GERMAN POWER GRID

By,

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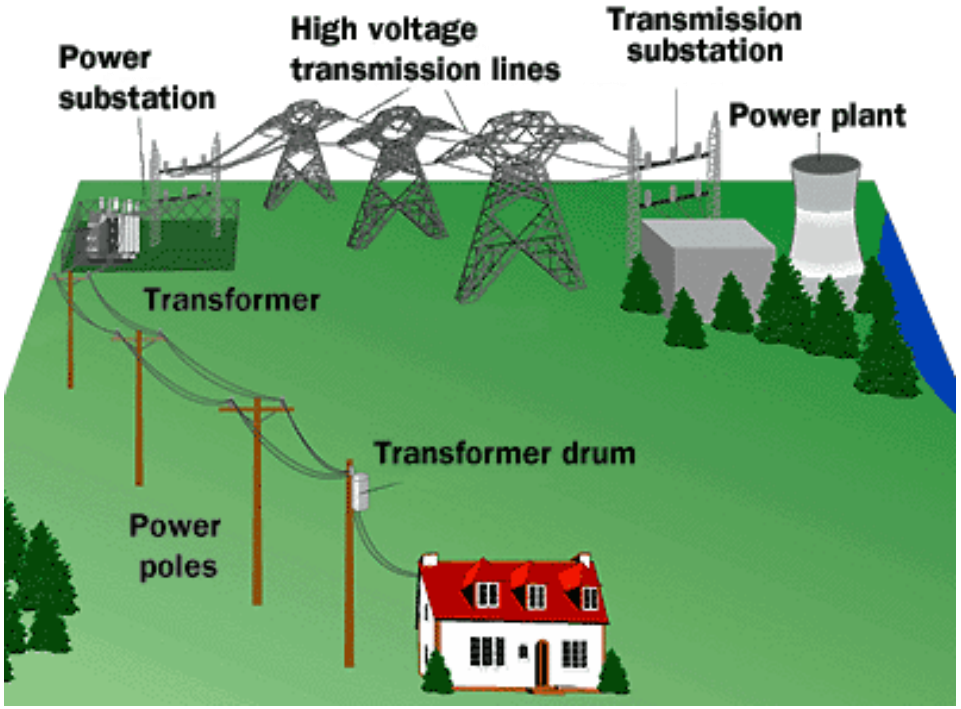


OVERVIEW

Introduction

- Network Description
  - Idea
  - Network formation

Analysis

- Network properties
  - Centrality
  - Configuration model
  - Percolation
  - Modularity
  - Community detection
  - Degree Distribution
- State Dynamics
  - Diffusion
  - SI, SIR, IC models

Network insights & Visualization

NETWORK DESCRIPTION

Idea: the system is modelled using the transmission data obtained from the open street map project to visualize the power production and its distribution based on the data obtain on November 2015

Network elements:

Generators: The main source of power that have only outgoing edges to powerplants and Substations. **Numbers: 19**

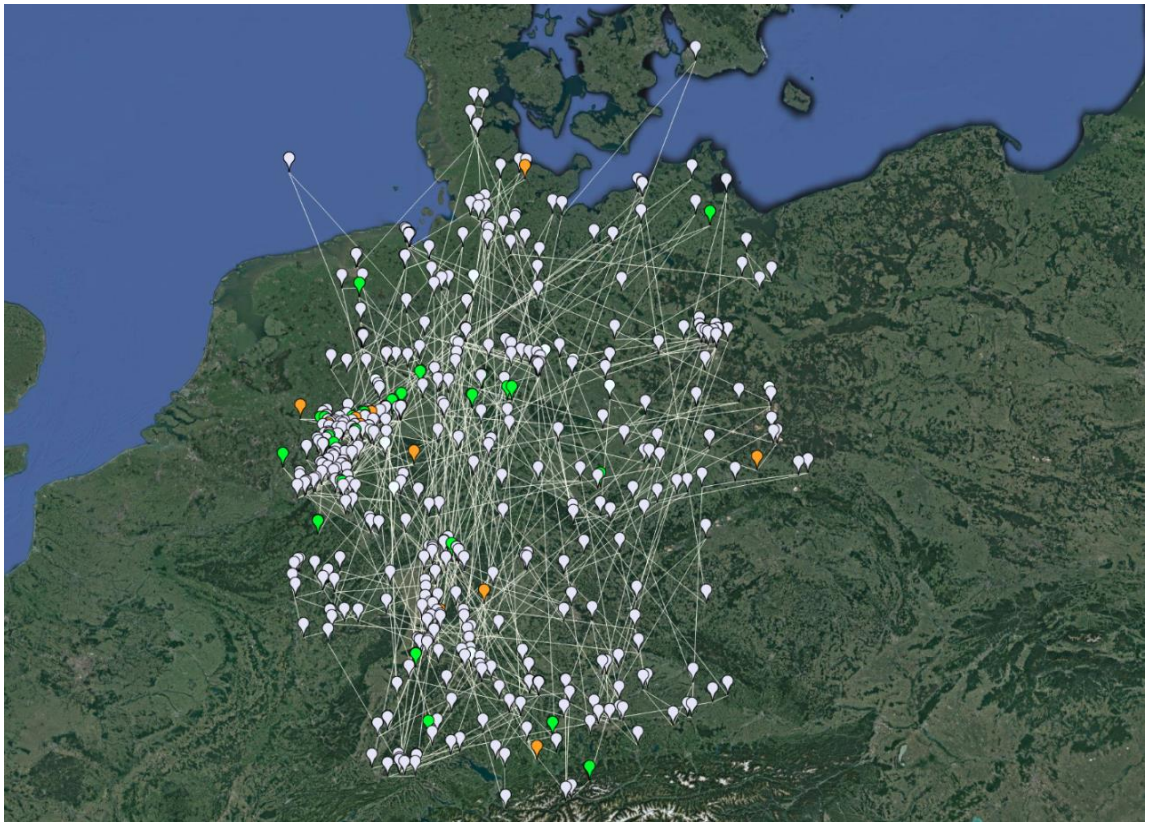
Power Plant: It contains multiple Generators and has outgoing edges to other powerplants and Substations. **Numbers: 14**

