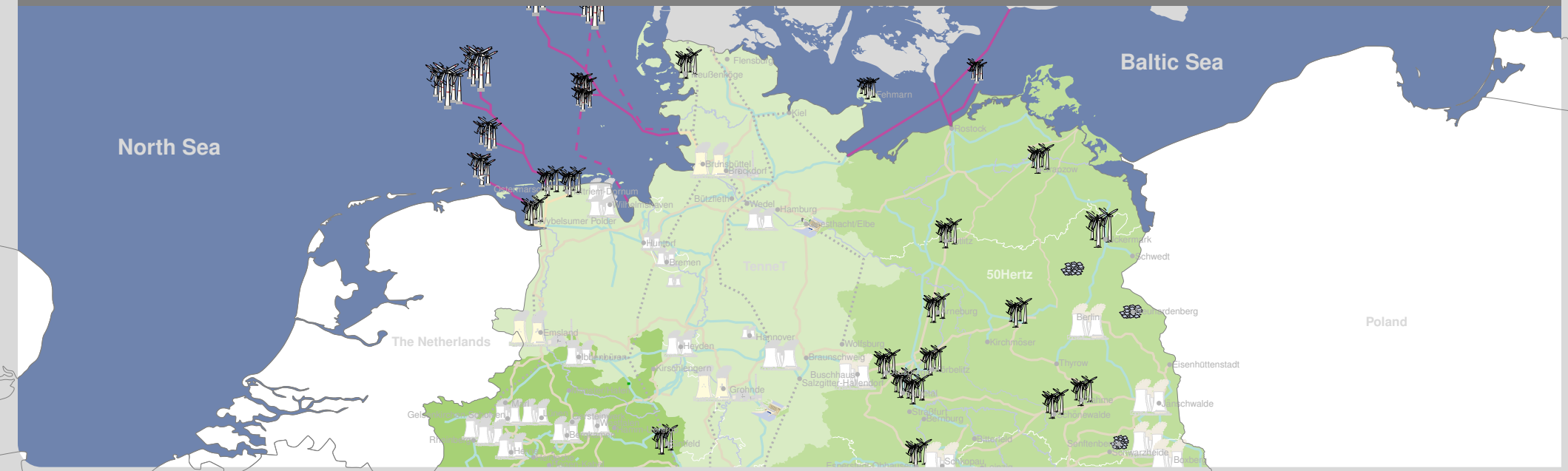
Karlsruhe Institute of Technology

A Simulated-Annealing-Based Approach for Wind Farm Cabling

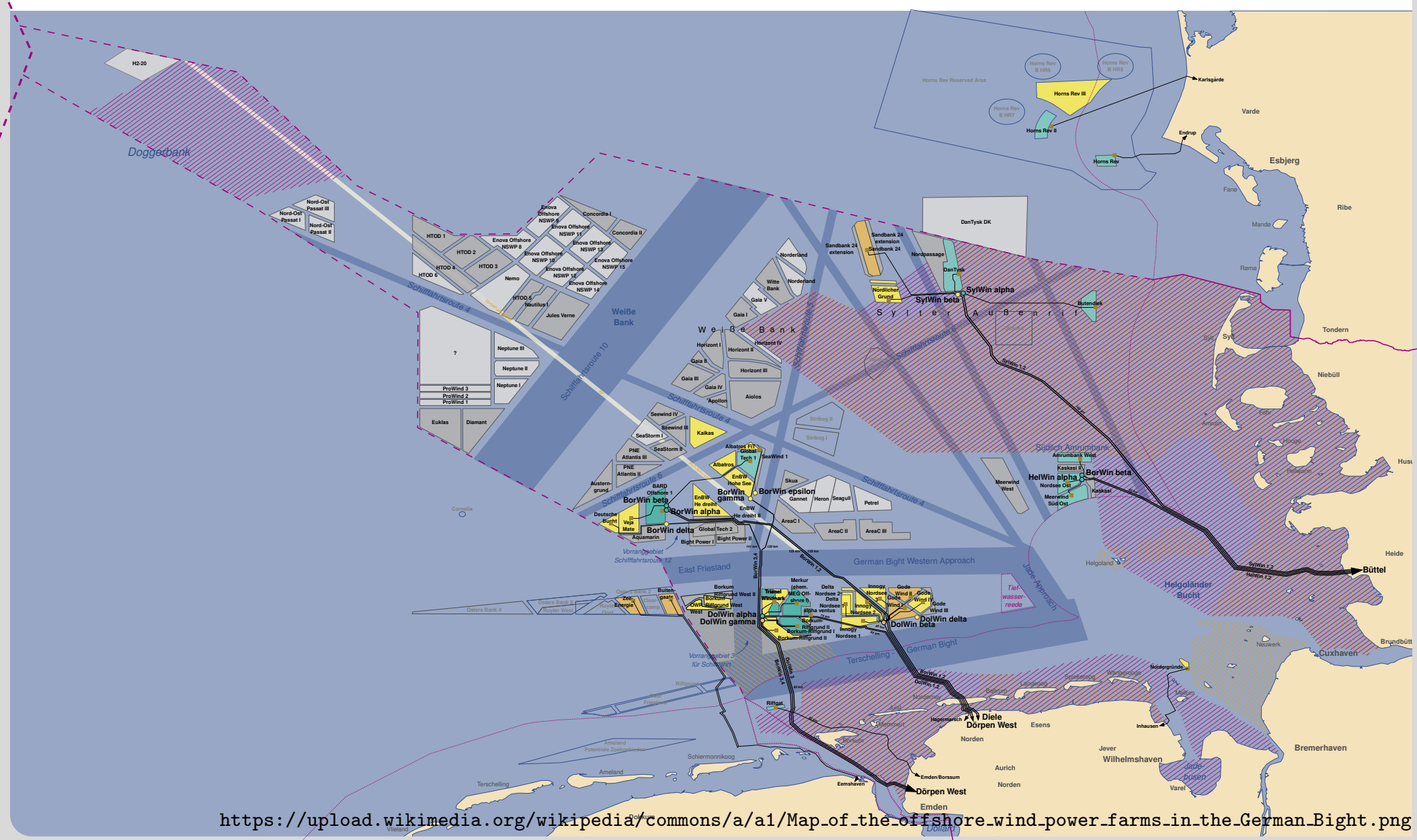
ACM e-Energy 2017 · May 19, 2017

Sebastian Lehmann, Ignaz Rutter, Dorothea Wagner and Franziska Wegner

INSTITUTE OF THEORETICAL INFORMATICS · ALGORITHMICS GROUP



Motivation

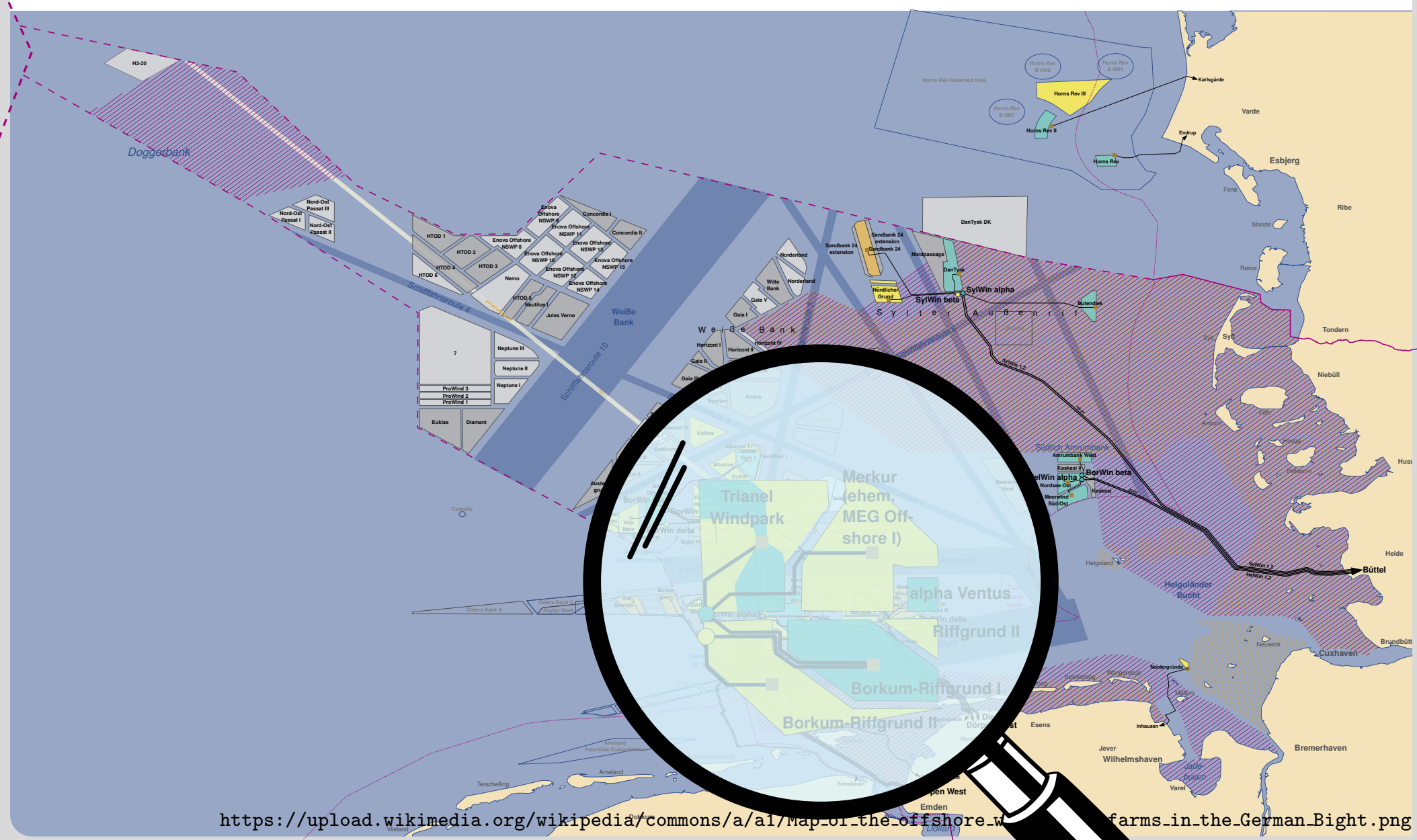


https://upload.wikimedia.org/wikipedia/commons/a/a1/Map_of_the_offshore_wind_power_farms_in_the_German_Bight.png

Sebastian Lehmann, Ignaz Rutter, Dorothea Wagner and Franziska Wegner – A Simulated-Annealing-Based Approach for Wind Farm Cabling

Institute of Theoretical Informatics
Algorithmics Group

Motivation



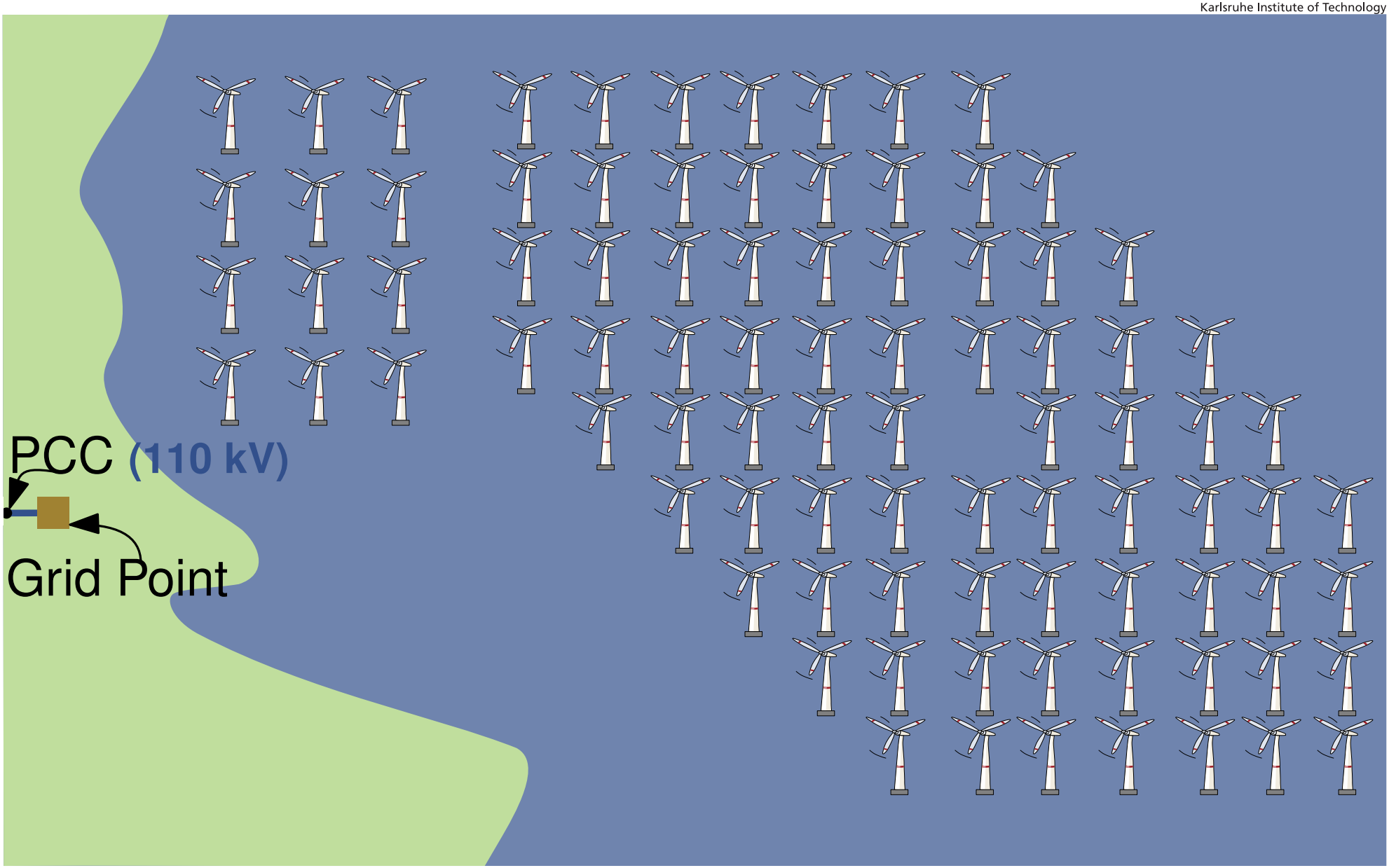
https://upload.wikimedia.org/wikipedia/commons/a/a1/Map_of_the_offshore_w[illegible]farms_in_the_German_Bight.png

Sebastian Lehmann, Ignaz Rutter, Dorothea Wagner and Franziska Wegner – A Simulated-Annealing-Based Approach for Wind Farm Cabling

