OPTIMIZATION OF CARBON CAPTURE, UTILIZATION, AND STORAGE (CCUS) HUB : A CASE STUDY IN SOUTH SUMATRA, INDONESIA

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Presented by:

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Presentation Outline

- Introduction
- Basic Theory
- Methodology
- Optimization Platform
- Case Study
- Result and Discussion
- Conclusion
- Recommendation

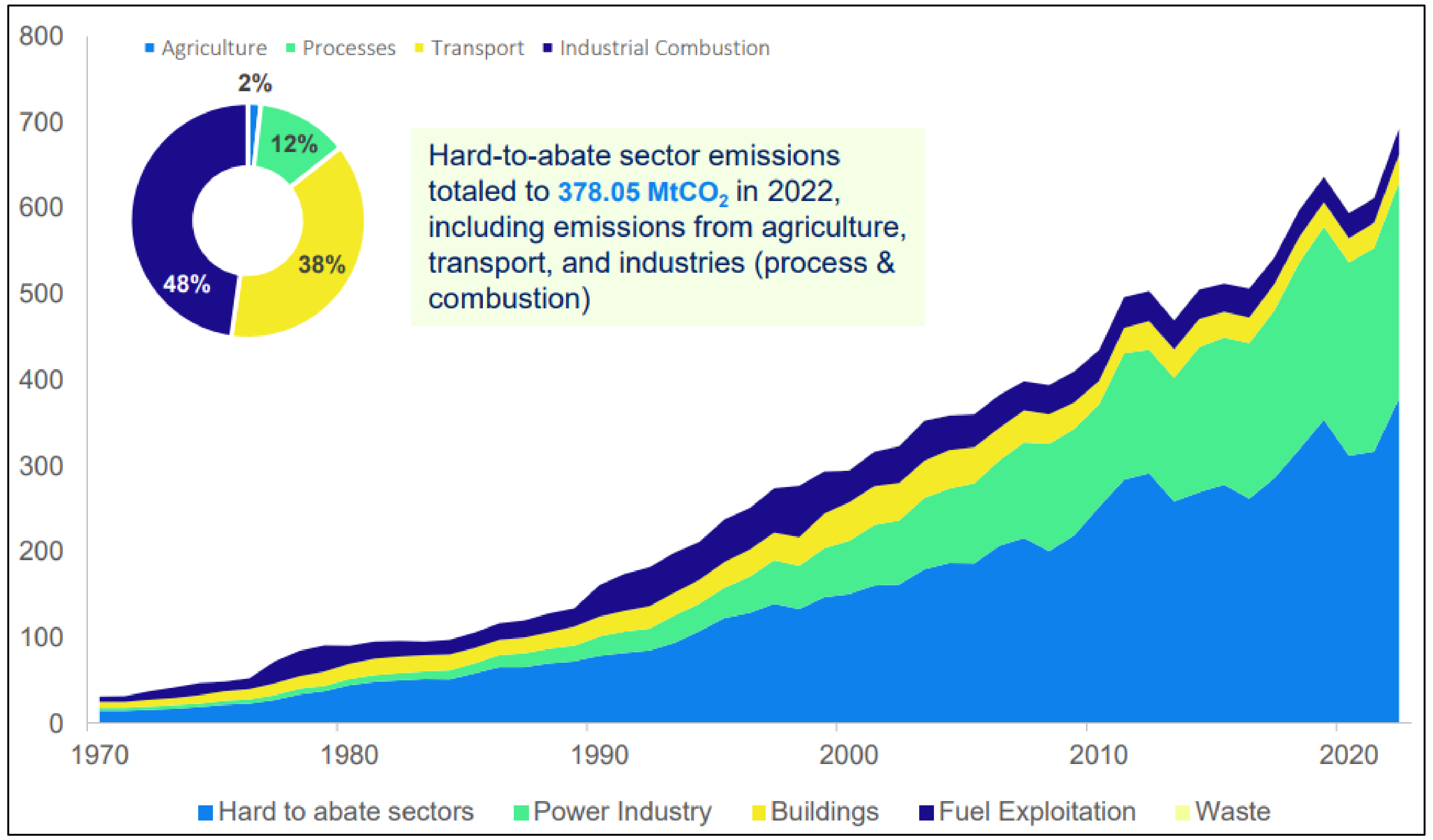
BACKGROUND

Current condition – As a developing country, Indonesia's increase in CO_2 emissions is inevitable, including to reach the target of 1 million BOPD of oil production and 12 BSCFD of gas production by 2030, making emissions reduction strategies essential to reaching NZE target by 2060.

Indonesia Current Condition

Indonesia Emas 2045 Vision
reach a GDP of US$9,100 billion (the world's fifth-largest economy)

Indonesia's GHG emission trend
Mt CO2-eq/year, 1970 – 2022



Reference : ICCSC analysis, ENDC RI (2022), Bappenas (2019)

Carbon Capture, Utilization, and Storage (CCUS) Opportunity

CCUS Opportunity
CCUS could be a promising strategy to achieve these dual objectives

PROBLEM

Commercial-scale CCUS Deployment : Complex Consideration

Design *including:* **CO2 source selection**, **pipeline routing**, **sink/reservoir assessment**.

OBJECTIVES

This study aims to **make a platform** to facilitate the understanding of :

CO_2 source and sink availability;

Pipeline network optimization;

Selection of sources and sinks;

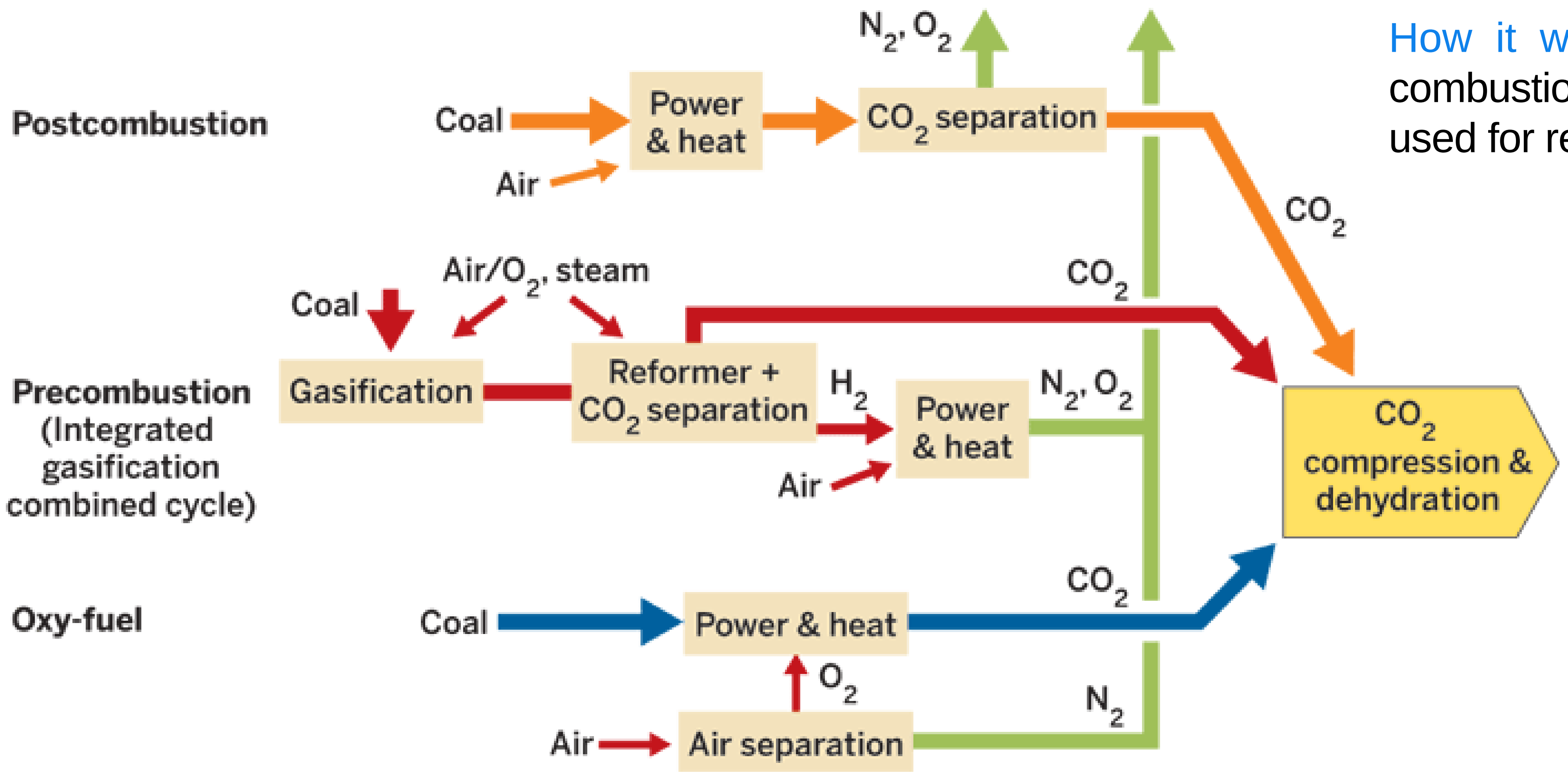
Determine CO_2 supply-demand conditions;

Estimation of the maximum CO_2 injection rate;

Estimation of the CO_2 price that make the project economically feasible.

BASIC THEORY

CCUS VALUE CHAIN



Reference : IPCC, Metz et al. (2005), ERIA (2021)

CO2 CAPTURE TECHNOLOGY

Post-combustion – Post-combustion CO2 capture is widely used in power plants because it can be easily added to existing facilities without major changes, making it a practical choice for reducing CO2 emissions from older plants.

How it work? – It works by separating CO2 from flue gases after combustion, using a liquid solvent process similar to methods already used for removing other pollutants.

Overall – Post-combustion capture offers a straightforward and effective way for power plants to capture their carbon emissions and meet environmental regulations.

BASIC THEORY

CO2 STORAGE CAPACITY

$$SC = \left(E_{oil} \times EUR_{oil} \times B_o + E_{gas} \times EUR_{gas} \times B_g\right) \times \rho_{CO_2}$$

Decline Curve Analysis (DCA)

$$q = \frac{q_i}{(1 + bDt)^{1/b}}$$

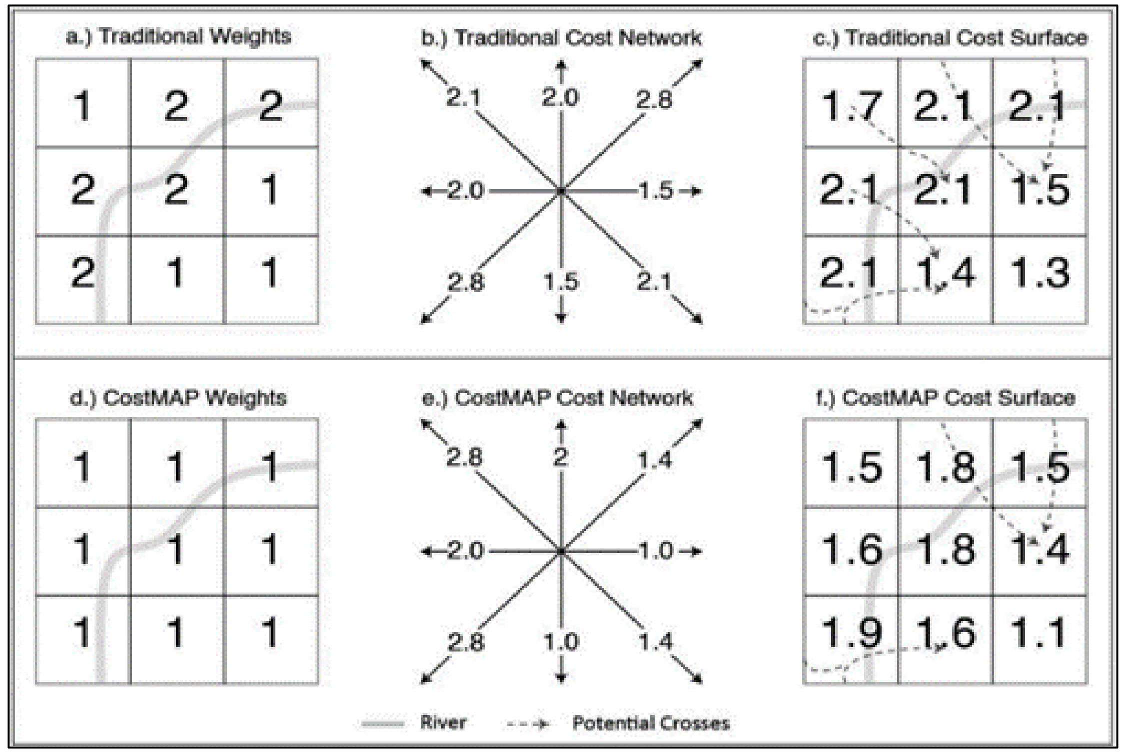
EOR RATIO

$$EOR_t^{RATIO} = \frac{\text{barrels of extra oil per year}}{\text{tonnes CO}_2\text{ injected per year}}$$

Reference : Brennan et al. (2010), USGS, Li et al. (2022), Arps (1945), Klokk et al. (2010)

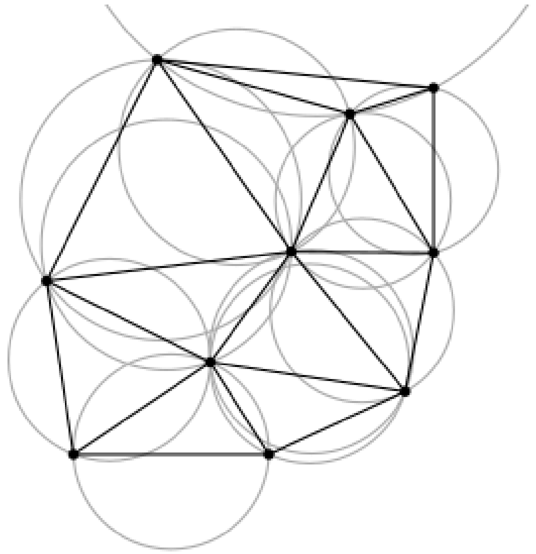
CO2 PIPELINE NETWORK OPTIMIZATION

Weighted Cost Surface



cost surface - a way of representing the cost or difficulty of moving through a certain area.