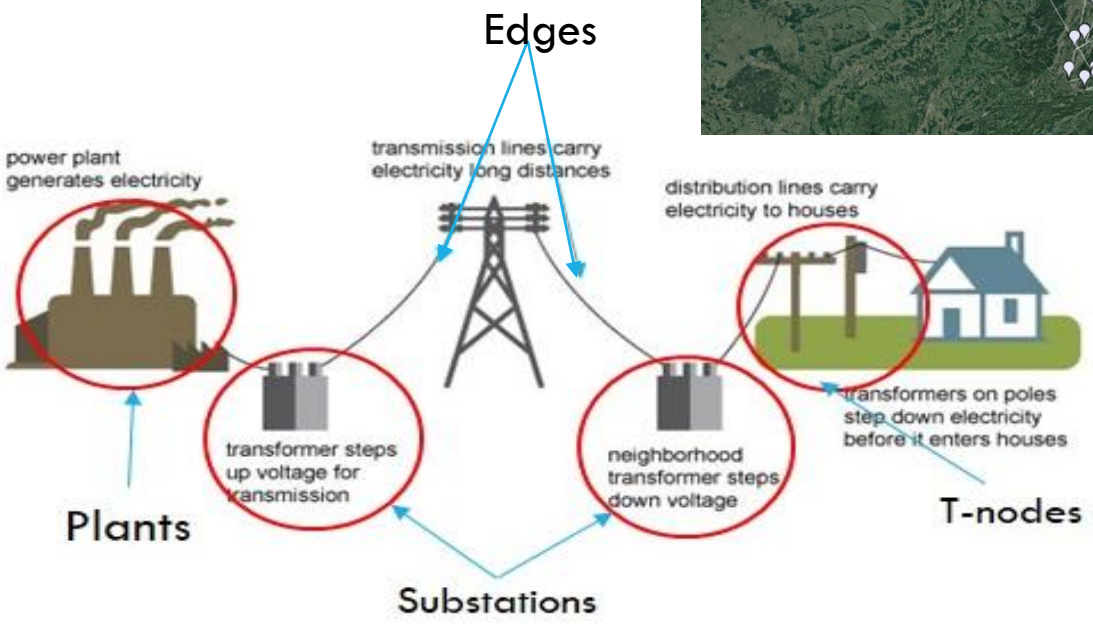
Substation: The substations step up(380kV) or step down(220kV) the voltage obtained from power plant, for either long distance transmission or local consumption. **Numbers: 422**

T nodes: T nodes used as splitters and combiners for routing transmitted power from the substations. The data associated with T node is the fuel source of incoming electrical power (eg. coal,wind,solar). **Numbers: 40**

Network Formation:

Nodes: 495
Edges: 700
Added Node and Edge Data to Classify
Nodes and edges by
-Fuel Source (Nodes)
-Type (Nodes)
-Voltage (Edges)





DEGREE CENTRALITY

Node No:	Centrality Score:	Type:	Location:
37	30.00	Substation	Sachsen-Anhalt
69	30.00	Substation	Hessen
117	30.00	Substation	Nordrhein-Westfalen
165	30.00	Substation	Nordrhein-Westfalen
52	28.00	Substation	Baden-Württemberg

Economical Significance:

- Coal mining and steel ore mining
- Chemical, leather or automobile manufacturing industries

EIGEN-VECTOR CENTRALITY:

Node No:	Centrality Score:	Type:	Location: (Districts)
81	0.1419	Substation	Brandenburg
428	0.1109	Power Plant	Brandenburg
280	0.0842	Substation	Sachsen
74	0.0757	Substation	Brandenburg
80	0.0544	Substation	Sachsen

Significance:

- the top 5 nodes are in nearby location
- Largest airport in Brandenburg
- Airfields, Theater
- Manufacturing, agriculture, and tourism

Page Rank Centrality Top 5

Node No:	Centrality score:	Type	Location
475	347.0516	T-node	Niedersachsen
474	197.6626	Substation	Niedersachsen
201	84.9733	Substation	Niedersachsen
481	73.9491	T-node	Niedersachsen
39	70.8099	Substation	Sachsen-Anhalt

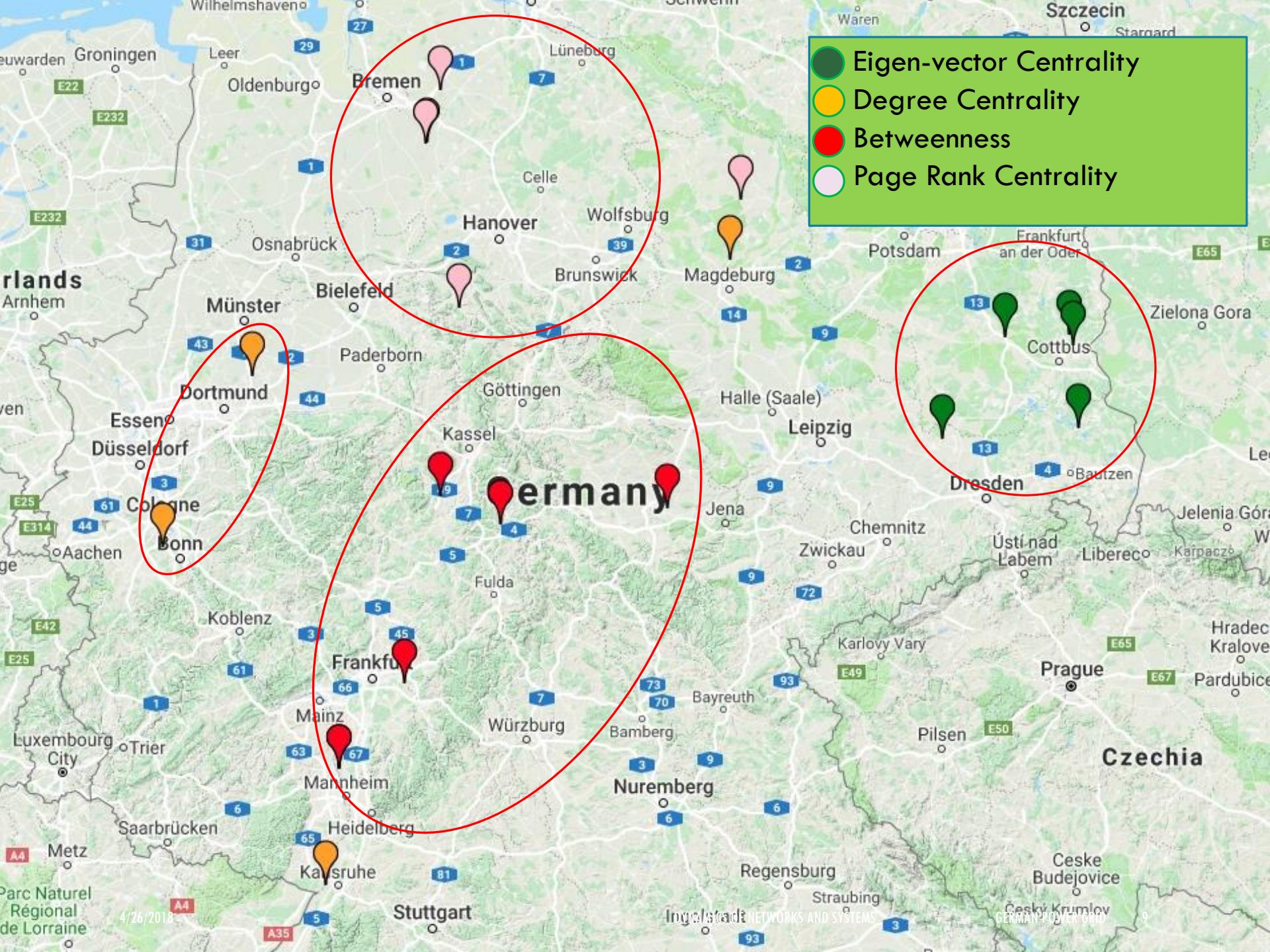
Significance:

- Niedersachsen's economy is predominantly based on agriculture, mining and manufacturing
- T-node corresponds to Deep geological repository (nuclear waste storage unit)
- Substation at Sachsen-Anhalt corresponds to a wind farm

Betweenness Centrality Top 5:

Node no:	Centrality Score:	Type:	Location:
51	(0.2547)	Substation	Hessen
31	(0.2496)	Substation	Hessen
246	(0.2471)	Substation	Hessen
32	(0.2155)	Substation	Thüringen
69	(0.2113)	Substation	Hessen

- Substations have higher betweenness centrality scores than other nodes as they form the interface between power generators and consumption
- Hessen – has one of the largest city Frankfurt
- Frankfurt has headquarters of numerous banks
- Many Chemical, pharmaceutical, mechanical and automobile industries are present in Hessen
- Thüringen – neighboring state with industrial dominace

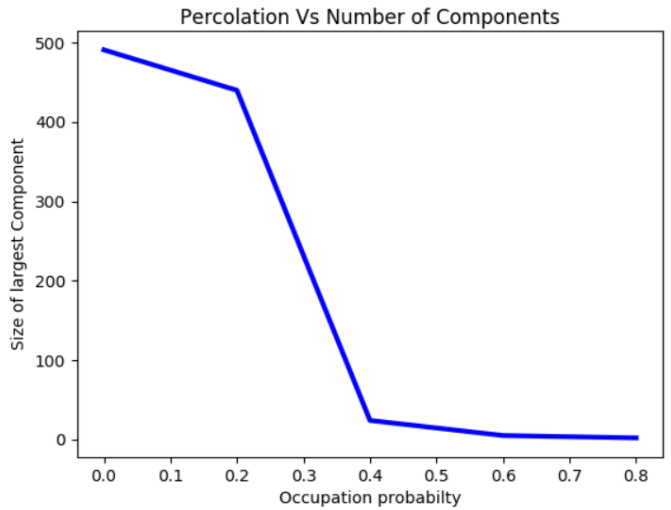

Eigen-vector Centrality
Degree Centrality
Betweenness
Page Rank Centrality
Bremen
Lüneburg
Celle
Hanover
Wolfsburg
Brunswick
Osnabrück
Bielefeld
Münster
Paderborn
Dortmund
Essen
Düsseldorf
Cologne
Bonn
Aachen
Göttingen
Kassel
Germany
Fulda
Koblenz
Frankfurt
Mainz
Würzburg
Mannheim
Heidelberg
Karlsruhe
Stuttgart
Nuremberg
Bamberg
Bayreuth
Regensburg
Straubing
Ingolstadt
Magdeburg
Potsdam
Frankfurt an der Oder
Cottbus
Zielona Gora
Halle (Saale)
Leipzig
Dresden
Bautzen
Jena
Chemnitz
Zwickau
Ústí nad Labem
Liberec
Karlovy Vary
Prague
Pilsen
Czechia
Ceske Budejovice
Luxembourg City
Trier
Saarbrücken
Metz
Groningen
Leer
Oldenburg
Wilhelmshaven
Arnhem
Waren
Szczecin
Stargard

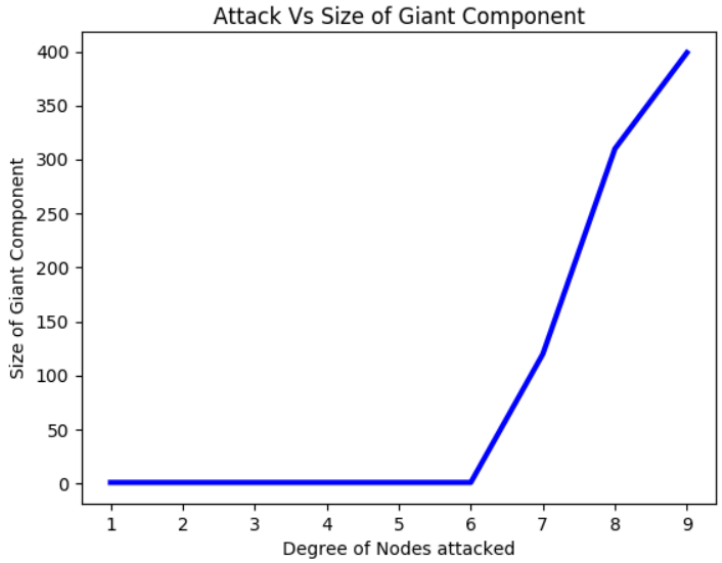
Network Statistics:
Clustering, Average Degree, Degree Distribution

Global Clustering:	0.145140388769
Global Clustering(Config model)	0.00917431192661
Clustering Coefficient:	0.00781228134111
Average Degree:	2
Diameter (German)-unweighted:	23
Config Model Diameter(avg.)	33
Modularity:	-0.72
Number of Components:	3
Maximum degree:	14
Friendship Paradox: (avg. degree of neighbors)	12
Control Reachability: (Minimum Number of nodes required to control the Entire Grid.)	225

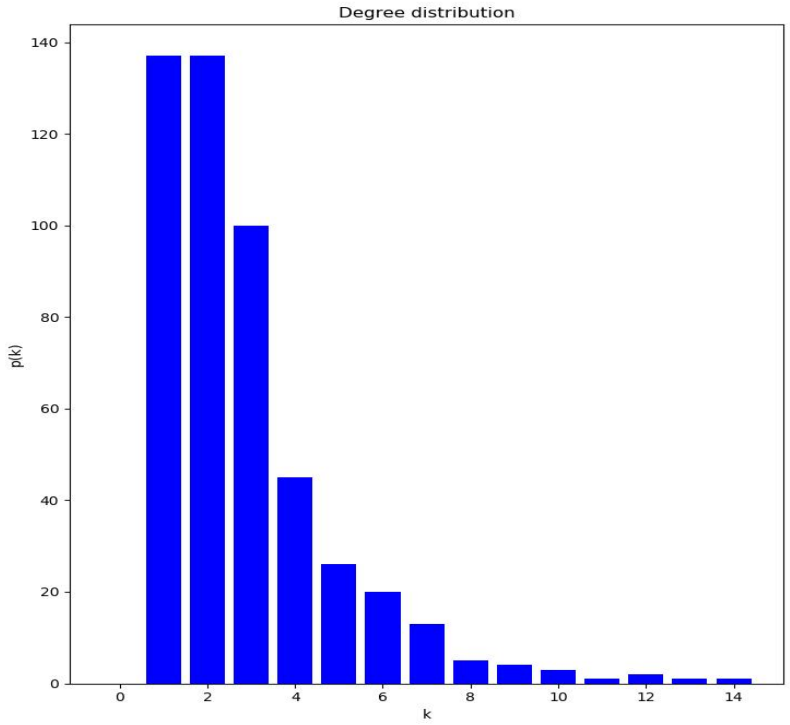
Network Statistics and Modifications:

