9th AIEE Energy Symposium:
Current and Future Challenges to Energy Security

Assessing the Economic and Sectoral Impacts of Carbon Capture and Storage Integration in KGEMM

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1. INTRODUCTION

- Climate change needs mitigation strategies that balance environmental sustainability with economic development.

- Saudi Arabia has set a headline CCS target of 44 million tons of CO_2 emissions by 2035 as a pillar of the Kingdom's long-term climate strategy.

  CCS is critical in achieving Saudi Arabia’s climate goals, a strategic advantage that aligns with Vision 2030, the Circular Carbon Economy framework, the country’s goal for energy innovation, and leadership in climate action.

- Two aspects are crucial for developing oil-exporting countries: *maintaining economic growth and transitioning to a low-carbon economy*

2. RESEARCH OBJECTIVE

- Examine different financing mechanisms for the announced 44 $MtCO_2$ target
- Quantify macroeconomic and sectoral implications of CCS deployment in Saudi Arabia
- Integrate a CCS module into the KAPSARC Global Energy Macroeconometric Model (KGEMM).

3. METHODOLOGICAL FRAMEWORK

- Total cost calculation for carbon capture and for transportation & storage (CC, TS)
- Current and future levelized costs (LCOC, LCOTS) for CC and TS were estimated for 2025–2035.
- Cost allocation across sectors: services, manufacturing, and construction.
- Expenditures allocated between domestic and foreign suppliers.

TOTAL COST ESTIMATION

The CO_2 capture and CO_2 transport & storage total cost, including investment per sector (utilities and industry) was calculated using the equations below:

$$TCO\_CAP_S(t) = CO2\_CAP_S(t) * LCOC_S(t)$$

$$TCO\_TS_S(t) = CO2\_TS_S(t) * LCOTS_S(t)$$

$LCOC_S(t)$ is the CO_2 capture levelized cost in the year t for Sector S;

$LCOTS_S(t)$ is the CO_2 transport and storage levelized cost in the year t for Sector S;

S - represents utility and industry sectors.

CURRENT LEVELIZED COST CALCULATION

Sector-specific CO_2 capture costs range in the KSA's energy and industrial sectors (Rowaihy et.al., 2025)

Sector	CO_2 (MTPA)	Average Cost ($/ton)
Electricity	184	76
Desalination	42	70
Petrochemicals	47	68
Refineries	49	56
Cement	36	68
Iron and Steel	18	74
Ammonia	9	11

$$LCOC_S(t_0) = \frac{\sum CO2_{i\_S} \cdot Cost_{i\_S}}{\sum CO2_{i\_S}}$$

$LCOC_S(t_0)$ is the levelized cost of CO_2 capture in 2025 for sectors S (utilities or Industry) as estimated from the weighted average of individual sub-sectors (i)

$CO2_{i\_S}$ is the CO_2 emissions in (Mt/y) for sub-sector i of the sector S;

$Cost_{i\_S}$ is the average CO_2 capture levelized cost ($/ton) for sub-sector i of the sector S;

$\sum CO2_{i\_S}$ is the total CO_2 emissions for sub-sectors i of sector S;

t_0 represents the current year, which is 2025.

S - represents the utility or industry sectors in the simulations.

FUTURE LEVELIZED COST CALCULATION

Projected levelized cost of CO_2 capture (LCOC) for utility and industrial sectors in Saudi Arabia (2025–2035)
(Fashihi et.al. (2019), IEA CCUS Project Database)

$$LCOC_S(t) = LCOC_S(t_0) * \left(\frac{CCSCap\_S(t)}{CCSCap\_S(t_0)}\right)^{\lambda}$$

