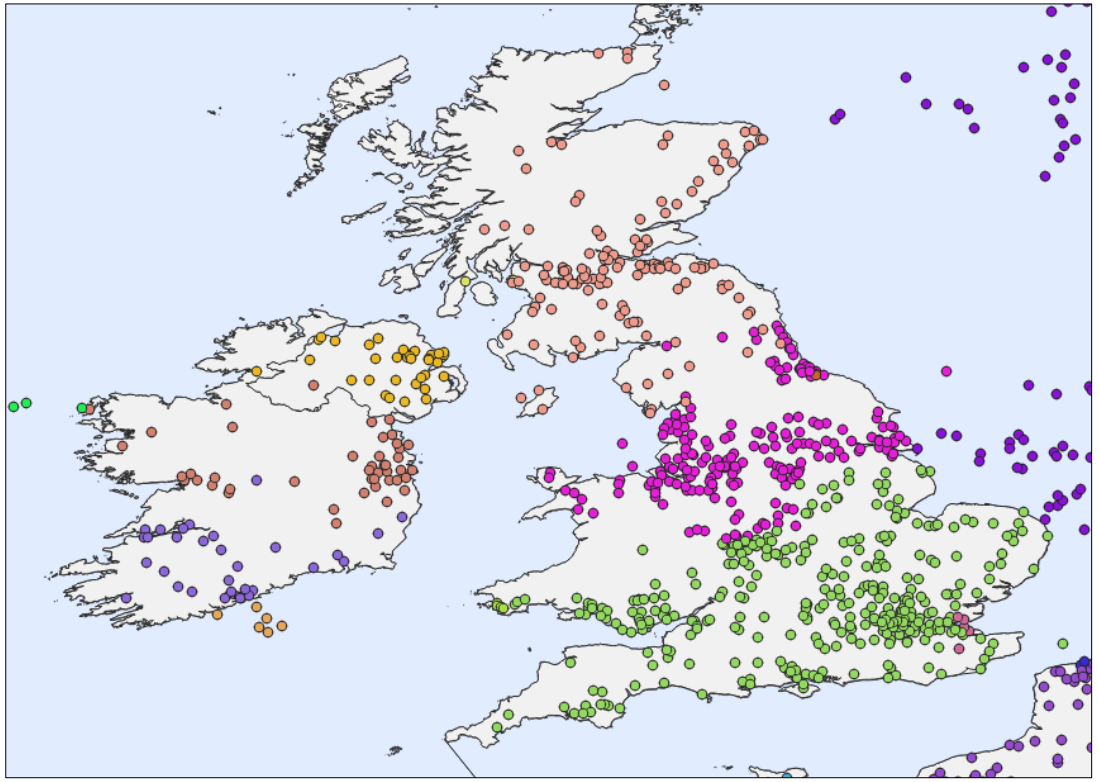


Clustering results: United Kingdom

K-means + connectivity

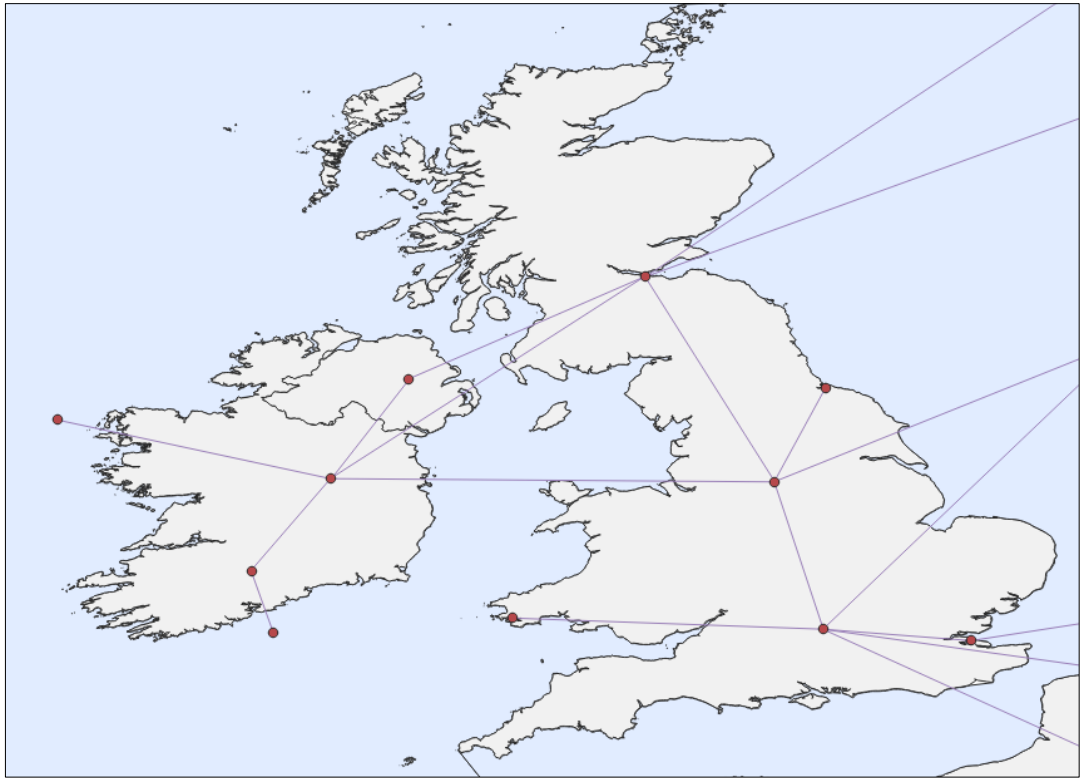


Girvan Newman

