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Edinburgh, UK
July 18 - 21, 2016

Large Scale Engineering Systems
Insight on Desalination for Agriculture in Saudi Arabia

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Outline

1. Project Context
2. Our Study – Methodology and Results
3. Related works
4. Conclusions

Strategic Sustainable Desalination Network (SSDN) Project

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As the Kingdom of Saudi Arabia (KSA) looks at solar and other renewable energy resources to supply energy to the water industry, there are significant issues related to desalination plant technology choices, investments, and operations. These single desalination plants are part of a larger network representing a region or spanning the entire country, since desalination and power plants are increasingly connected together with water pipelines and electricity transmission lines. The water/energy network analysis can investigate and identify candidate locations for renewable solar desalination plant investments, after accounting for existing assets and current investment plans. The goal of SSDN project is to develop a **strategic sustainable desalination network** platform for planning the efficient deployment of a renewable energy based desalination network in KSA. The framework will take into account key performance attributes, such as sustainability, optimality, strategic security and robustness as well as the ideal phasing and deployment of the network. These attributes will span multiple dimensions, including spatial (network topology), temporal (multiple phases) and technical (available technologies). By building simulations that leverage key principles, such as robust, large-scale and multi-disciplinary optimization routines, the SSDN project will ensure the desired characteristics of the proposed plans are achieved across all mentioned dimensions. In addition, SSDN will also take uncertainty into consideration, which is critical for a secure and sustainable existence of the Kingdom in the face of an uncertain future.

SSDN Project - Research Questions

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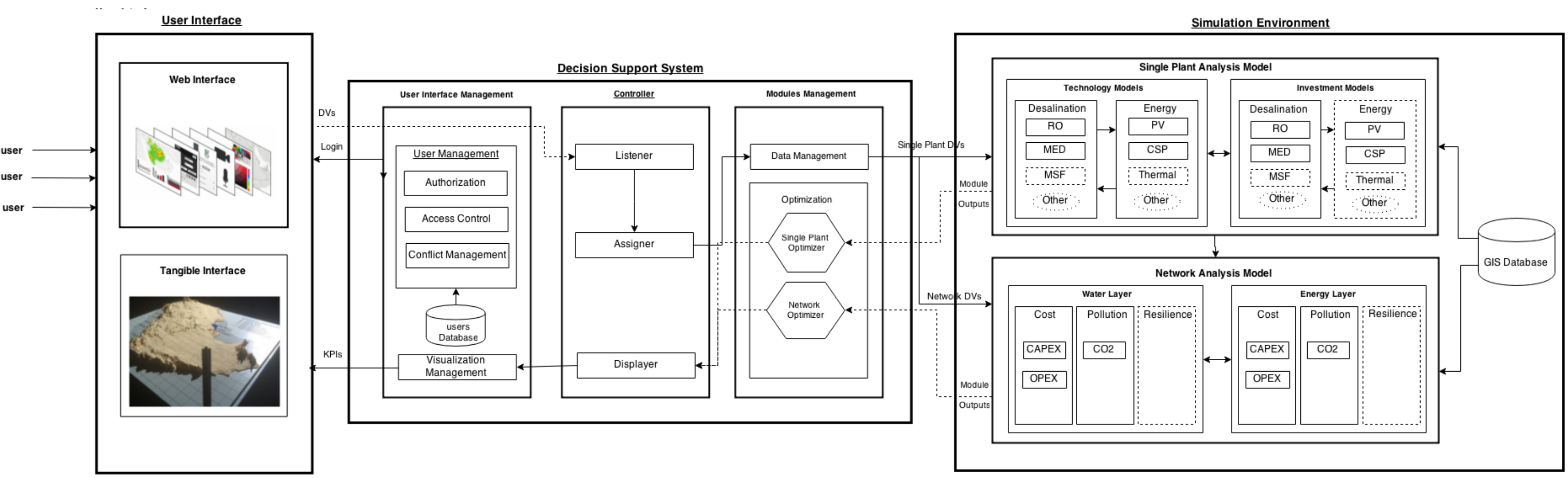
- Can solar desalination technology replace traditional desalination in KSA over time and be competitive?
- What are the optimal technology choice, location, and size of solar desalination plants?
- Should solar power generation (PV, CSP) and desalination operation be co-located in the same place or should they be separated with long-distance transmission?
- What are the priorities for usage of solar desalinated water as part of the larger KSA infrastructure network? Can we do more agriculture?

Project Context – List of Models



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Network Analysis

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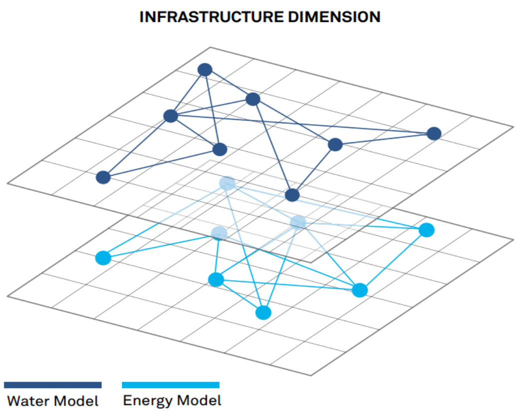
The **Water/Energy Network Model** evaluates every single plant as **one node connected in a large network**.