Cost Surface Multi-Layer Aggregation Program (CostMAP) - a tool that uses pre-existing GIS data to create rasterized cost surfaces.

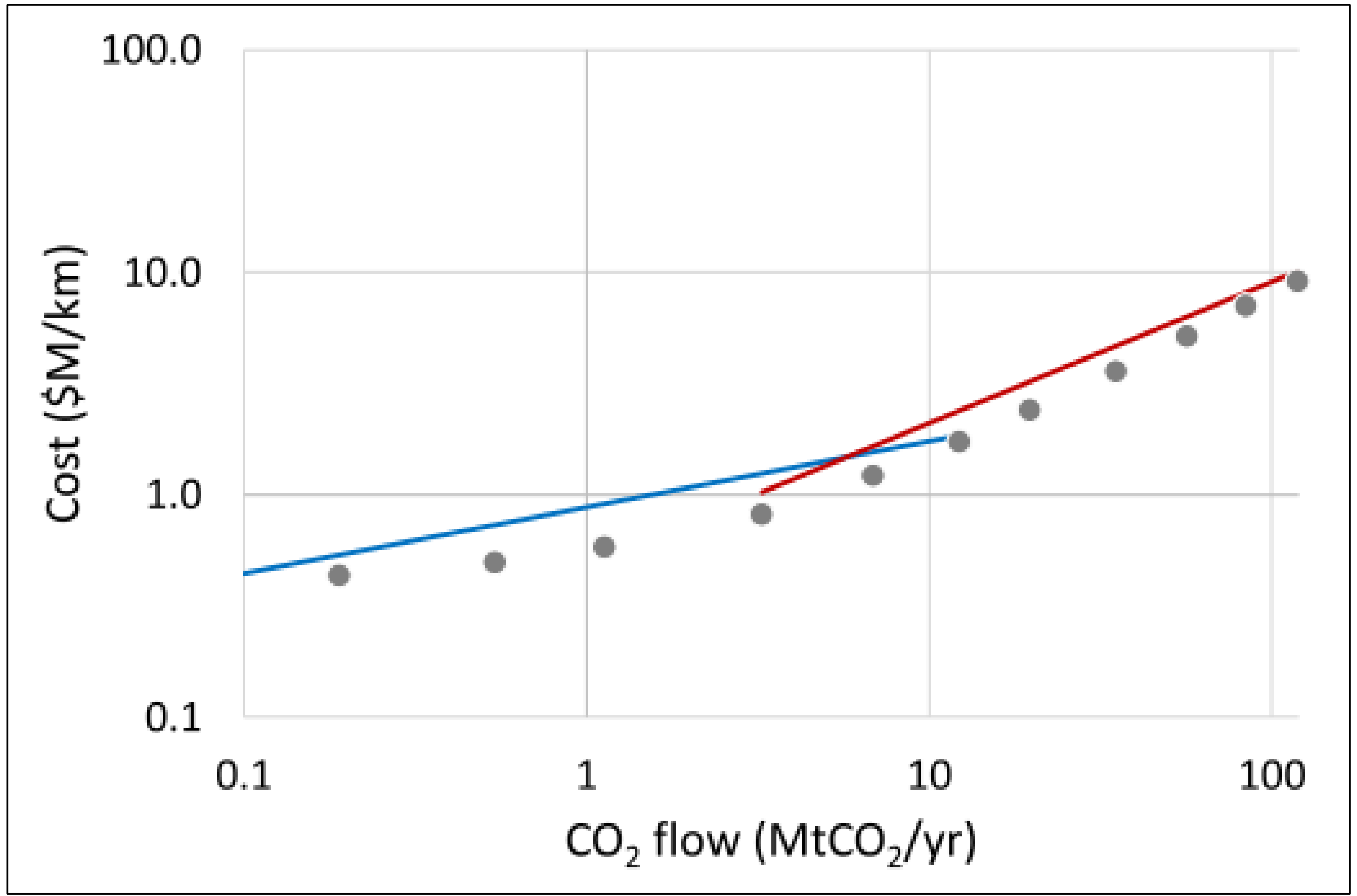


Delaunay Triangulation (DT) has been effectively used to generate a set of node pairs for which cost paths can be determined.

Integrating DT into raster LCP extraction using algorithms like Dijkstra's could produces optimal candidate networks.

BASIC THEORY

TRANSPORT COST MODEL



Reference : Jones et al. (2022), Morgan et al. (2022), Middleton et al. (2020)

Transport cost :

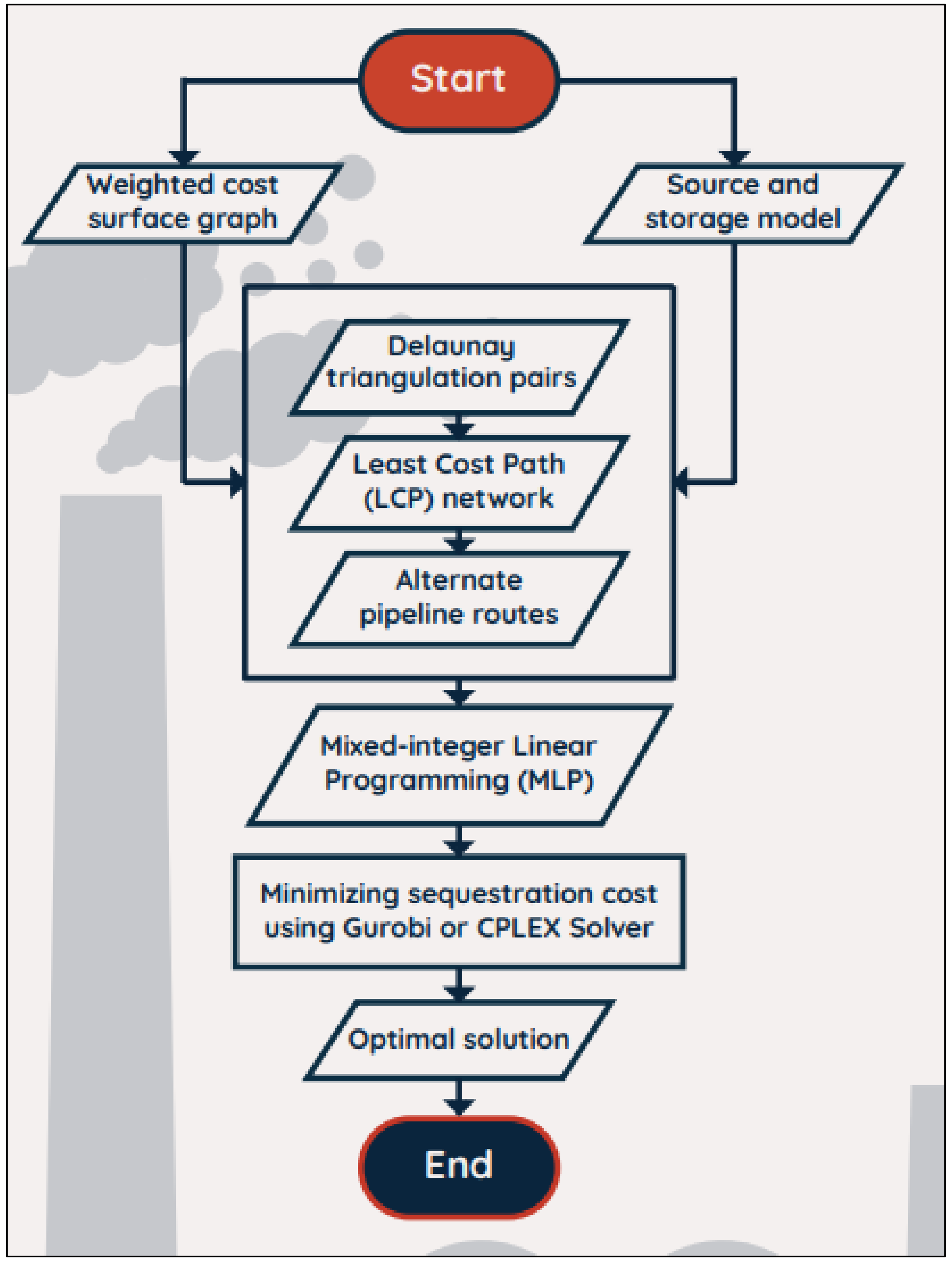
- *Pipeline construction or build cost*
- *Pipeline operation cost*

NETL Transport Cost Model :
An excel-based tool uses VBA macros to provide realistic cost breakdowns, including capital and operating costs, based on user inputs.

NETL Transport Cost Model vs Pipeline Cost Trends :
Using pipeline trends instead of explicit pipeline capacities (i.e., diameters) reduces the number of integer variables in the model (average absolute error (AAE) : 3%)

MATHEMATICAL MODEL

$$\underbrace{min \sum_{i \in S} (F_i^S + V_i^S a_i)}_{\text{capture cost}} + \underbrace{\sum_{j \in R} (F_j^R r_j + V_j^R b_j)}_{\text{storage cost}} + \underbrace{\sum_{a \in A} \sum_{c \in C} \beta_{ac} y_{ac}}_{\text{pipe build cost}} + \underbrace{\sum_{a \in A} \sum_{c \in C} \alpha_{ac} f_{ac}}_{\text{pipe use cost}}$$



CAPTURE MODEL

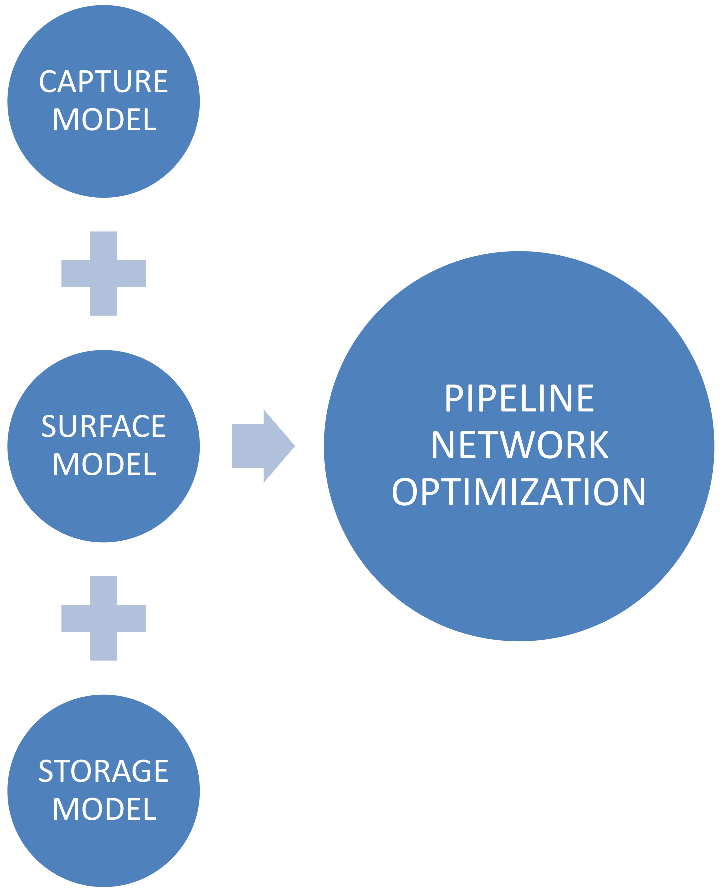
The capture model evaluated and tabulated the ***distribution of CO2 emitter locations, annual CO2 emissions****, and* ***capture costs.***

