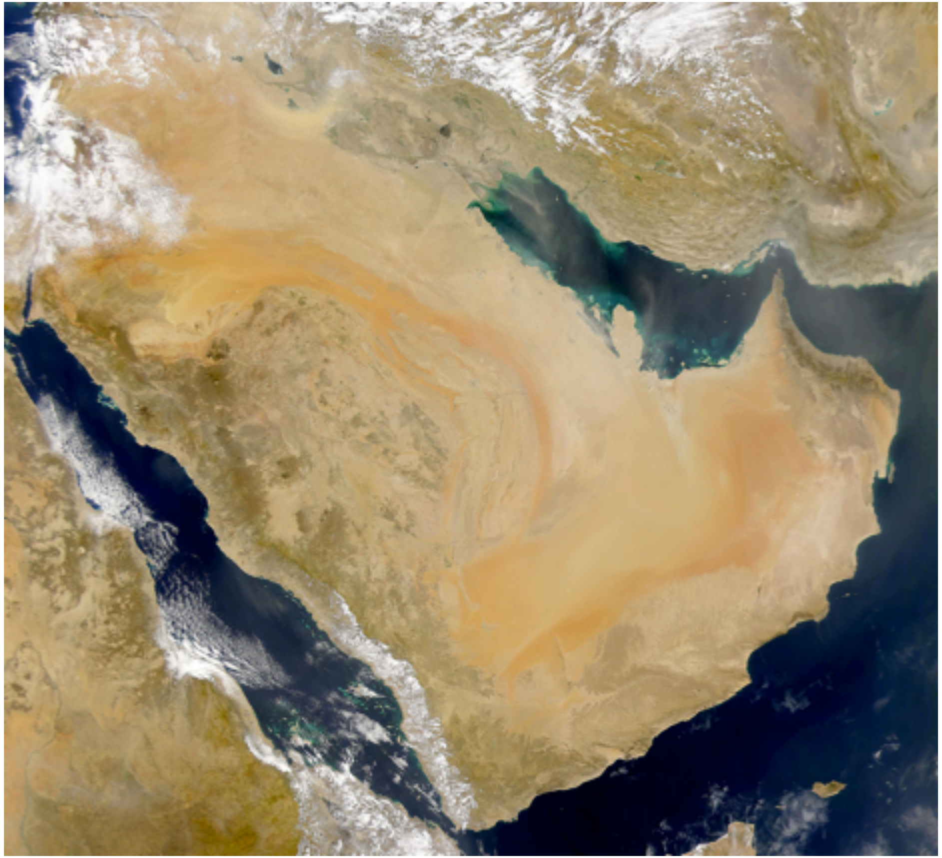
26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016

A Graph Theoretic Framework for Integrated and Co-optimized Power System Planning

(SSDN) Strategic Sustainable Desalination Network
Center for Complex Engineering at KACST & MIT

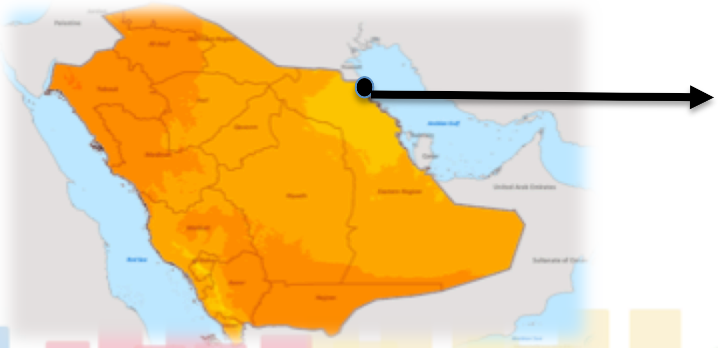
Abdulaziz Khiyami, Takuto Ishimatsu,
Olivier de Weck, Anas Alfaris