Infrastructure dimension

→ **Multi-commodity network flow**

$$x_{ij} = \begin{bmatrix} \text{Water} \\ \text{Energy} \end{bmatrix}$$



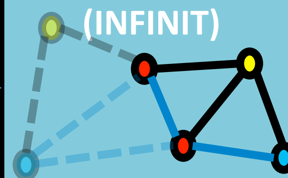
USER:

List of Potential Locations
- GPS coordinates
- Attributes

Technology Library
- Energy consumption
- CAPEX/OPEX
- CO2 emission

Multi-Objective Function
- CAPEX/OPEX
- CO2 emission
- …

KSA Water/ Energy Network Model (INFINIT)



CONTEXT:

Future Demand Profile by City
- Potable water
- Non-potable water
- Electricity

Natural Resources by Location
- Water availability
- Solar radiation intensity

Existing Infrastructures
- Desal/power plants
  - GPS coordinates
  - Capacity
  - Remaining lifetime
  - Energy consumption
  - OPEX
  - CO2 emission
- Pipelines/powerlines
  - Distance
  - Capacity
  - OPEX

RESULTS:

Pareto-Optimal Investment Portfolios
- Location and time
- Design capacity
- Technology choice

Interdependent Network Flow with Induced Internal Transformation (INFINIT) model

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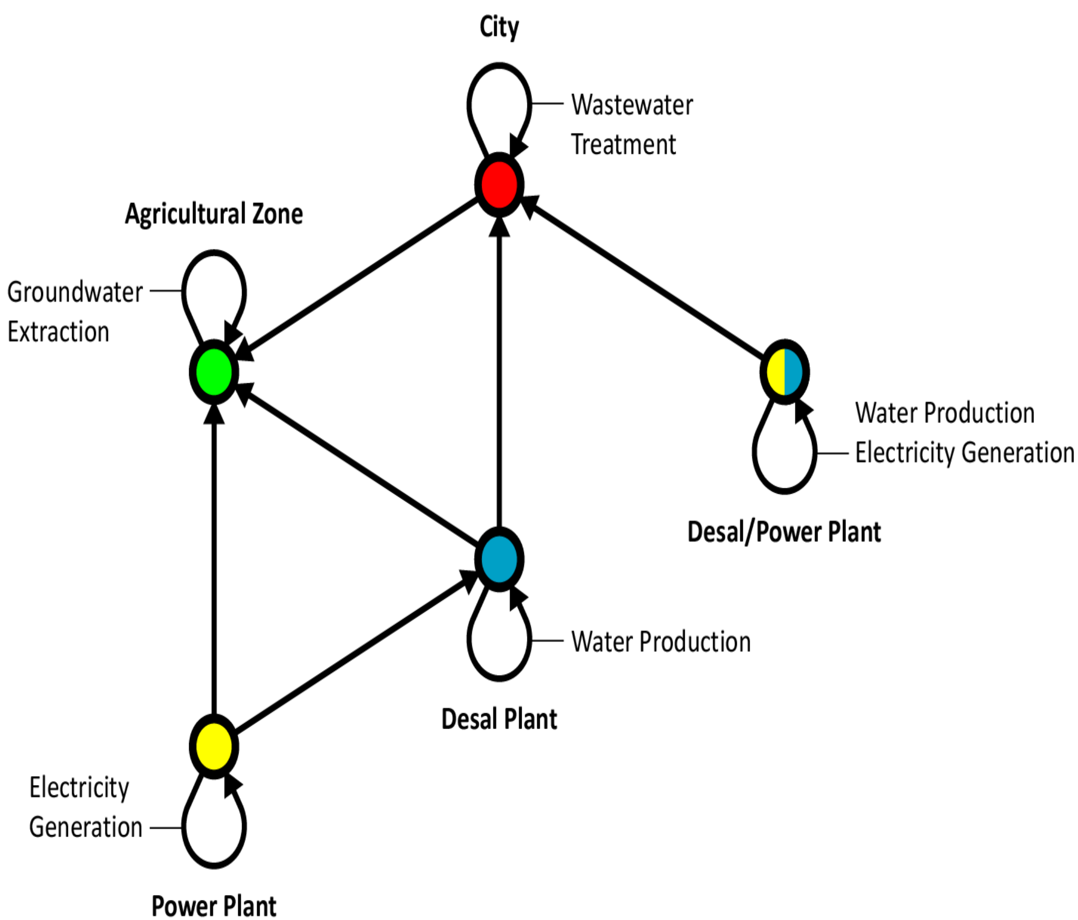
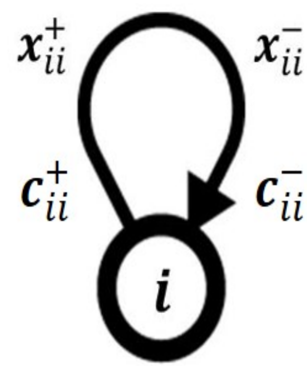
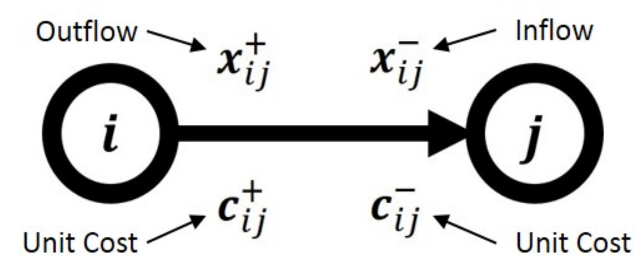




A Loop Edge:
An edge connecting a node to itself, modeling a resource processing "**facility**"
- Desalination plant
- Power plant
- Waste water treatment



A Normal Edge:
An edge connecting a node to another, modeling a resource transporting "**conduit**"
- Water pipeline
- Electricity transmission line

Overview of Mathematical Formulation

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In this paper, the INFINIT model defines three sets of decision variables: (1) flow amount on arc *i,j*, denoted by ***xij±***, (2) capacity expansion of arc *i,j*, denoted by ***yij***, and (3) a binary variable representing whether arc *i,j* is used/invested or not, denoted by ***zij***. The mathematical formulation of the INFINIT problem is presented below:

Minimize:

$$\mathcal{J} = \sum_{(i,j)\in\mathcal{A}} \mathcal{J}_{ij} \quad \textbf{(eq.1)}$$

subject to:

$$\sum_{j:(i,j)\in\mathcal{A}} \boldsymbol{A}_{ij}^{+}\boldsymbol{x}_{ij}^{+} - \sum_{j:(j,i)\in\mathcal{A}} \boldsymbol{A}_{ji}^{-}\boldsymbol{x}_{ji}^{-} \le \boldsymbol{b}_i \quad \forall\, i \in \mathcal{N} \quad \text{(eq.2)}$$

$$\boldsymbol{B}_{ij}\boldsymbol{x}_{ij}^{+} = \boldsymbol{x}_{ij}^{-} \quad \forall\,(i,j) \in \mathcal{A} \quad \text{(eq.3)}$$

$$\boldsymbol{l}_{ij}^{+} \le \boldsymbol{x}_{ij}^{+} \le \boldsymbol{u}_{ij}^{+} + \boldsymbol{y}_{ij} \quad \forall\,(i,j) \in \mathcal{A} \quad \text{(eq.4)}$$

$$\boldsymbol{0} \le \begin{bmatrix} \boldsymbol{x}_{ij}^{+} \\ \boldsymbol{x}_{ij}^{-} \\ \boldsymbol{y}_{ij} \end{bmatrix} \le \mathcal{M}\boldsymbol{z}_{ij} \quad \forall\,(i,j) \in \mathcal{A} \quad \text{(eq.5)}$$

$$\boldsymbol{z}_{ij} \in \{0,1\} \quad \forall\,(i,j) \in \mathcal{A} \quad \text{(eq.6)}$$

where *Jij* is a contribution from arc *i,j* to the overall objective function in the form of a weighted linear sum of ***xij±***, ***yij***, and ***zij***, ***bi*** denotes the net supply/demand vector at node *i*, ***lij*** and ***uij*** represent the lower bound and the capacity of arc *i,j*, respectively, and *M* is a sufficiently large number for the so-called big-*M* method. ***Aij±*** is called a *flow equilibrium matrix*, and ***Bij*** is called a *flow transformation matrix*.

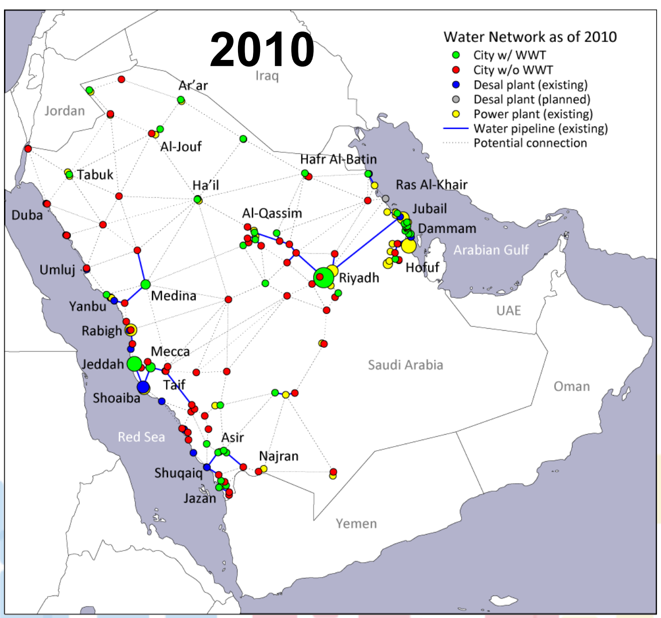
Example : Development of Saudi Potable Water Network

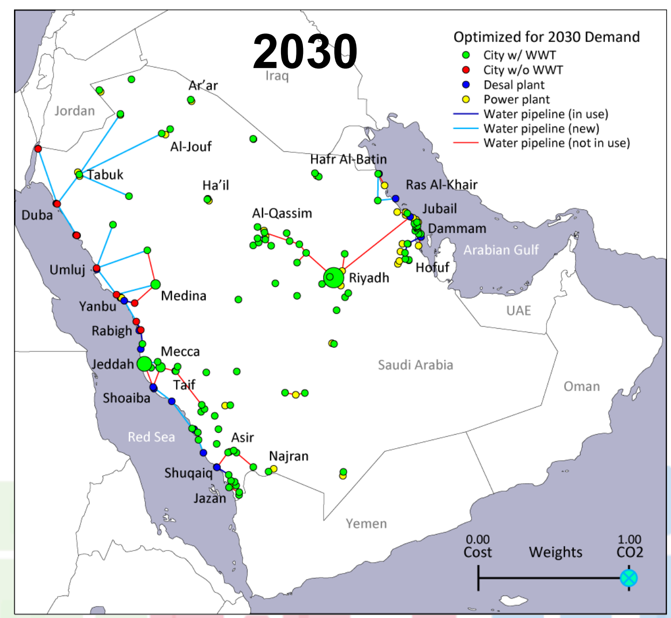
Include:

- All cities >20,000 inhabitants
  - 97 Cities, 78% of total population
- Desalination Plants
  - 47 Plants, 5.43 Million cubic meters per day
  - For drinking water considered (no industry)
- Working Pipelines