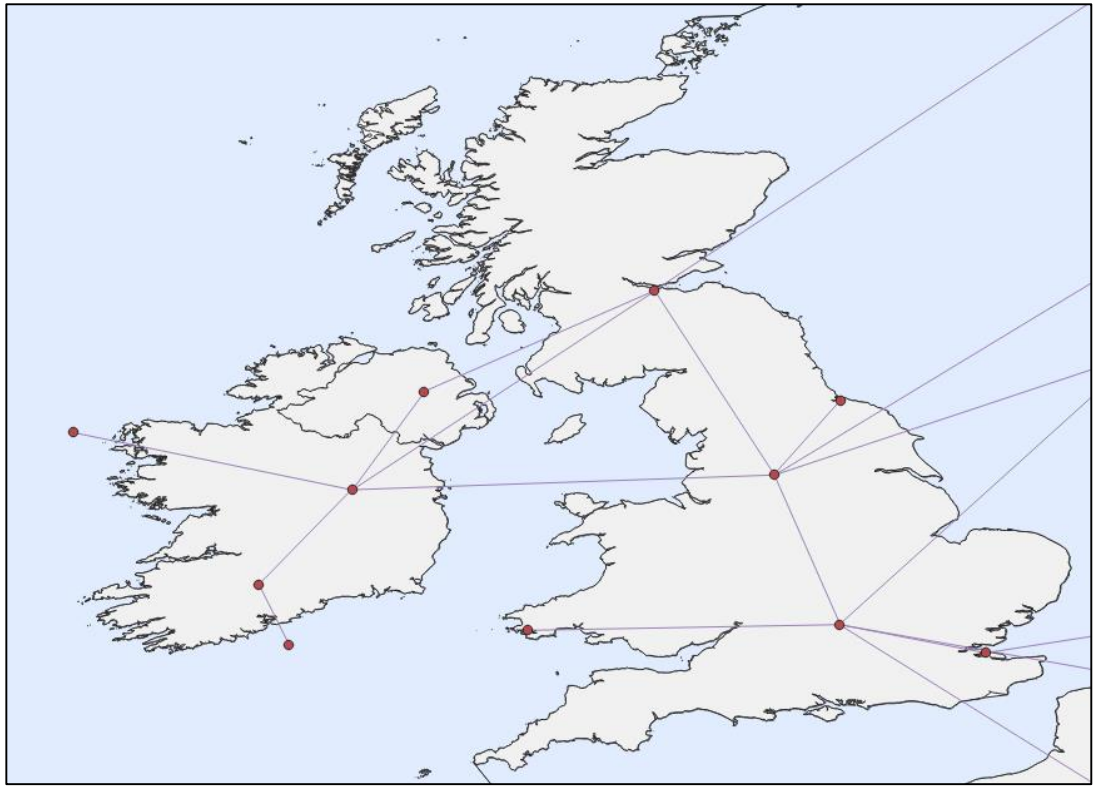


Clustering results: United Kingdom

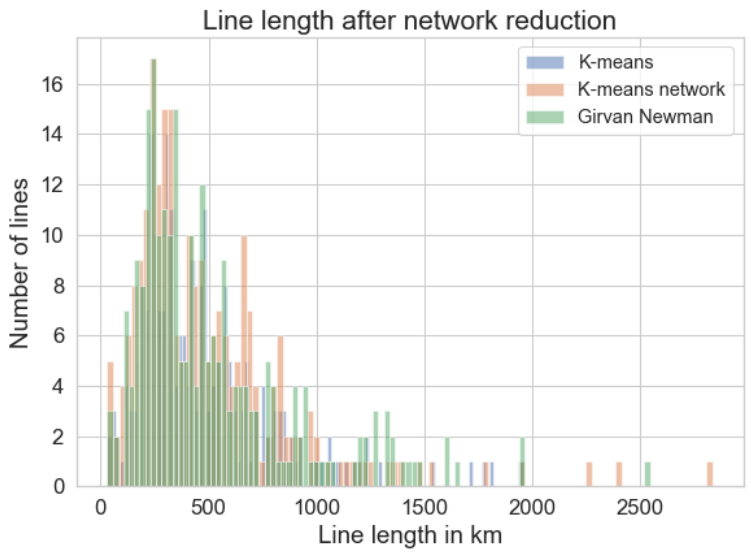
K-means + connectivity

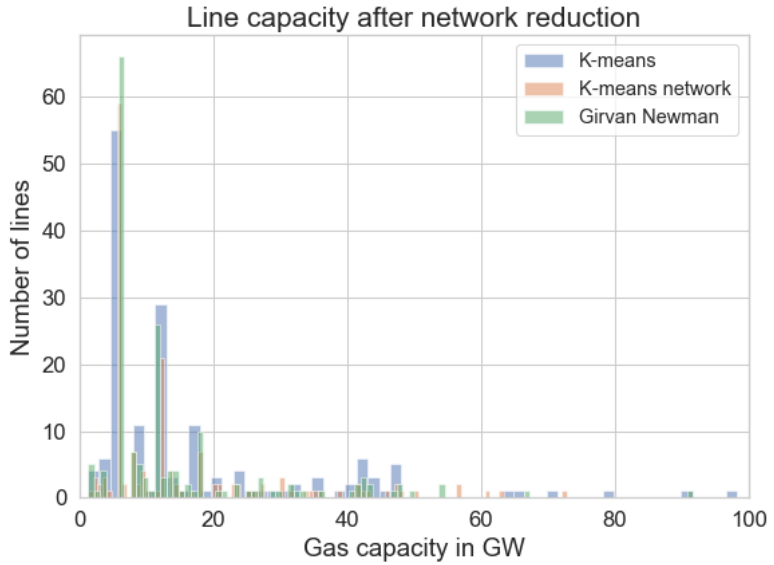