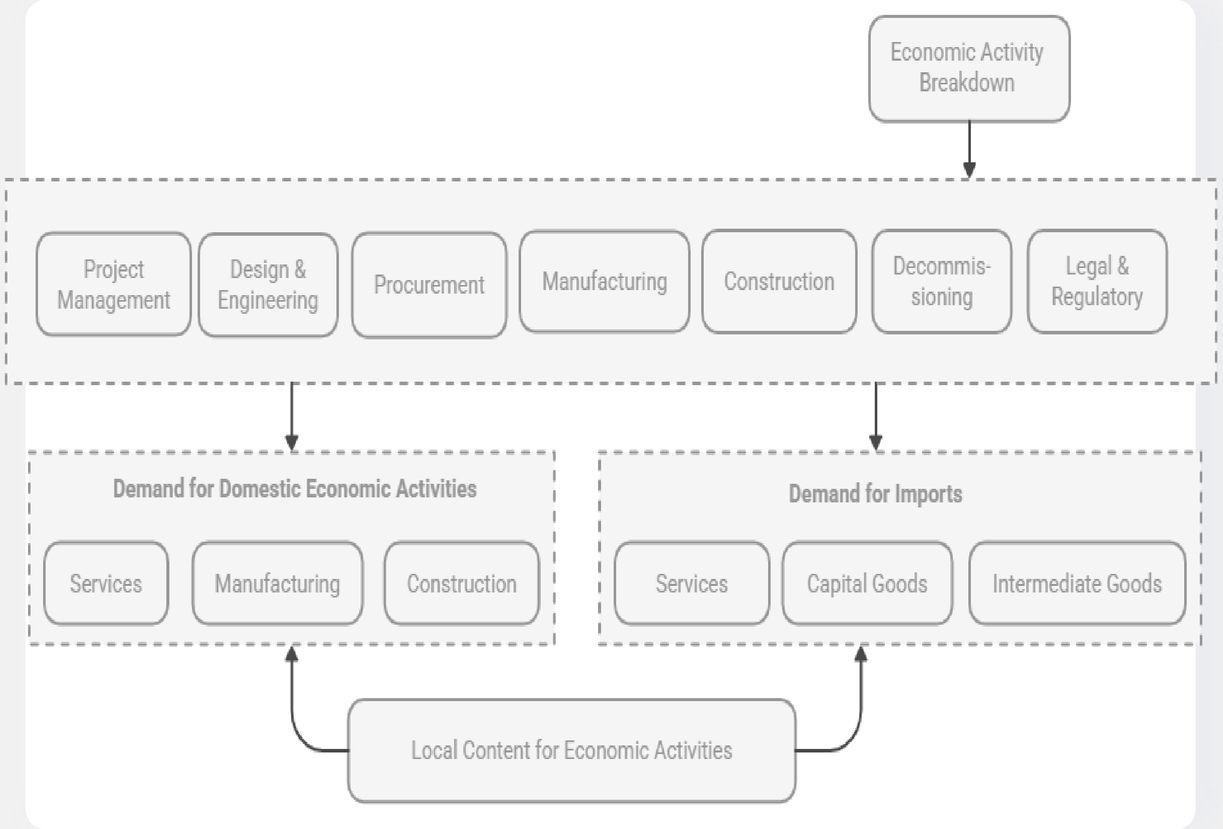
$$\lambda = \frac{\ln\ (1 - LR)}{Ln2}$$

Sector	Average LCOC, $/ton CO_2			Average LCOTS, $/ton CO_2		
	Current	2030*	2035*	Current	2030**	2035**
Utilities	75	68	53	50	42	33
Industry	62	45	31	50	42	33

Note:
* Based on a learning rate, LR of 10% for the utilities sector and 15% for the industrial Sector
** Based on a learning rate of 10%

$LCOC_S(t)$ is the estimated levelized cost of CO_2 capture in the industrial Sector S in year t (t can be 2030 or 2035)
$CCSCap(t_0)$ - CCS capacity installed globally as of 2025 (circa. 50 Mt/year)
$CCSCap(t)$ - CCS capacity installed globally in the year t
LR is a learning rate (assumed 10% for utilities, λ = -0.15, and 15% for industry, λ = -0.23)
t_0 is the current year, which is 2025, and t is the future years, which is 2030 or 2035.
S - represents the utility and industry sectors

ALLOCATION OF TOTAL COST AMONG ECONOMIC ACTIVITIES, LOCAL AND FOREIGN SUPPLIERS



Based on the Odeh and Haydock (2012).

The allocation is based on an *economic activity breakdown*, which contains the economic modeling techniques and supply chain assumptions used in the literature (e.g., see Odeh and Haydock, 2012).

- Seven economic activities are identified:
  - **project management**, covering front-end planning, coordination, and contract administration.
  - **design and engineering**, where detailed drawings and process specifications are produced.
  - **procurement**, funding the purchase of **manufacturing** goods, such as compressors, pipelines, absorbents, and other capital goods.
  - **construction and installation**.
  - **decommissioning**, ensuring that obsolete equipment can be dismantled safely and sites remediated.
  - **legal and regulatory** spending for permits, compliance monitoring, and liability management.

The next step is classifying it between **domestic** and **foreign** suppliers. This classification is based on the local content framework for economic activities.