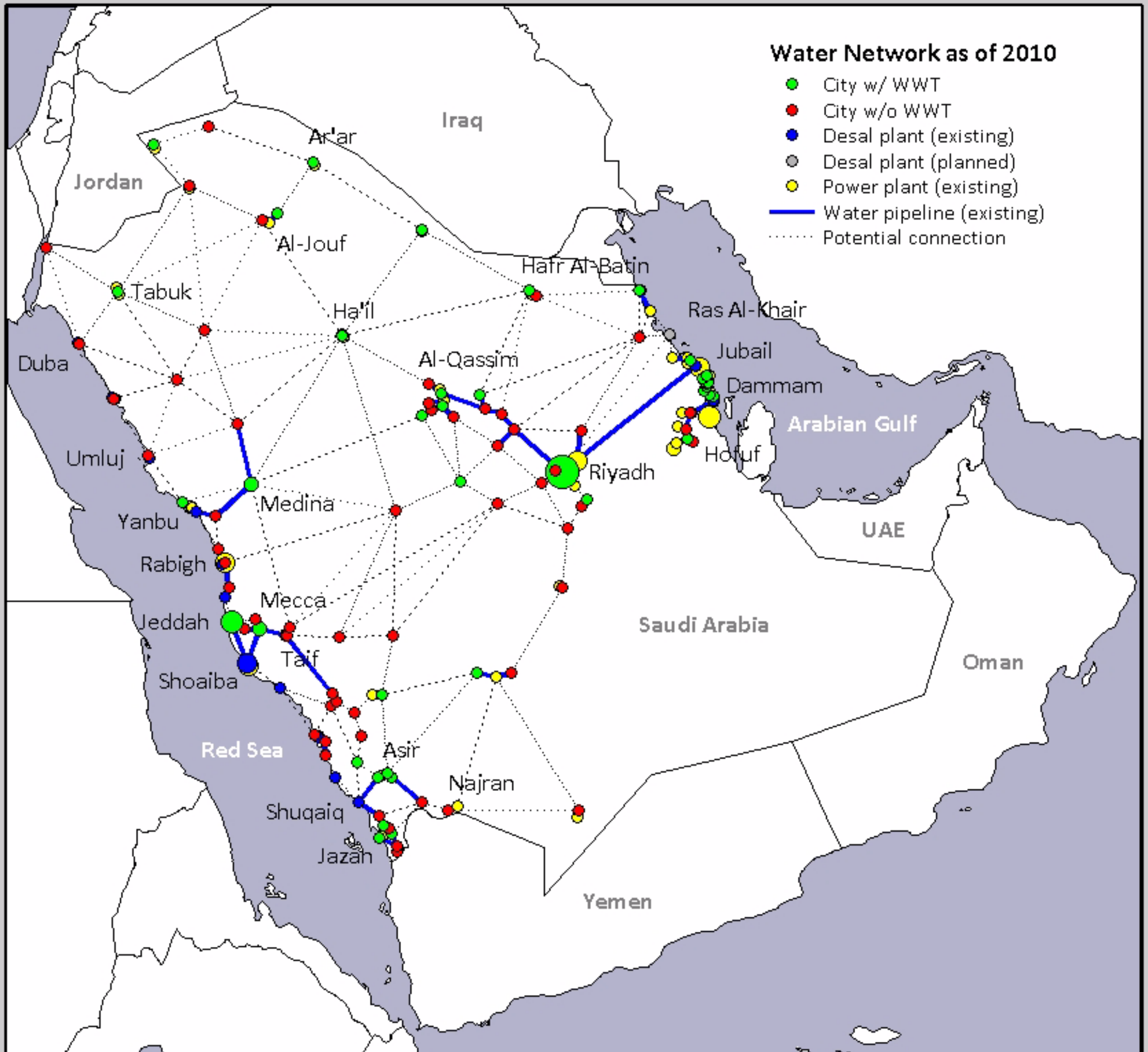
Consider:

- Potential pipelines
- Potential desalination plants
- Expansion / replacement / retirement of existing capacity





Video – Potable Water



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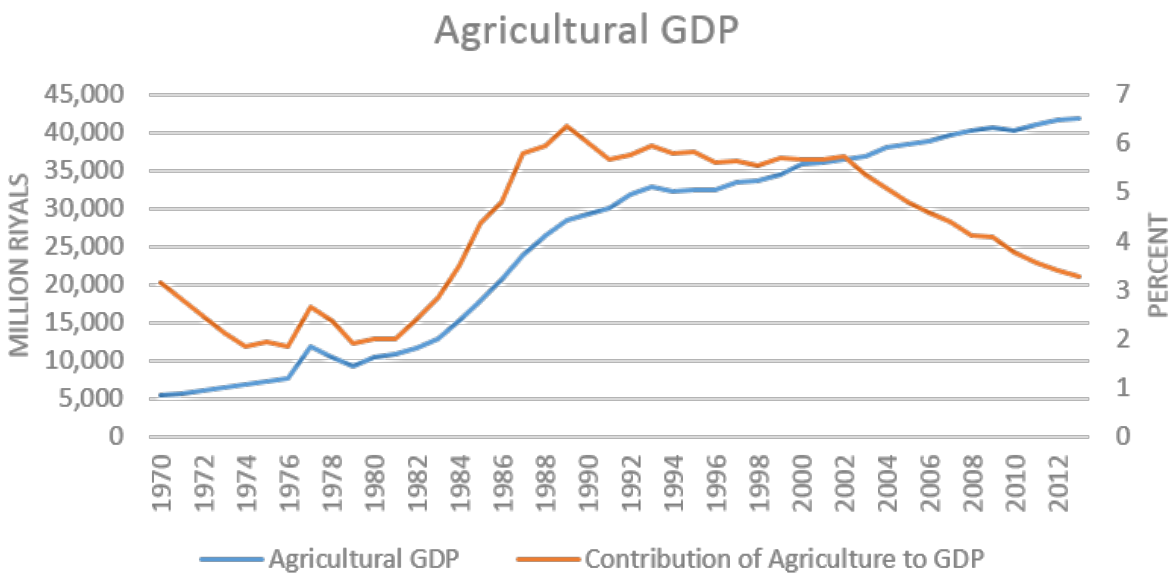
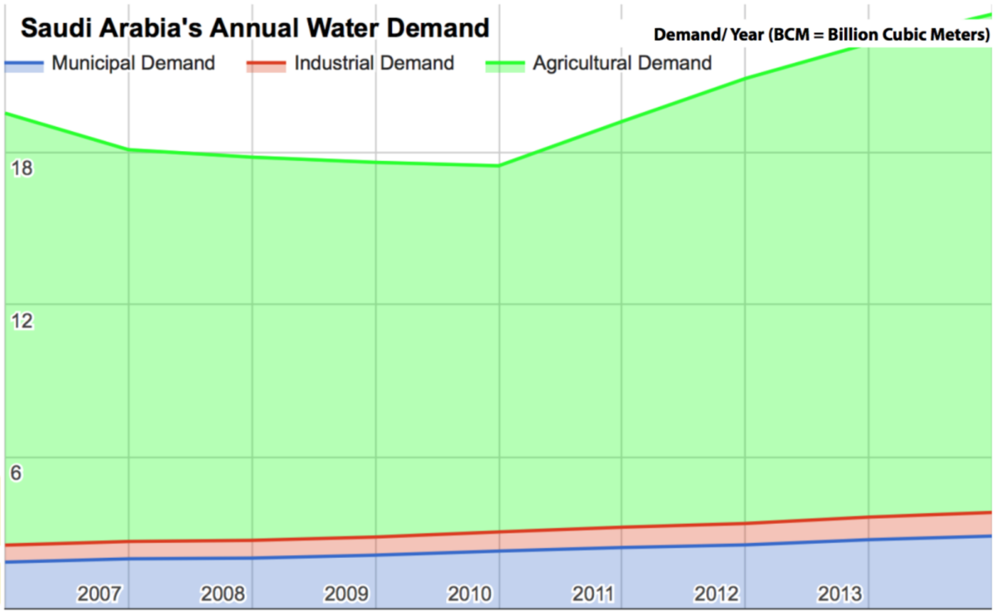
Why Desalination for Agriculture