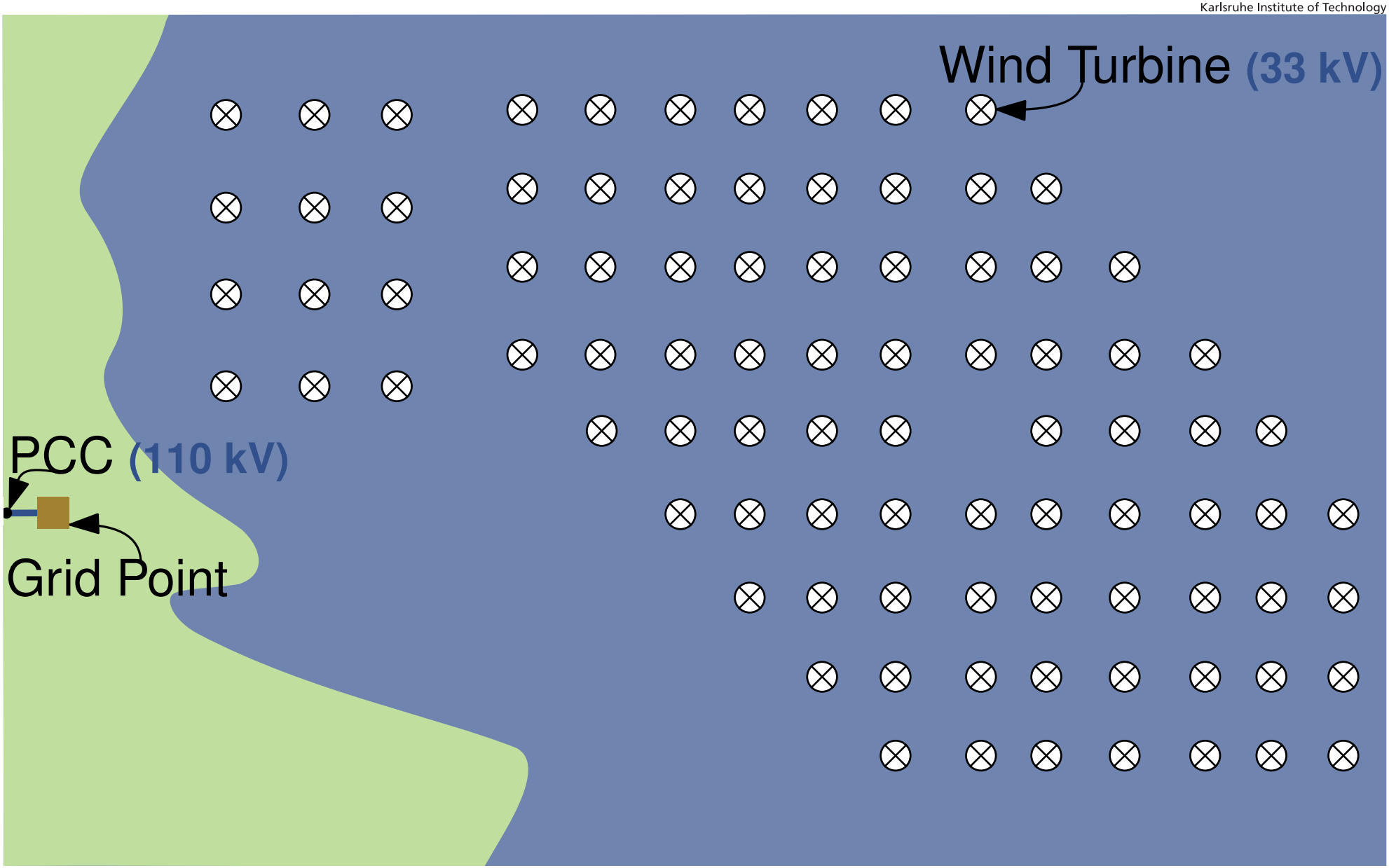
Wind Farm Cabling

Wind Farm Cabling

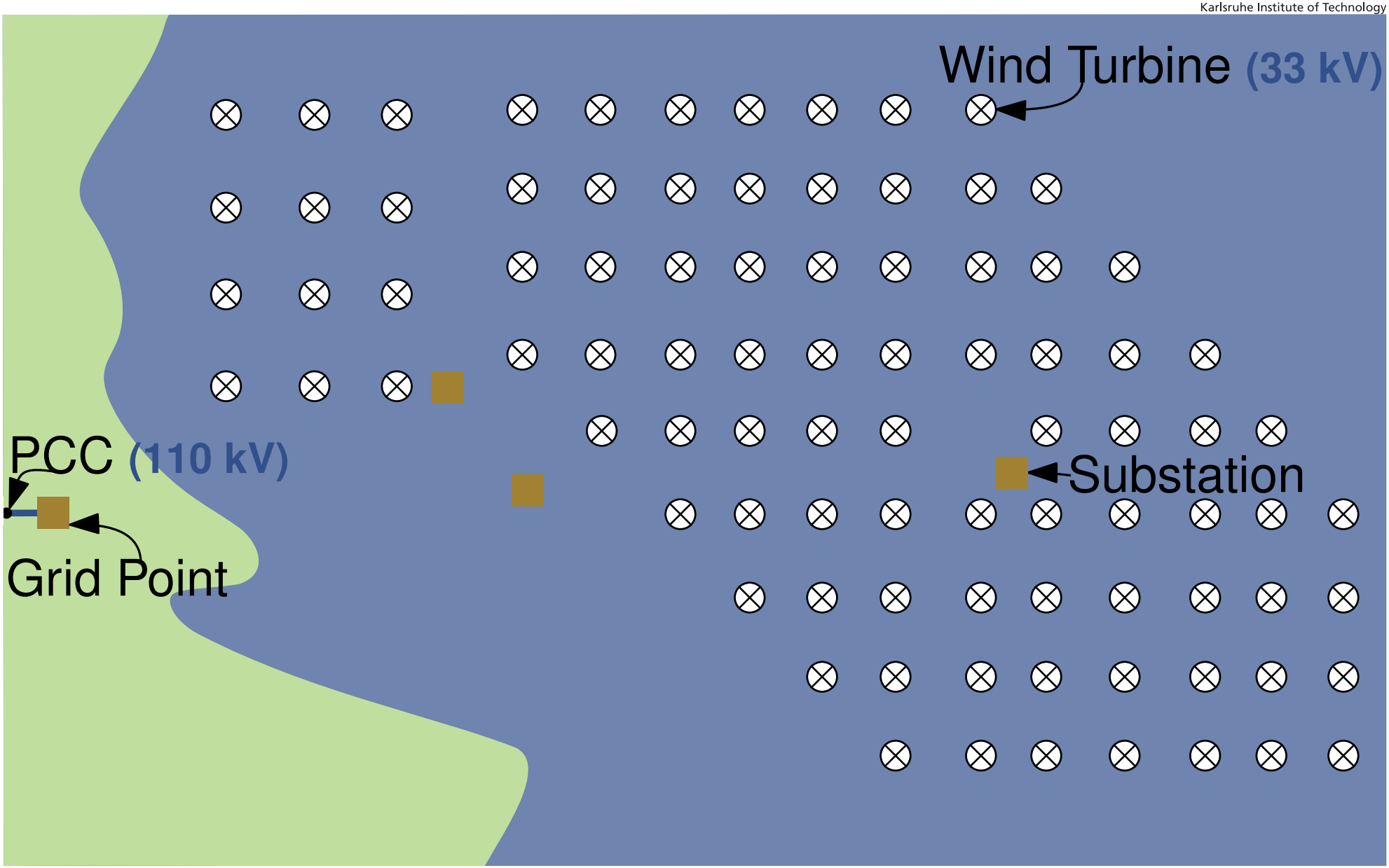
Wind Farm Cabling



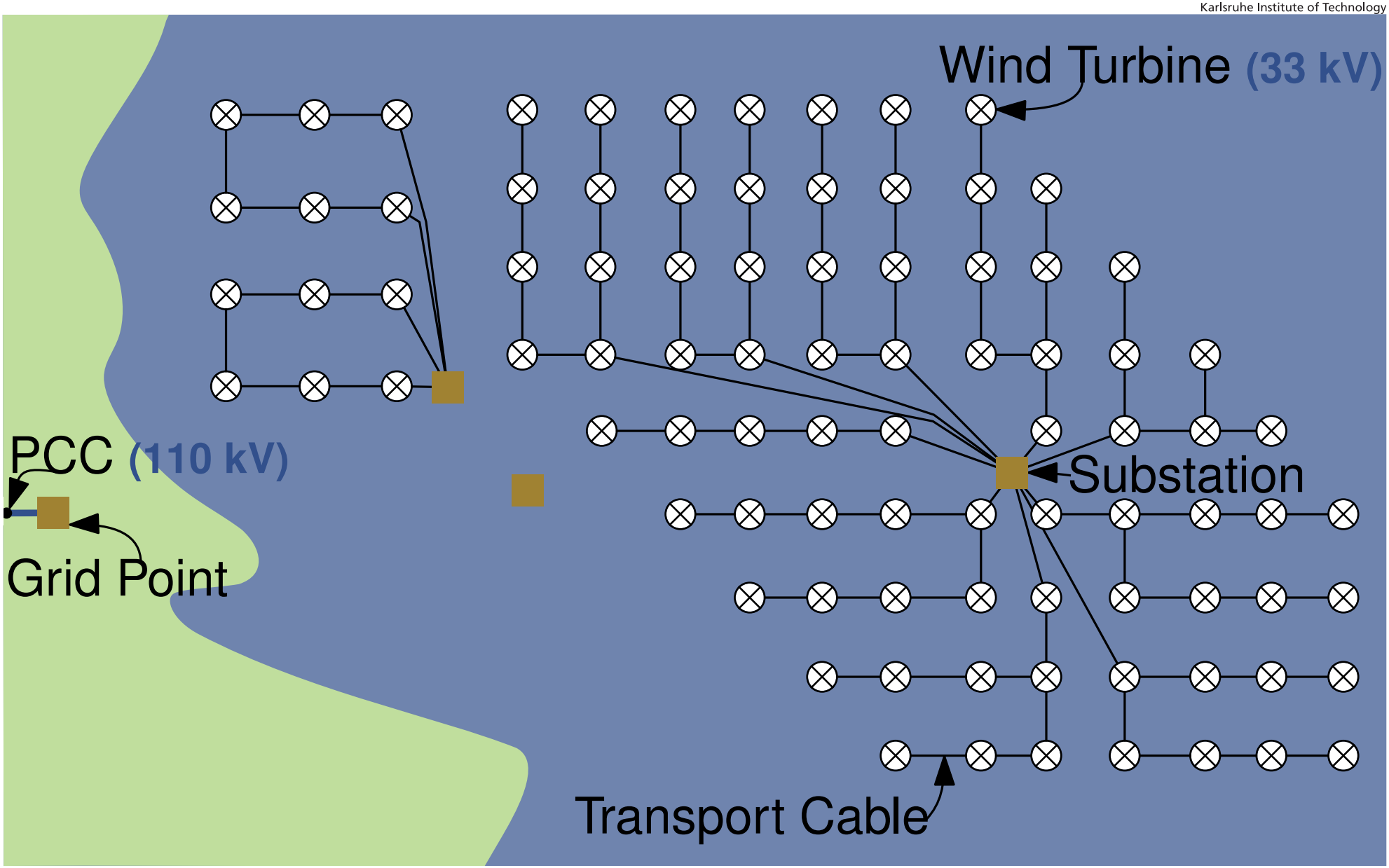
Wind Farm Cabling



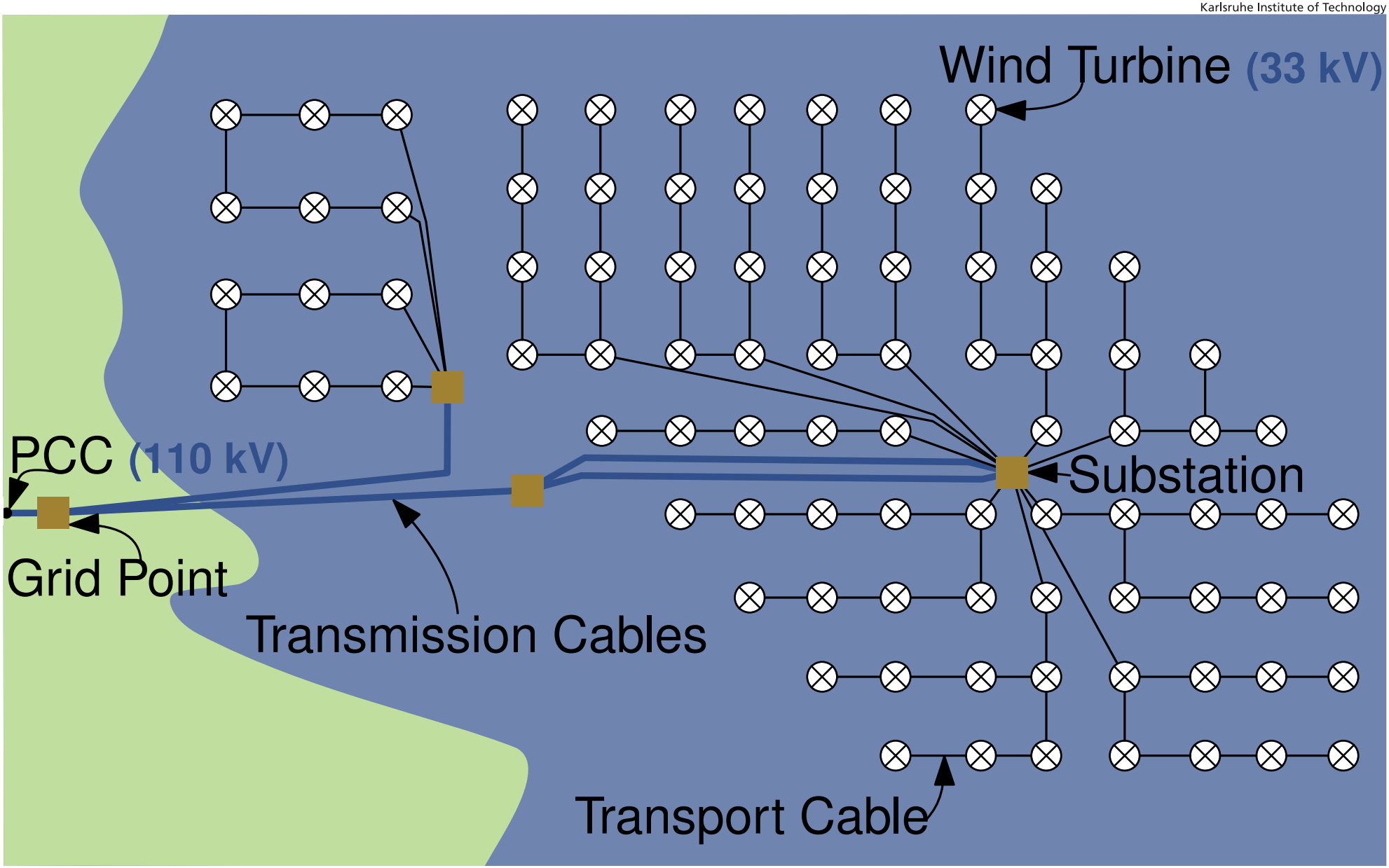
Wind Farm Cabling



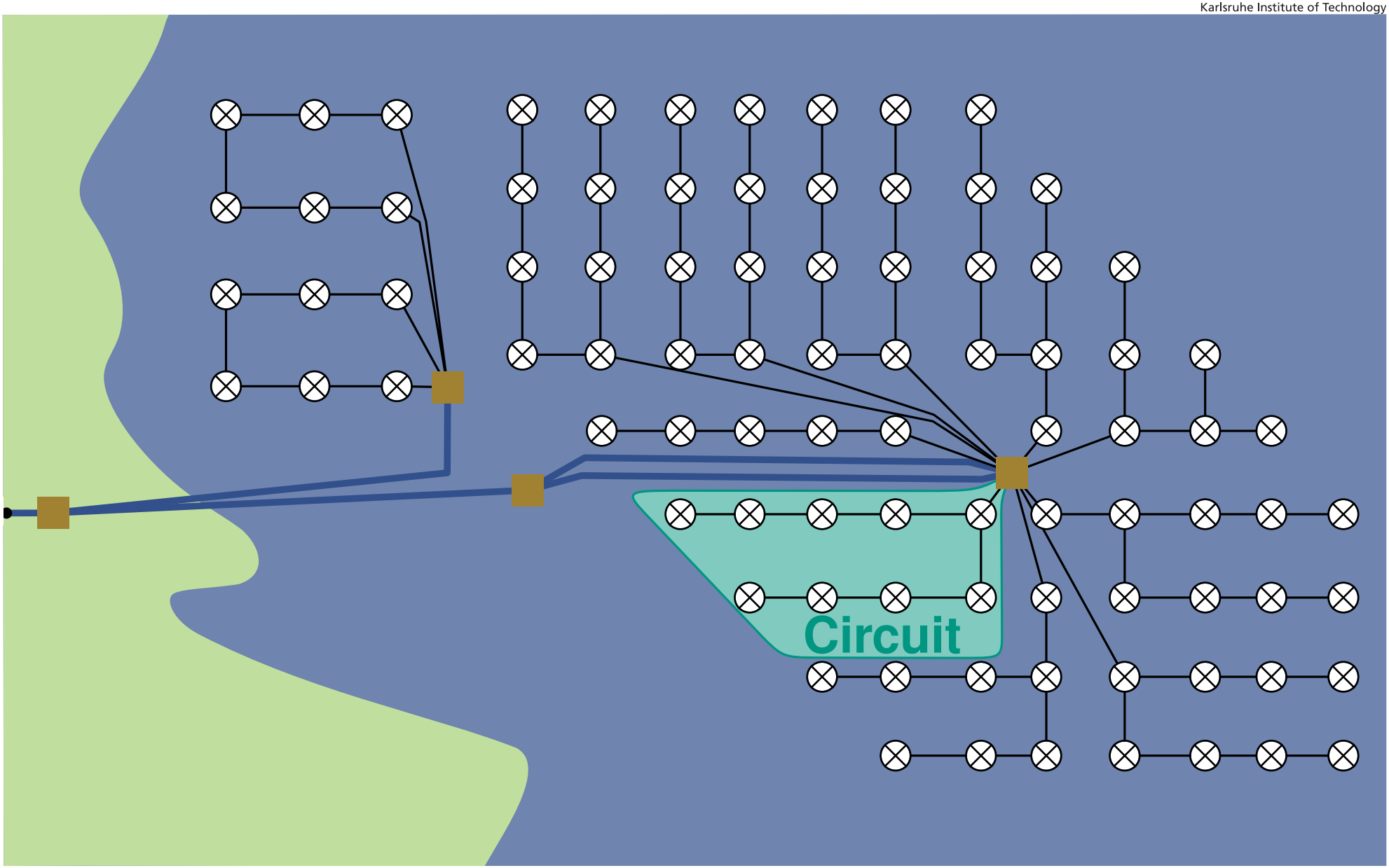
Wind Farm Cabling



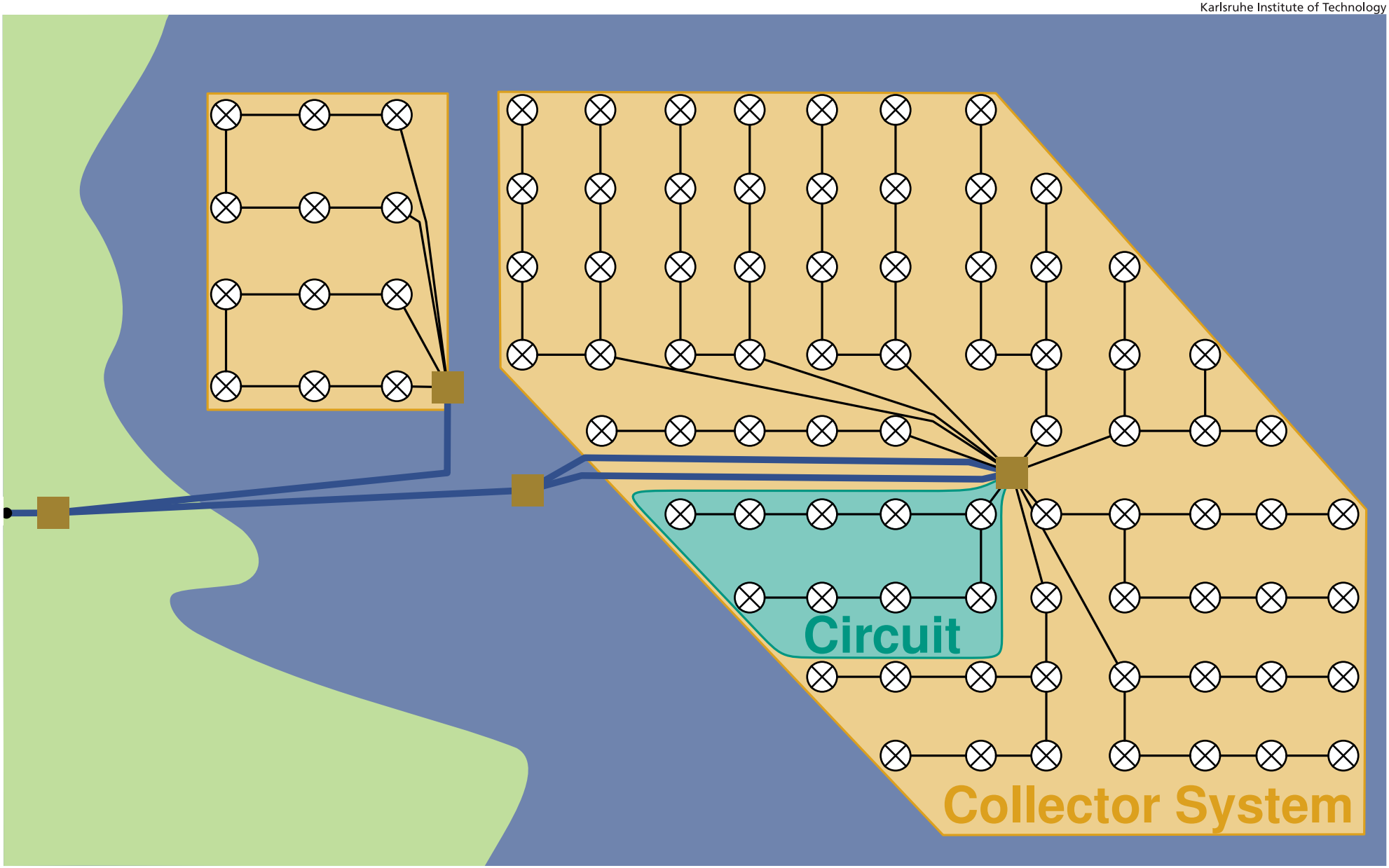
Wind Farm Cabling



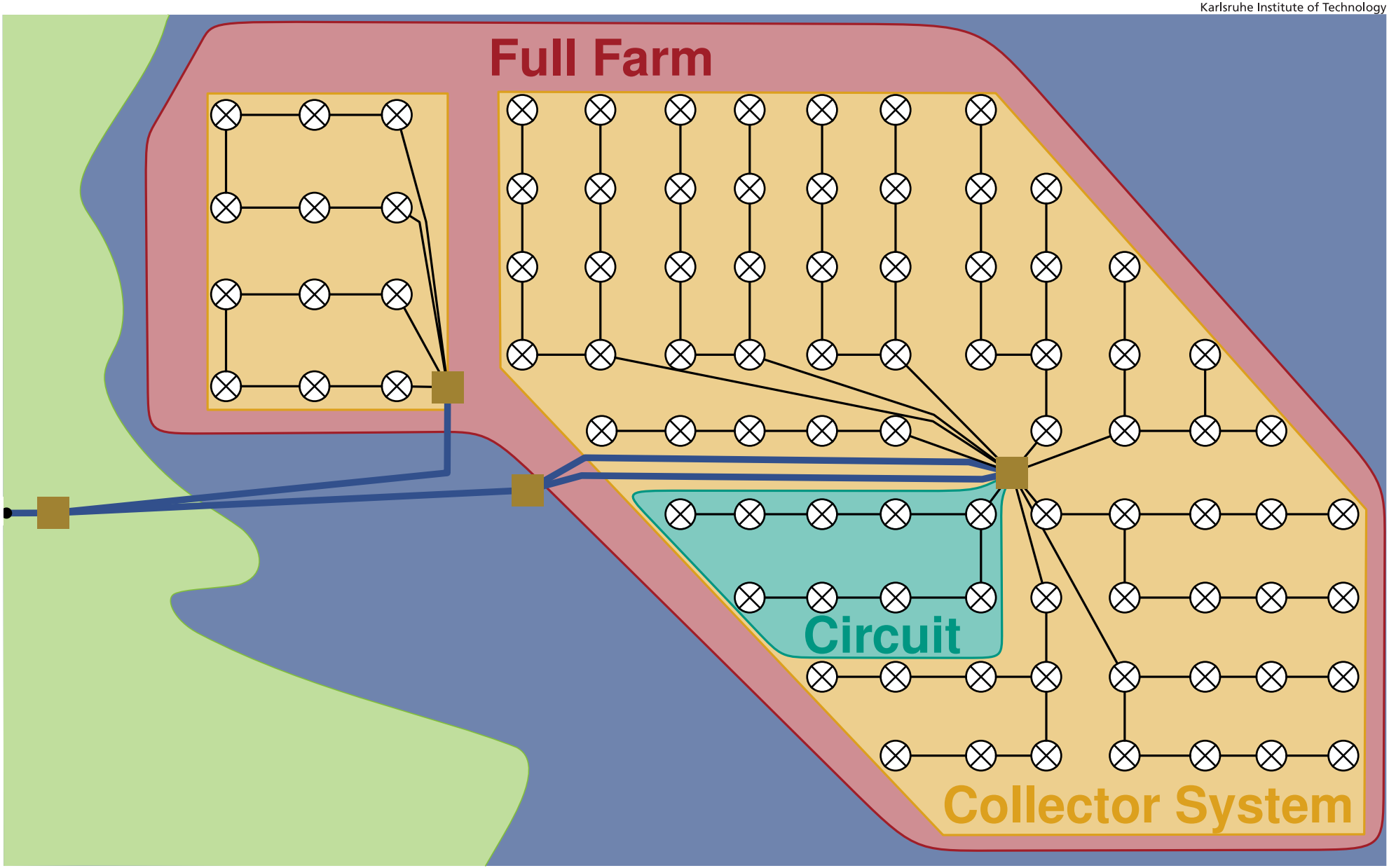
Wind Farm Cabling



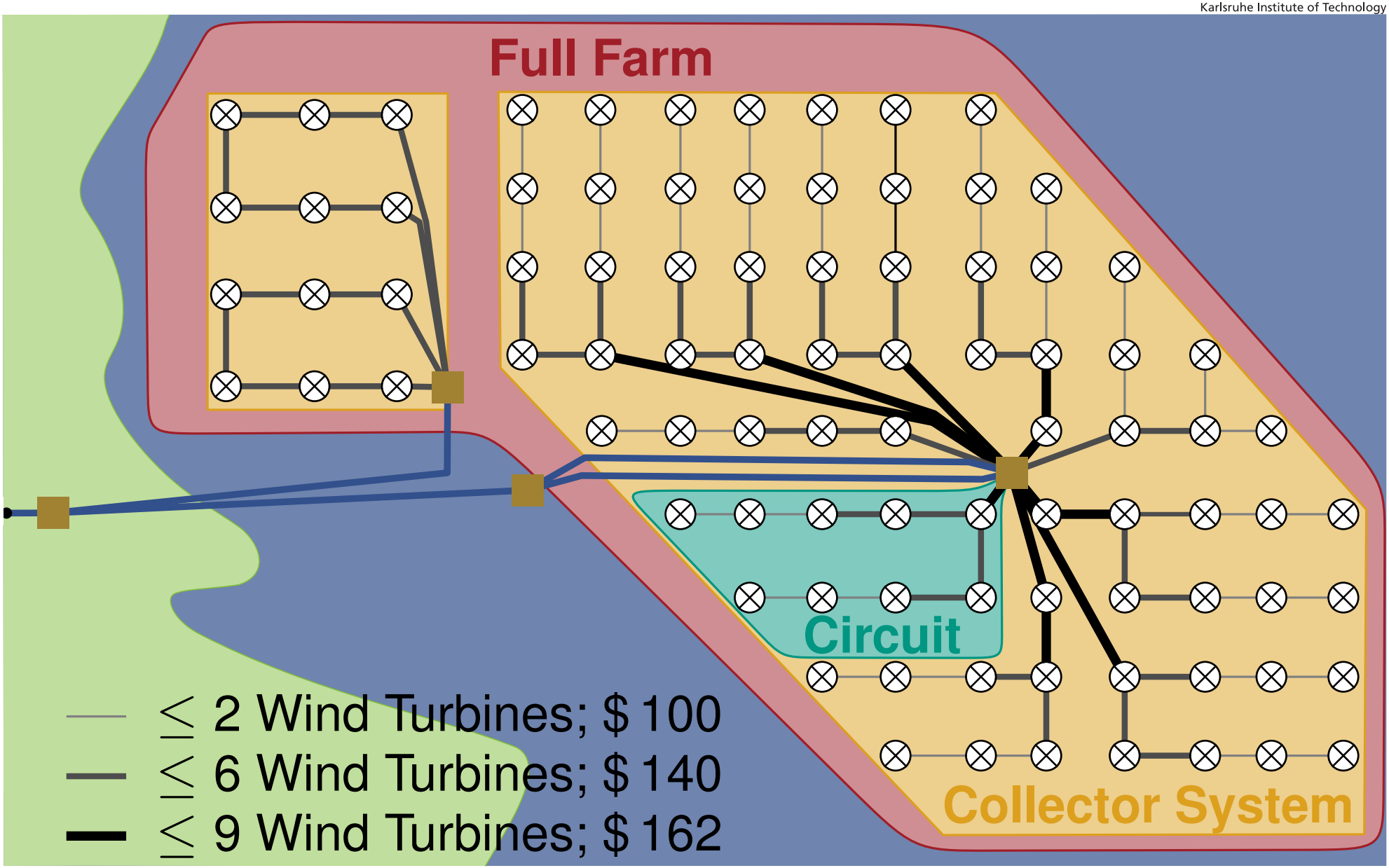
Wind Farm Cabling



Wind Farm Cabling



Wind Farm Cabling

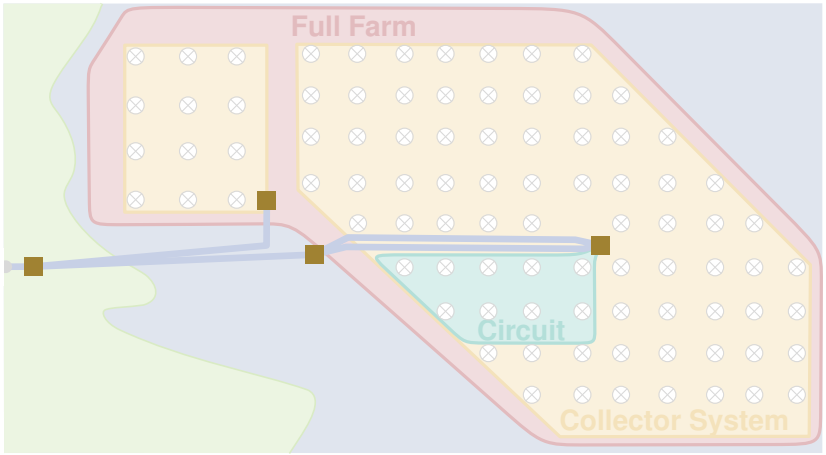


Sebastian Lehmann, Ignaz Rutter, Dorothea Wagner and Franziska Wegner – A Simulated-Annealing-Based Approach for Wind Farm Cabling

Institute of Theoretical Informatics
Algorithmics Group

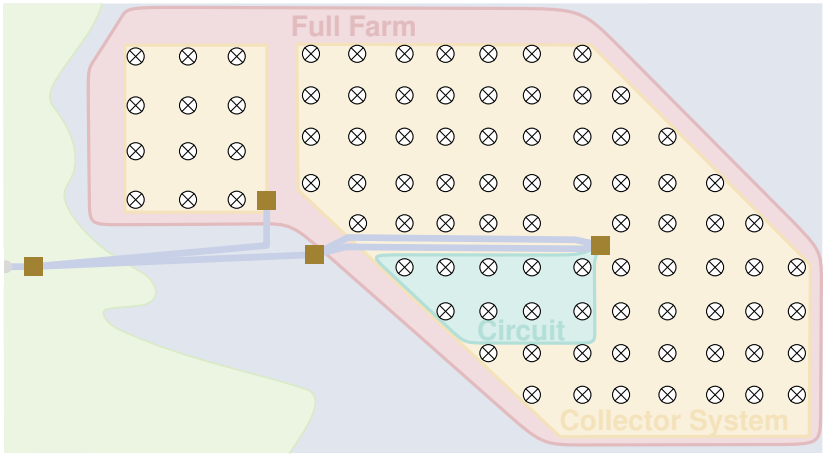
Wind Farm Cable Layout Problem

Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)



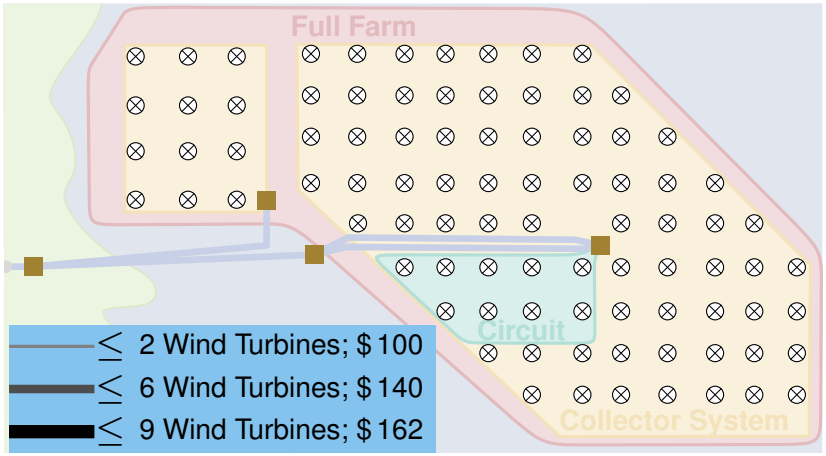
Wind Farm Cable Layout Problem

Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)



Wind Farm Cable Layout Problem

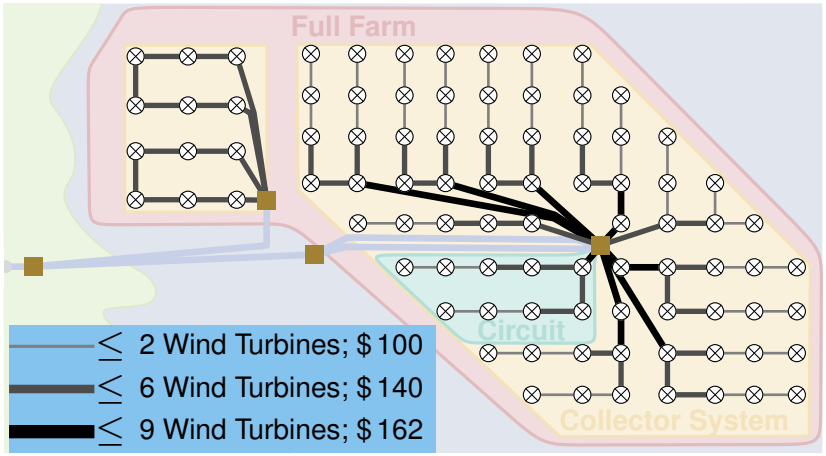
Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)



Wind Farm Cable Layout Problem

Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)

find for each edge: the **cable type**

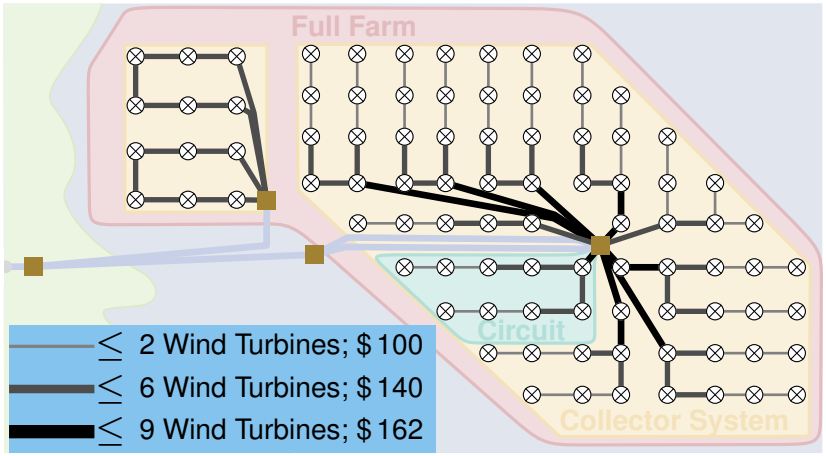


Wind Farm Cable Layout Problem

Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)

find for each edge: the **cable type**

minimizing **total cable cost**



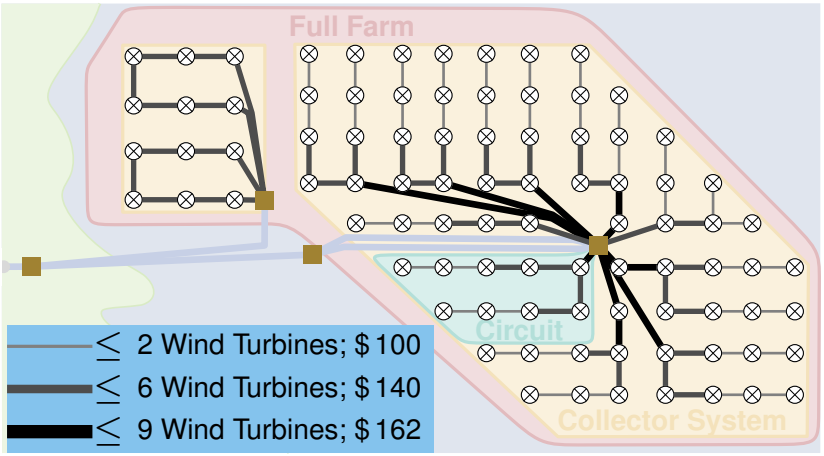
Wind Farm Cable Layout Problem

Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)

find for each edge: the **cable type**

minimizing **total cable cost**

subject to cable capacity constraints
substation capacity constraints
flow conservation constraints



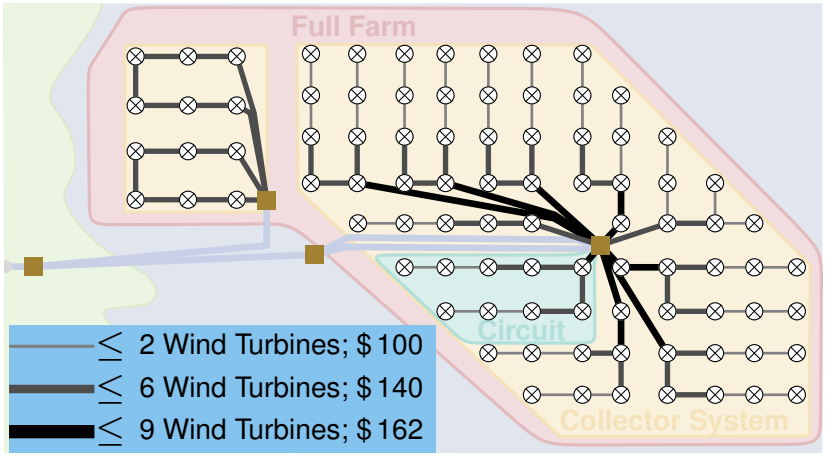
Wind Farm Cable Layout Problem

Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)

find for each edge: the **cable type**

minimizing **total cable cost**

subject to cable capacity constraints
substation capacity constraints
flow conservation constraints

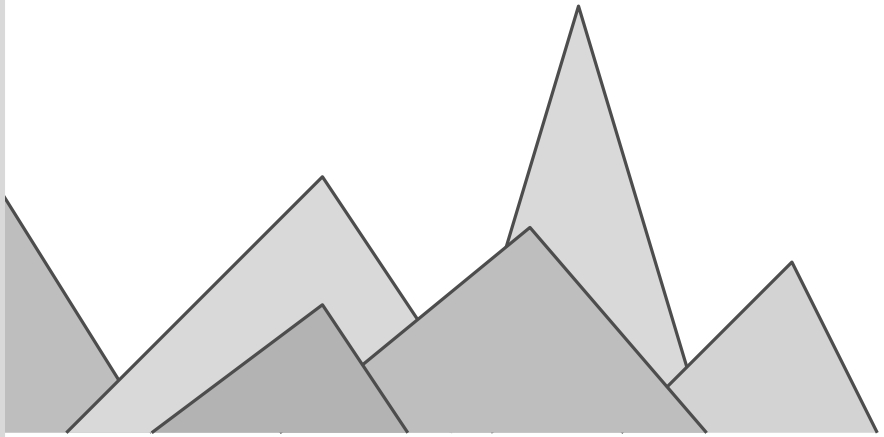


Wind farm planning problem $\Leftrightarrow$ Minimum cost flow problem
using **[Leibfried et al., 2015]**

$$\mathrm{OPT}(\mathcal{N}_{\mathrm{FFP}}) \leq \sum_{j \in V_S} \mathrm{OPT}(\mathcal{N}_{\mathrm{SP}}(j)) \leq \sum_{j \in V_S} \sum_{i \in \mathbb{N}} \mathrm{OPT}(\mathcal{N}_{\mathrm{CP}}(j, i))$$