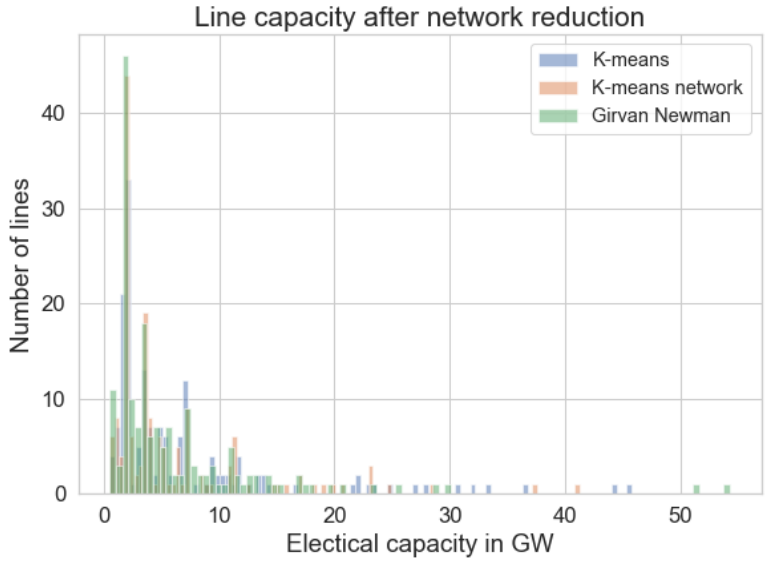
Girvan Newman



Comparison metrics for the different methods







Total length in 1000 km

K-means	113.1
K-means network	119.3