Background



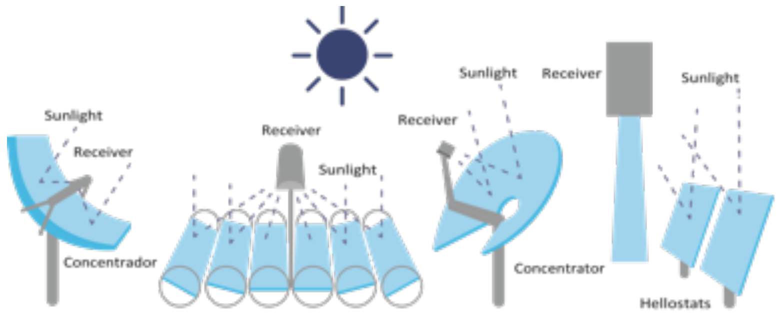
Strategic Sustainable Desalination Network: Research Questions

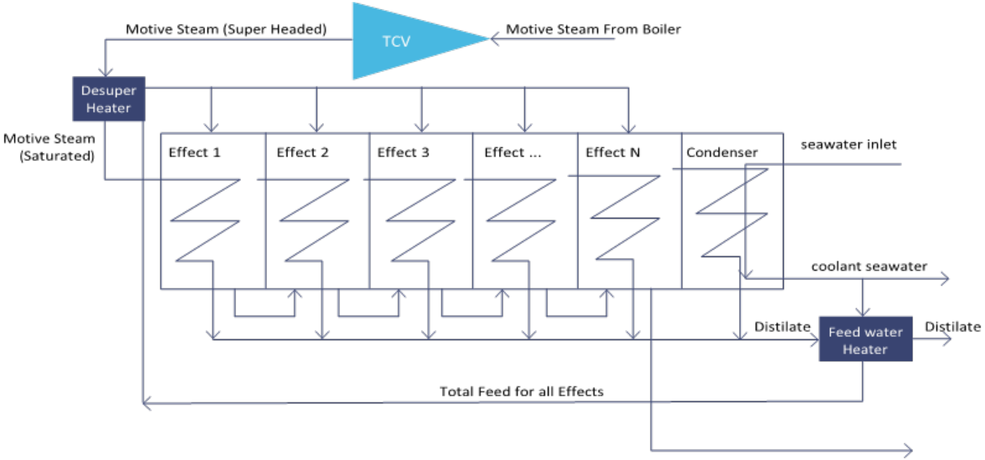
- Competitiveness of renewable desalination over time ?
- Optimal technology choice, location and size of plants ?
- Timing of investments in national assets?
- Water end-use sectors and opportunity cost?
- Related infrastructure impact on economy of KSA?



CSP&MED

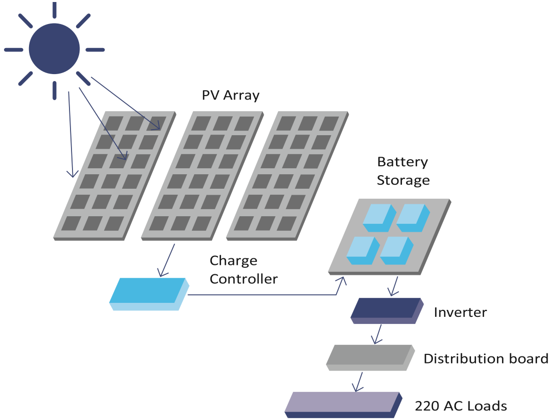
Thermal Energy for thermal desalination process