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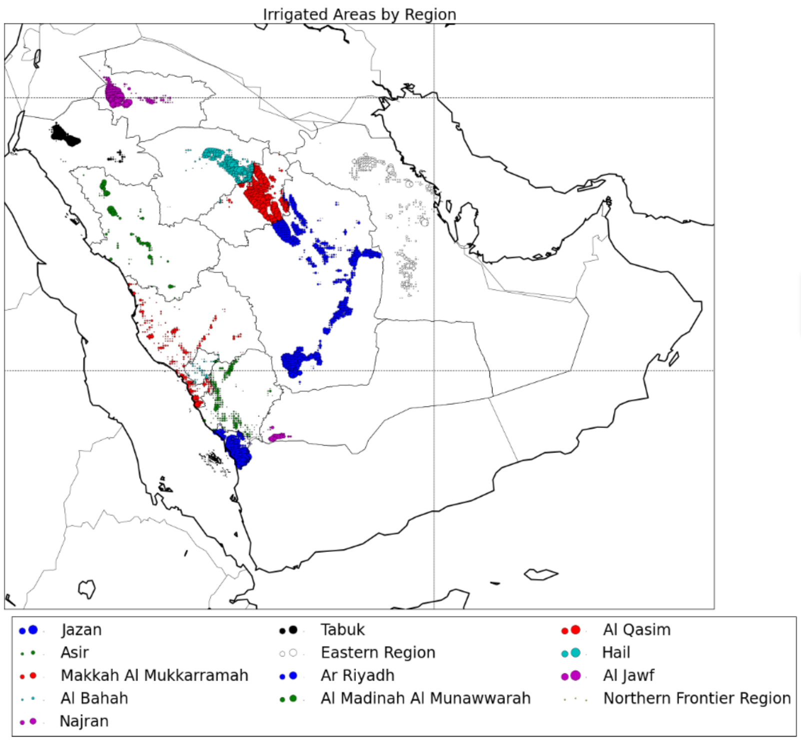
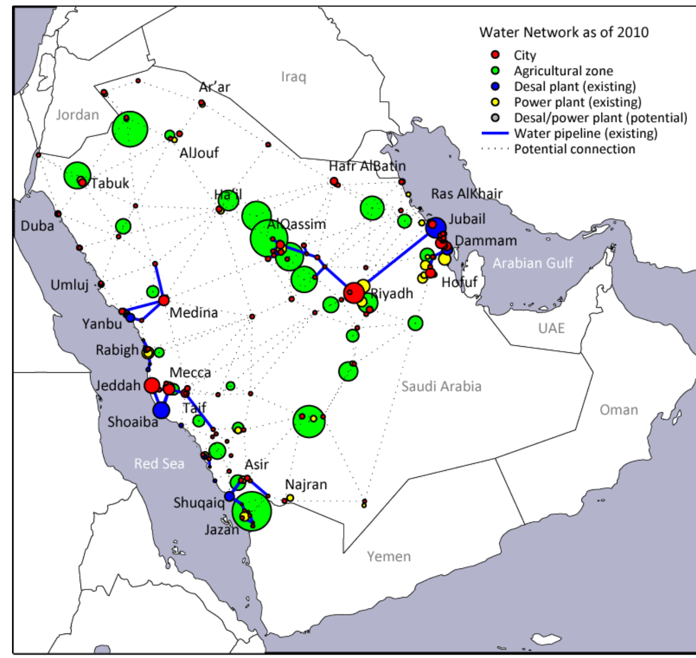
Initial Data