SURFACE MODEL

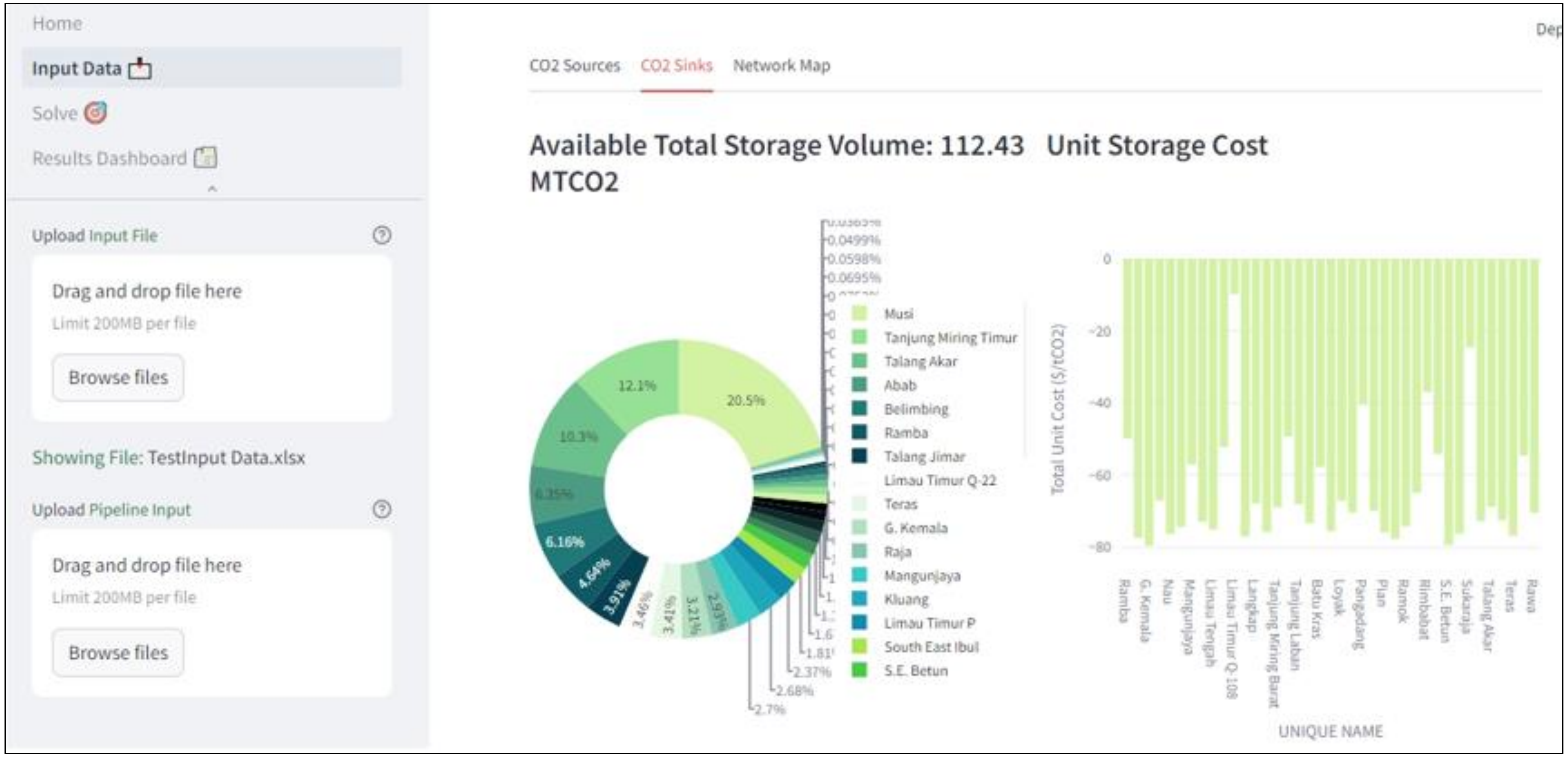
The surface model analyzed GIS data, including ***land cover, population, digital elevation model (DEM), roads, rivers, and pipelines****, processed using ArcGIS Pro to create ASCII files, which were then processed with CostMAP to produce a* ***weighted cost surface graph****.*

STORAGE MODEL

The storage model assessed the ***distribution of oil and gas fields****,* ***storage cost****, estimated their* ***EUR using the exponential DCA method****, and evaluated* ***CO2 storage capacity*** *using the United Stated Geological Survey* ***(USGS) methodology.***



USER INTERFACE : INPUT PAGE

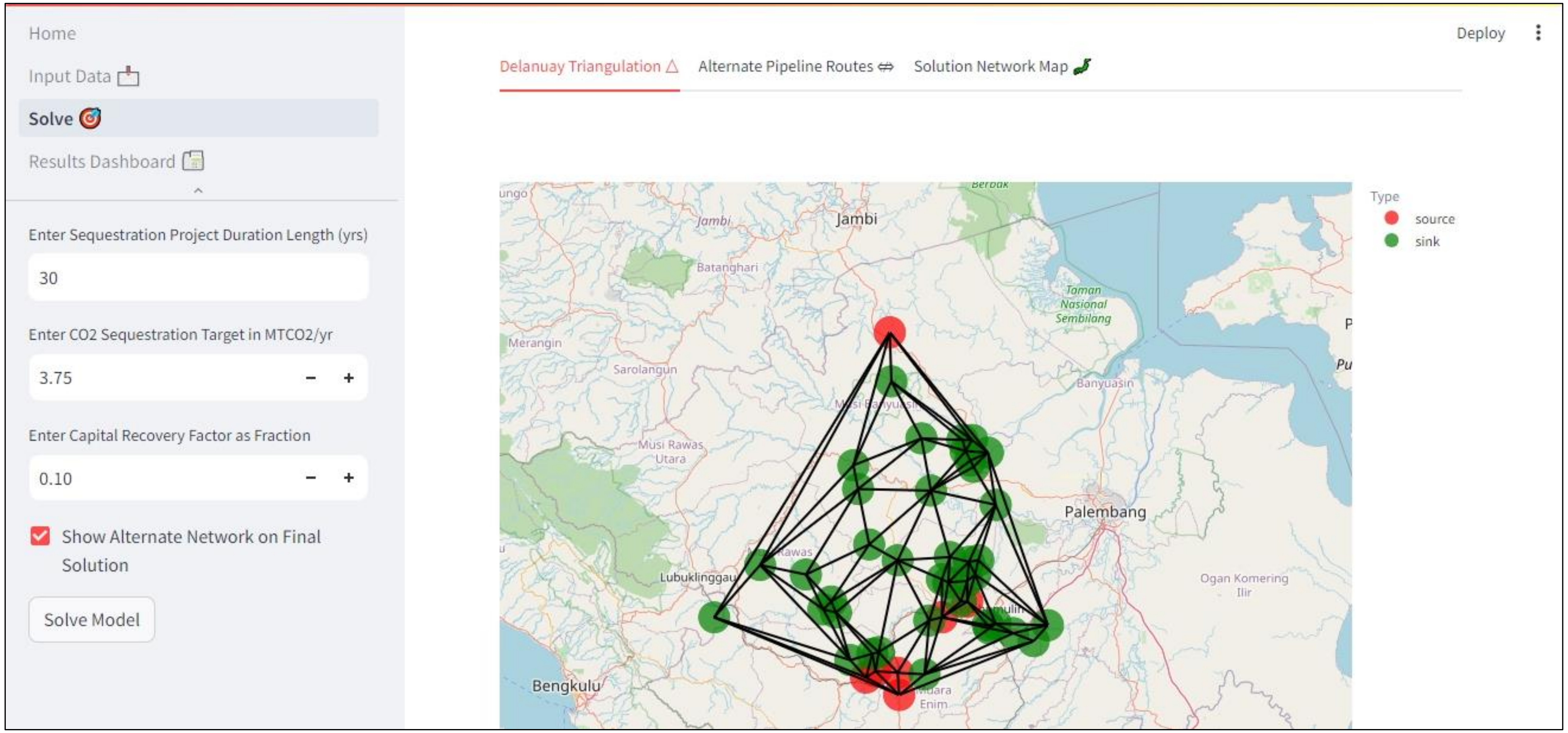


In input page, user can input :

- ***CO2 source and sink location coordinate***
- ***CO2 capture & storage capacity***
- ***Capture & injection cost***

OPTIMIZATION PLATFORM

USER INTERFACE : SOLVE PAGE

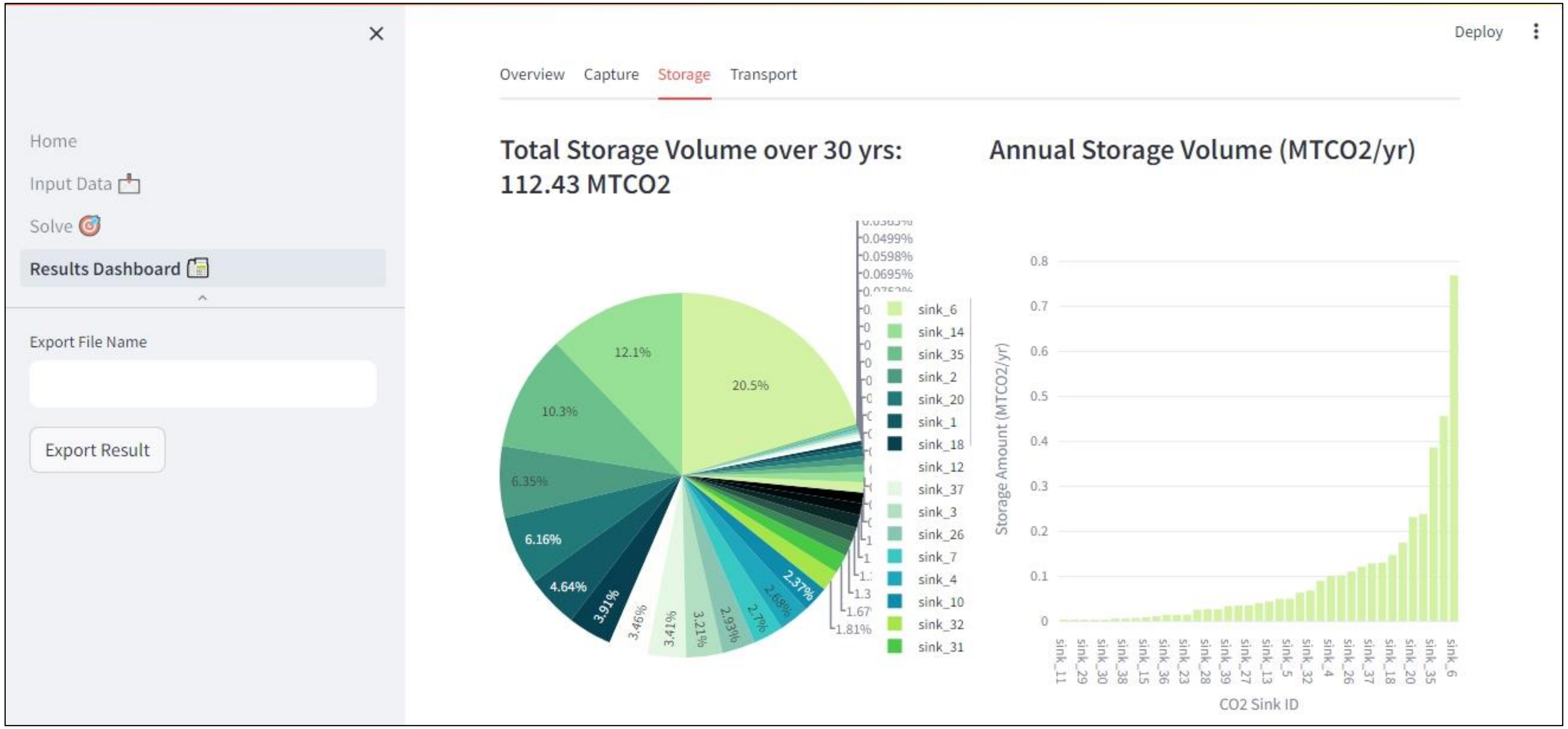


In solve page, user can input :

- ***Length project duration***
- ***CO2 sequestration target***
- ***Capital recovery factor (CRF)***