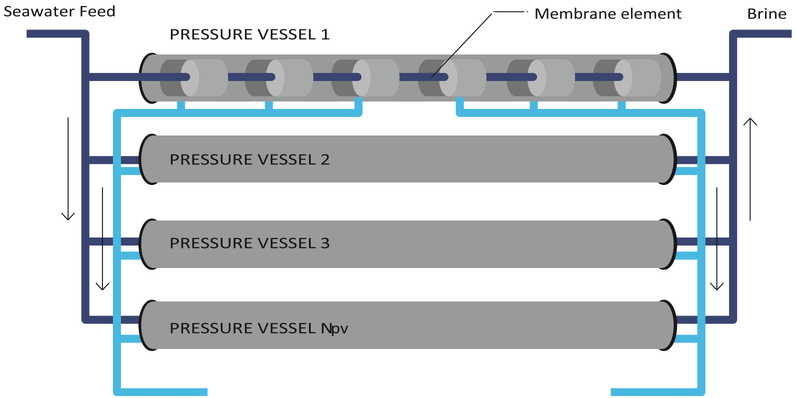




PV & RO

Electrical energy for mechanical desalination process





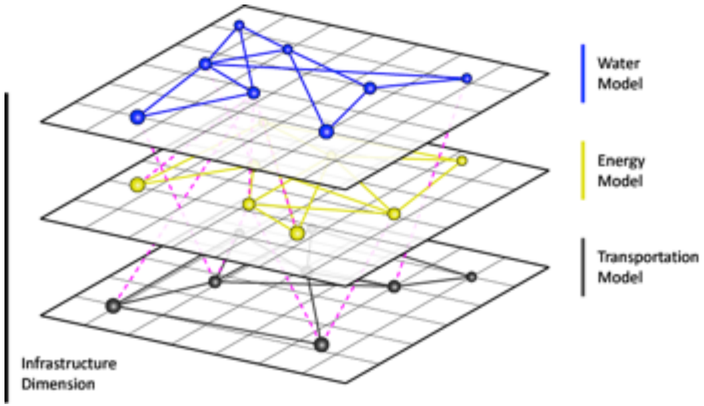
Water-Energy Nexus

Water for Energy
    -Cooling
Energy for Water
    -Desalination

Saudi Arabia is worlds largest desalination market

Over one fifth of all electric generation is co-generating desalination and power

Royal decree for all new generation to be co-generation



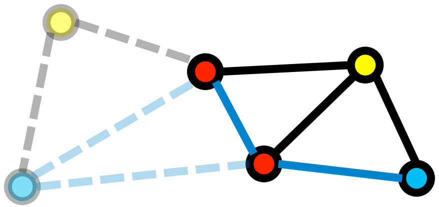
Research Questions for Network Model

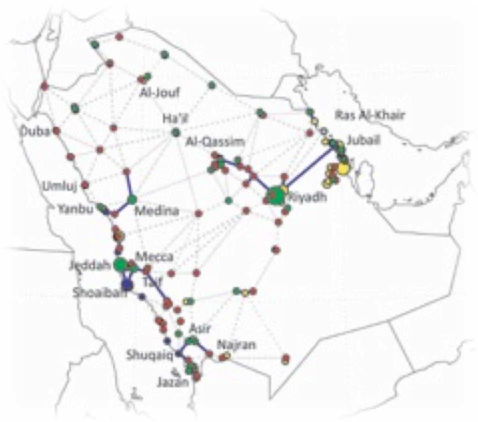
If **solar desalination technology** can replace traditional desalination,

- **What** technologies should be invested in?
- **Where** should they be located in the KSA water/energy network?
  - Should solar power generation and desalination be **co-located** or **separated**?
- **When** should they be built?
  - Optimal **staged deployment**

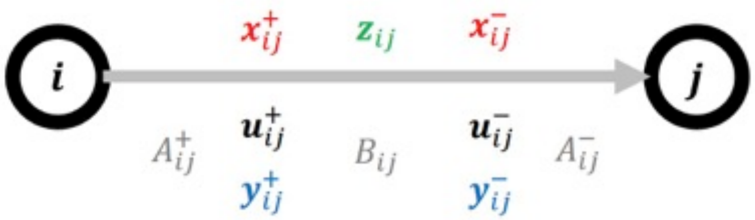
INFINIT model

Interdependent Network Flows with Induced Internal Transformation





INFINIT model



$x_{ij}^{\pm}$: Usage (production/transport)

$y_{ij}^{\pm}$: Design capacity (potential edge)

z_{ij} : Use/Build or not $\{0,1\}$

$u_{ij}^{\pm}$: Capacity (existing edge)

Minimize:

$$\mathcal{J}=\sum_{ij:(i,j)\in\mathcal{A}} \mathcal{J}_{ij}$$

Multi-objective function: CAPEX/OPEX/CO2

subject to:

$$\sum_{j:(i,j)\in\mathcal{A}} A_{ij}^{+} x_{ij}^{+} - \sum_{j:(j,i)\in\mathcal{A}} A_{ji}^{-} x_{ji}^{-} \le b_i \quad \forall i \in \mathcal{N}$$