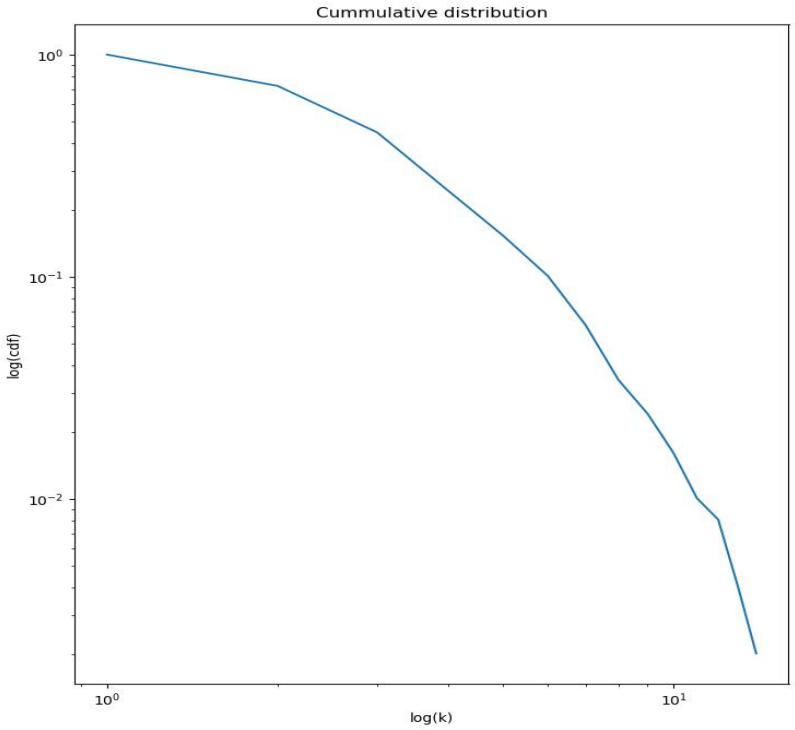
Network Diameter:	23
Diameter (US grid:-4914 nodes)	46
Diameter(perfect lattice:-495 nodes)	46
Simulated Percolation (Random):	
Number of Edges after percolation	28
Number of components after percolation	467
Diameter after percolation	8
Simulated Attacks:	
Number of Edges after Attack on high degree nodes	629
Number of components after Attack	19





Degree Distribution:

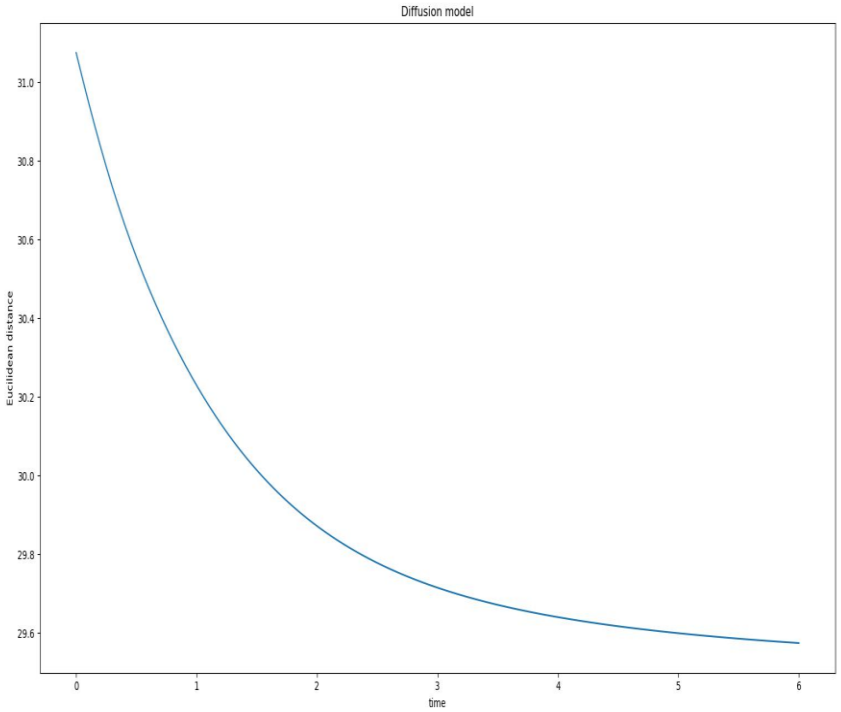


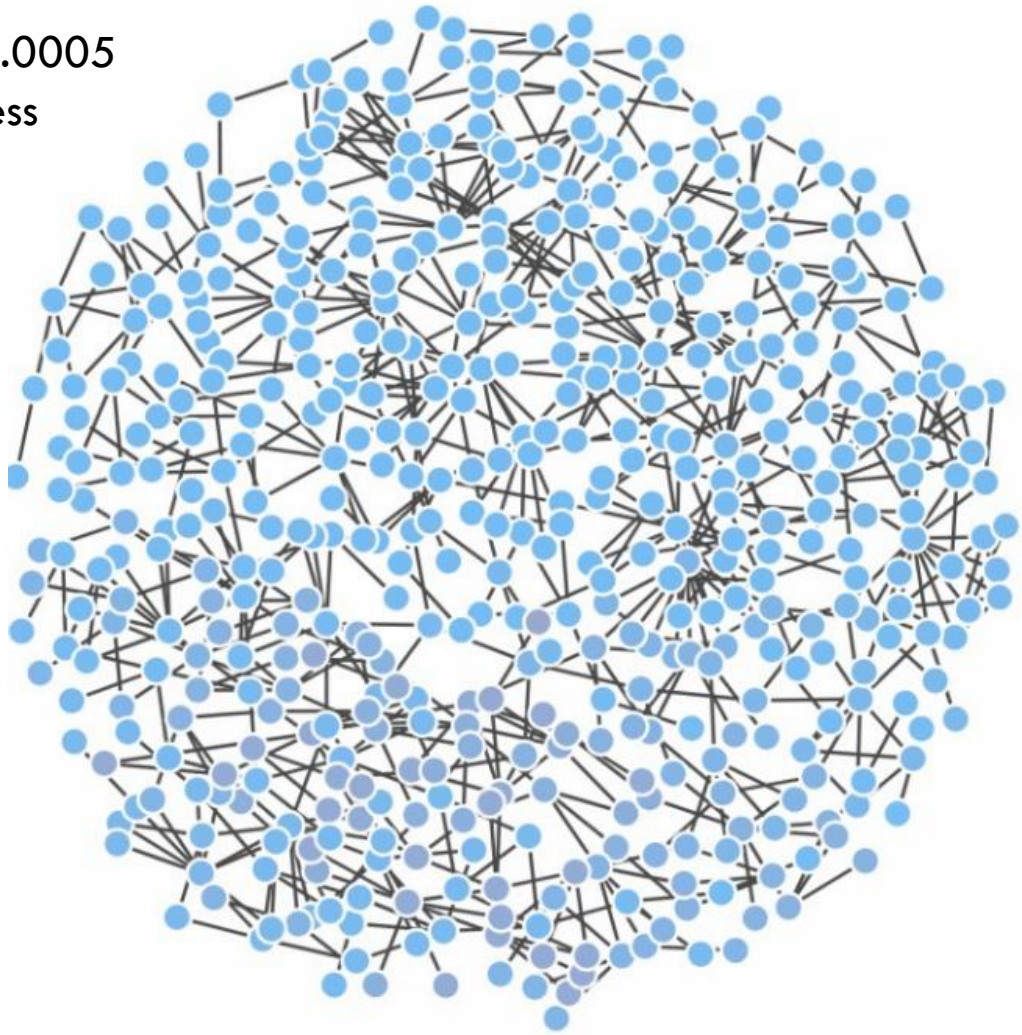


Network follows power law distribution due to the presence of about 8 hubs with degree above 10; alpha=6.45 +/- 1.93