OPTIMIZATION PLATFORM

USER INTERFACE : RESULTS DASHBOARD

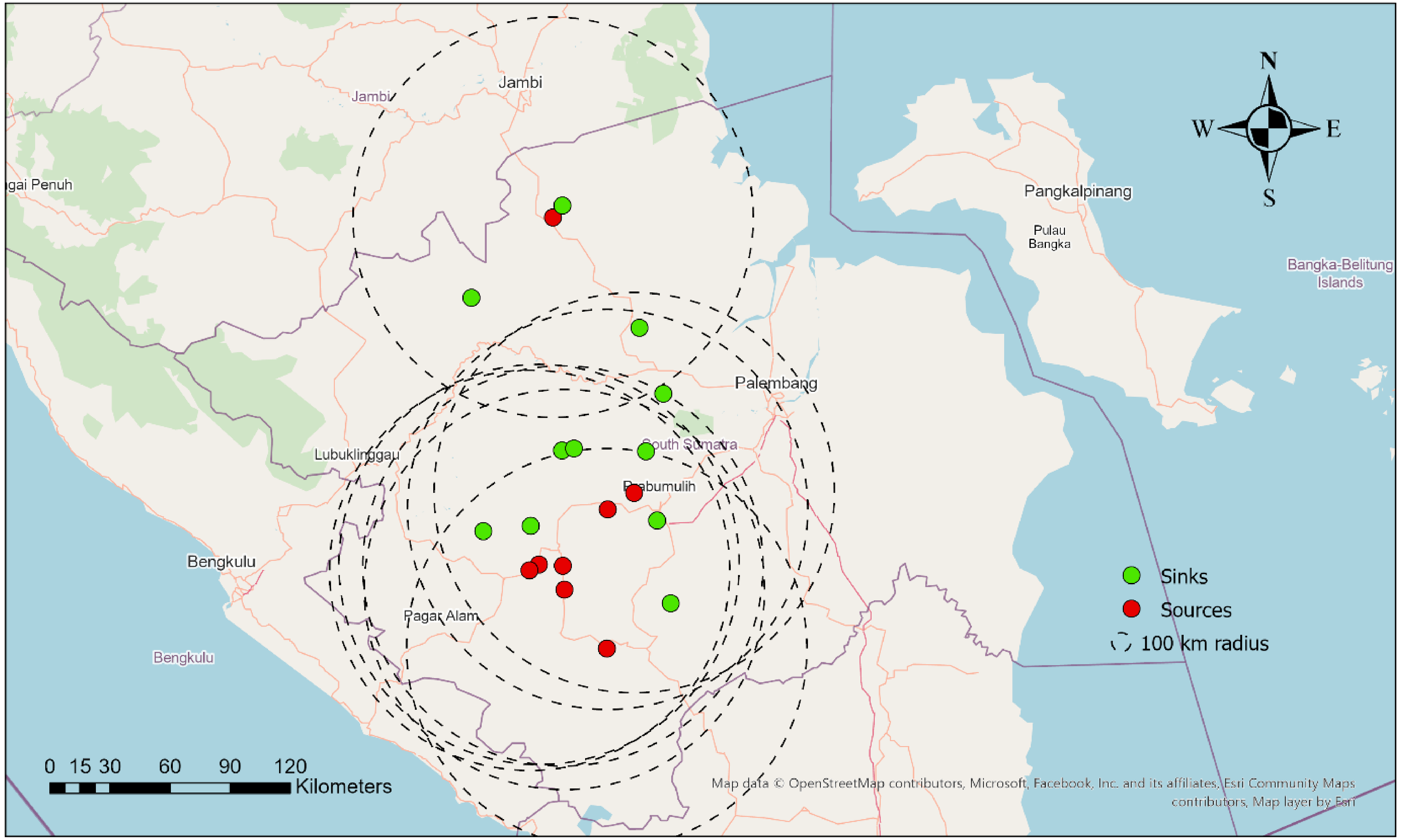


After optimization process was complete, user can see :

- ***Capture, transport, storage cost***
- ***Amount of CO2 captured and stored***
- ***Solutions breakdown***

CASE STUDY

AREA OVERVIEW



Field screening criteria :

- ***Fields were either onstream or have ceased production***
- ***Pressure and temperature of the main producing formations were within the ranges required for supercritical CO_2***
- ***The author only considered fields with CO_2 storage capacity > 5 Mt***
- ***Fields were within a 100 km radius of CO_2 sources***

The application of above criteria reduces the number of suitable fields from 71 to 11.

CASE STUDY : DATASET DESCRIPTION

CO2 SOURCES DATA

8 coal power plants (capacity > 30 MW)

Total CO2 amount : 14.4 $MtCO_2$/year

Source: Global Coal Power Plant Tracker (2024)

CAPTURE COST

Reference – The capture cost analysis was conducted using the post-combustion method with amine absorbent (capture efficiency 90%) by referring to RITE's study (2005).

Base cost – A basic cost breakdown of a capturing site at a retrofitted coal-fired power plant with a generating capacity of 540 MW and a capture capacity of 1 $MtCO_2$/year is one of the various scenarios offered by RITE's study.

Cost adjusment – A Plant Cost Index (PCI) published by Japan's METI was applied to adjust the costs from year 2005 (**PCI2005 : 130**) to the year 2020 (**PCI2020 : 160.2**).

SURFACE DATA

Degree precision versus length

decimal places	decimal degrees	DMS	Object that can be *unambiguously* recognized at this scale	N/S or E/W at equator	E/W at 23N/S	E/W at 45N/S	E/W at 67N/S
0	1.0	1° 00′ 0″	country or large region	111 km	102 km	78.7 km	43.5 km
1	0.1	0° 06′ 0″	large city or district	11.1 km	10.2 km	7.87 km	4.35 km
2	0.01	0° 00′ 36″	town or village	1.11 km	1.02 km	0.787 km	0.435 km
3	0.001	0° 00′ 3.6″	neighborhood, street	111 m	102 m	78.7 m	43.5 m
4	0.0001	0° 00′ 0.36″	individual street, large buildings	11.1 m	10.2 m	7.87 m	4.35 m
5	0.00001	0° 00′ 0.036″	individual trees, houses	1.11 m	1.02 m	0.787 m	0.435 m

Surface data :

- ***Landcover, population, aspect, slope (0.000833 decimal degree cell size)***
- ***Roads, rivers, railroads, pipeline (0.00833 decimal degree cell size)***

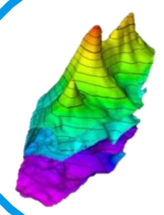
Reference : Food and Agriculture Organization (FAO) Land Cover Land Use database, WorldPop Hub, USGS.

CASE STUDY : DATASET DESCRIPTION

CO2 SINKS DATA

CO2 STORAGE CAPACITY ESTIMATION

Oil and gas production



Reservoir properties

STORAGE COST

Reference – The storage cost were evaluated based on RITE's study which classifies storage costs based on :

- ***Field location* (onshore *or* offshore)**
- ***Depth of sink* (1000 m and 2000 m)**
- ***Injectivity rate* (100 kt/year and 500 kt/year)**

PCI was also applied to adjust storage costs from 2005 to 2020

CO2 INJECTION RATE

Maximum production rate → Maximum injection rate

$$r_{inj\ max} = \frac{q_{max}}{N_w} \times \rho_{CO2} \times F$$

Reference : IPA Publications, RITE (2005), Li et al. (2022)

RESULT AND DISCUSSION

CO2 SOURCES AND SINKS AVAILABILITY

8 coal power plants, 14.4 $MtCO_2$/year

11 sinks, 418.9 $MtCO_2$

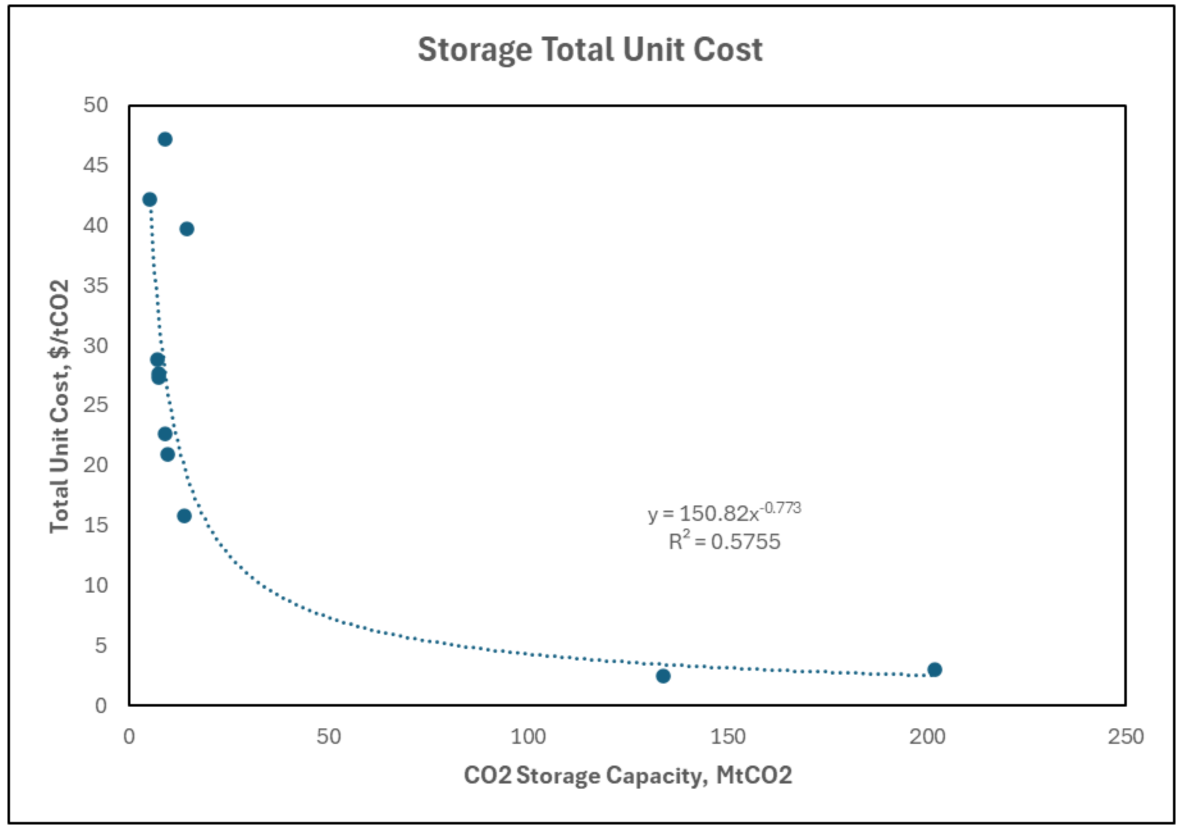
CAPTURE AND STORAGE COST

Capture cost – operating capture cost of $38.48/t$CO_2$ and various fixed cost.
Storage cost – generally, larger storage capacities and higher well injectivity capacities result in lower storage costs

Capture Cost

No	Power plant	Fixed Cost ($M)	Operating Cost ($/t$CO_2$)
1	Bangko Tengah power station	892.53	38.48
2	Banjarsari power station	185.94	38.48
3	Bukit Asam Muara Enim power station	297.51	38.48
4	Keban Agung power station	260.32	38.48
5	Shenhua Guohua power station	297.51	38.48
6	Sumbagsel-1 power station	260.32	38.48
7	Sumsel-1 power station	520.64	38.48
8	Sumsel-5 power station	260.32	38.48

Storage Cost



RESULT AND DISCUSSION

CO2 PIPELINE NETWORK OPTIMIZATION

Device – ASUS A43E with 6GB RAM and Intel(R) Core(TM) i3-2310M CPU @2.10GHz processor

OPTIMIZATION RESULTS USING DECARBONSYSTEM

Project Duration (yrs)	30
Capital Recovery Factor (%)	10
Annual Target Capture (MTCO2/yr)	14.4
Annual Actual Capture (MTCO2/yr)	13.96
Annual Storage Amount (MTCO2/yr)	13.96
Total Cost ($M/yr)	788.88
Capture Cost ($M/yr)	636.41
Transport Cost ($M/yr)	39.74
Storage Cost ($M/yr)	112.73