Net supply/demand (mass balance at each node)

$$x_{ij}^{+} = x_{ij}^{-} \quad \forall (i,j)\in\mathcal{A}$$

Flow Transformation

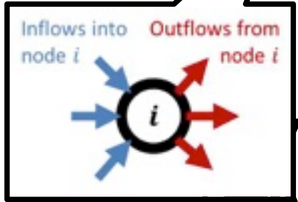
$$0 \le x_{ij}^{\pm} \le u_{ij}^{\pm} z_{ij} \quad \forall \text{ existing } (i,j)\in\mathcal{A}$$

Flow bound for existing edges

$$0 \le x_{ij}^{\pm} \le y_{ij}^{\pm} \le \mathcal{M} z_{ij} \quad \forall \text{ potential } (i,$$

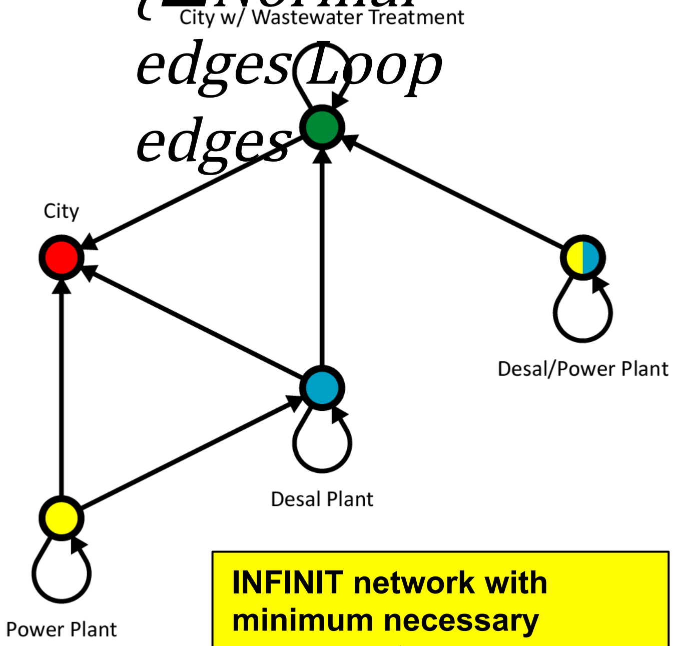
Flow bound for potential edges

Decision binary

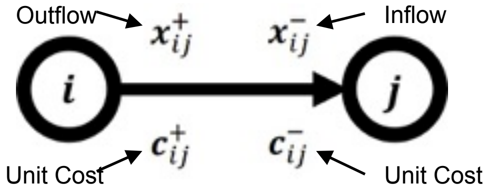


INFINIT model

Edges {■Normal edges Loop edges



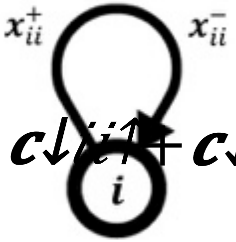
INFINIT network with minimum necessary components



A Normal Edge:

An edge connecting a node to another, modeling a resource transporting "**conduit**"

- Water pipeline
- **Electricity transmission line**



c↓ii↑+ c↓ii↑−

A Loop Edge:

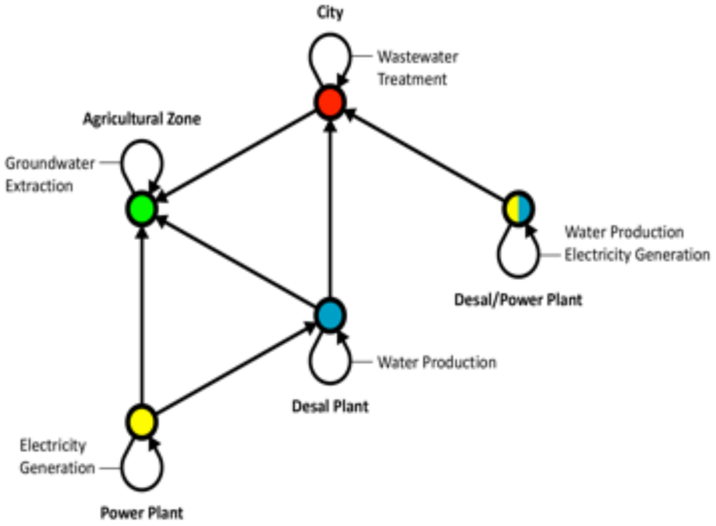
An edge connecting a node to itself, modeling a resource processing "**facility**"