Simulated Annealing

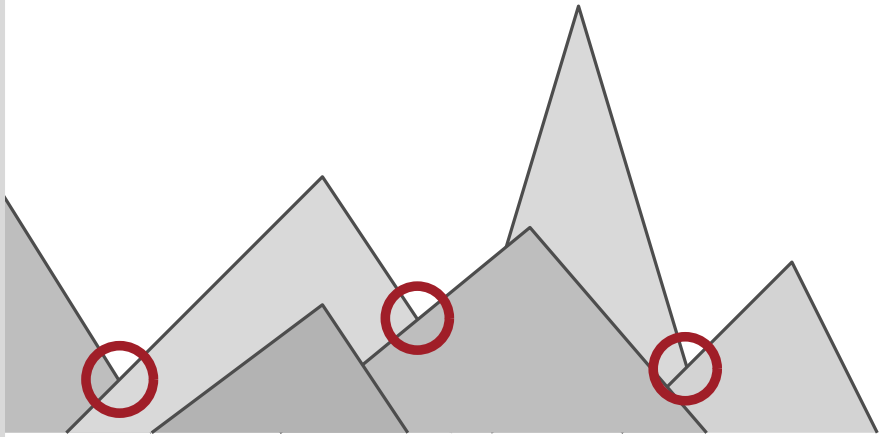
Metropolis Algorithm



Cooling Schedule

Simulated Annealing

Metropolis Algorithm

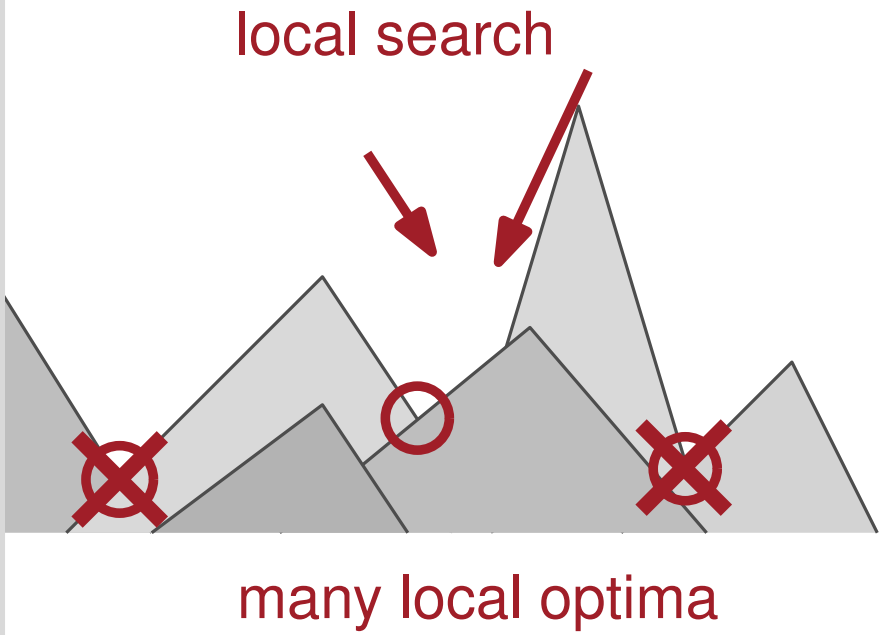


many local optima

Cooling Schedule

Simulated Annealing

Metropolis Algorithm

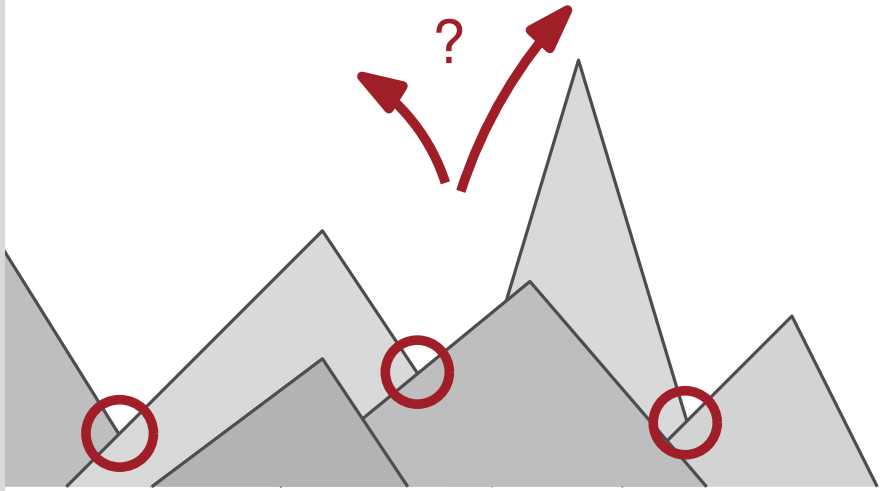


Cooling Schedule

Simulated Annealing

Metropolis Algorithm

escape local optimum

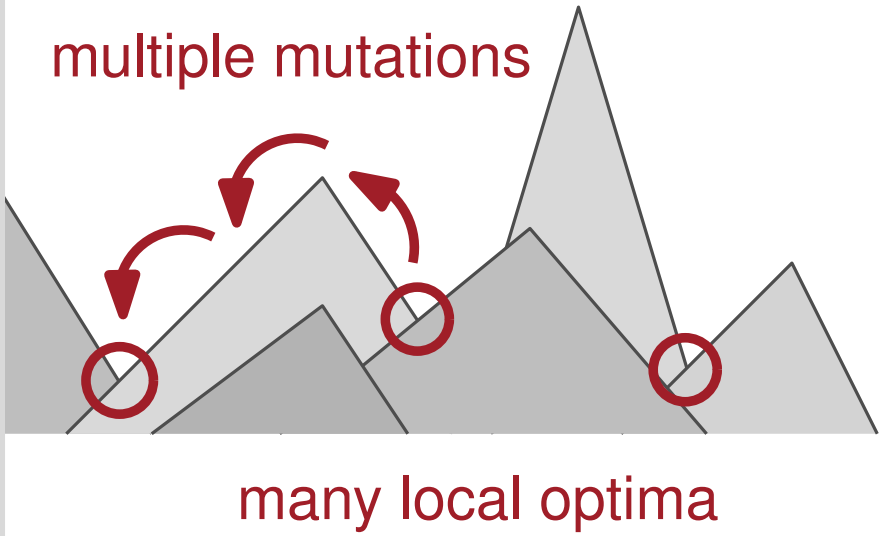


many local optima

Cooling Schedule

Simulated Annealing

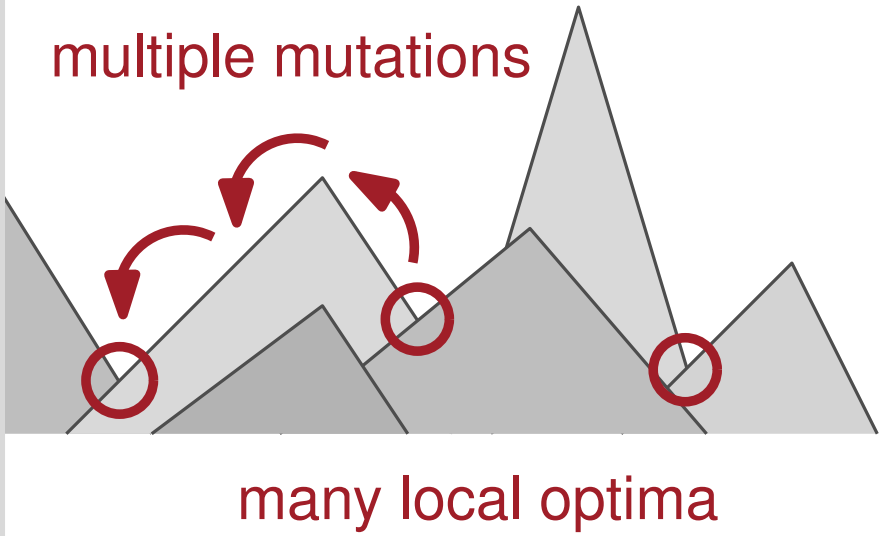
Metropolis Algorithm



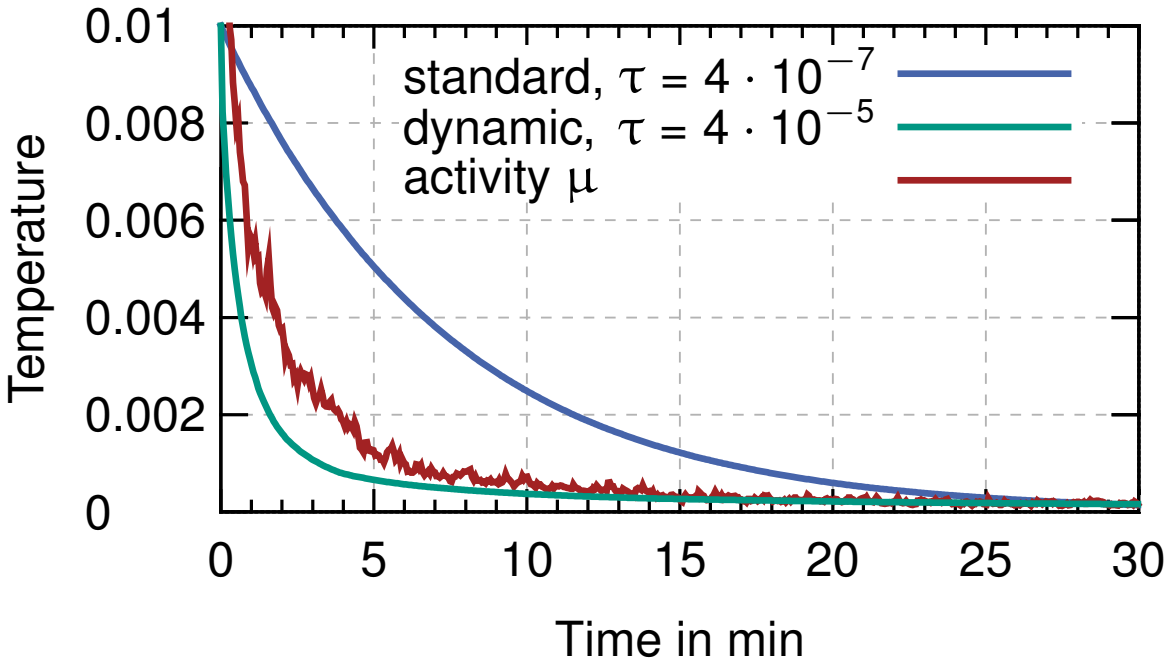
Cooling Schedule

Simulated Annealing