Capture and store 418.9 MtCO2

~527.95 km of new pipeline

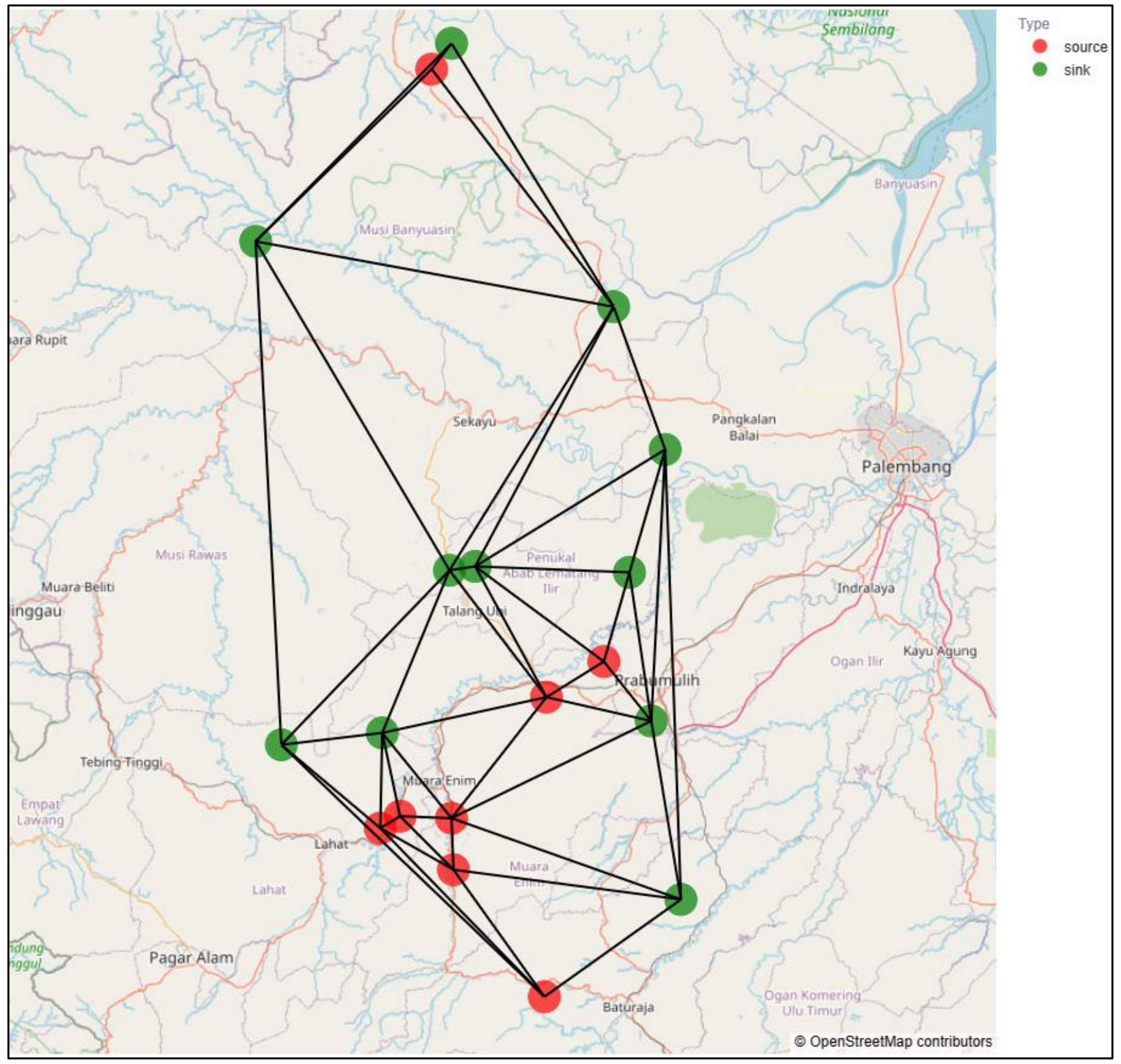
- Capture unit cost = $45.59/tCO2
- Transport unit cost = $2.85/tCO2
- Storage unit cost = $8.08/tCO2