- Desalination plant
- **Power plant**

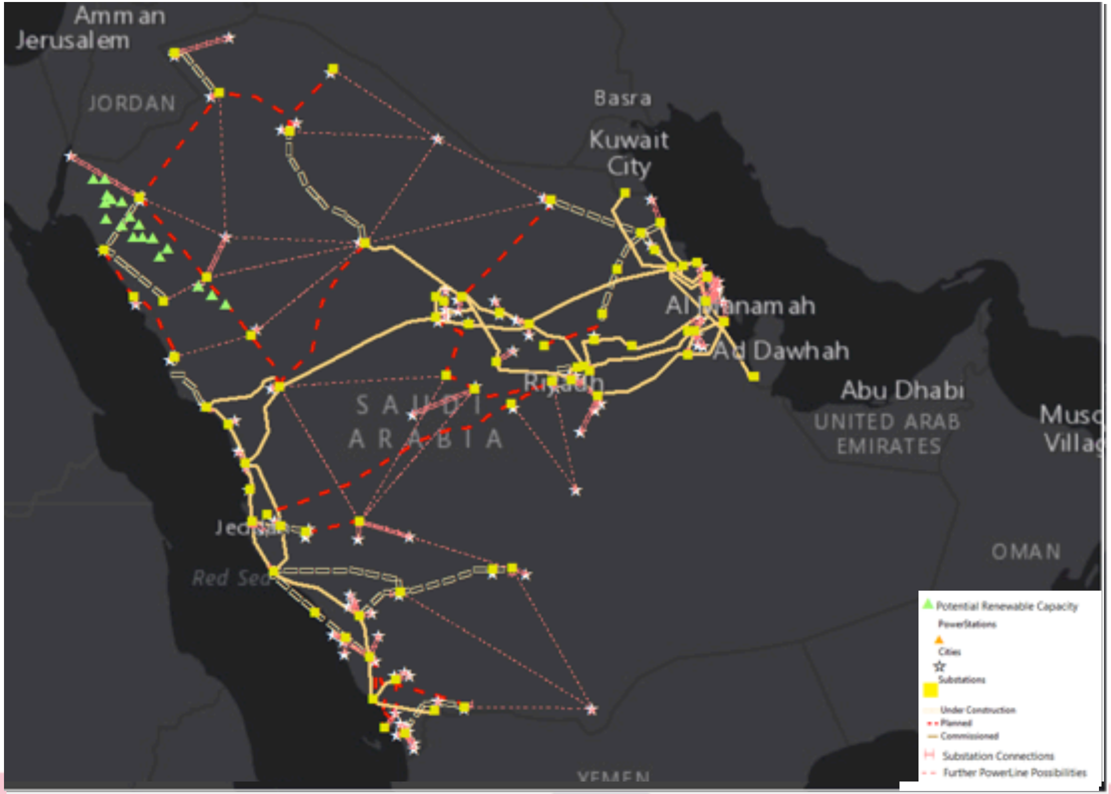
INFINIT Energy Layer

INFINIT model includes:

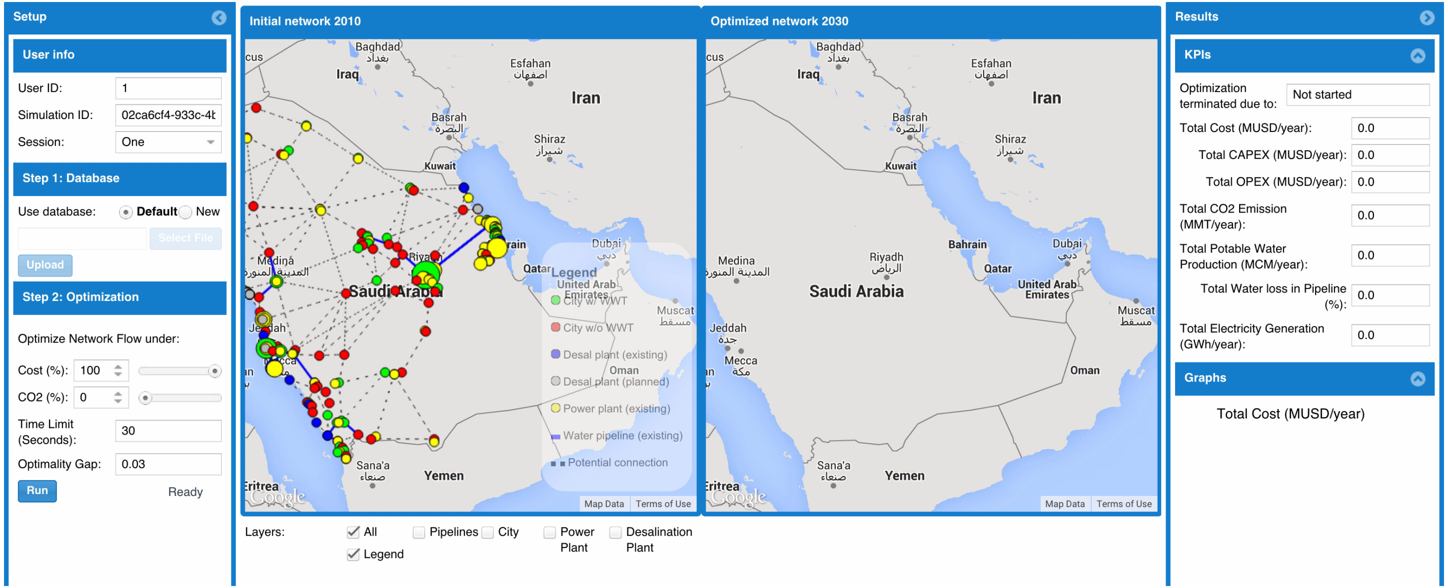
- All cities >20,000 inhabitants
  - 97 Cities, 78% of total population
- Power Plants
  - 65 Power Plants
  - 1/3 co-generation
- High-Voltage Transmission Network