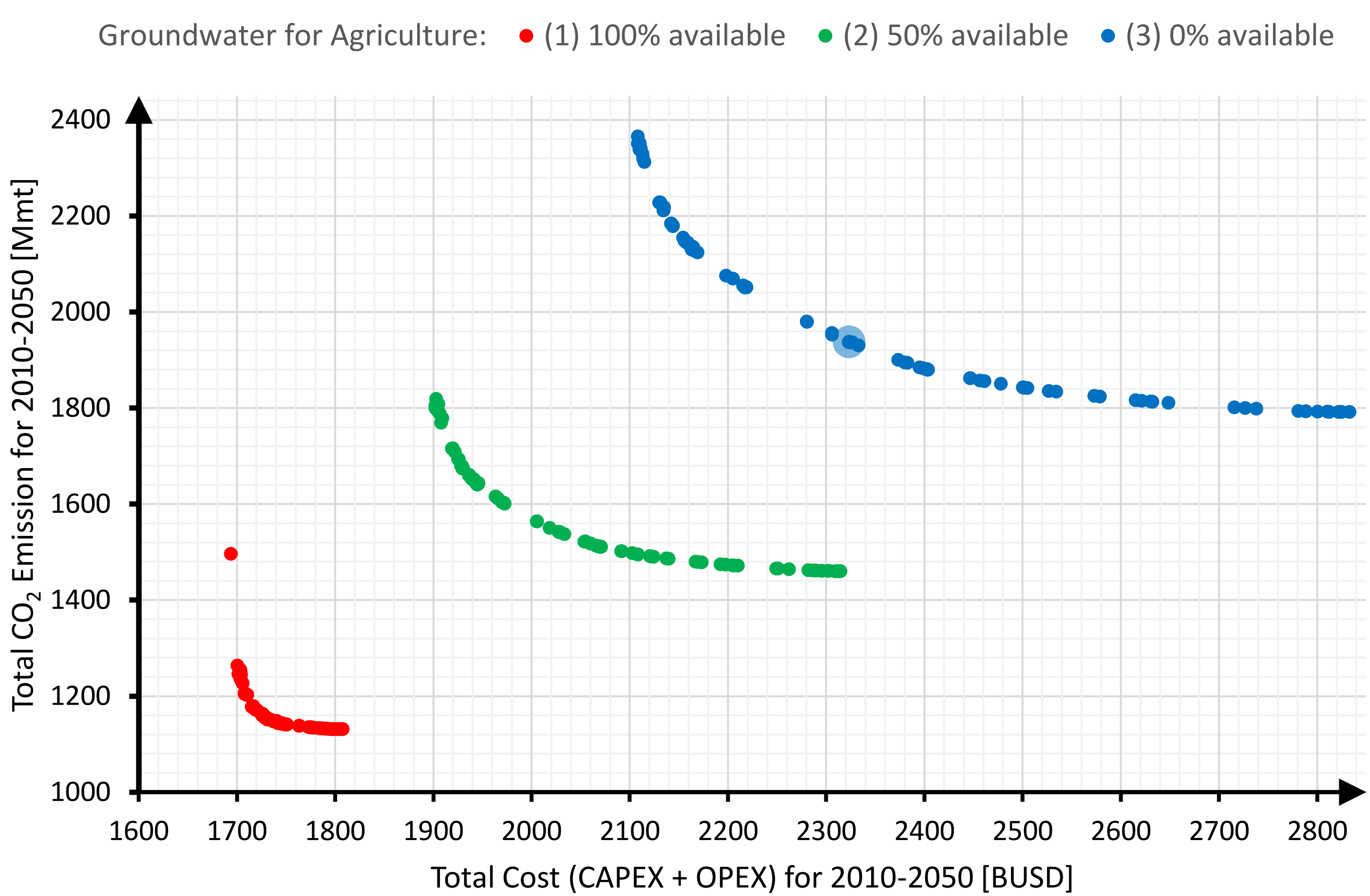
Clustering



Agricultural zones used to assess desalination for agriculture; size of circles indicate water demand.

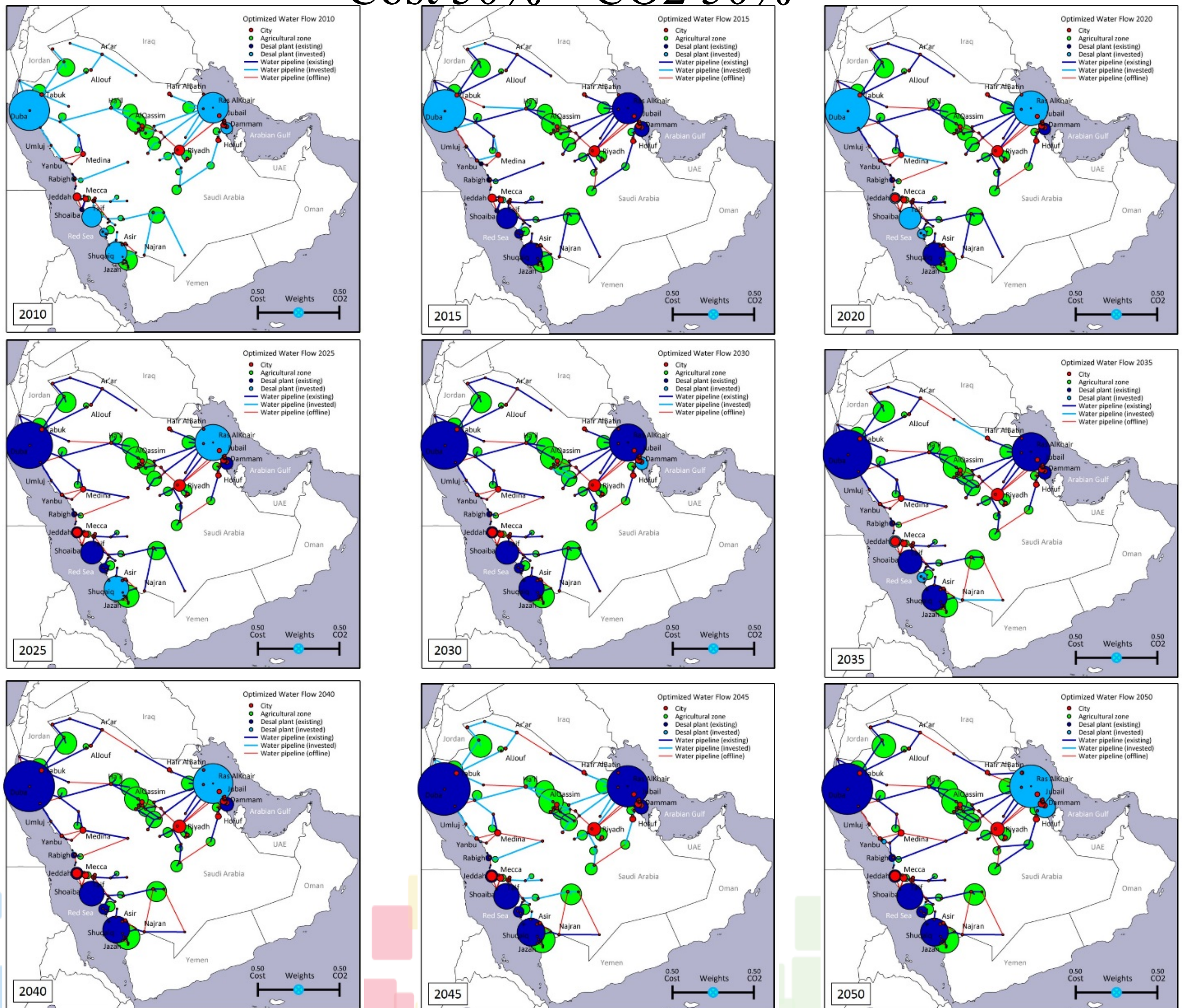
Regional distribution of irrigated areas across KSA → 27 agricultural zone nodes