$56.5/tCO2

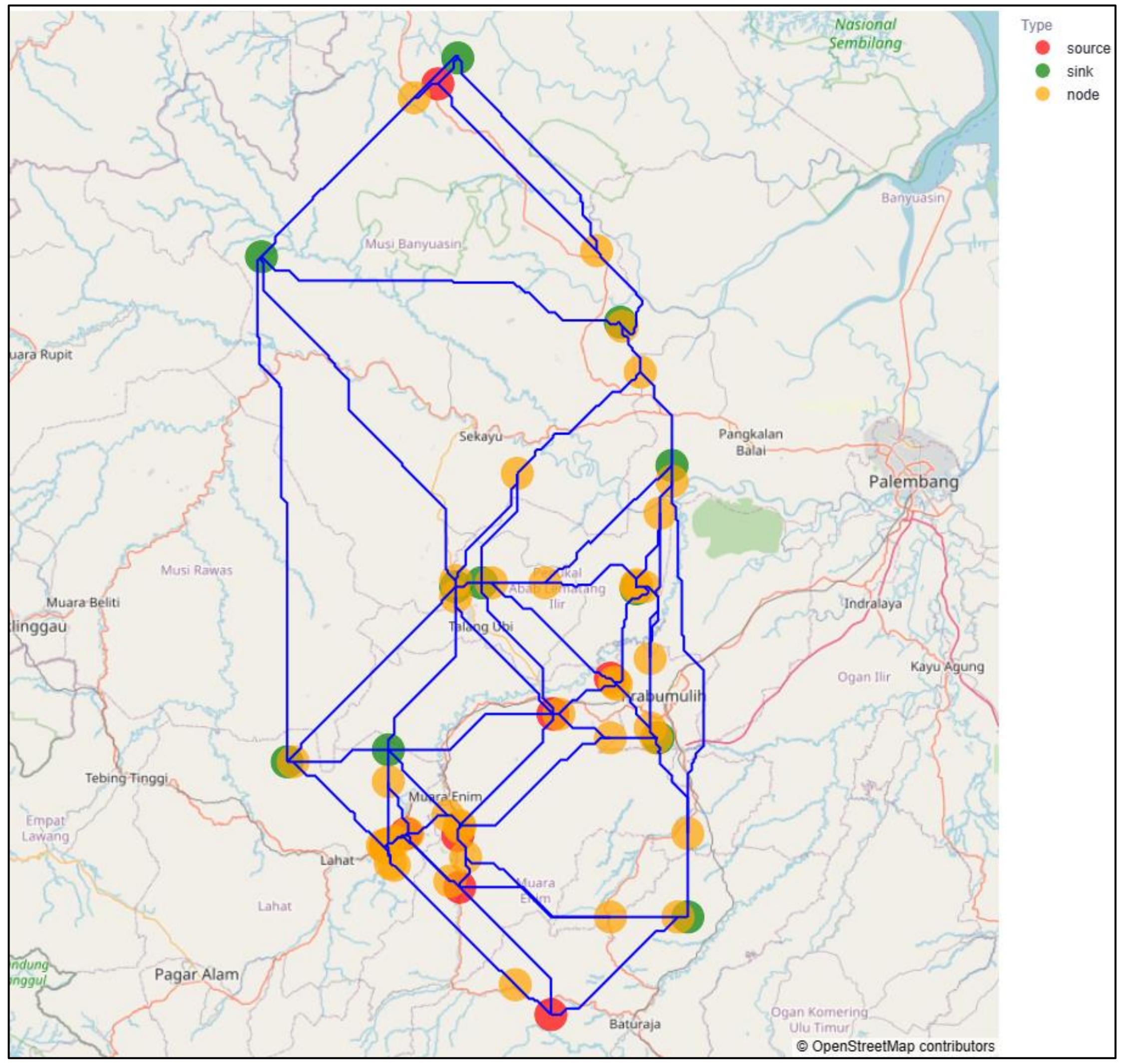
RESULT AND DISCUSSION

OPTIMIZATION RESULTS USING DECARBONSYSTEM

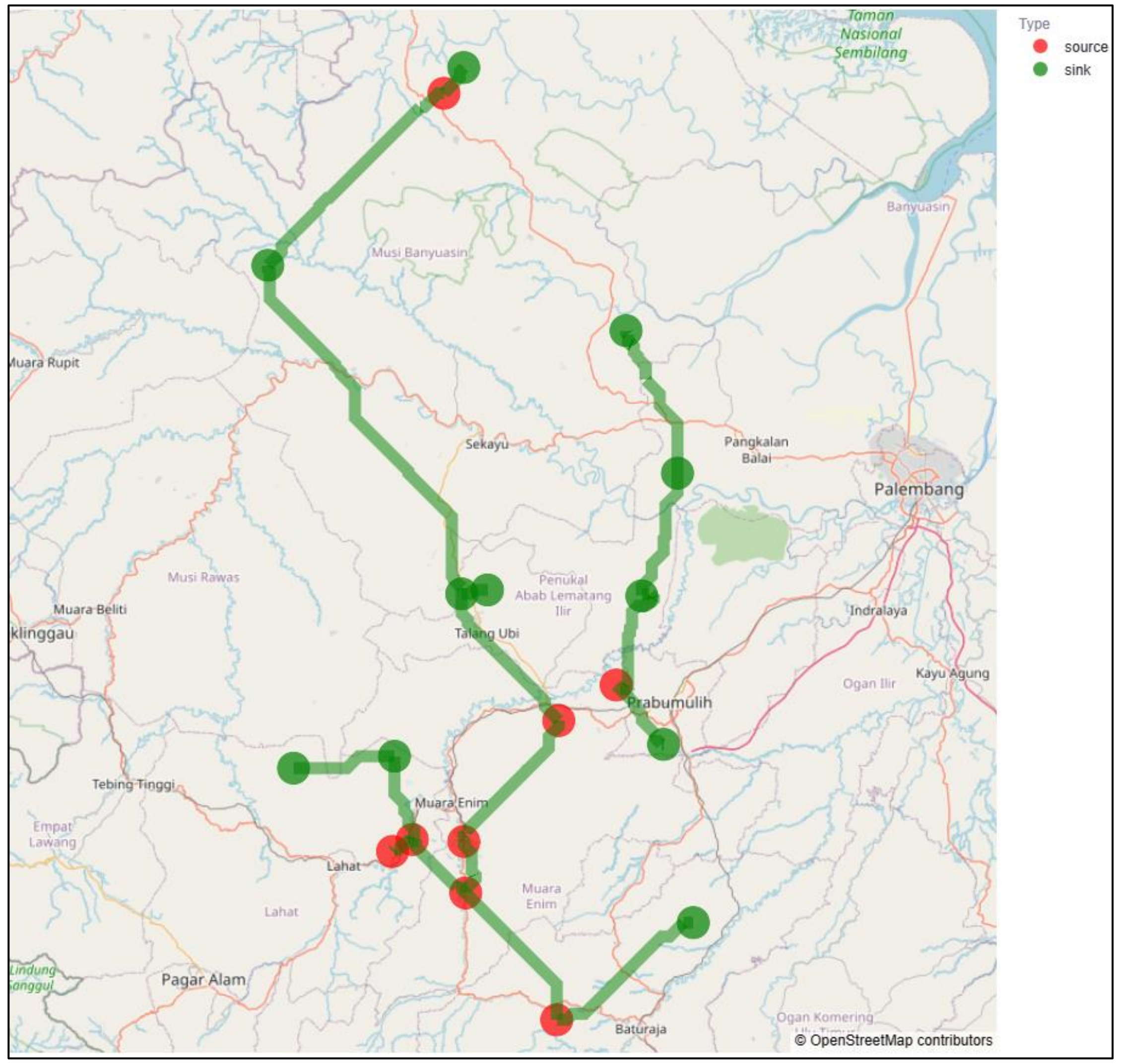
DELAUNAY TRIANGULATION



ALTERNATIVE PIPELINE ROUTES



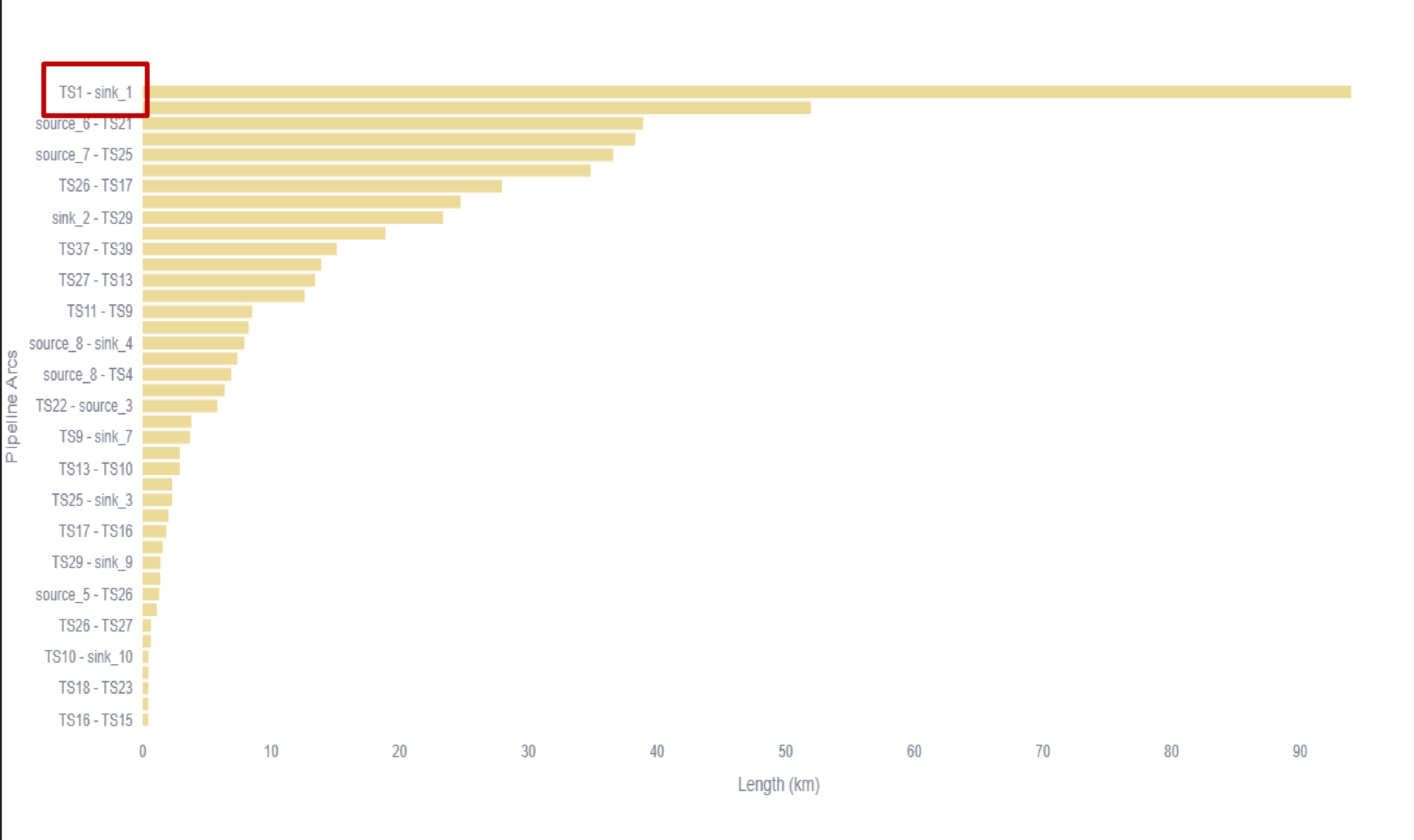
SOLUTION NETWORK MAP



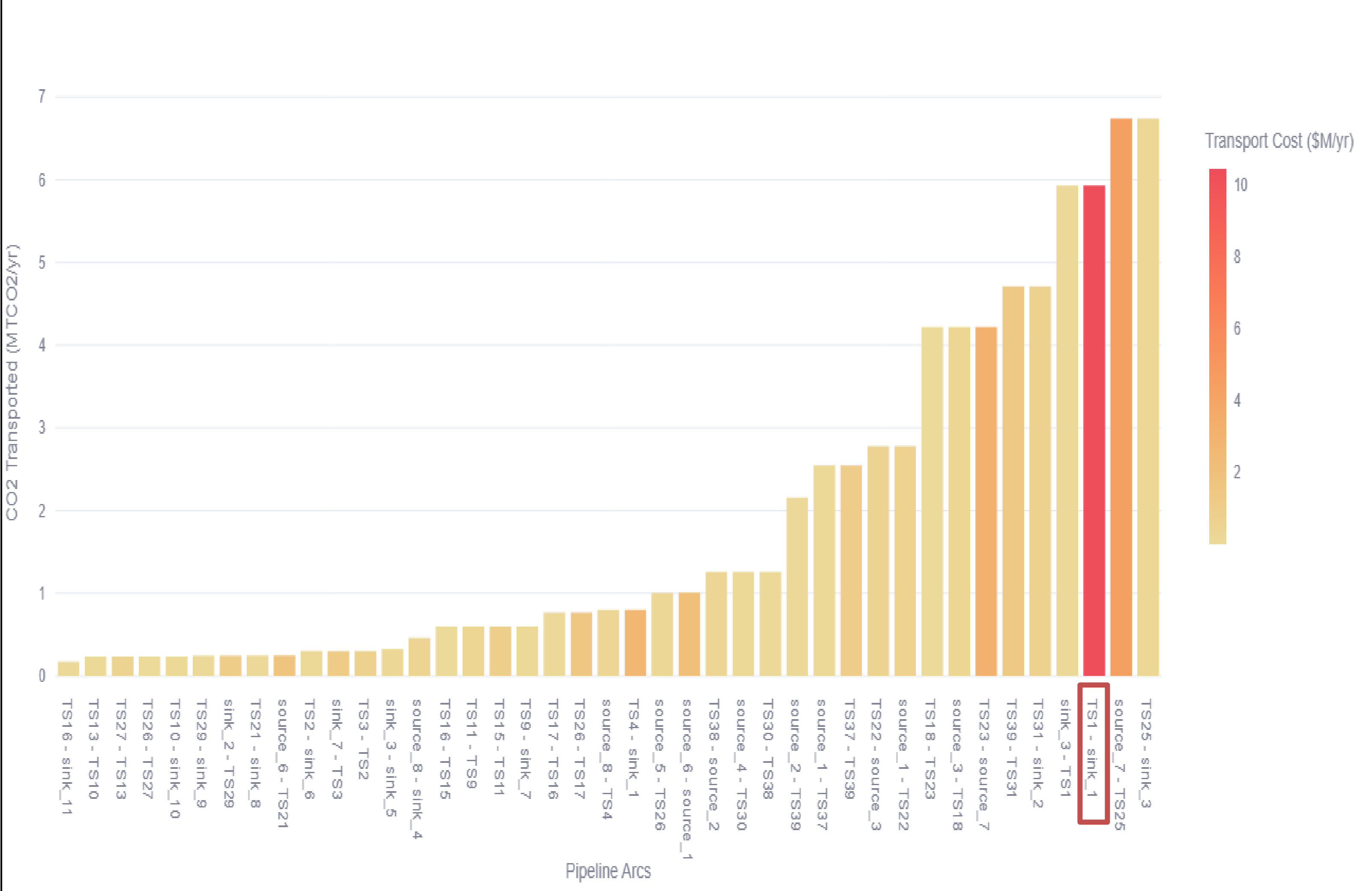
RESULT AND DISCUSSION

SOLUTIONS BREAKDOWN : PIPELINE

Pipeline Arcs Profile



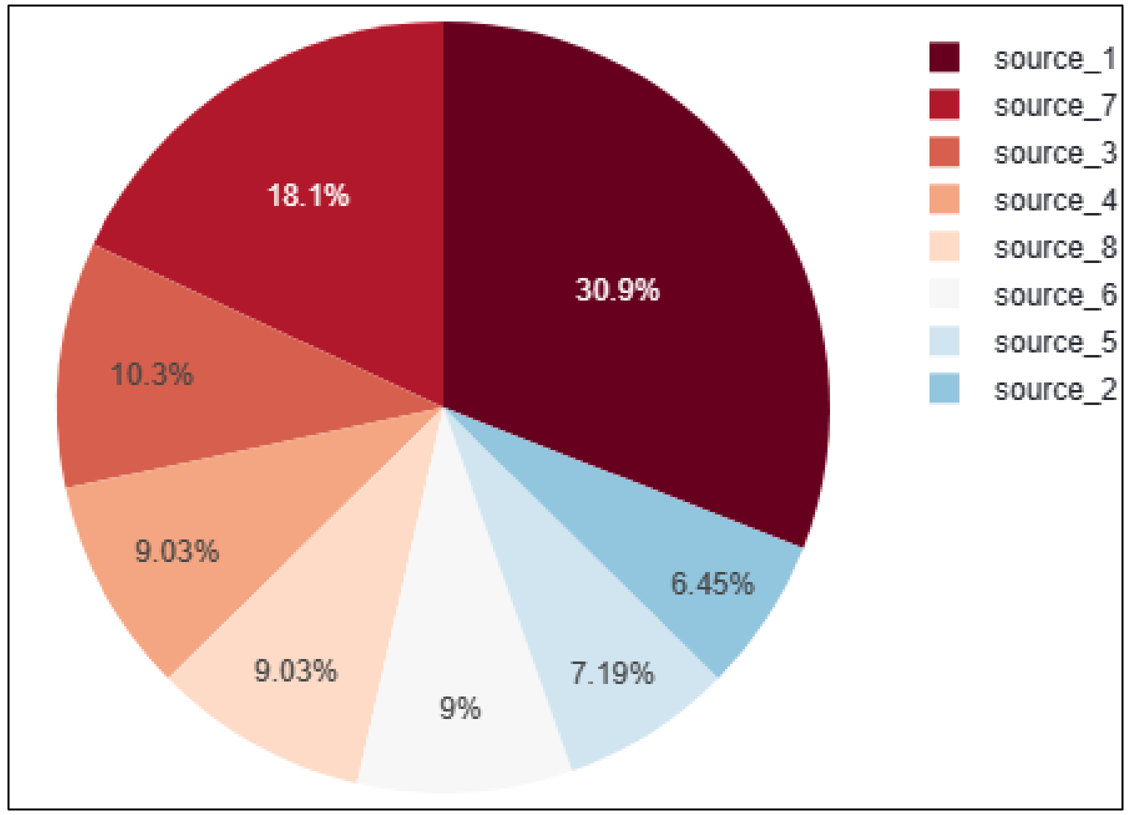
Transport Cost for Each Pipeline Arc



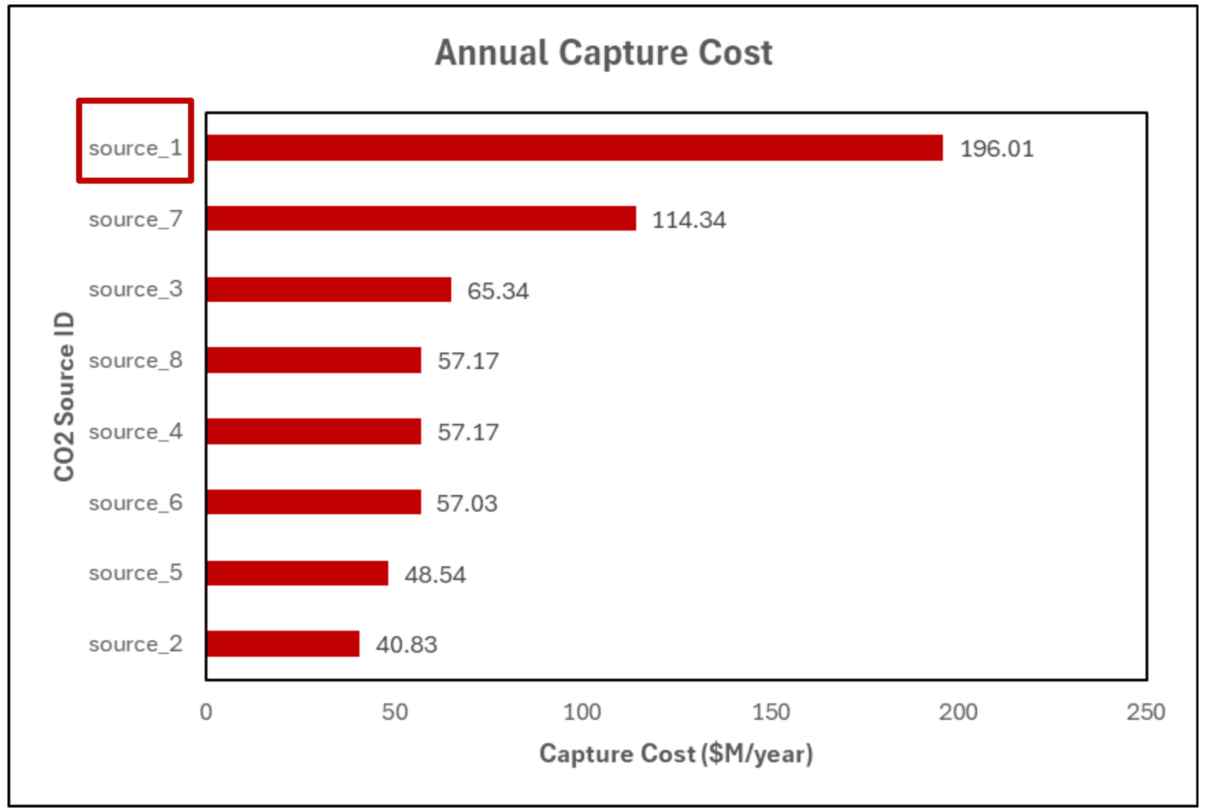
RESULT AND DISCUSSION

SOLUTIONS BREAKDOWN : SELECTED SOURCES

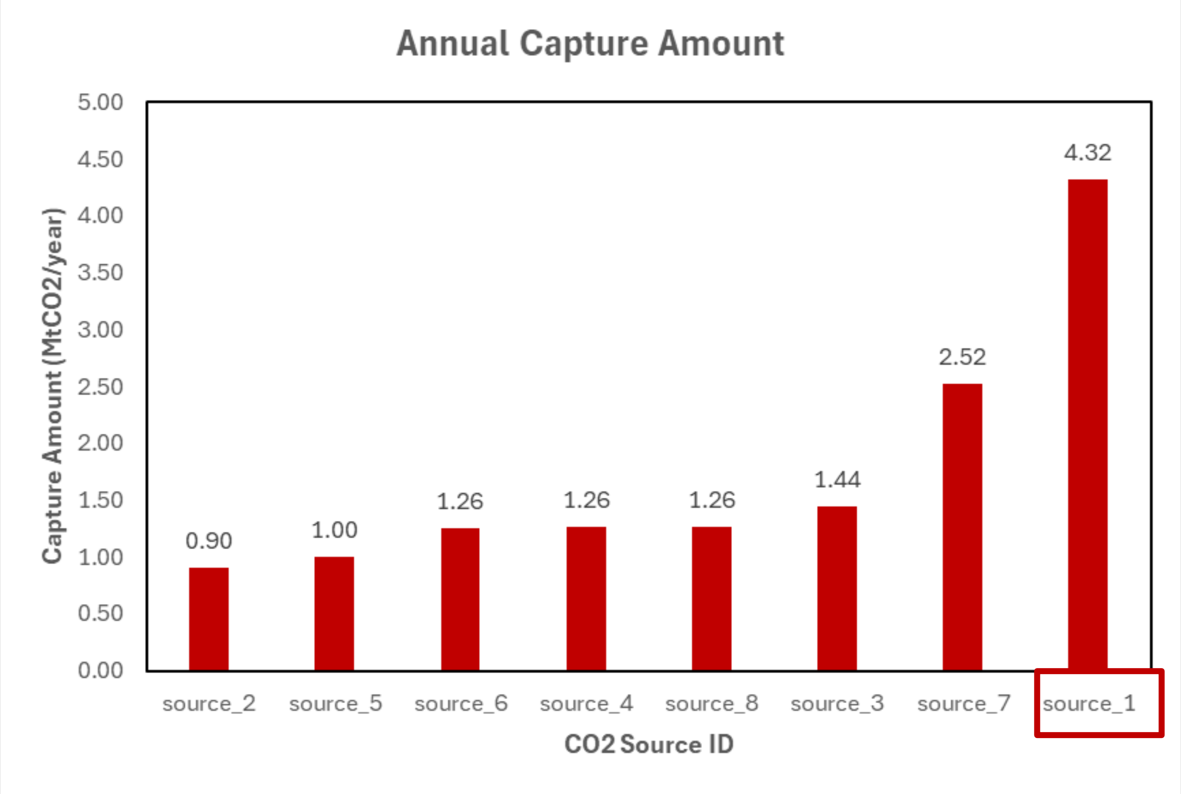
Total Capture Vol. Over 30 Years



Annual Capture Cost for Each Source

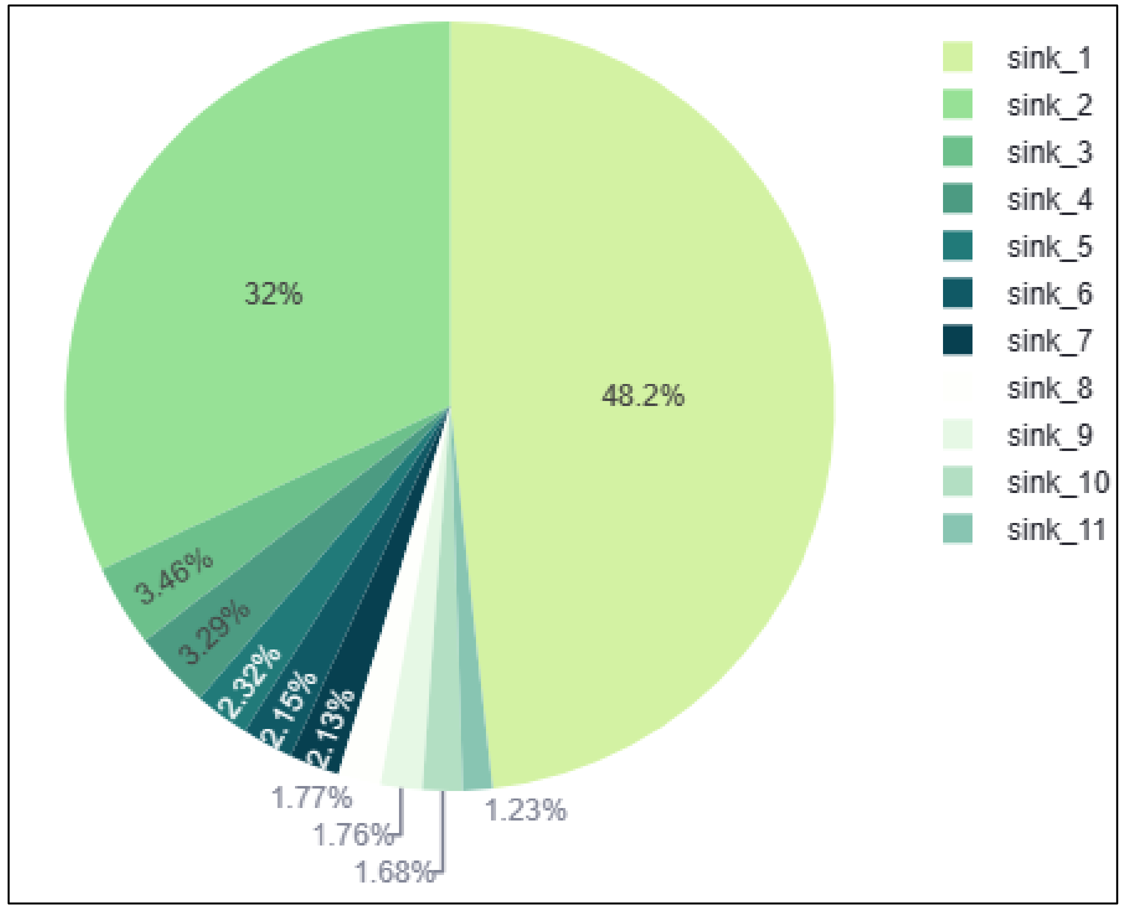


CO2 Captured Amount for Each Source

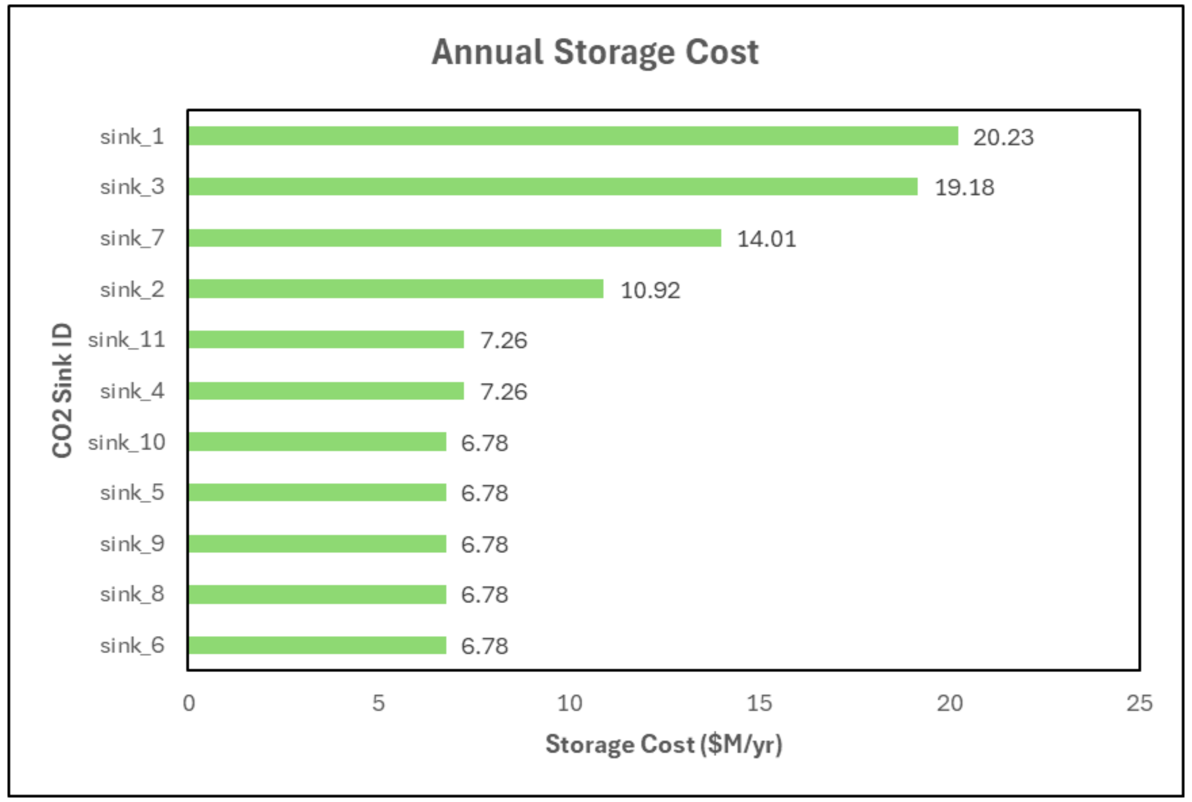


SOLUTIONS BREAKDOWN : SELECTED SINKS

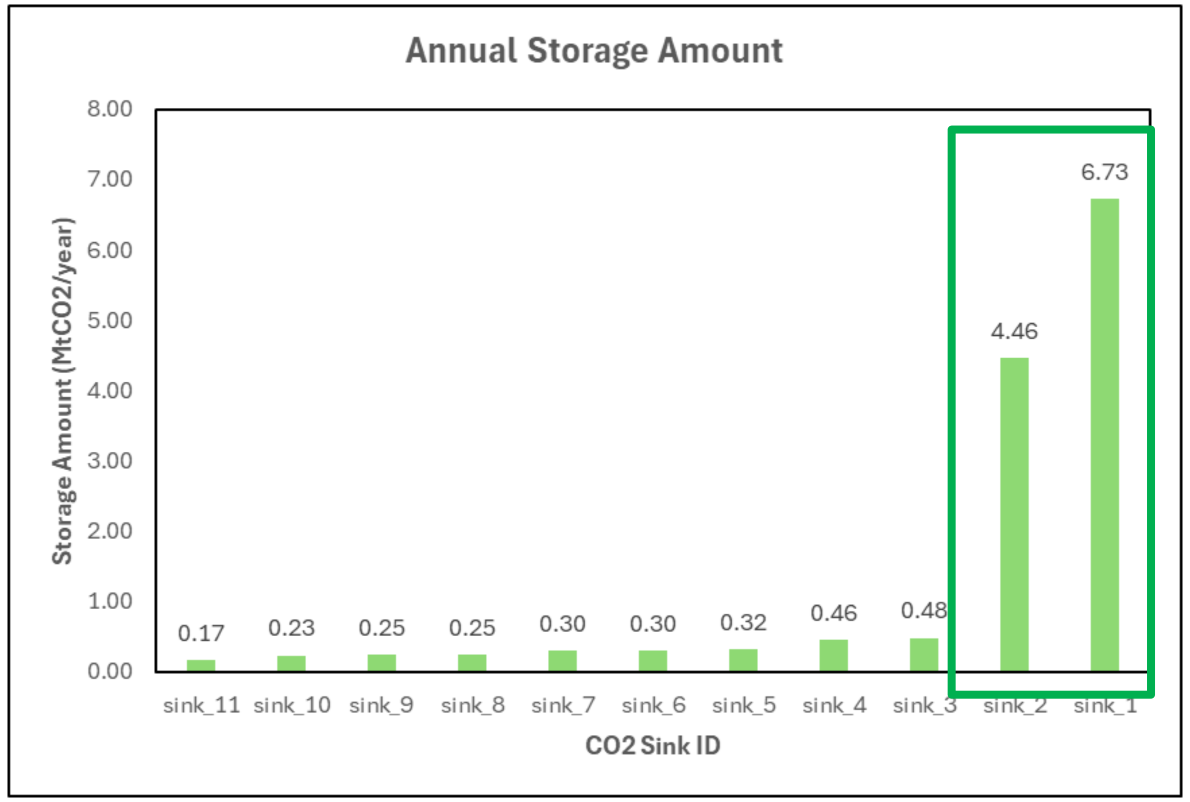
Total Storage Vol. Over 30 Years



Annual Storage Cost for Each Sink



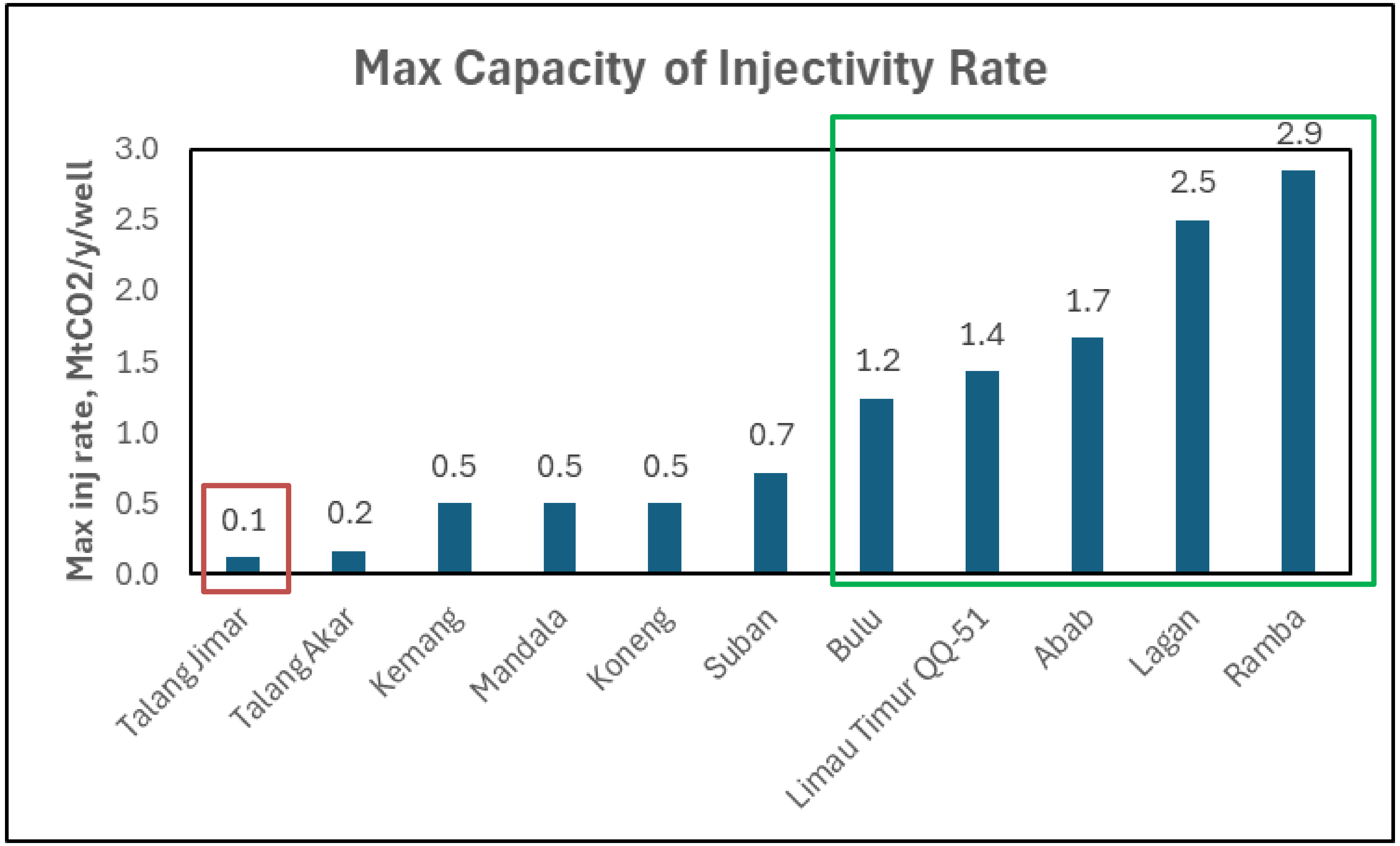
CO2 Storage Amount for Each Sink



Sink 1 (Suban) – Storage unit cost of \$3/tCO2

Sink 2 (Lagan) – Storage unit cost of \$2.45/tCO2

MAXIMUM CO2 INJECTION RATE



Max Injection Rate – The value of maximum injection capacity is depending on the fields' oil and gas production capacities

Max Injection rate >= 0.5 MtCO2/year – Injection well of 500 ktCO2/year will be used

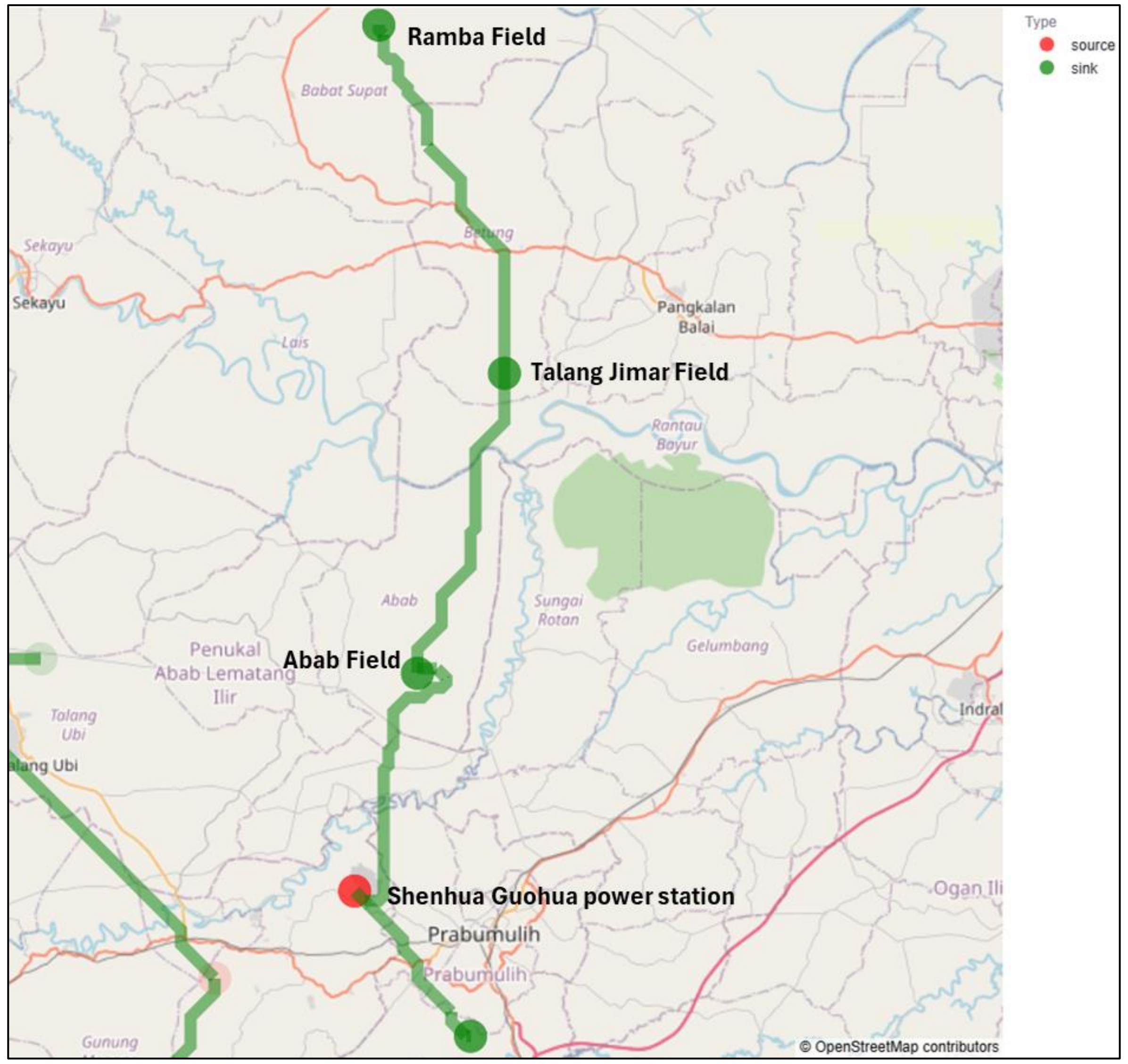
Max Injection rate < 0.5 MtCO2/year – Injection well of 100 ktCO2/year will be used