Diffusion:

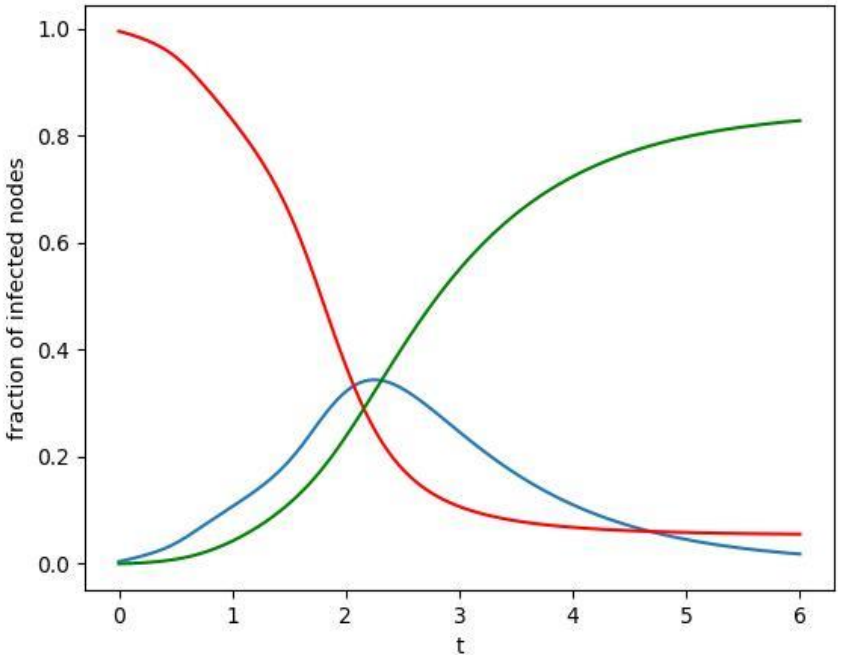
Diffusion Quantity: 10,000 units c=10 dt=0.0005
It takes a longer time for the diffusion process to percolate through the network due to Sparse connectivity.



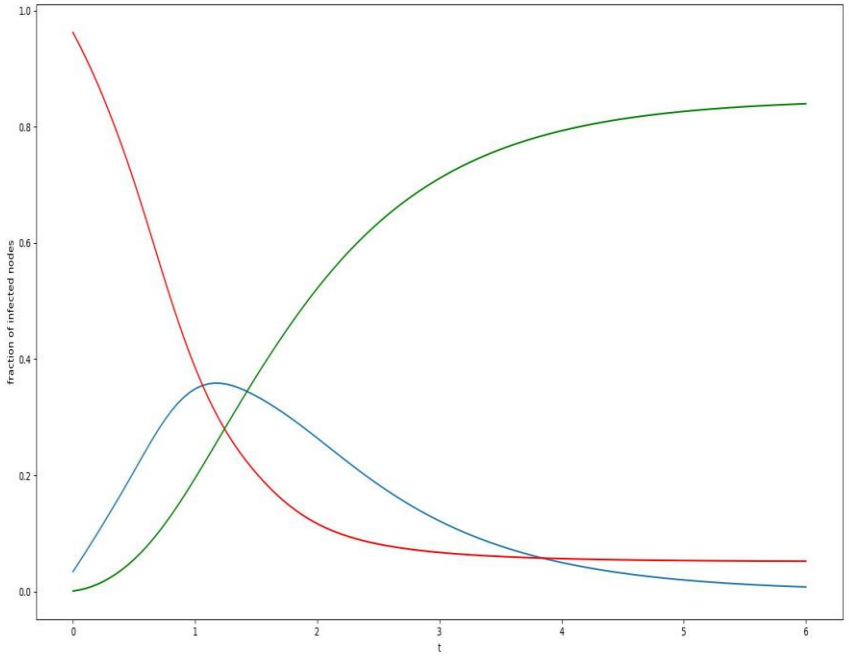


SIR MODEL:

gamma =1, beta = 1

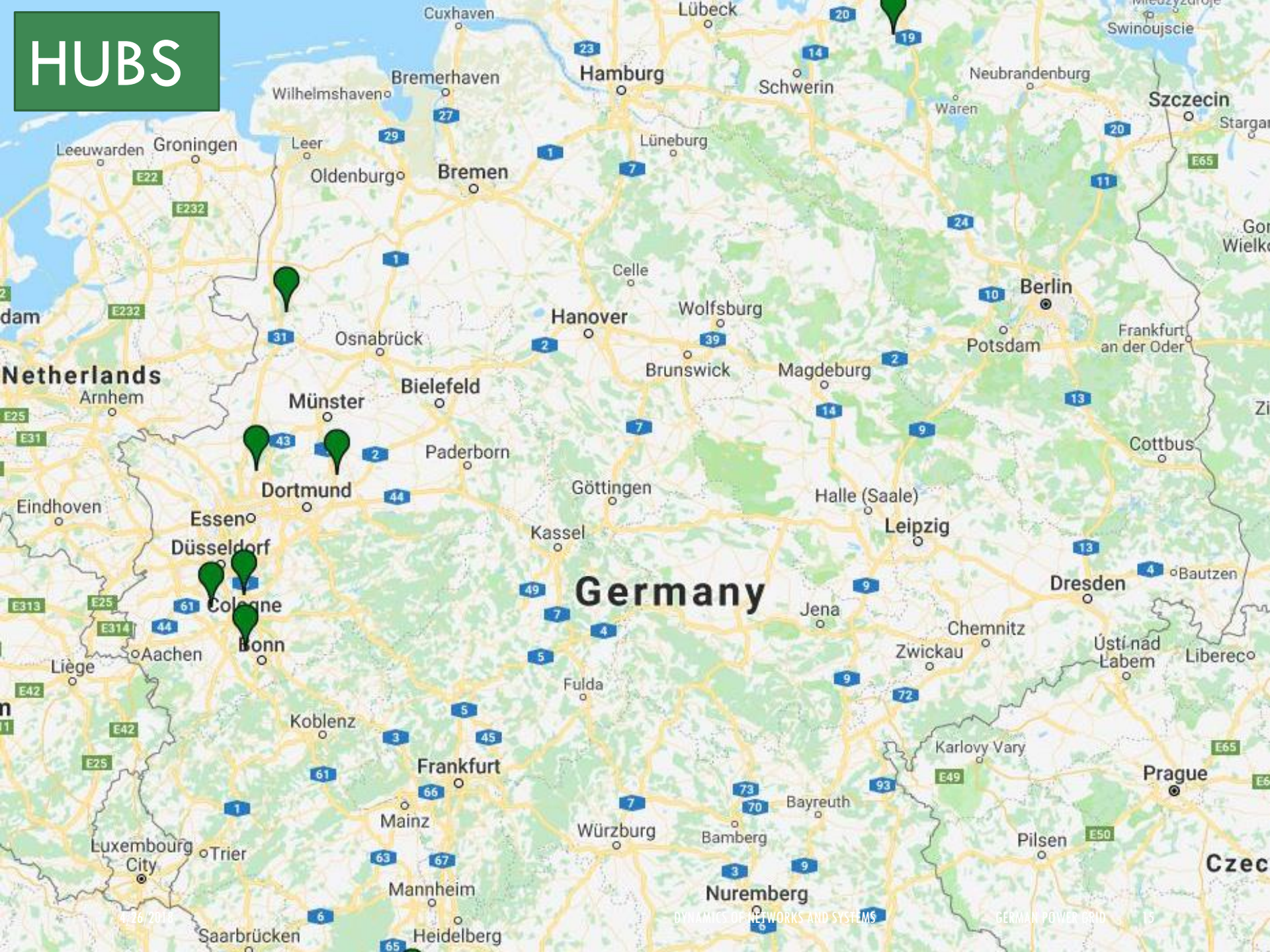


Seed nodes as substation that are network hubs(8)



Seed node as a Single Power Plant(Node-428)

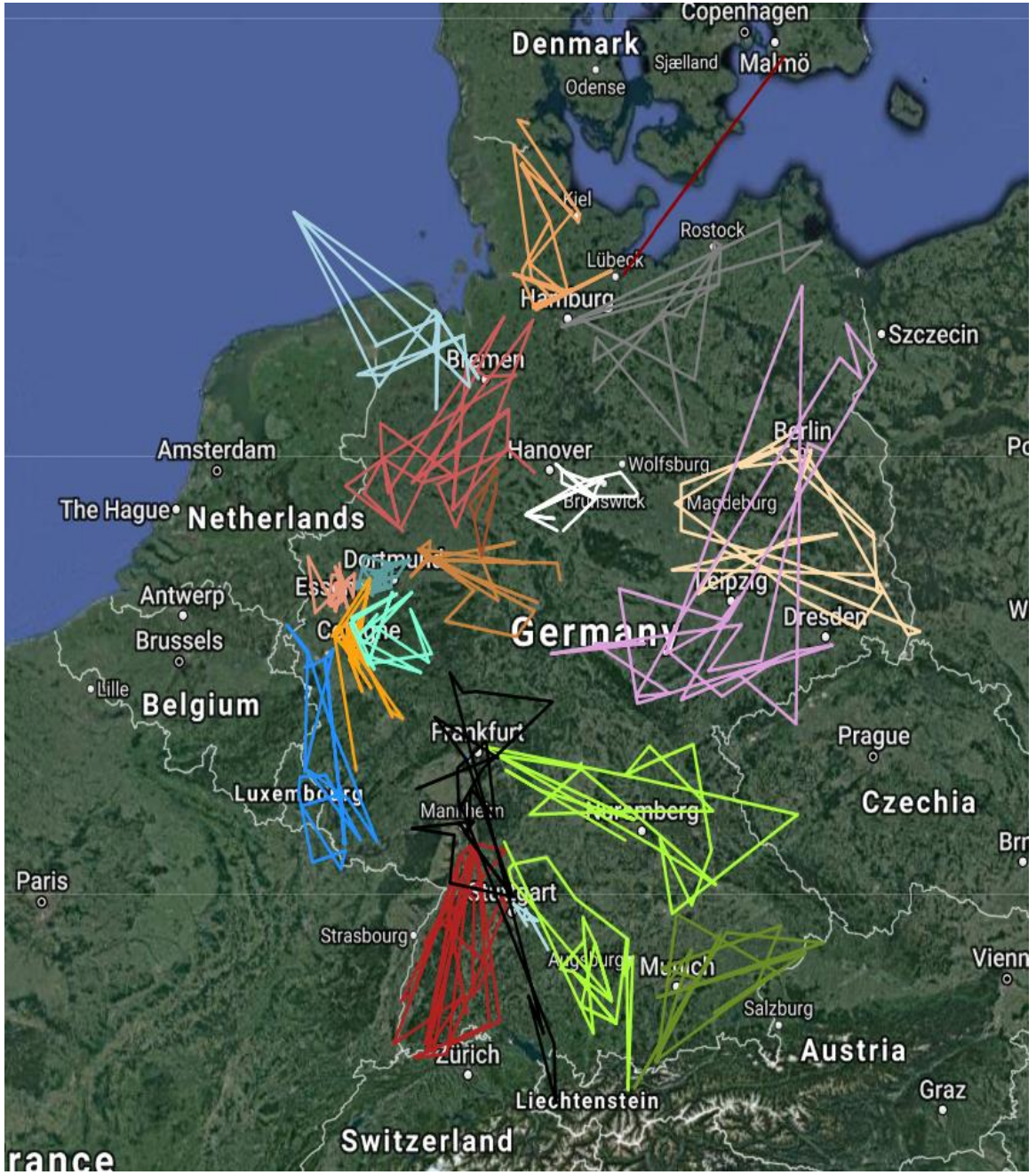
HUBS


Cuxhaven
Lübeck
Swinoujscie
Bremerhaven
Wilhelmshaven
Hamburg
Schwerin
Neubrandenburg
Waren
Szczecin
Leeuwarden
Groningen
Leer
Oldenburg
Bremen
Lüneburg
Celle
Berlin
Potsdam
Frankfurt an der Oder
Hanover
Wolfsburg
Brunswick
Magdeburg
Osnabrück
Netherlands
Arnhem
Münster
Bielefeld
Paderborn
Cottbus
Dortmund
Eindhoven
Essen
Düsseldorf
Göttingen
Halle (Saale)
Leipzig
Kassel
Cologne
Bonn
Aachen
Liège
Germany
Dresden
Bautzen
Jena
Chemnitz
Zwickau
Ústí nad Labem
Liberec
Fulda
Koblenz
Frankfurt
Karlovy Vary
Prague
Mainz
Bayreuth
Würzburg
Bamberg
Pilsen
Luxembourg City
Trier
Mannheim
Nuremberg
Saarbrücken
Heidelberg

Community Detection:

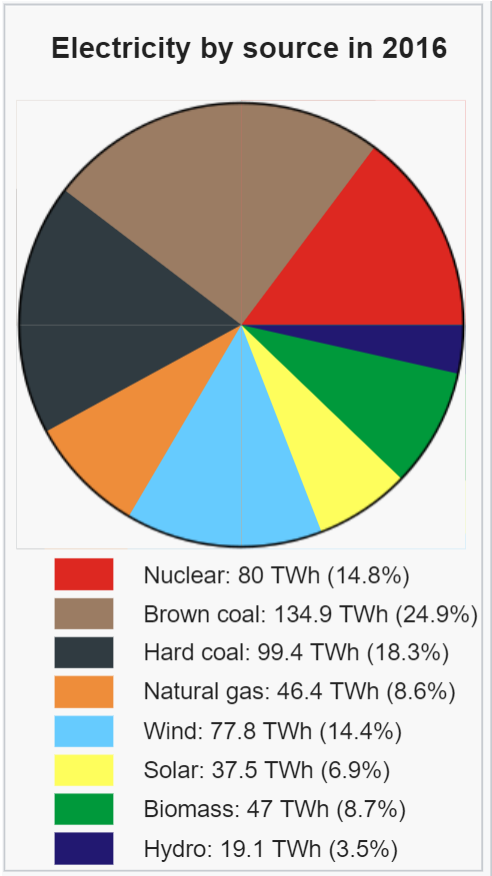
Number of communities: 22

Communities are generally formed between nodes closer geographically



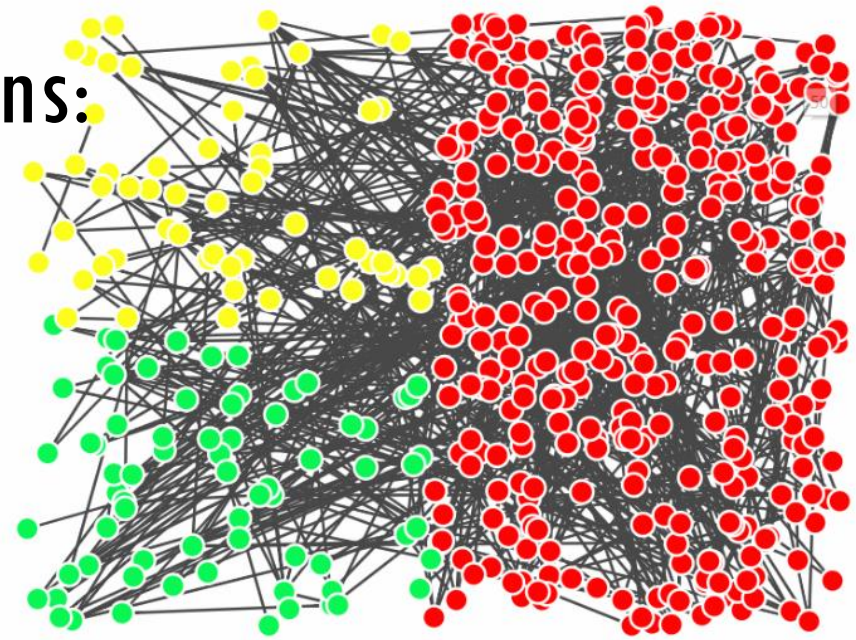
Network insights & Visualizations:

Renewable source: 14.5%
Non Renewable source: 73.7%
Combined (50 –50): 11.7%



(Wikipedia)

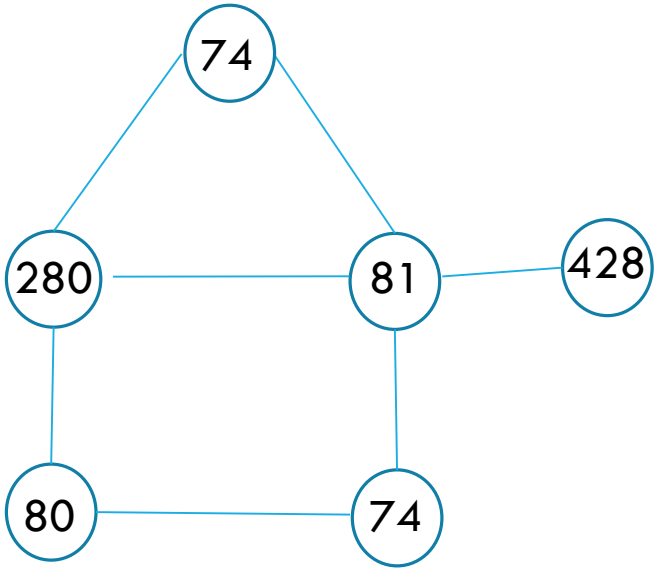
Real World data:
Non-Renewable ~ 67%
Renewable ~ 33%



- Renewable
- Non renewable
- Both

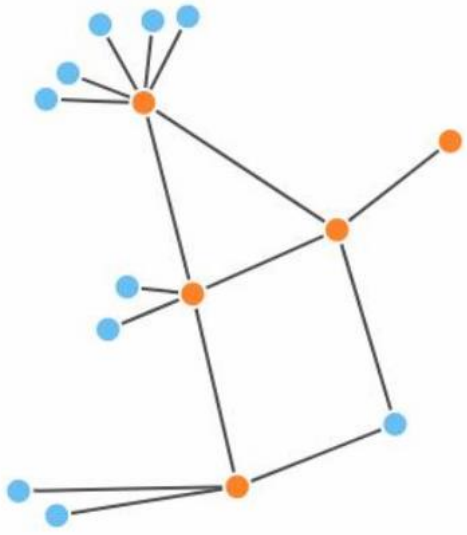
Overall Network composition:
Domestic lines: 47.48% powered by 3 power plants
Industrial Lines: 52.52% powered by 5 power plants

(Added After presentation) Nodes in Eigenvector Centrality:



We can see the nodes in eigenvector centrality from a closed cycle and hence they keep passing around their centrality score hence maintaining the initial score they started with.

Nodes in Eigenvector Centrality:	Neighbors:
81	**74**, 79, **280**, **428**
428	**81**
280	**74**, **80**, **81**, 279, 282
74	10, 45, 71, 73, **81**, **280**, 292
80	79, **280**, 290, 291

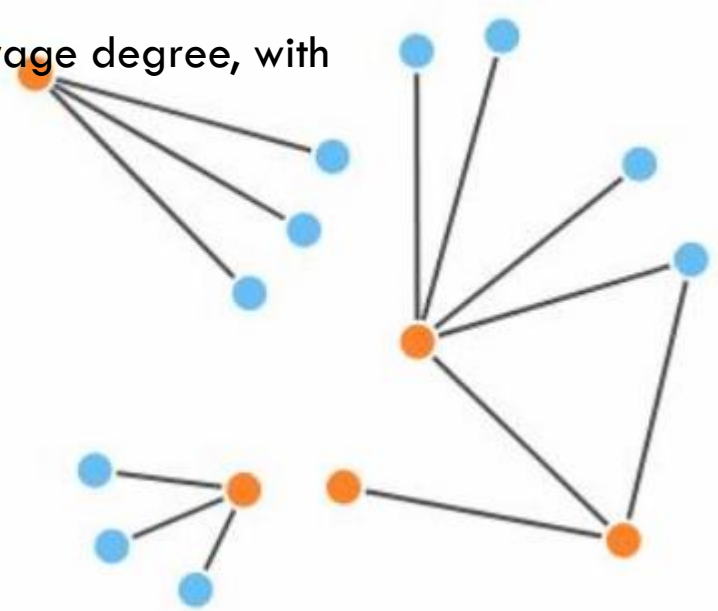


(Added After presentation)
Page Rank Centrality:

Page rank depends on the following:

1) Number of links it receives
2) Link behavior (domestic or industrial)
3) Node centrality Score

It selects the nodes mostly with degree greater than average degree, with industrial lines from substations.