Metropolis Algorithm

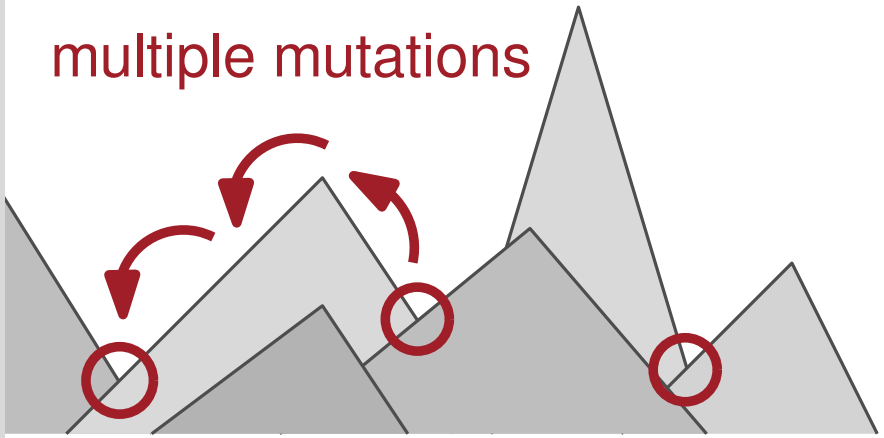


Cooling Schedule



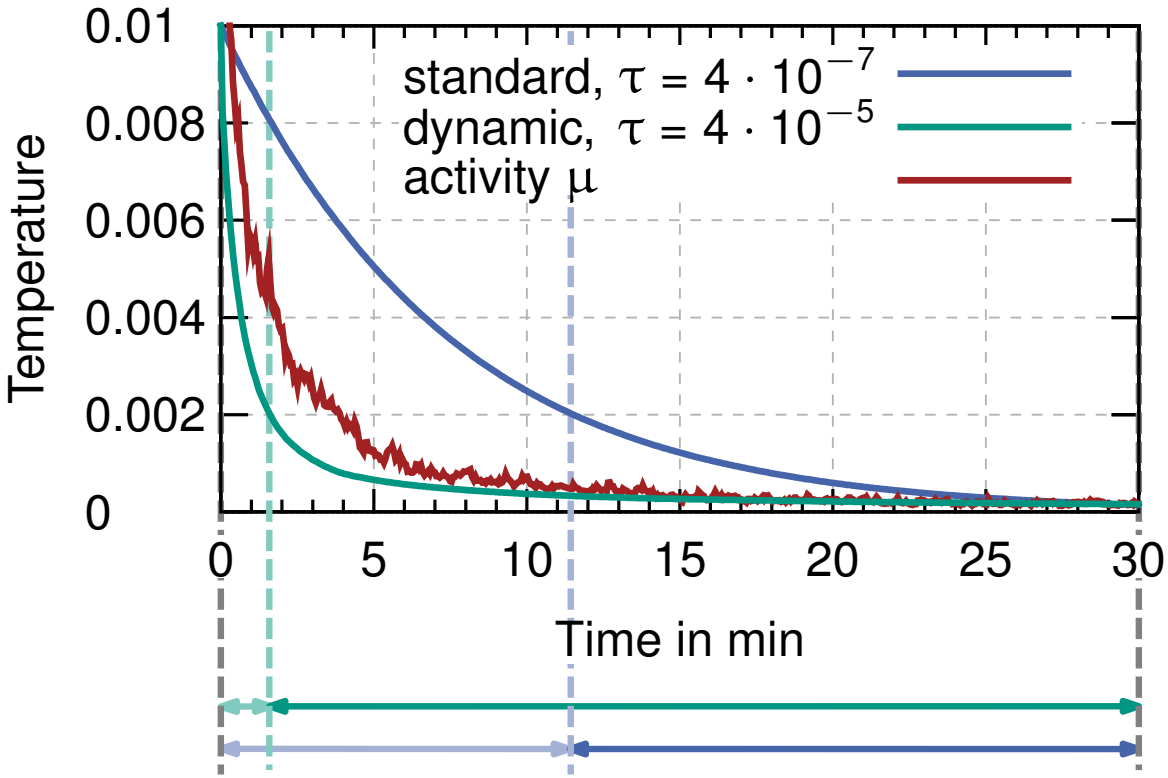
Simulated Annealing

Metropolis Algorithm



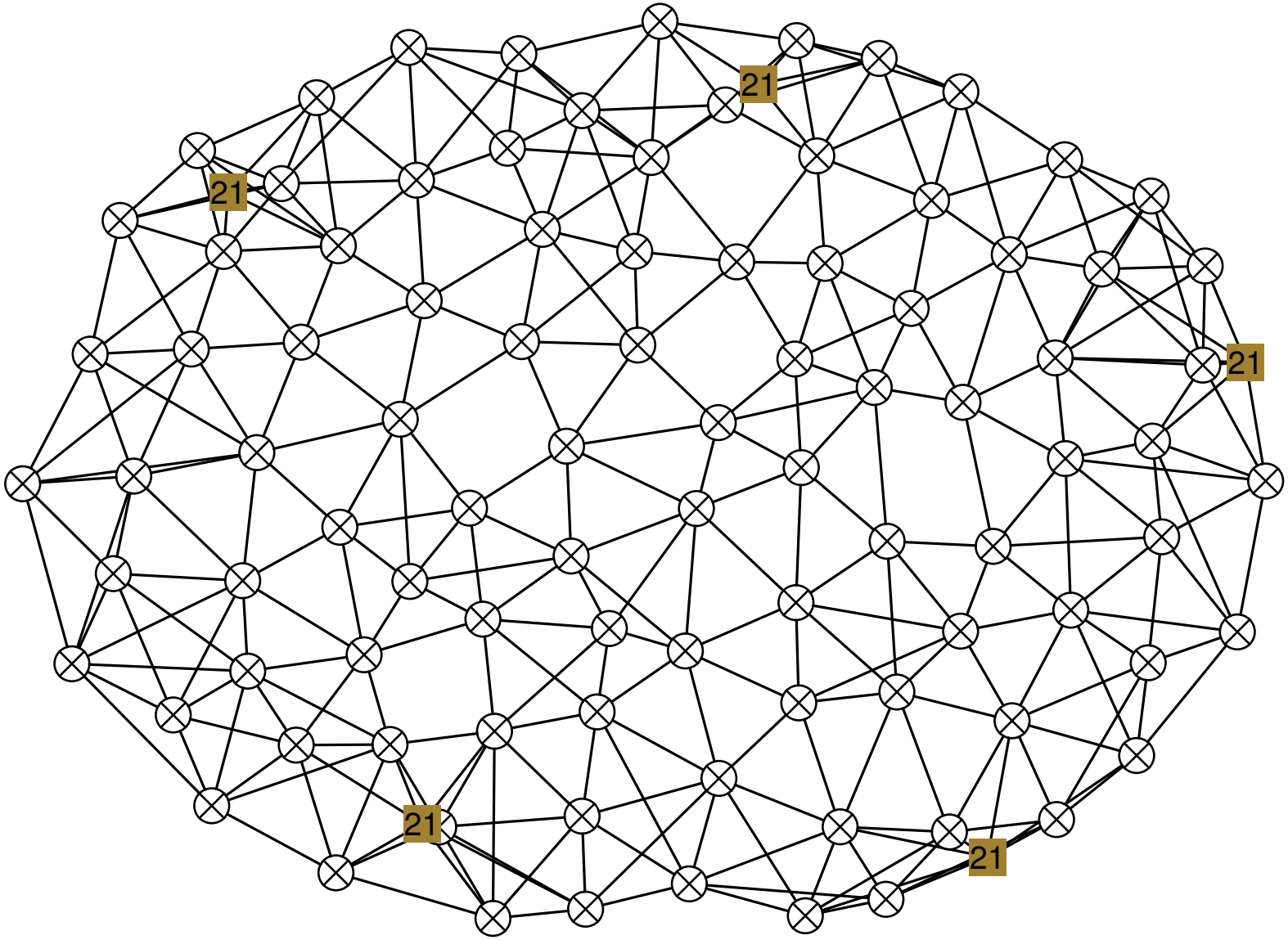
Diversification

Cooling Schedule

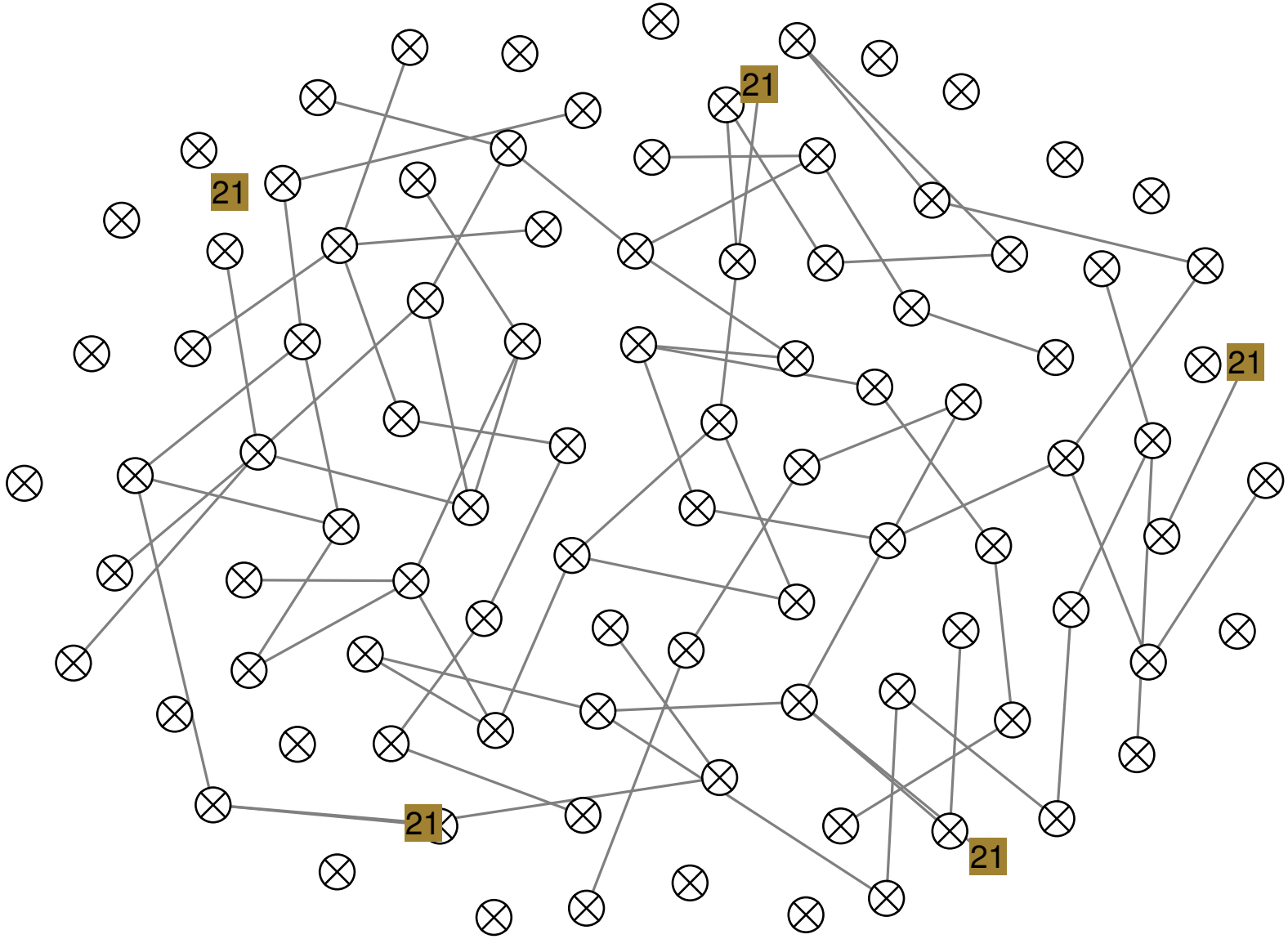


Diversification Intensification

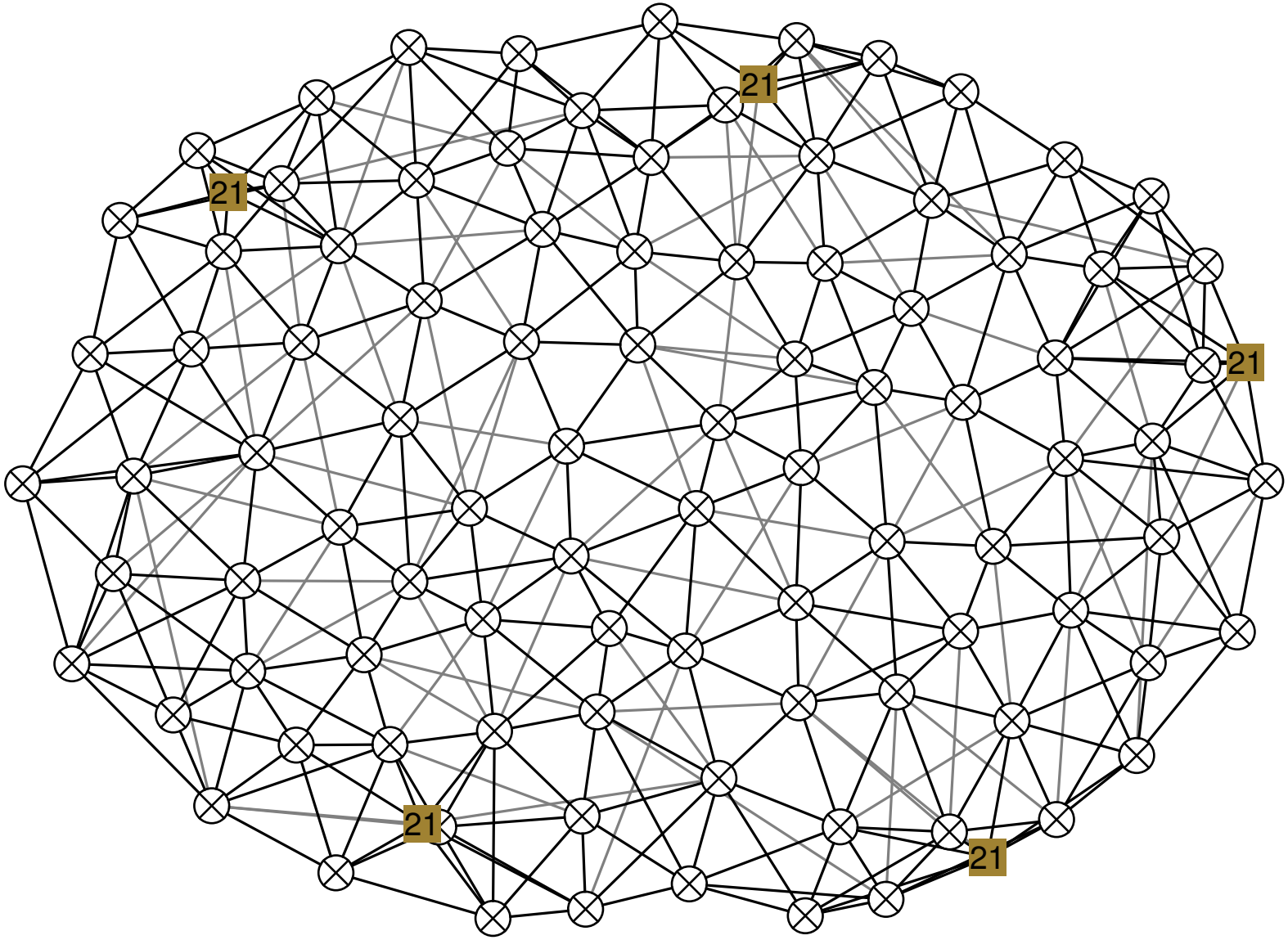
Benchmark Sets



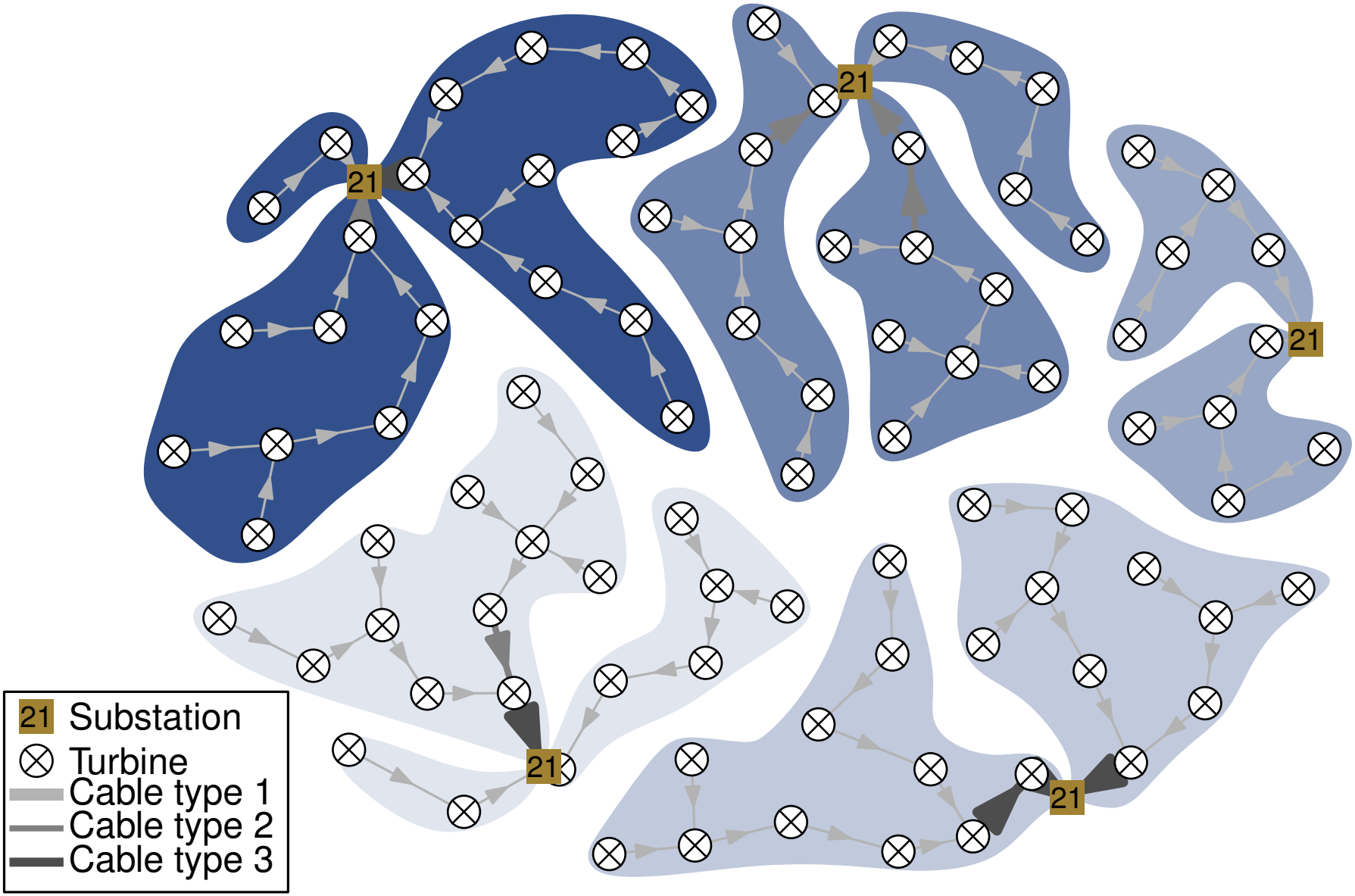
Benchmark Sets



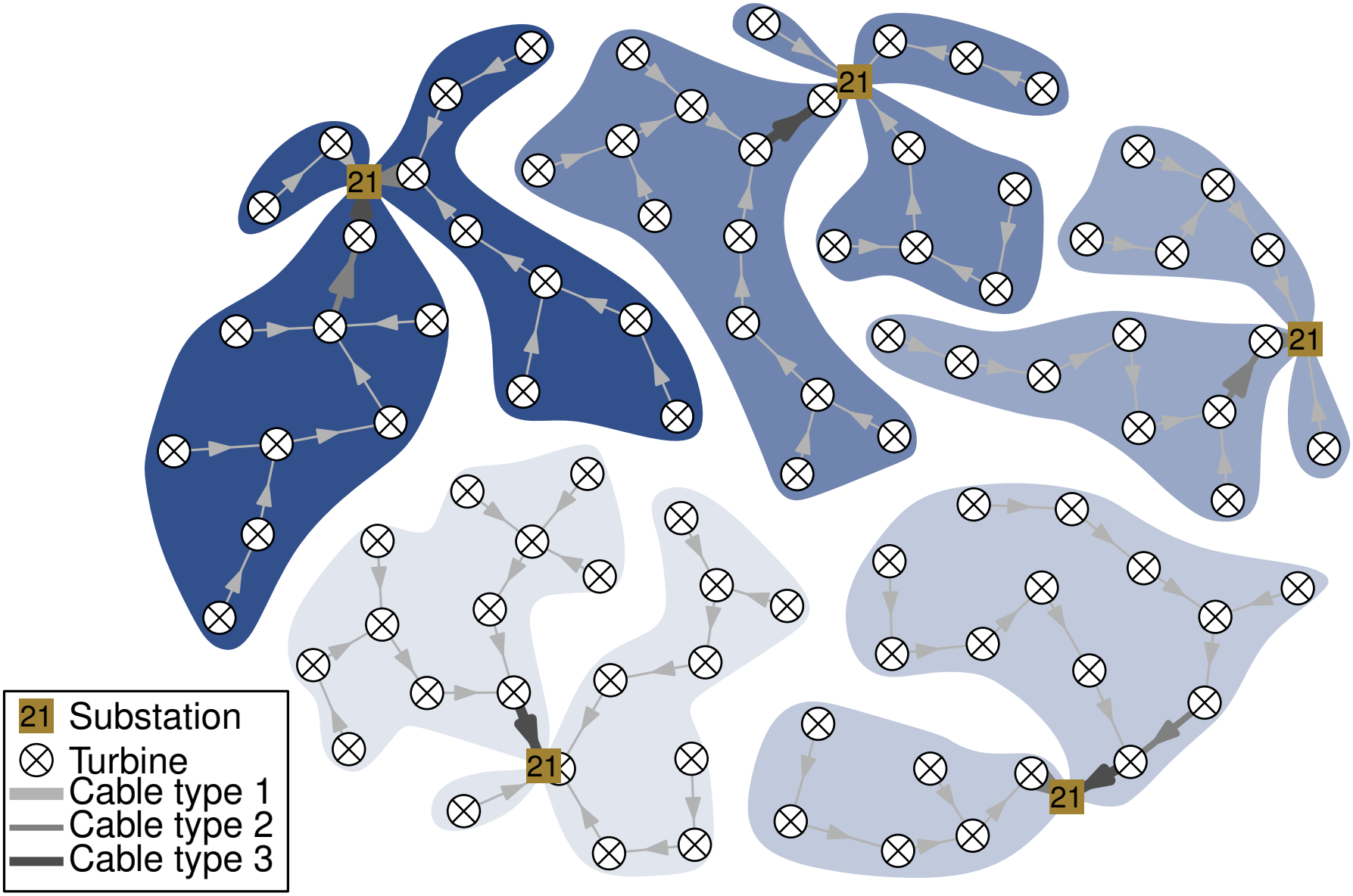
Benchmark Sets



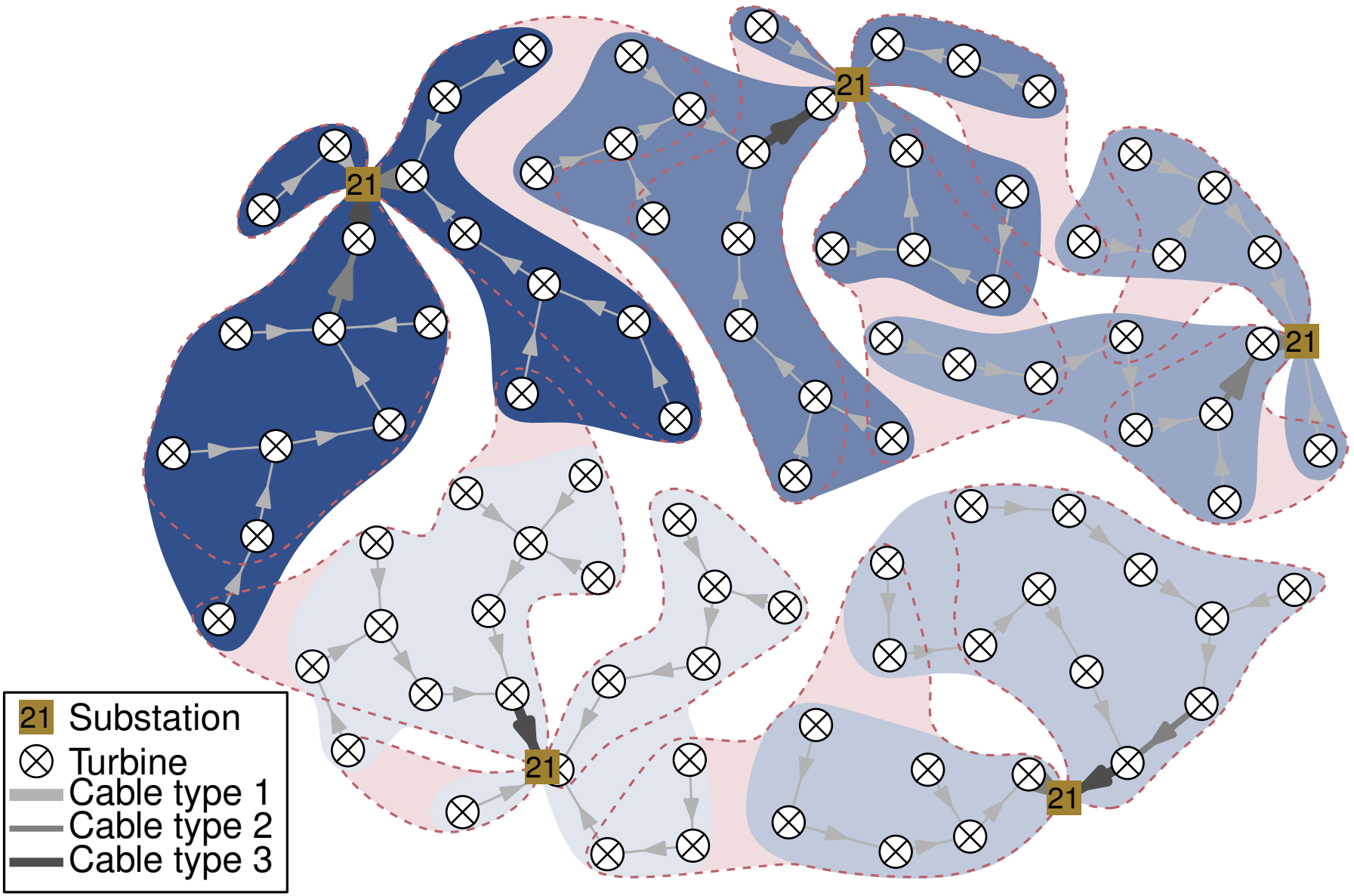
Benchmark Sets



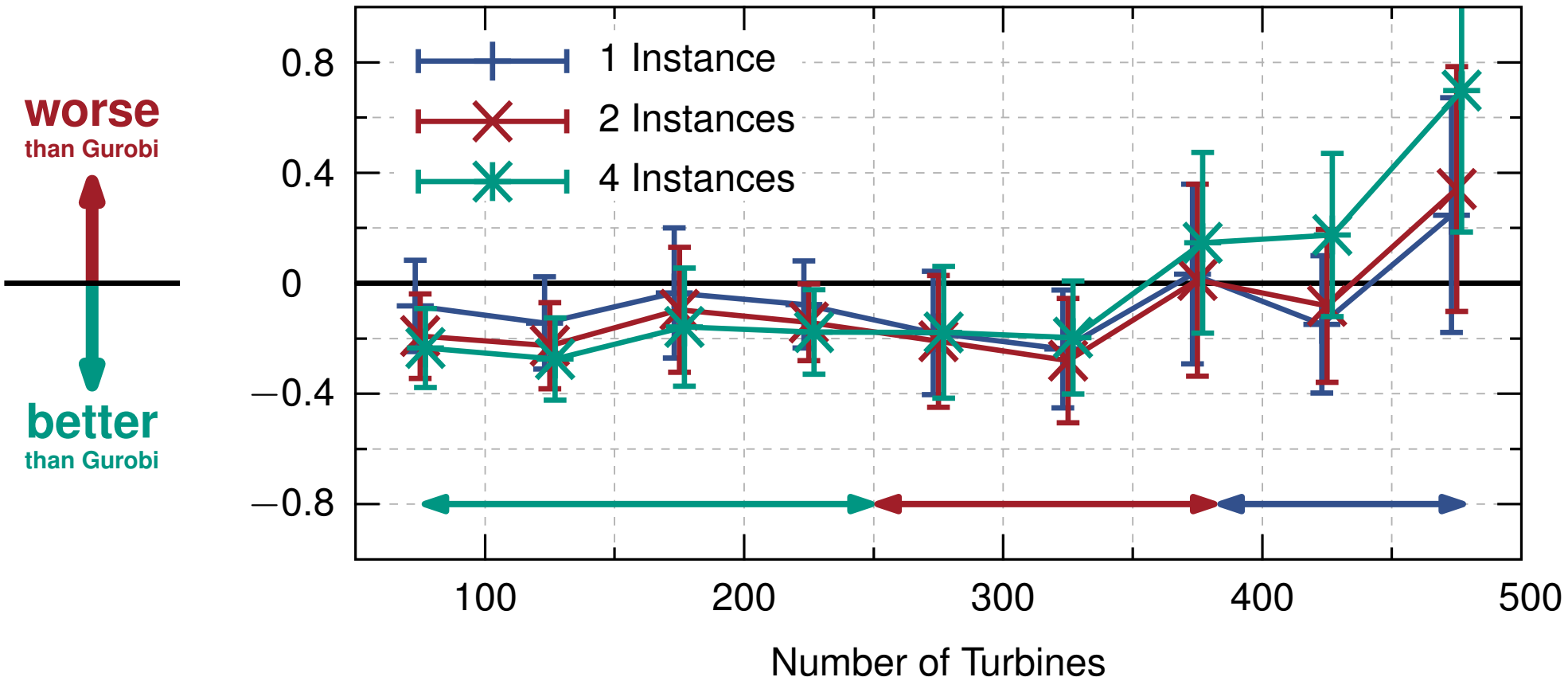
Benchmark Sets



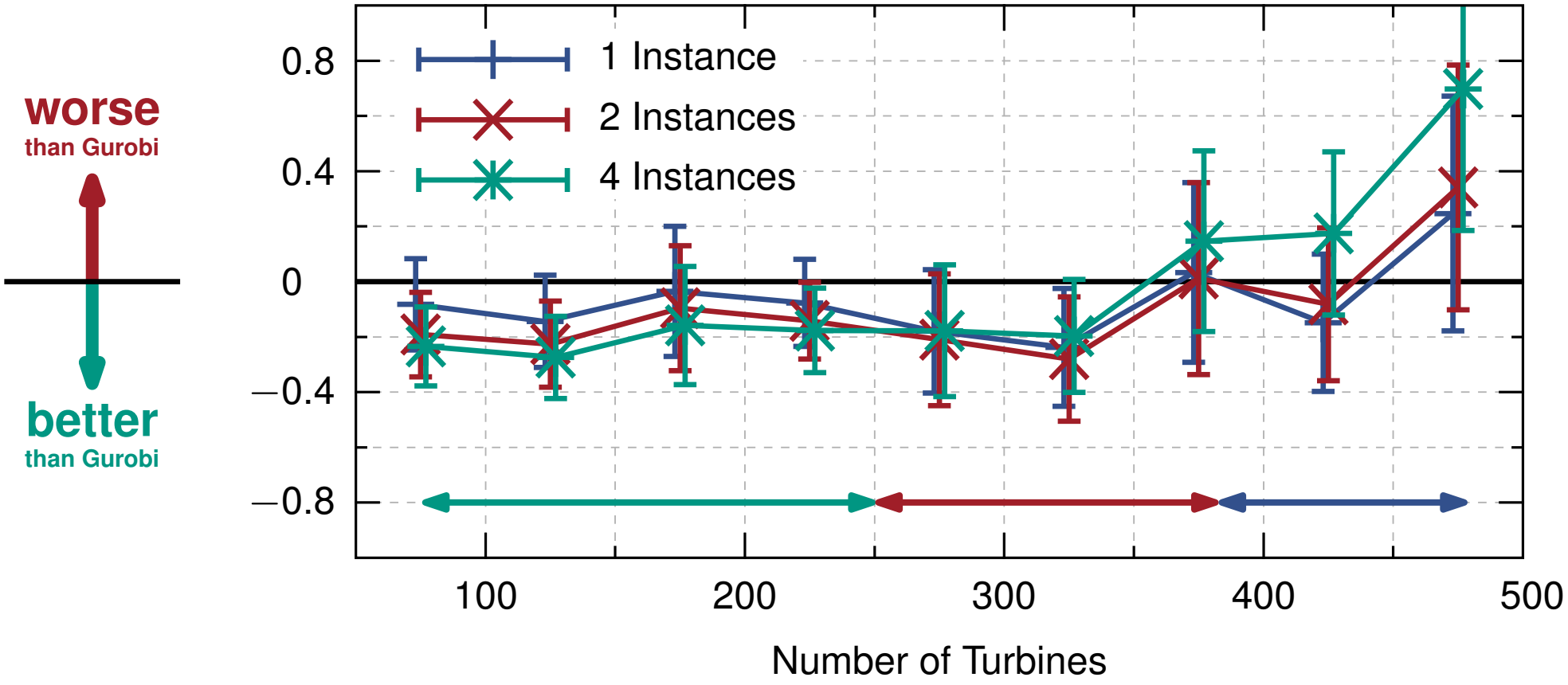