Girvan Newman	126.6

Total gas capacity in GW (lines)

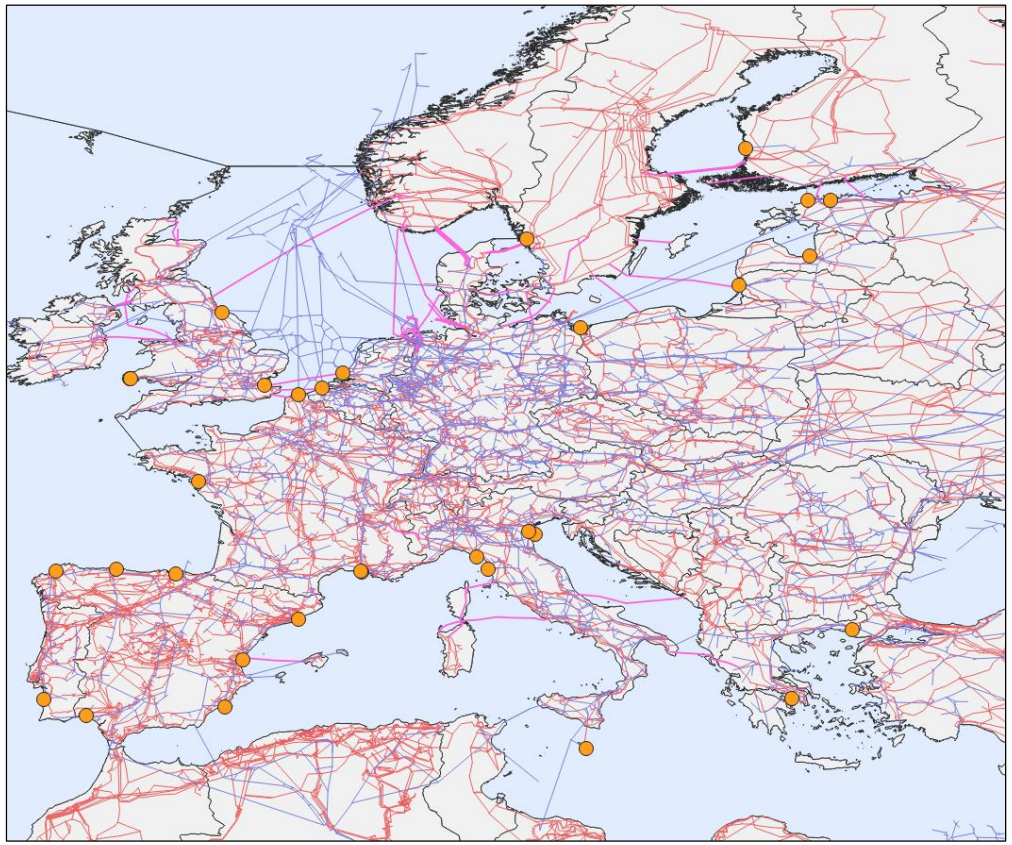
K-means	2940 (163)
K-means network	2385 (159)
Girvan Newman	2506 (175)