Build up of Energy Layer

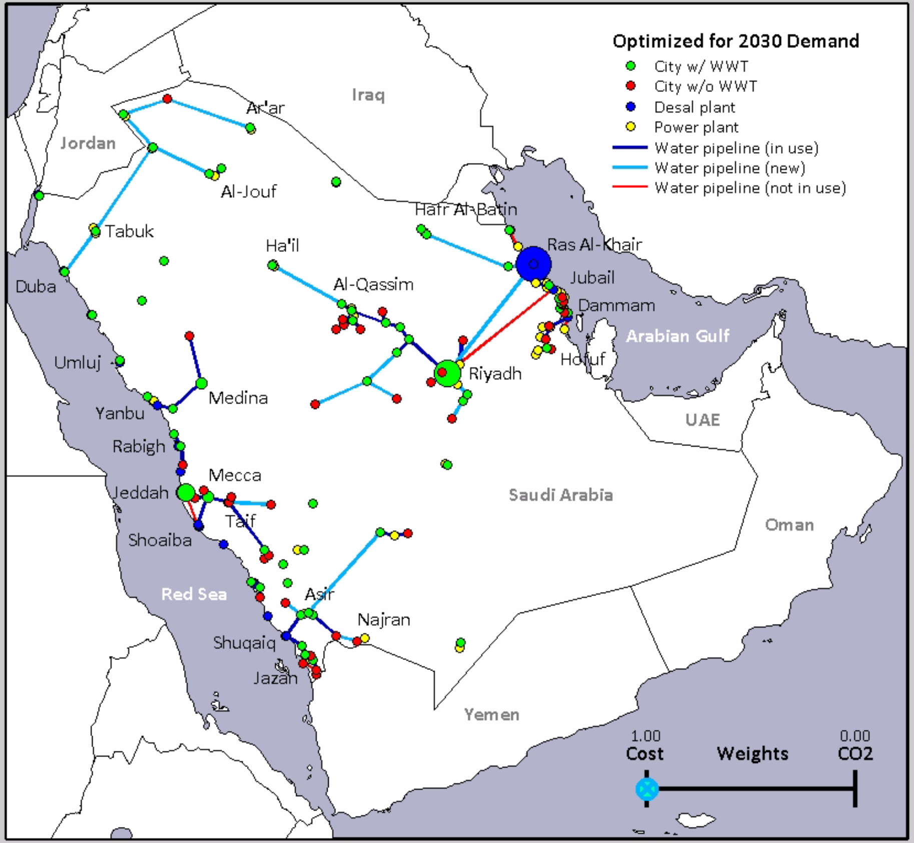


Use Case:
Decision Support System Network Tool

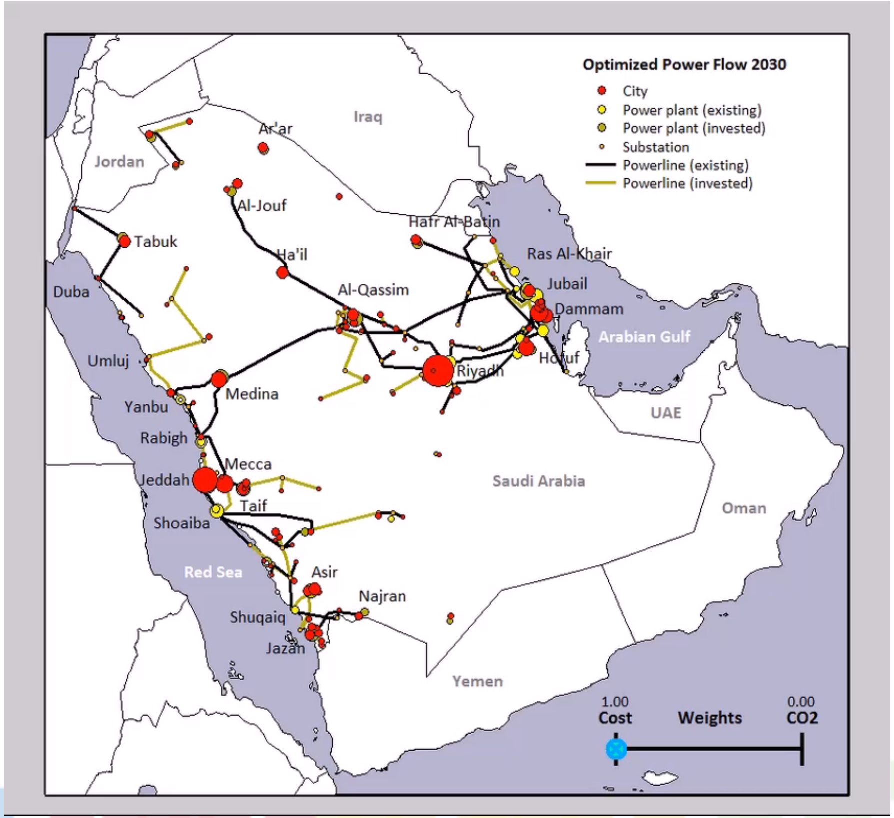


26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016

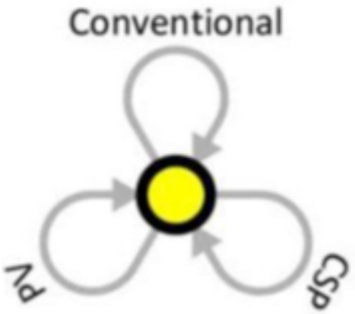
Use Case:
Analysis tool - Water Layer



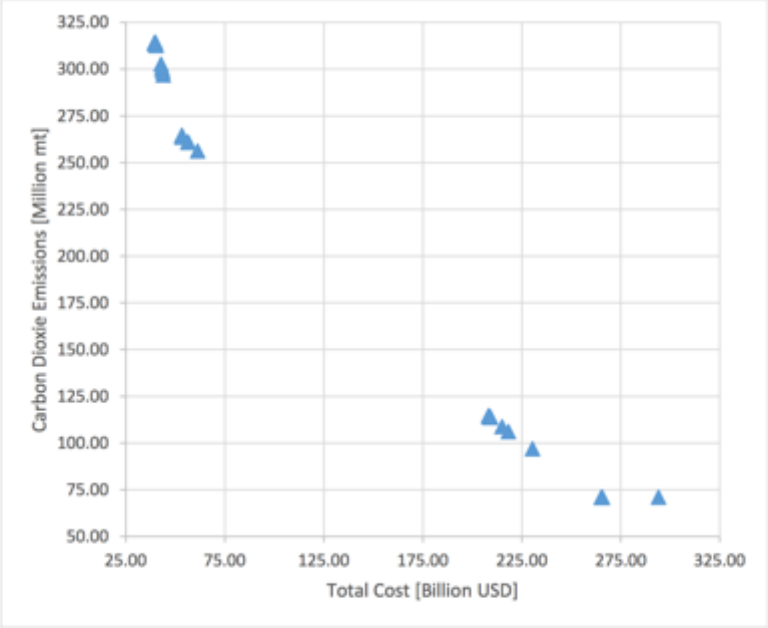
Energy Layer: Cost & Sustainability Tradeoffs



Potential Power Plants



Energy Layer Pareto Front

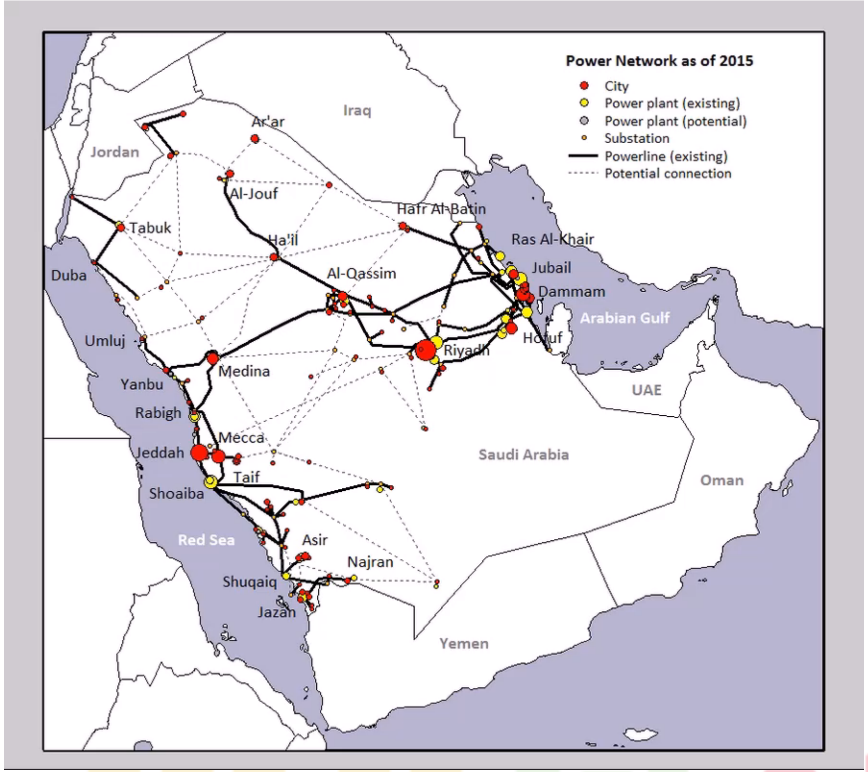


- clear phase change Gas → PV occurs at 0.35
- PV is a brand- new technology
  - At certain environmental threshold, the preference is suddenly shifted to PV
- CSP is never chosen by model due to cost
  - Operational benefits of CSP (energy storage, power dynamics) are unconsidered

Summary & Conclusion

- Logistical approach to electric power system planning
- Allows for the co-optimization of water and power infrastructure by providing Pareto-optimal investment portfolios.
- Simplifying assumptions are used to characterize the power system.
  - Realistic operational constraints likely to severely impact the fidelity of the model.
  - Benchmarking is necessary to improve the models handling of the operational requirements of the power system.
  - Temporal characteristics of generation technologies such as ramping rates, intermittency, and downtime must be addressed.
  - Tradeoff between detail of the model representations vs. the feasibility of the computation and parameter data that can be achieved.
- Temporal Optimization
  - Static network flow problem in the spatial dimension.
  - Evolution of network over time requires optimal staged deployment of future infrastructure projects over time.

Progress: Time-evolving Network



26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016