Benchmark Sets



Multiple Instances of Simulated Annealing

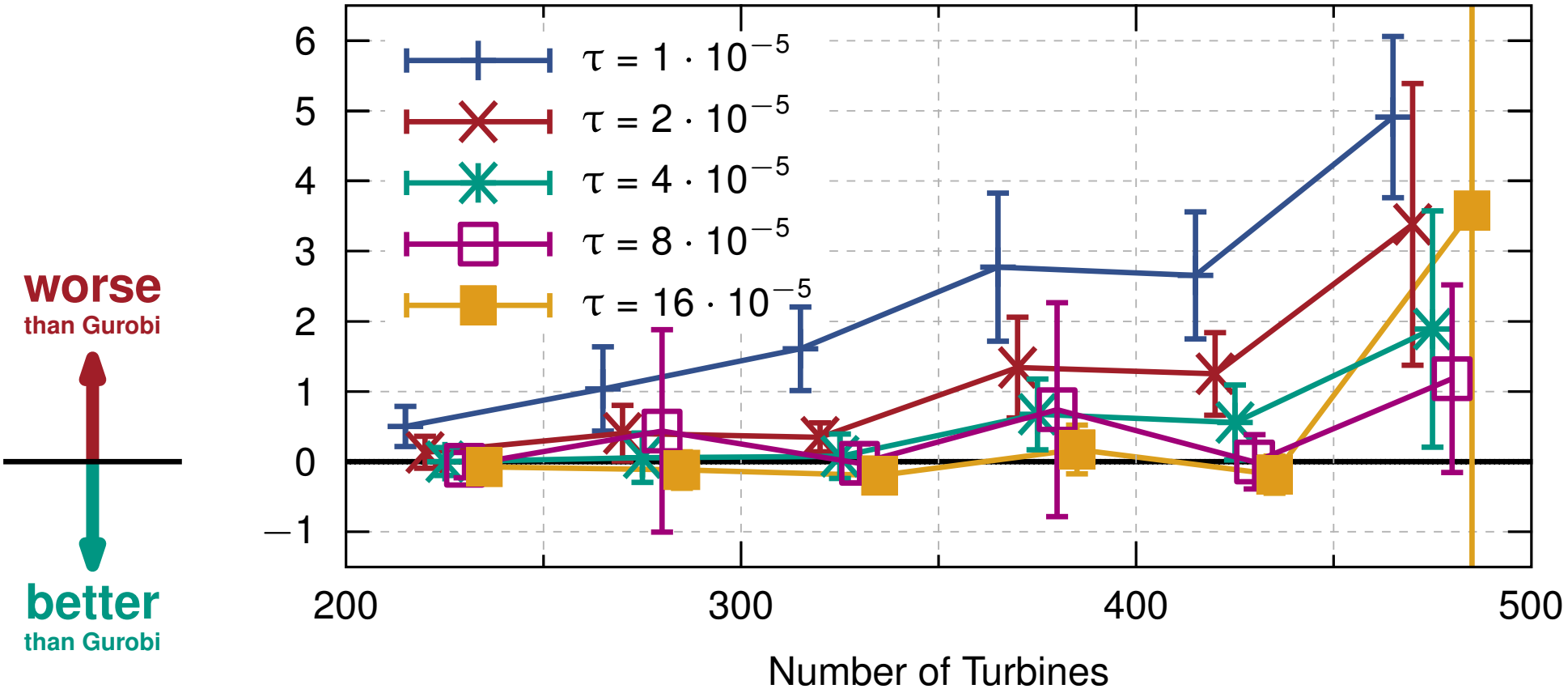


Multiple Instances of Simulated Annealing

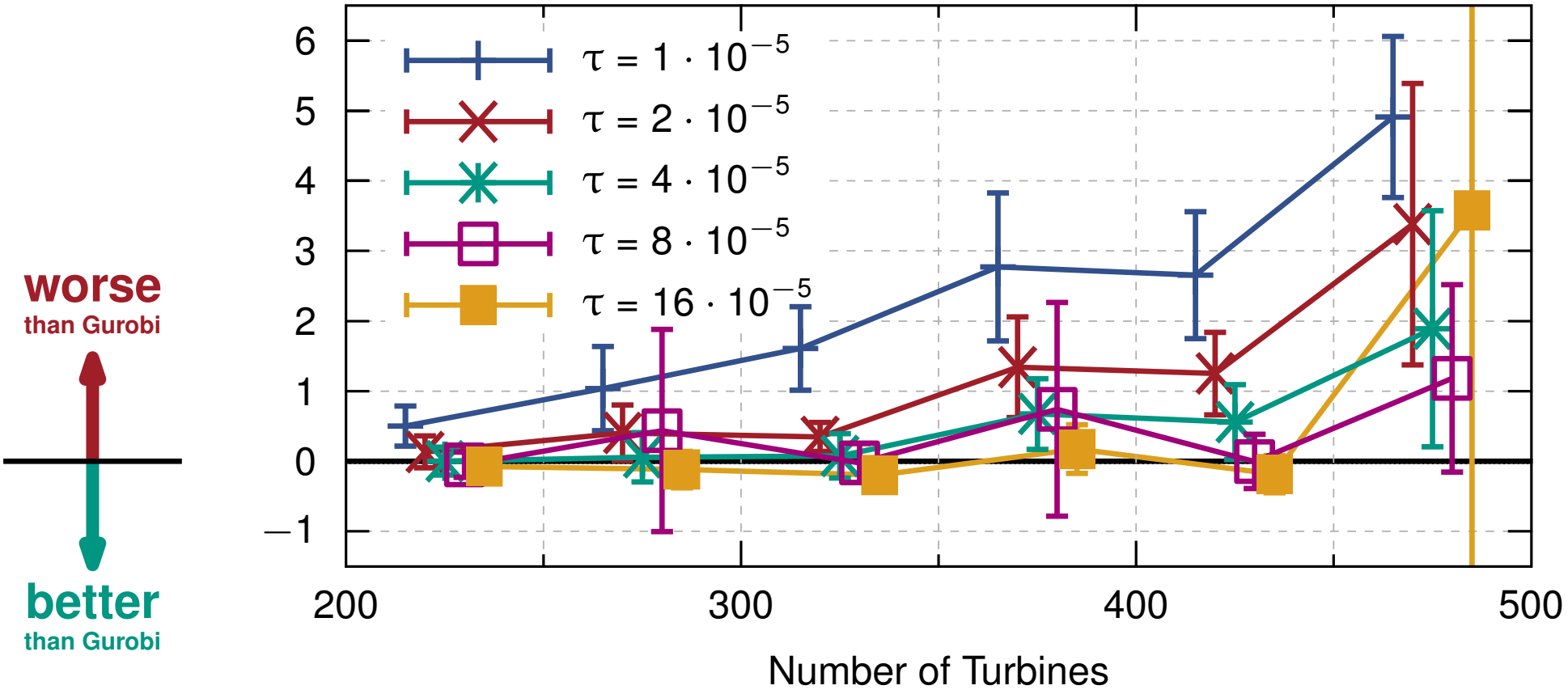


Results depend on a **random seed**.
Multiple instances reduce the overall computation time. This causes a reduced time spend for the intensification phase.

Performance Influence of the Thermal Conductivity and Capacity τ

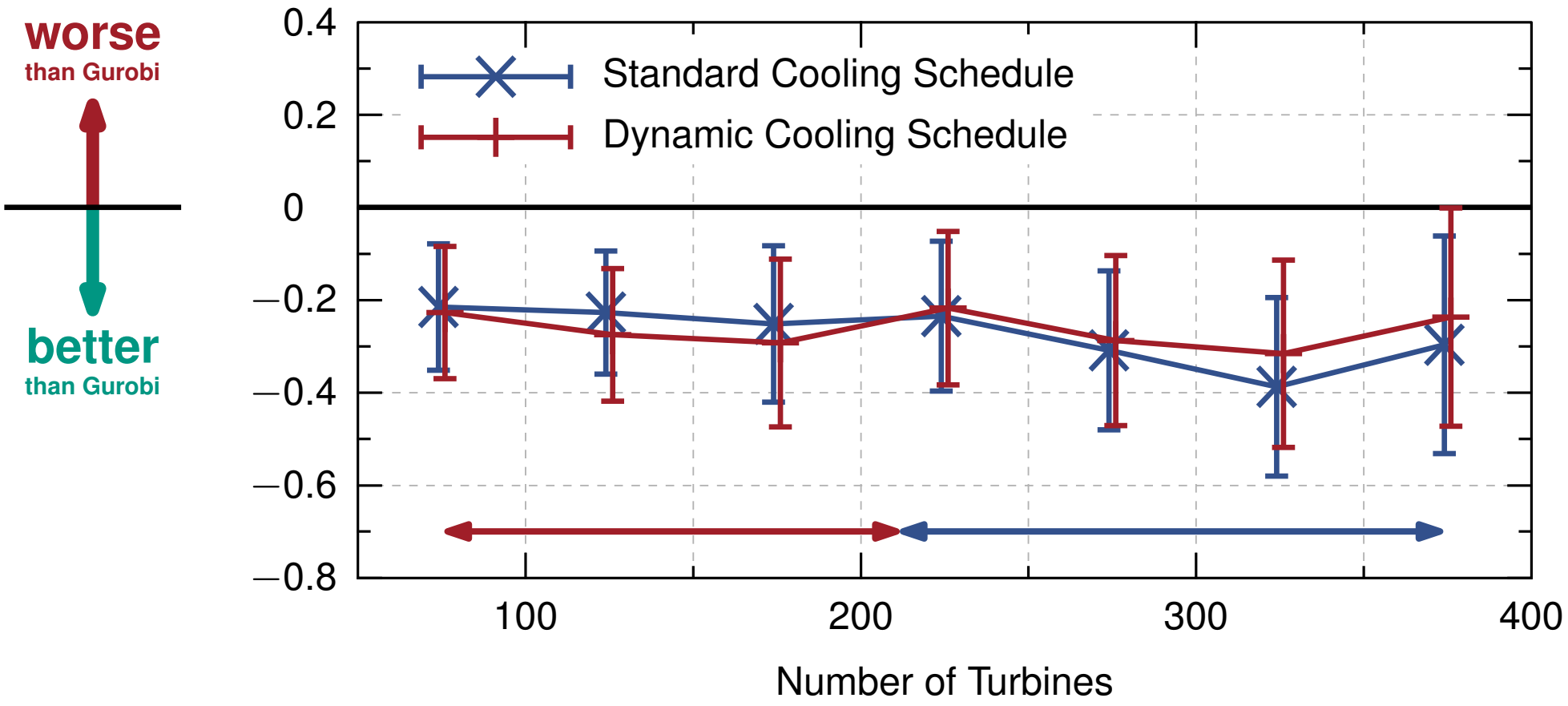


Performance Influence of the Thermal Conductivity and Capacity τ

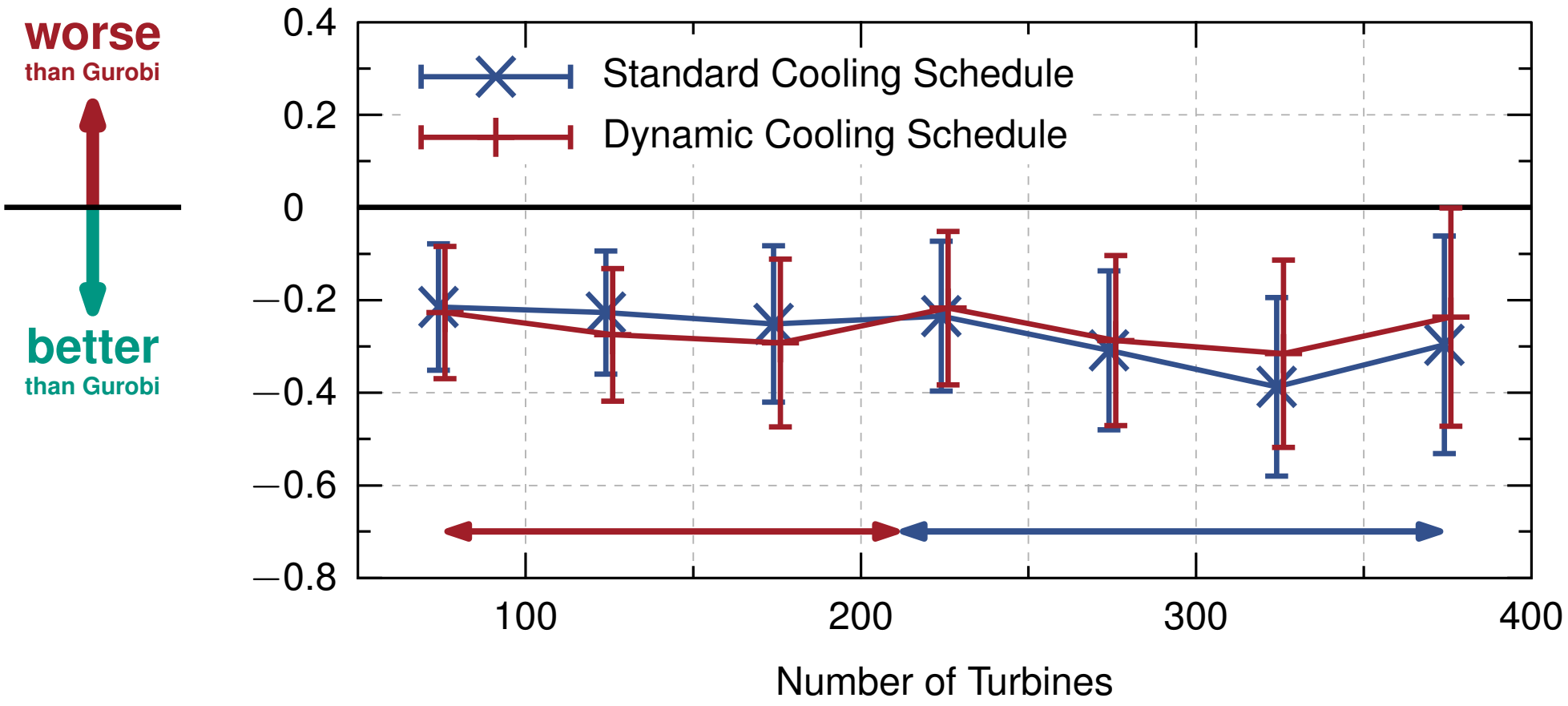


Parameter tuning is difficult for the cooling schedule.