Page Rank Centrality nodes & their neighbors

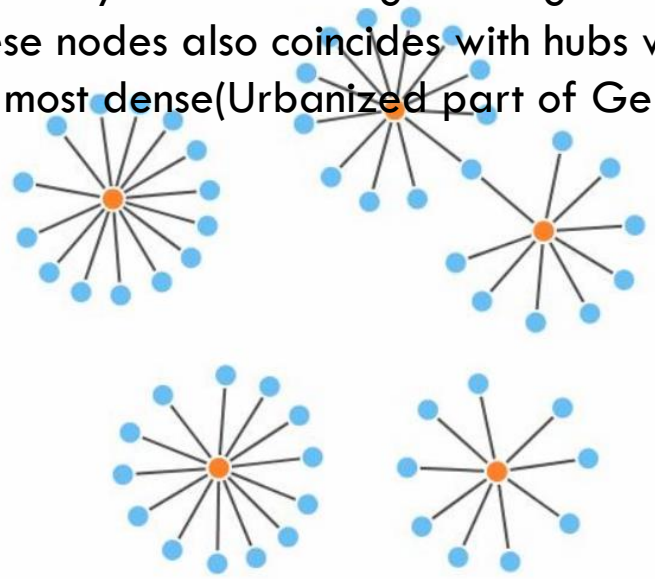
(Added After presentation)

Betweenness Centrality:

We can see that nodes that appear in betweenness centrality are all substations and they appear in the central part of Germany as they form a interface between the western and eastern half of the power grid. These nodes appear on maximum number of shortest paths in the network.

Degree Centrality:

In Degree Centrality nodes with highest degree are seen to appear in top 5. the location of these nodes also coincides with hubs with degree greater then 10 as they appear in the most dense(Urbanized part of Germany) part of Network.



Nodes in Degree Centrality

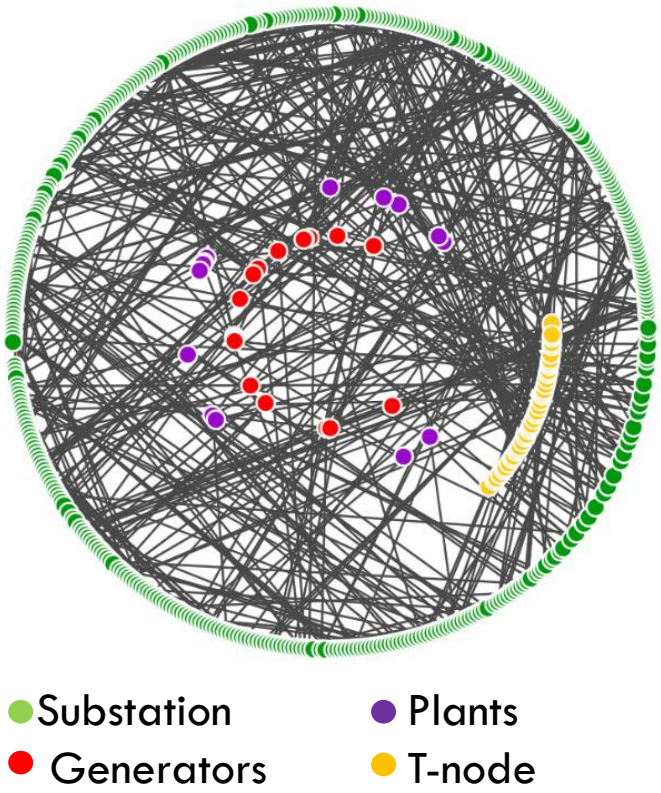
(Added After presentation)

Modularity:

Modularity groups were formed on the basis of type of node:
Groups "plant", "generator", "substation", "t-node"

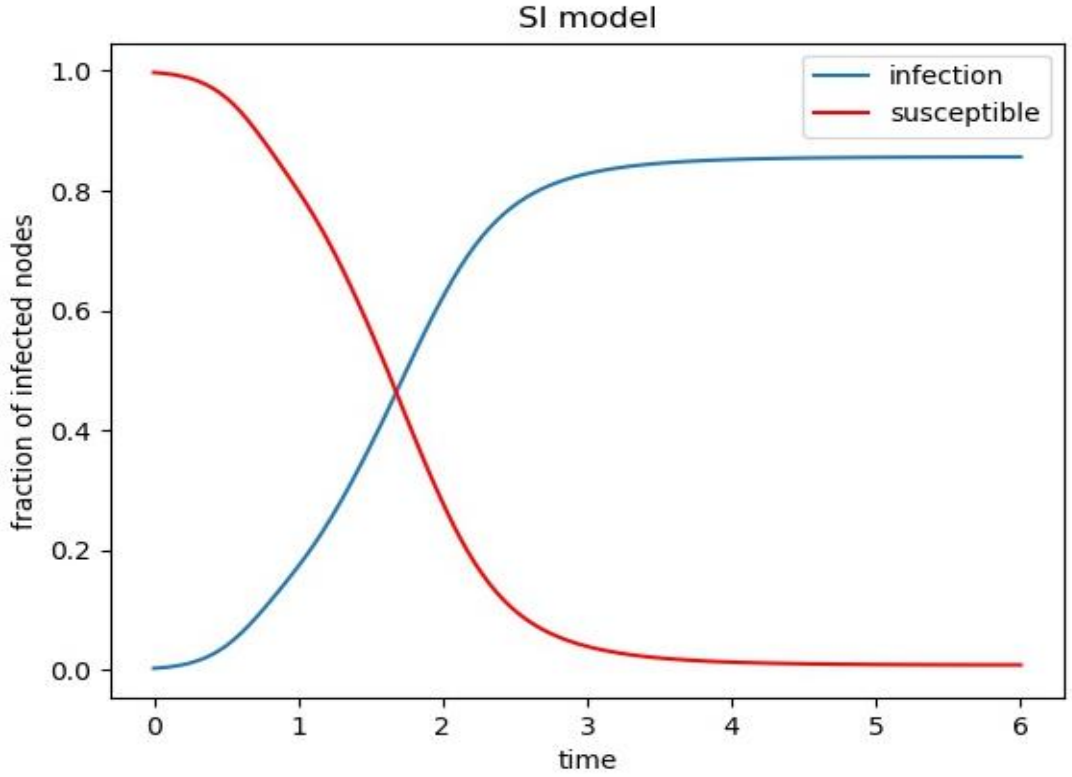
The resulting Modularity score was: -1.5207 / -2.1007

Q-max



We see a high modularity in the network as the maximum number of nodes in the network are comprised of Substations. And since they are used to step up or step down the voltage these nodes are often connected to each other through out the network.

(Added After presentation)
SI Model:



For beta = 1, about 85% of the network gets infected.
The remaining 15% doesn't get infected due to the presence of small communities