ALLOCATION OF THE TOTAL COST AMONG ECONOMIC ACTIVITIES

Breakdown of total expenditure of CCS by economic activities and local content. (Odeh and Haydock (2012))

Activity	CO_2 capture			CO_2 Transport & Storage		
	Total cost split, % [1]	Domestic share, % [2]	Import share, % [3]	Total cost split, % [1]	Domestic share, % [2]	Import share, % [3]
Project Management	10	70	30	10	70	30
Design & Engineering	15	70	30	10	70	30
Procurement	5	70	30	5	70	30
Manufacturing	35	55	45	35	70	30
Construction & Installation	25	100	0	30	100	0
Commissioning	5	30	70	5	30	70
Legal & Regulatory	5	70	30	5	70	30

Note:

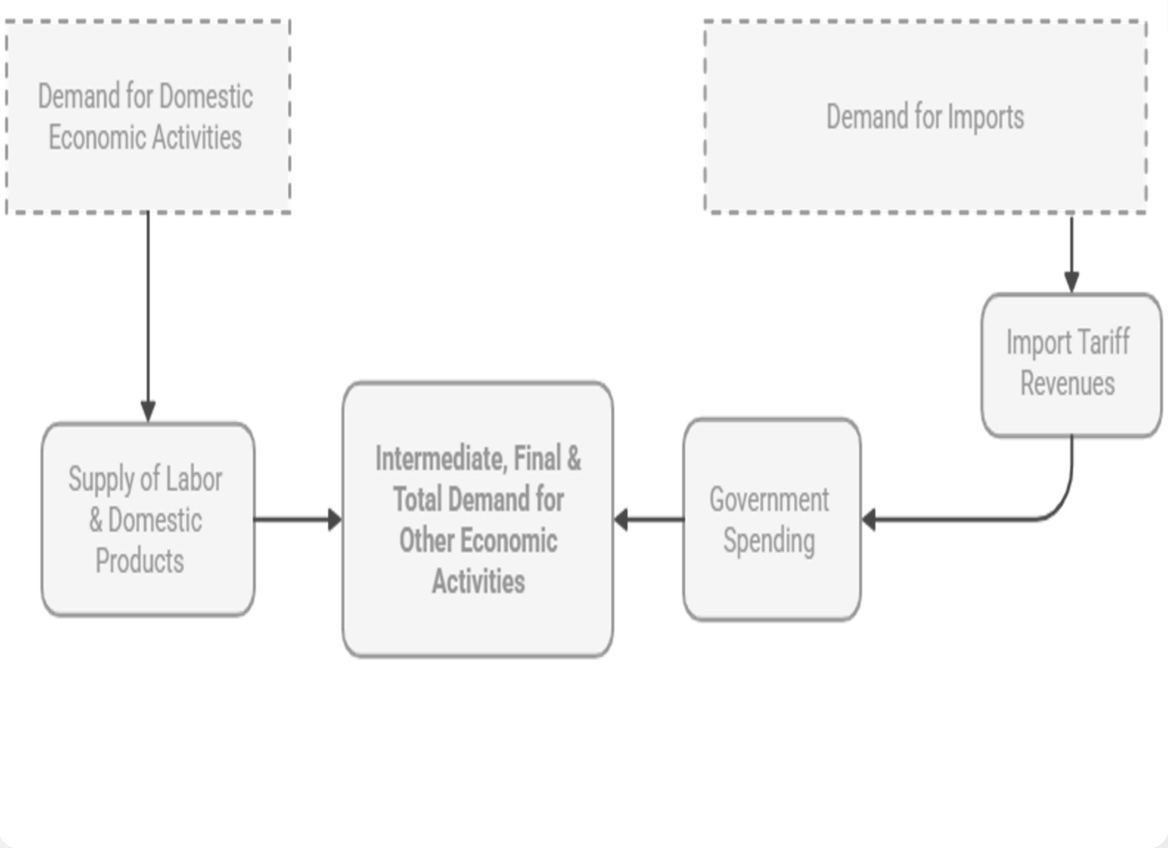
[1] The share of activity i (e.g., project management) in the total CO_2 capture or T&S cost.

[2] The local content of activity i (i.e., the share of activity i which is undertaken within Saudi Arabia).

[3] The proportion of activity i that is imported.