Cooling Schedule Performance

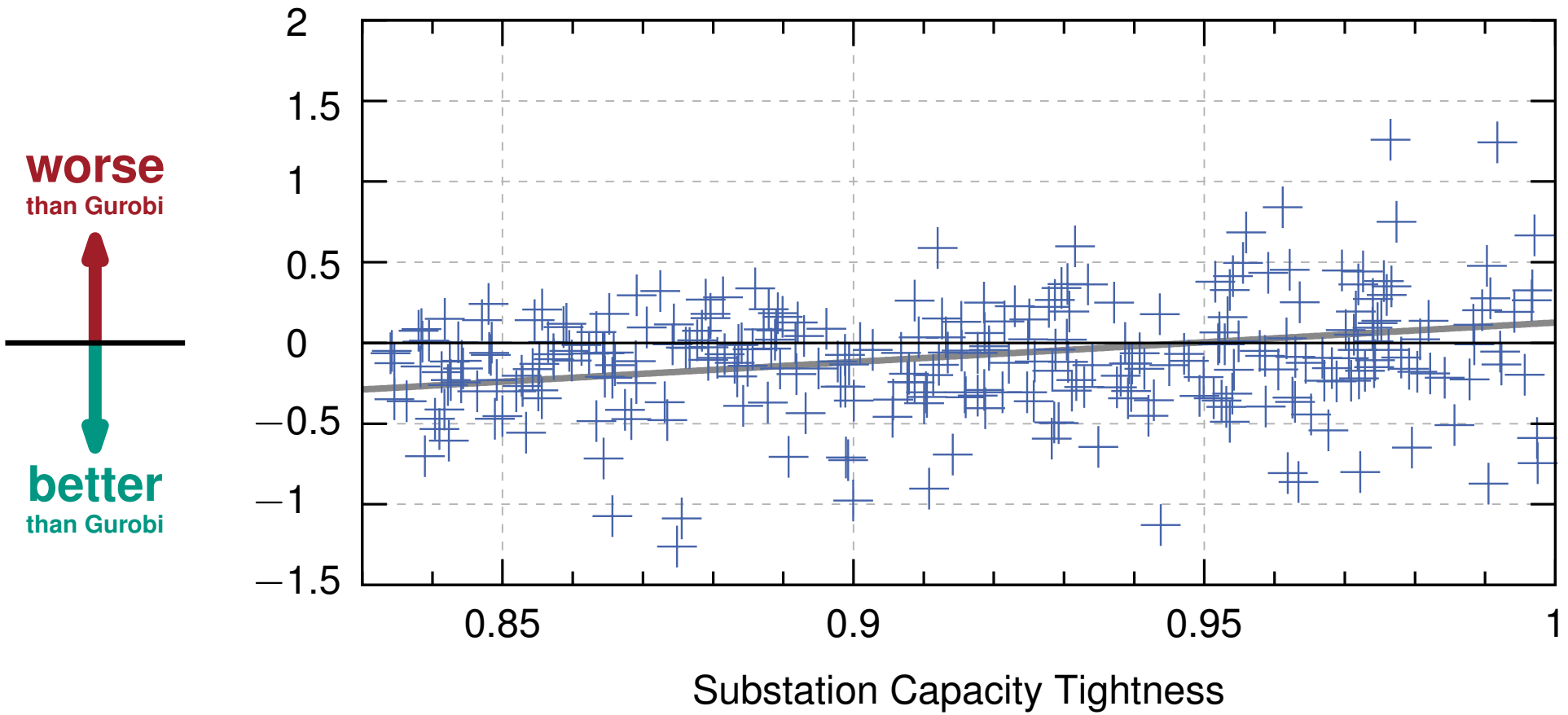


Cooling Schedule Performance

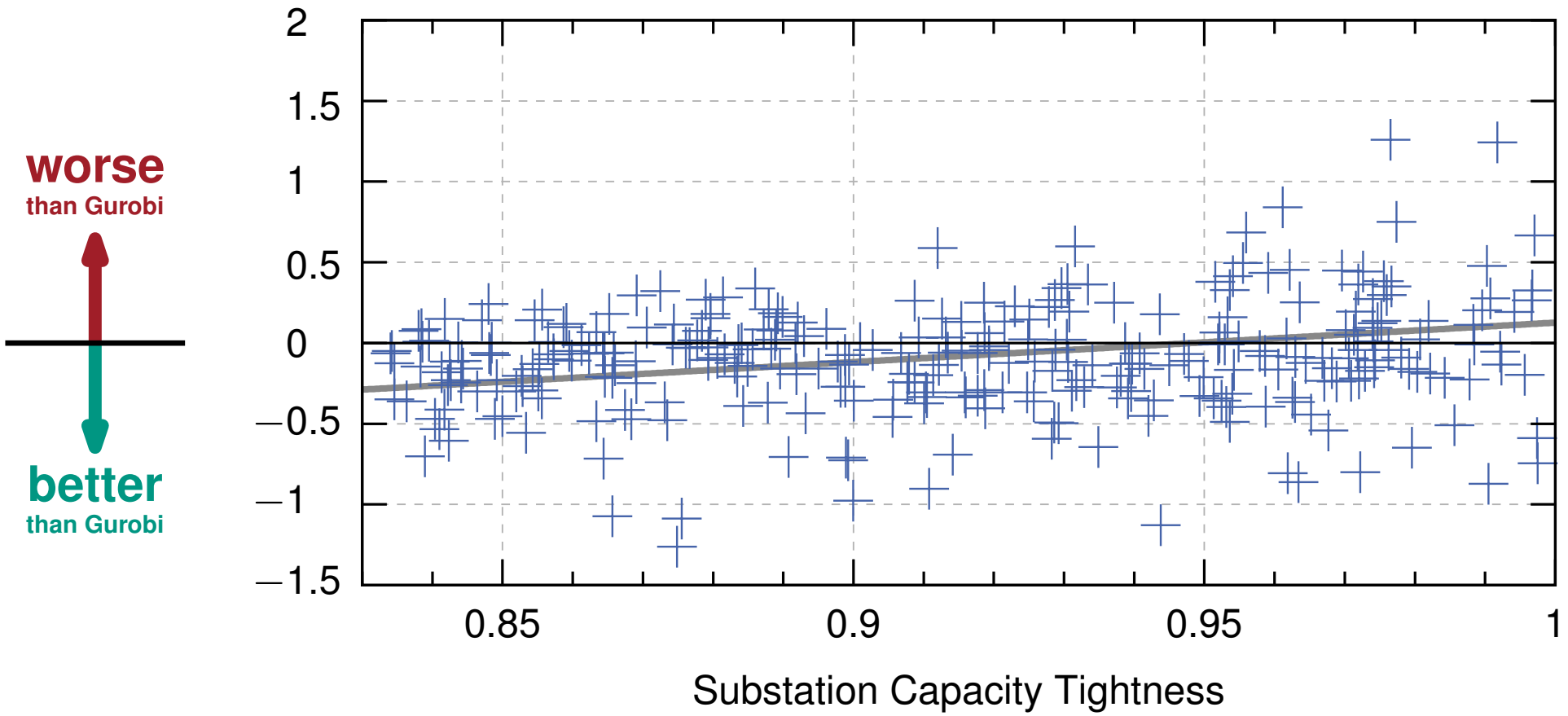


The **dynamic** outperorms the **standard** one without parameter tuning.
Parameter tuning improve the standard one for larger instances.

Performance Influence of the Substation Capacity Tightness



Performance Influence of the Substation Capacity Tightness



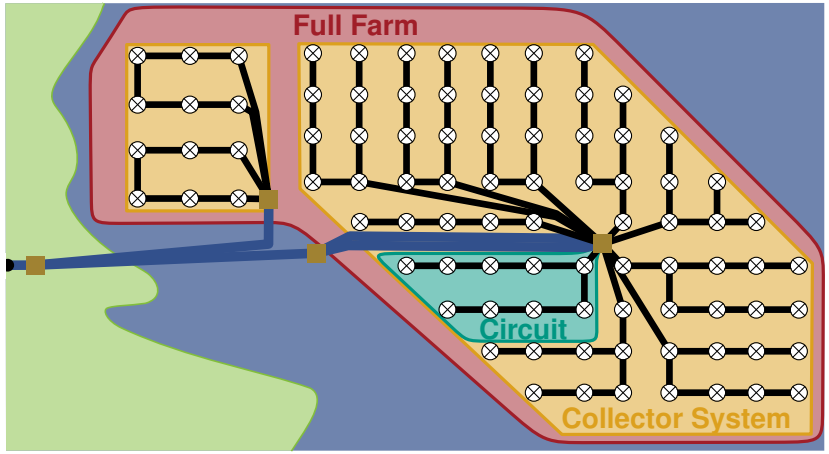
The **tighter** the substation capacity or the **more** substations the harder the instance is to solve. Thus, the solution quality reduces with same duration.

Conclusion & Future Work

Karlsruhe Institute of Technology

Circuit Problem
Substation Problem
Full Farm Problem

Conclusion & Future Work

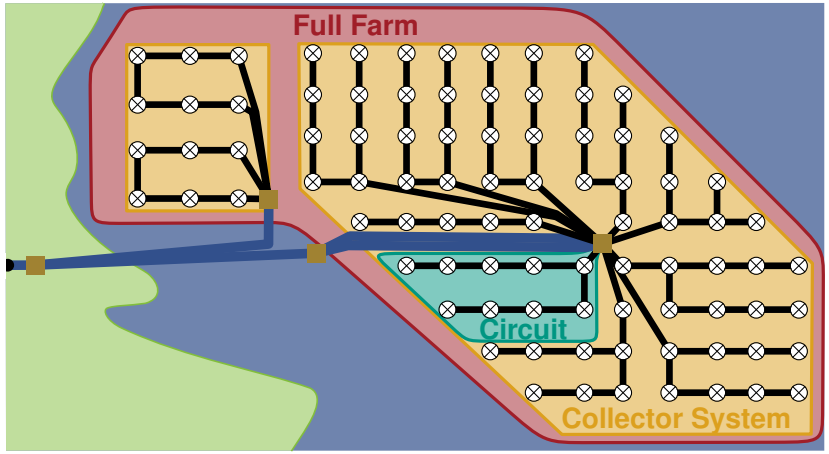


Circuit Problem

Substation Problem

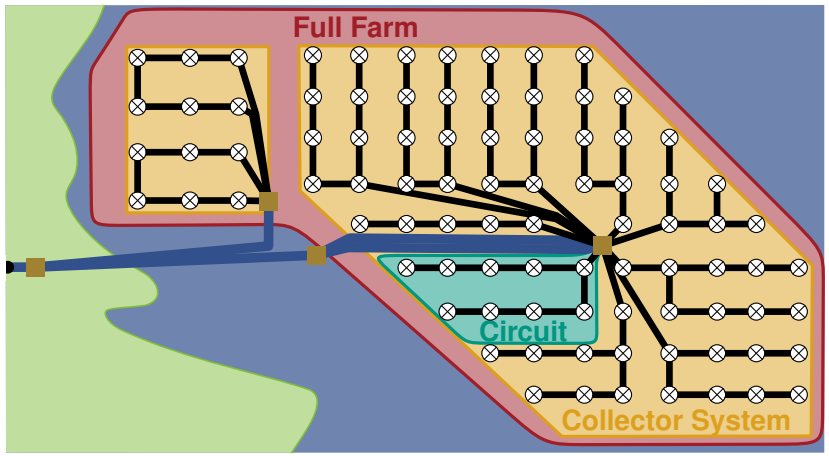
Full Farm Problem

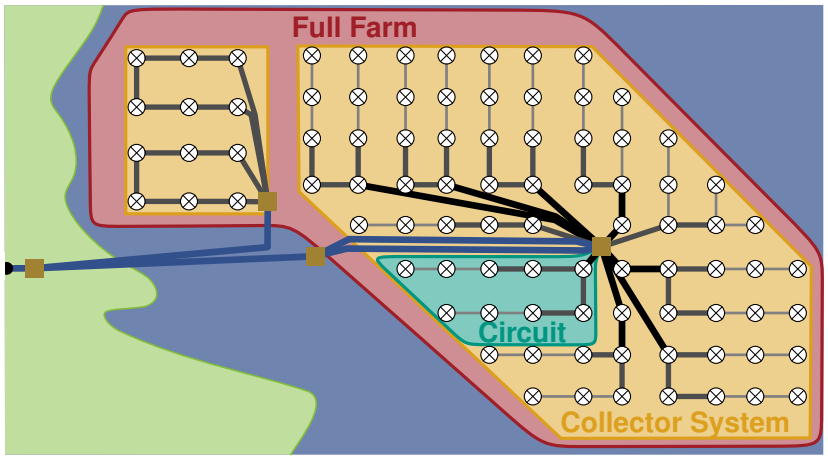
Conclusion & Future Work



P (MST)	Circuit Problem
NP-hard (CMST)	Substation Problem
NP-hard (Heuristics)	Full Farm Problem

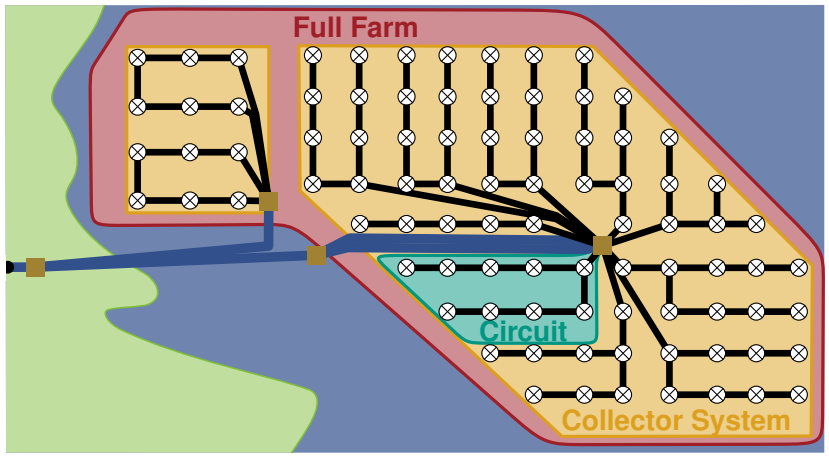
Conclusion & Future Work

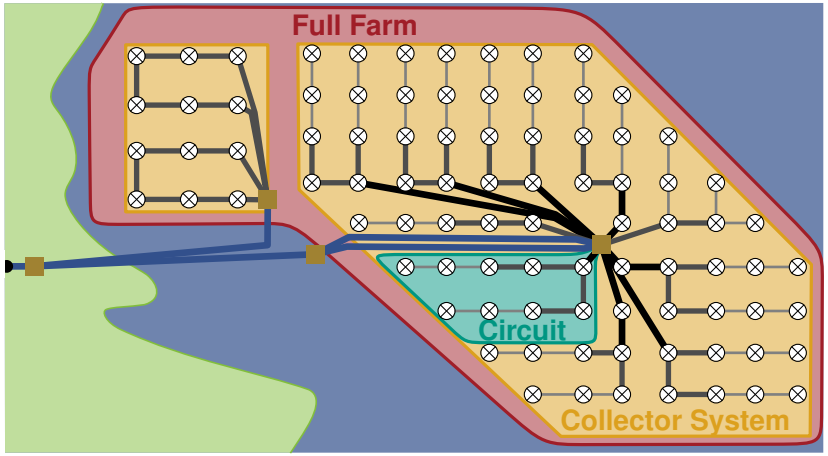




P (MST)	Circuit Problem
NP-hard (CMST)	Substation Problem
NP-hard (Heuristics)	Full Farm Problem