Groundwater vs. desalination for agriculture: Pareto-optimal solutions



Resulting network from 2010 to 2050

Cost 50% – CO2 50%



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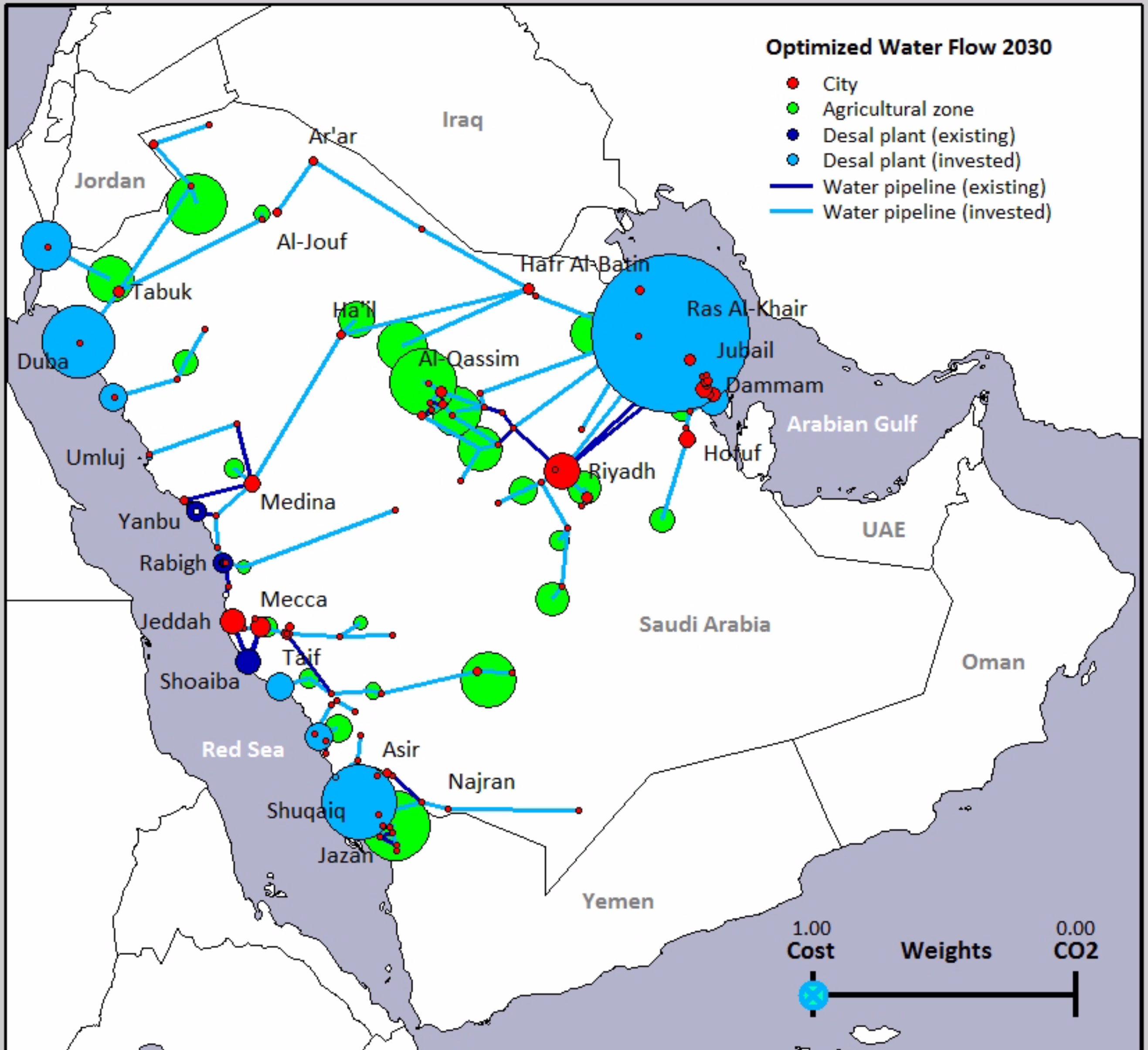
Video – Water for Agriculture