SECTORAL AND MACROECONOMIC EFFECTS OF CCS-RELATED EXPENDITURE

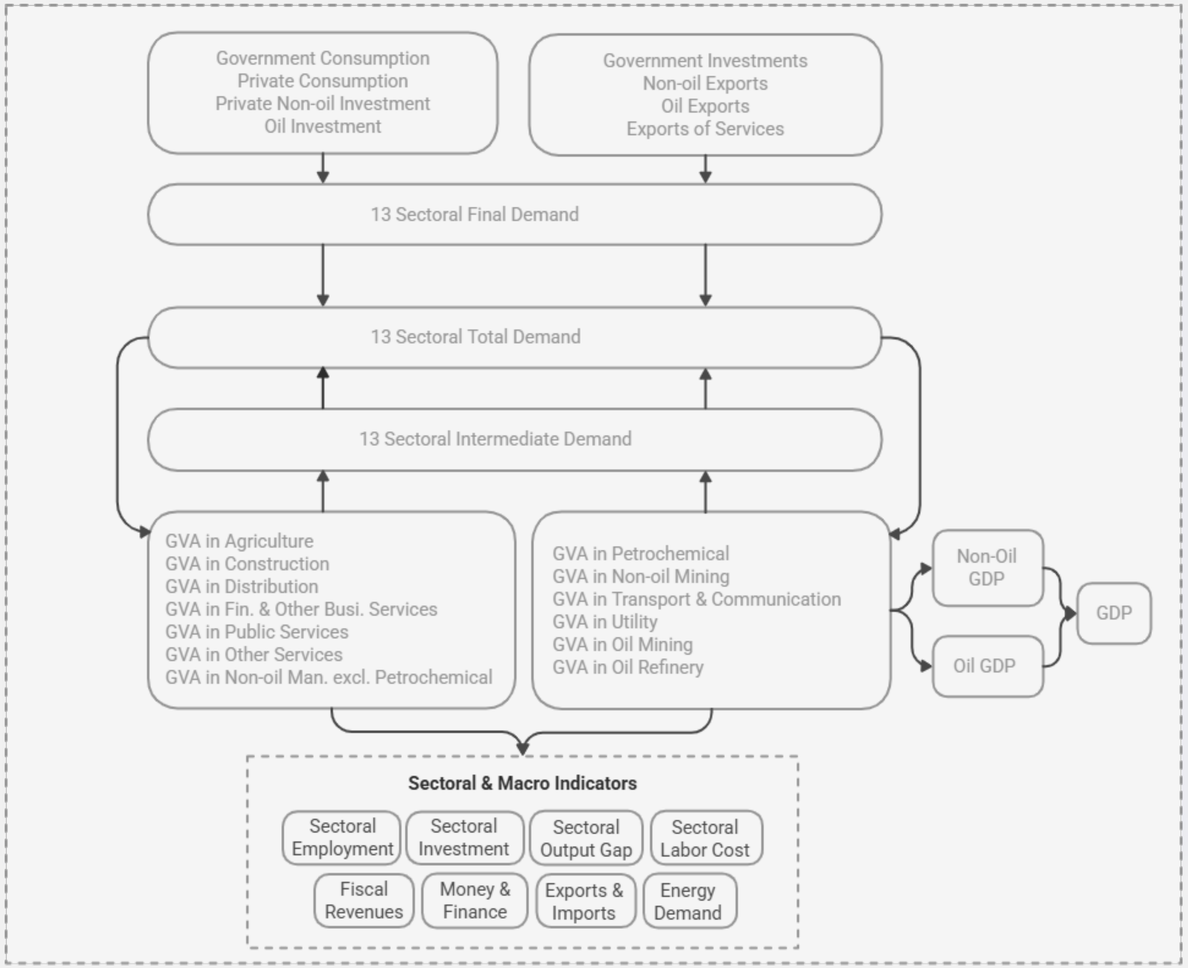
A short representation of economic effects



Domestic economic activities of services, manufacturing, and construction lead to an increase in the supply of employment and production of these sectors, which in turn positively spills over to other economic activity sectors, resulting in changes in macroeconomic indicators.

SECTORAL AND MACROECONOMIC EFFECTS OF CCS-RELATED EXPENDITURE

Detailed representations of economic effects



- The representations of demand for goods and services in the KGEMM reflect the comprehensive framework of the Input-Output model/table.

- In the KGEMM, demand for goods and services is broken into (i) intermediate demand, final demand, and total demand, and (ii) across 13 sectoral economic activities. The intermediate demand is the interaction between 13 economic activity sectors, where they buy and sell from each other.