The low injectivity is mainly attributed to poor reservoir quality, leading to increased costs for injection, storage, and monitoring in CCS/CCUS projects (Li et al., 2022).

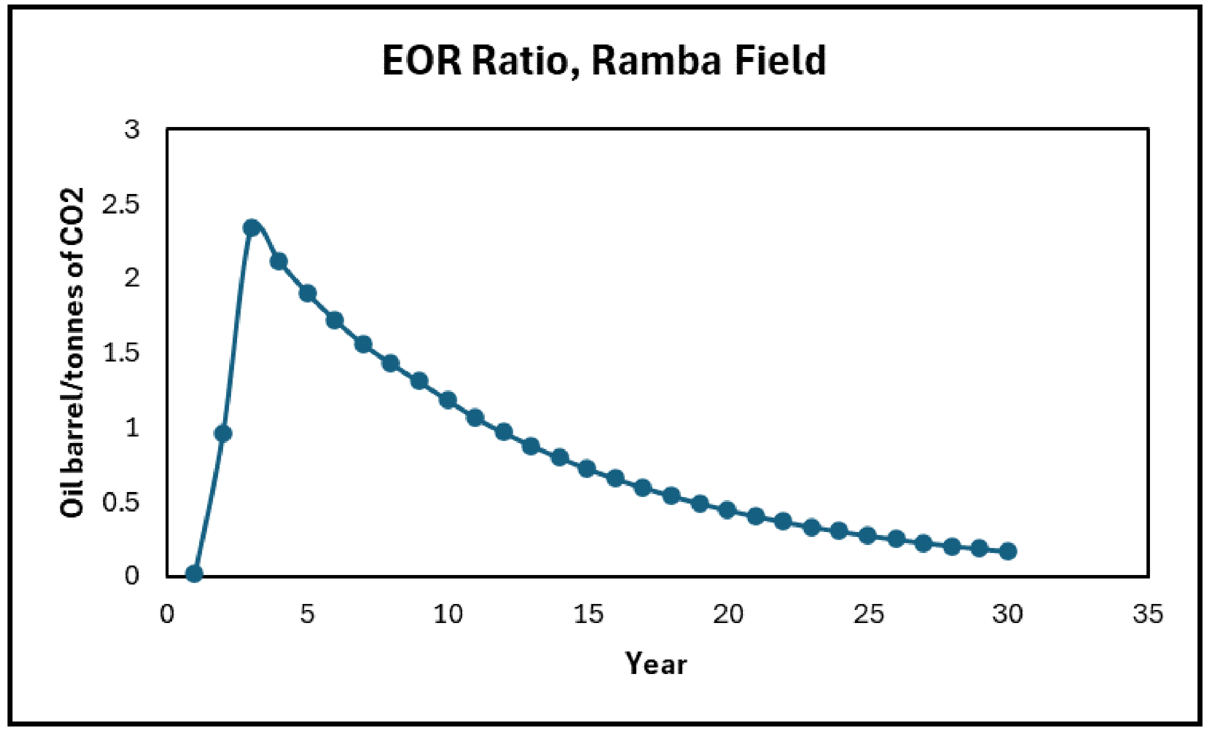
RESULT AND DISCUSSION

CCUS-EOR EVALUATION : RAMBA FIELD

Pipeline Network



EOR Ratio



~101.6 km of new pipeline

0.29 MtCO2/y was injected

Incremental oil recovery of 7.33 MMbbl

RESULT AND DISCUSSION

ECONOMIC EVALUATION

Project lifetime = 30 years | 10 sinks CCS, 1 sink CCUS-EOR									
No	Cost Assumption	Cost				MARR, %	Carbon Price, $/tCO2	Carbon Price (break even), $/tCO2	Note
		Capture, $/tCO2	Transport, $/tCO2	Storage, $/tCO2	Total Cost, $/tCO2				
1	- Capture cost, RITE (US$ 2005) - Storage cost, MEDCO	36.99	2.85	1.82	41.66	15	60.98	34.17	Transport cost > storage cost
2	- Capture cost, RITE (US$ 2020) - Storage cost, MEDCO	45.59	2.85	1.82	50.26	15	74.32	42.76	Transport cost > storage cost
3	- Capture cost, RITE (US$ 2005) - Storage cost, RITE (US$ 2005)	36.99	2.85	6.55	46.39	15	72.53	38.90	
4	- Capture cost, RITE (US$ 2020) - Storage cost, RITE (US$ 2020)	45.59	2.85	8.08	56.51	15	89.36	49.02	

Storage costs, RITE (also used by DIPA LEMIGAS)

- ***Field location*** **(*onshore* or *offshore*)**
- ***Depth of sink*** **(*1000 m and 2000 m*)**
- ***Injectivity rate*** **(*100 kt/year and 500 kt/year*)**

Storage costs, MEDCO

- ***Uniform for all injection wells***

CONCLUSION

The following points were the conclusions from this study :