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Web Based User Interface

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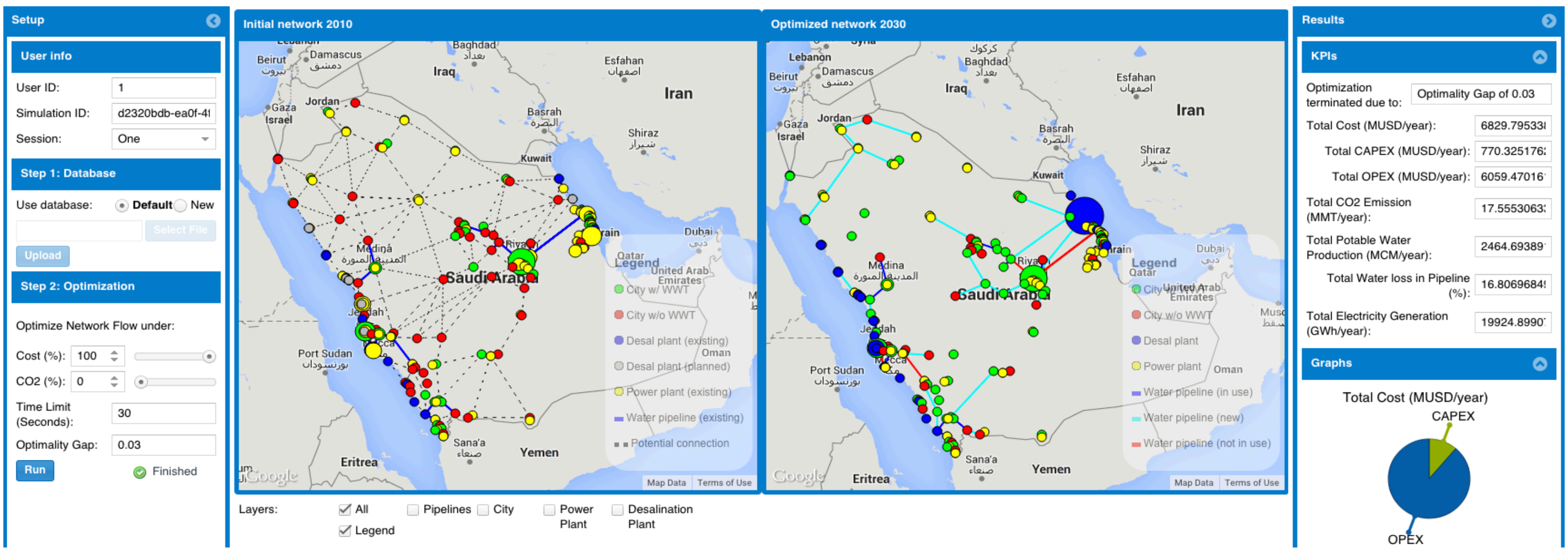
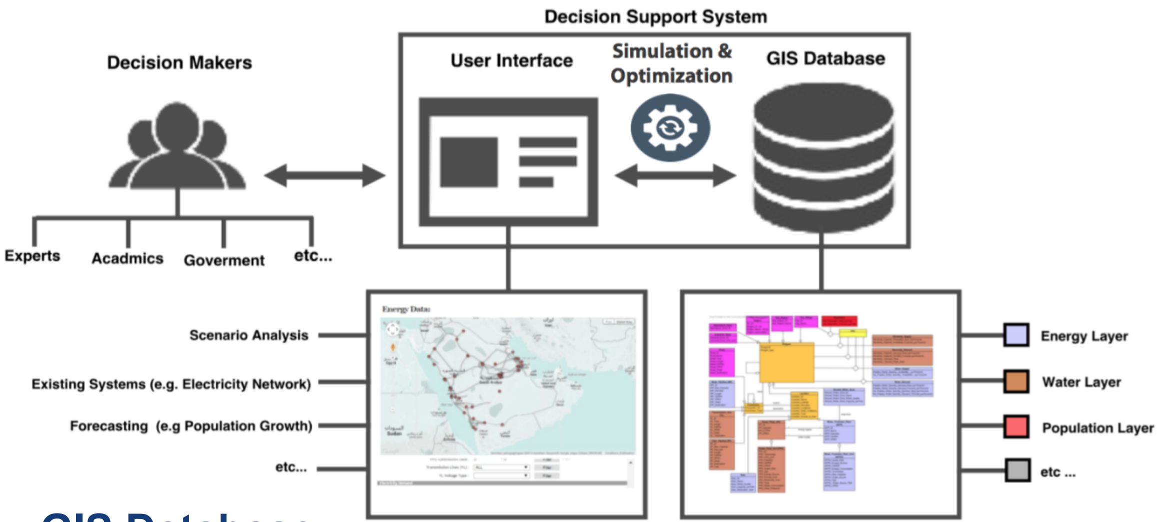
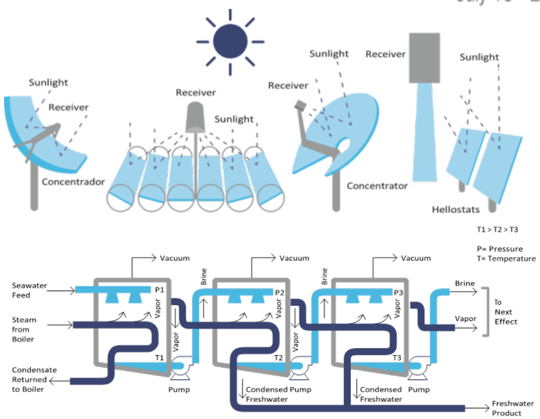


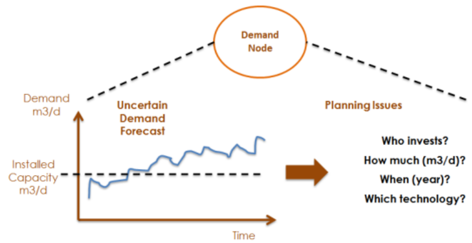
Related Works



GIS Database

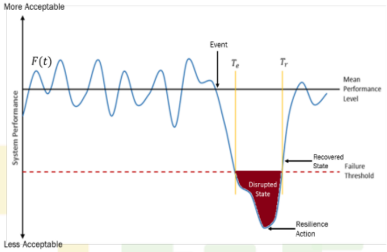


Solar Desalination Library

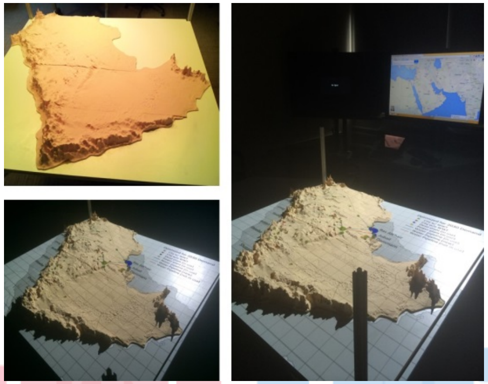


Investment Model

Dust Mitigation Model



Resilience Model



3D Map

Conclusions

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- The concept of "Desalination for Agriculture" in the context of the Kingdom of Saudi Arabia.

- The objective is not to emphasize specific results, but to demonstrate one way of evaluating this concept from an infrastructure network perspective.
  - Many alternatives, factors and issues to be addressed in the context of desalination for agriculture.

Perspectives

- Identify a list of guidelines and best practices in order to support policy makers` decisions for a long term planning through scenario analysis and multidisciplinary optimization.
  - Consideration of solar desalination and waste water treatment for more sustainable agricultural system.
  - Support decisions in term of investment in new infrastructures over time (location and deployment) taking into account uncertainty, addressing internal changes (population and economic growth, etc.) as well as potential external changes (international trade market and natural environmental constraints, etc.)

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END

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VIDEO 3D MAP

VIDEO POWER SYSTEM OVER TIME