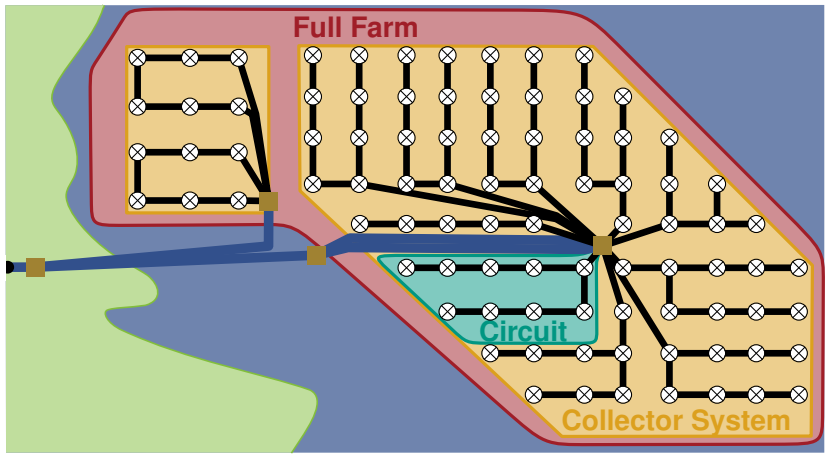
Conclusion & Future Work

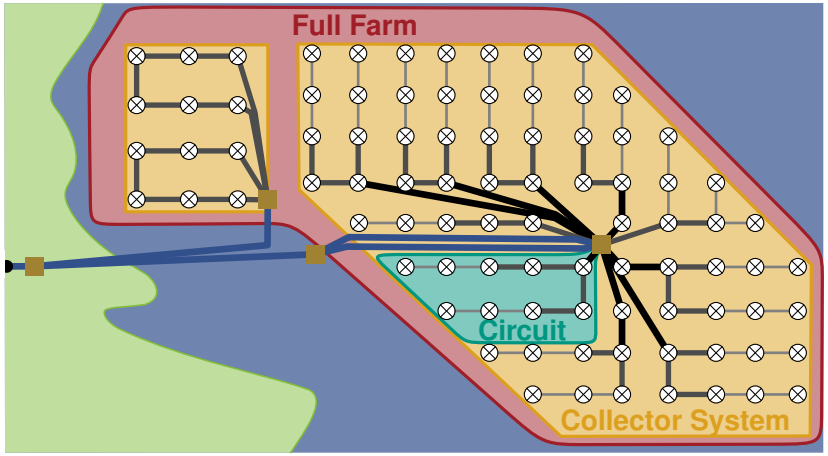




P (MST)	Circuit Problem	NP-hard
NP-hard (CMST)	Substation Problem	NP-hard
NP-hard (Heuristics)	Full Farm Problem	NP-hard

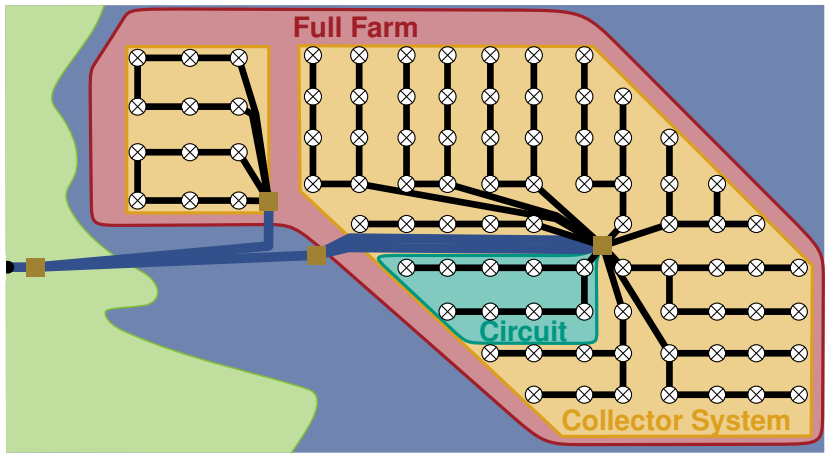
Conclusion & Future Work

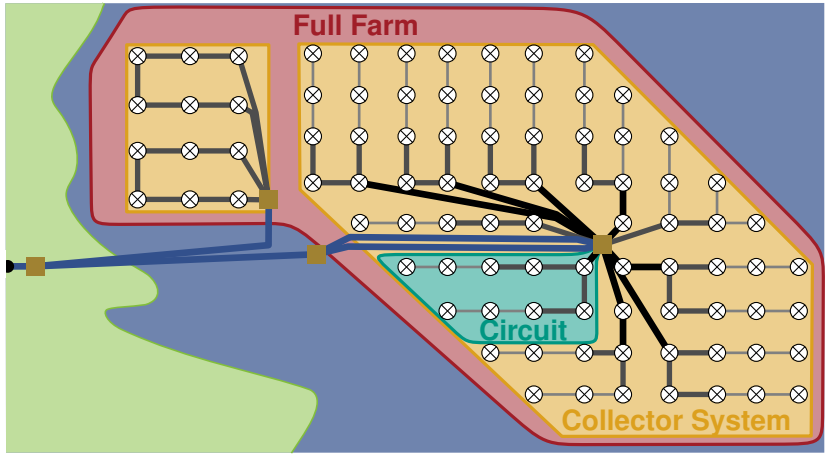




P (MST)	Circuit Problem	NP-hard (Clustering)
NP-hard (CMST)	Substation Problem	NP-hard
NP-hard (Heuristics)	Full Farm Problem	NP-hard

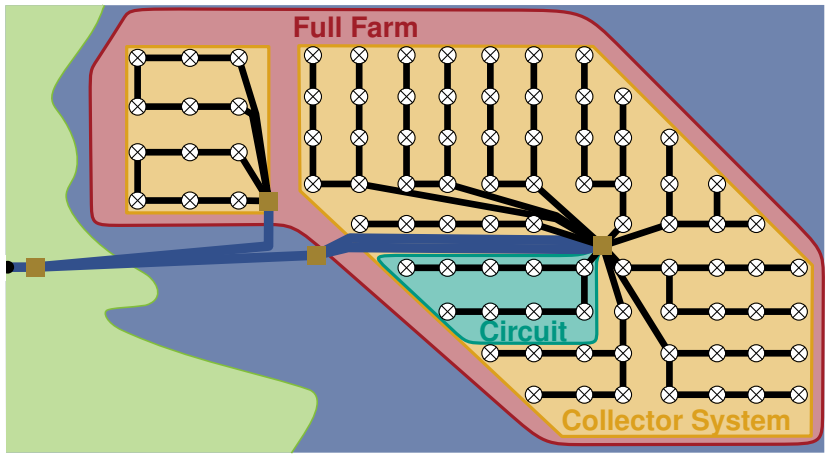
Conclusion & Future Work

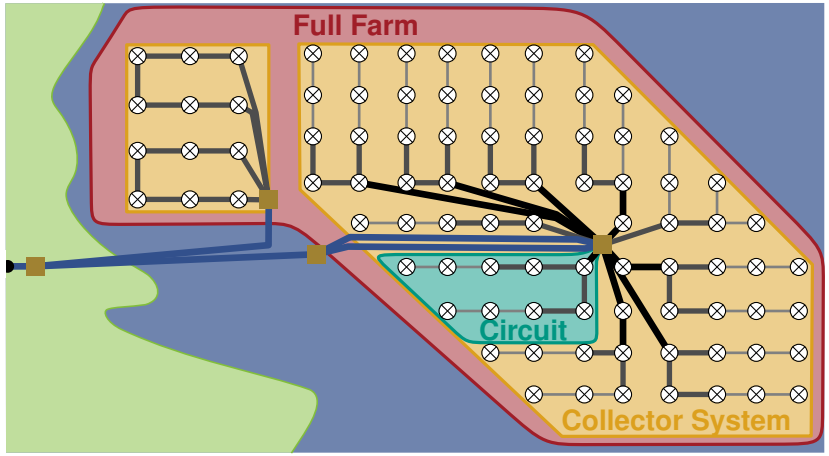




P (MST)	Circuit Problem	NP-hard (Clustering)	Simulated Annealing
NP-hard (CMST)	Substation Problem	NP-hard	
NP-hard (Heuristics)	Full Farm Problem	NP-hard	

Conclusion & Future Work

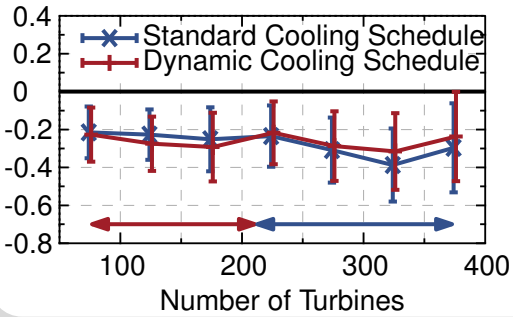


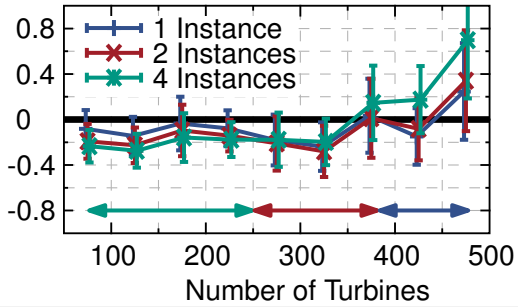


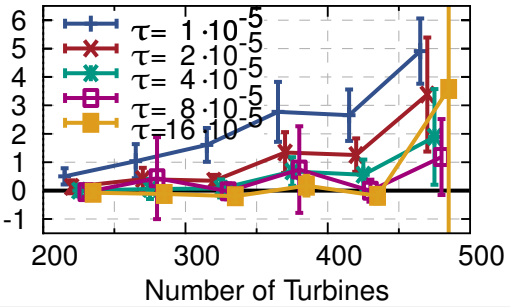
P (MST)	Circuit Problem	NP-hard (Clustering)
NP-hard (CMST)	Substation Problem	NP-hard
NP-hard (Heuristics)	Full Farm Problem	NP-hard

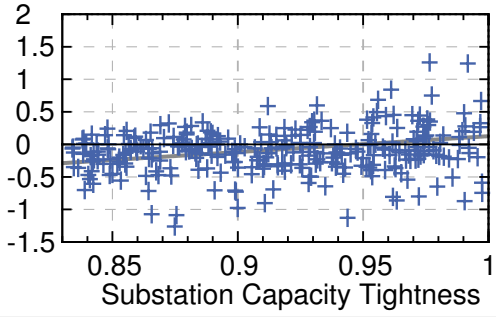
Simulated Annealing

Results

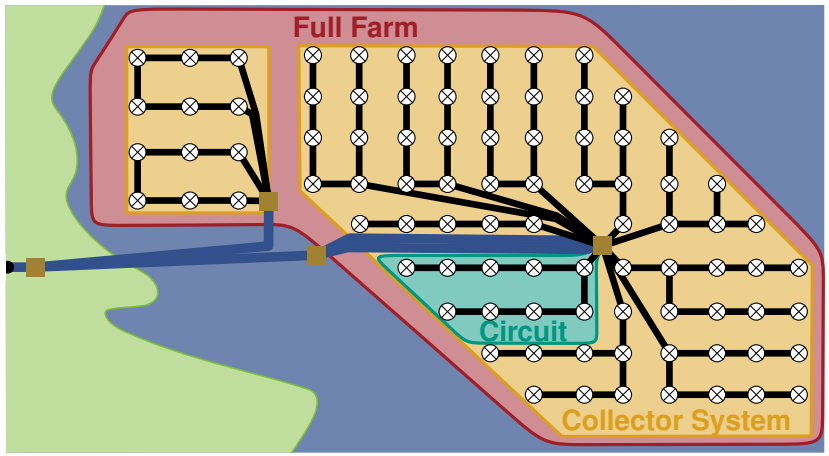


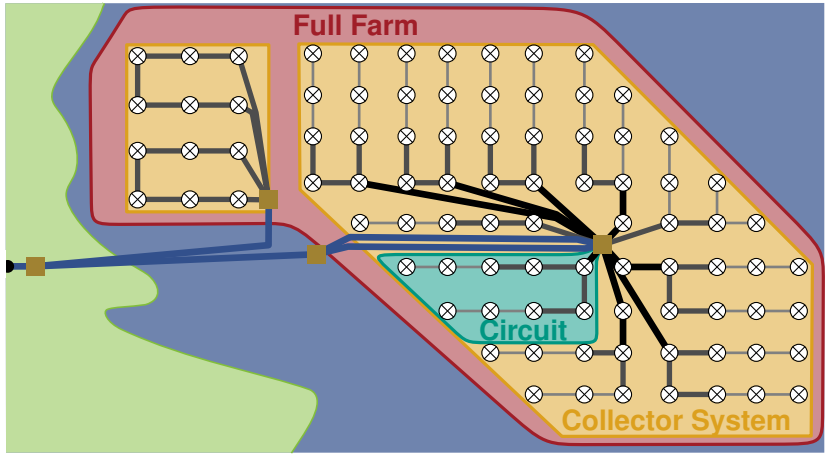






Conclusion & Future Work

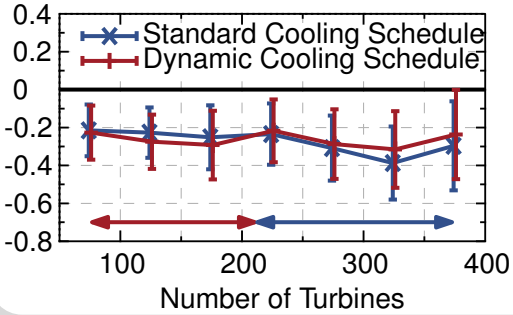


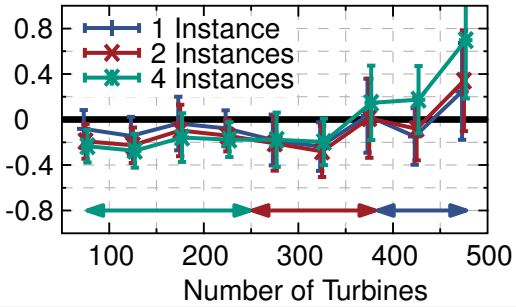


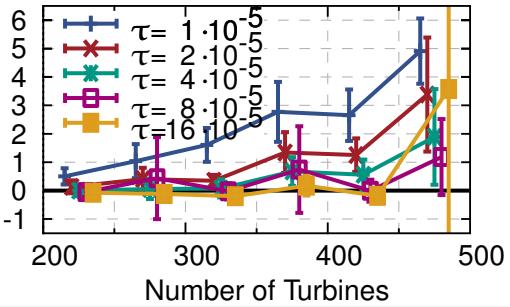
P (MST)	Circuit Problem	NP-hard (Clustering)
NP-hard (CMST)	Substation Problem	NP-hard
NP-hard (Heuristics)	Full Farm Problem	NP-hard

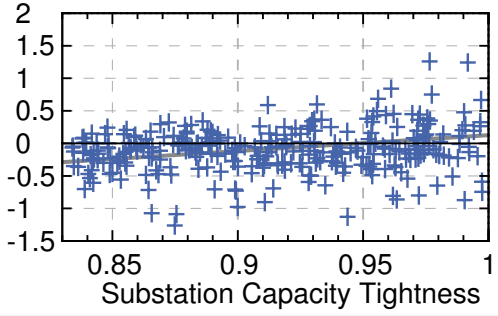
Simulated Annealing

Results&Future Work

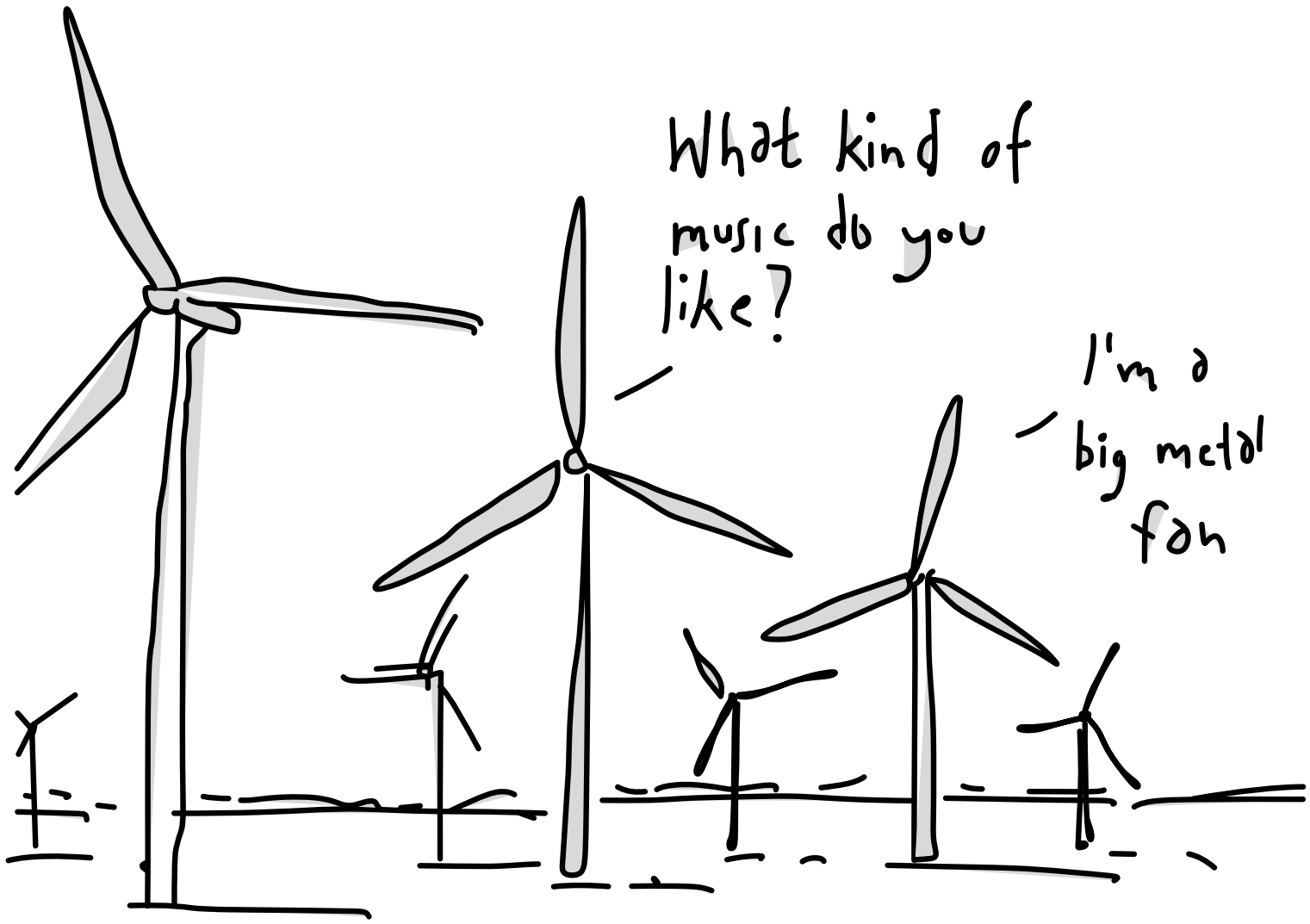








Are you a metal fan, too?



https://s-media-cache-ak0.pinimg.com/originals/8f/51/d3/8f51d30e4e60a97fc5b2fada2ecacd85.jpg