Total electrical capacity in GW (lines)

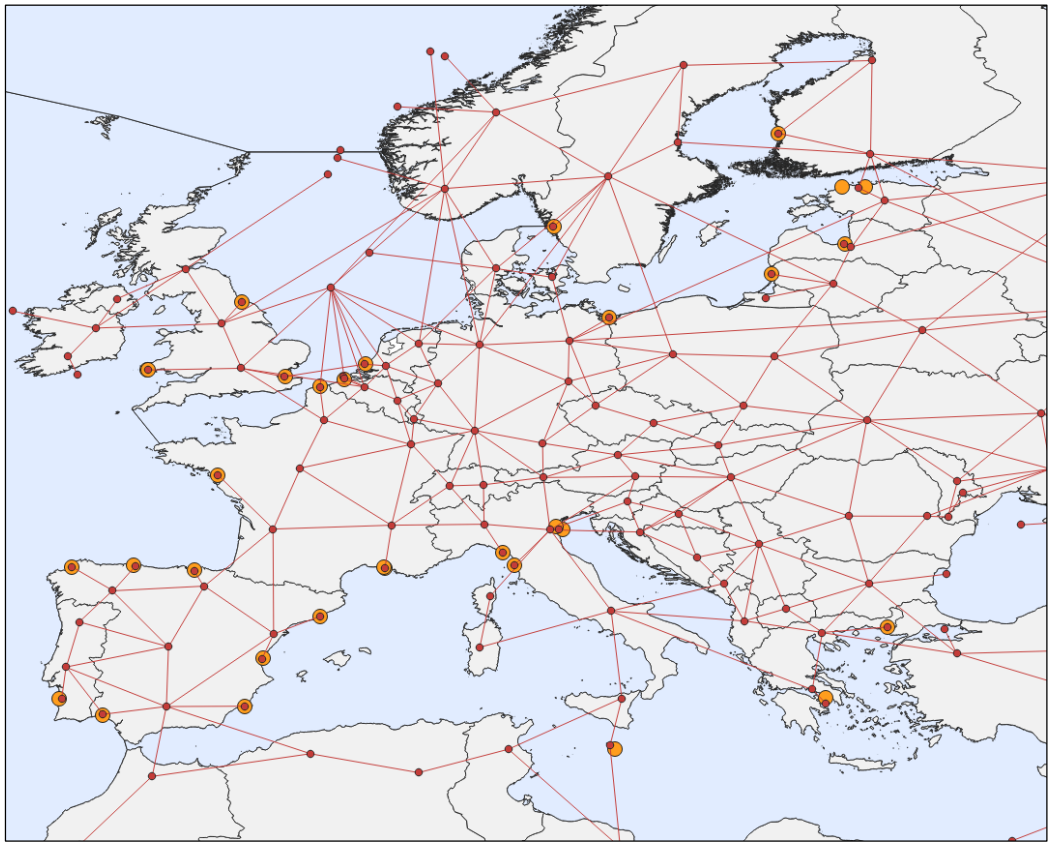
K-means	1102 (164)
K-means network	910 (159)
Girvan Newman	1050 (173)

Topology reduction applied to the full network

full network topology (~12000 nodes)



reduced network topology (~100 nodes)
with seperate LNG clusters (+ 28 nodes)



HVAC grid
HVDC lines
gas pipelines
LNG terminals

Conclusions and future work

- Trade-offs between clustering speed and capturing the bottlenecks in transfer capacity
- Network connectivity information required to achieve reasonable results
- Girvan Newman graph partitioning can be further adapted to specific requirements

- Sensitivity analysis on the different approaches
- Separate clustering of electricity and gas networks
- Addition of TYNDP PCIs for transmission lines and pipelines
- Evaluation of systematic scaling effect on energy system models

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Acknowledgements

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