DecarbonSystem Platform: Developed with Python and open-source tools, it integrates CCUS value chain models for flexible assessments.

Study Area: South Sumatra includes 8 coal power plants and 11 oil/gas fields with a CO_2 source capacity of 14.4 $MtCO_2$/year and storage capacity of 418.9 $MtCO_2$.

Optimization Results: 13.96 $MtCO_2$/year can be captured and stored over 30 years, transported via 527.95 km of new pipeline, with Bangko Tengah as the primary CO_2 source (31%) and Suban (48.2%) and Lagan (32%) as the largest storage sites.

CO_2 Oversupply: 0.44 $MtCO_2$/year.

Max. Injection Capacity: Lagan, Bulu, Ramba, Abab, and Limau Timur QQ-51 fields have injection capacities exceeding 1 $MtCO_2$/year/well, with Ramba having the highest at 2.9 $MtCO_2$/year/well.

Cost Breakdown: Capture costs \$45.59/tCO_2, transport costs \$2.85/tCO_2, and storage costs \$8.08/tCO_2, totaling **\$56.51/tCO_2**.

CCUS-EOR Potential: The Ramba field can potentially recover an additional 7.33 MMbbl of oil.

Economic Feasibility: A CO_2 price of \$89.36/tCO_2 is needed for feasibility, with a break-even price of \$49.02/tCO_2 at a MARR of 15%.

RECOMMENDATION

Future study should take into consideration of :

1	Multiple oil and/or gas existing pipelines to evaluate the scenario analysis **if the existing pipeline will be converted into CO_2 pipeline.**
2	Account for geological uncertainty regarding the potential volume of CO_2 stored during optimization.

THANK YOU!