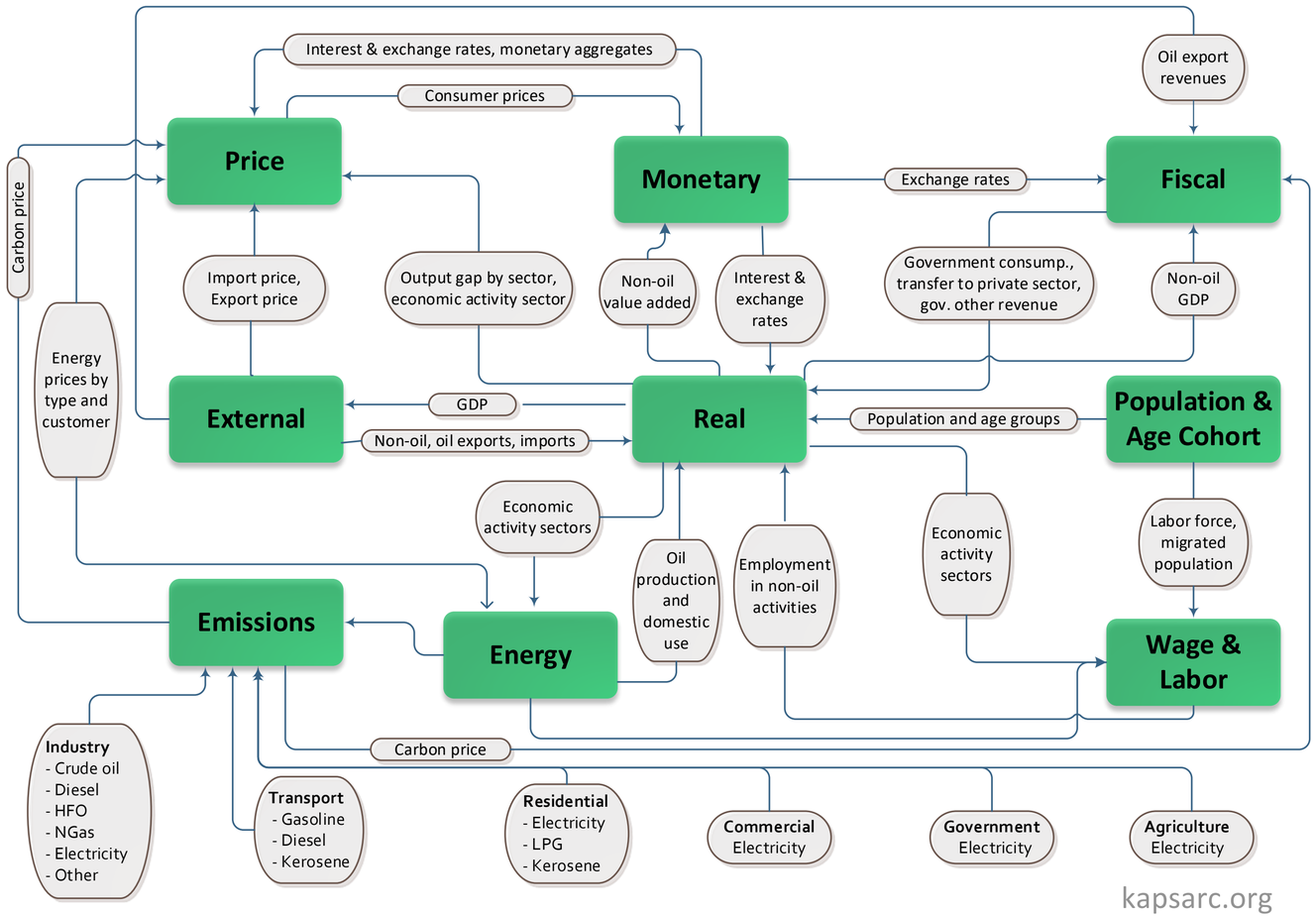
4. SCENARIO ANALYSIS

- Macroeconometric modelling framework - KGEMM
- Simulation assumptions.
- Scenario inputs and designing.

MACROECONOMETRIC MODELLING FRAMEWORK - KGEMM

KAPSARC Global Energy Macro-econometric Model is a policy tool used to assess the impact of domestically made decisions and global changes on Saudi Arabia's economic-energy-environmental indicators at aggregate and disaggregate levels (Hasanov et al., 2023).

- Hybrid Macro-econometric Model
- Contains Input-Output Model Elements
- CO2 ⟷ Energy ⟷ Economic Feedback.
- About 1000 time series variables, 300+ equations
- 9 blocks interacting with each other to represent economic-energy-environmental linkages in KSA.
- Macroeconomy & 13 economic activity sectors of KSA.
- Sectoral Indicators (e.g., Value Added, Employment, Investments, Wages, Prices).

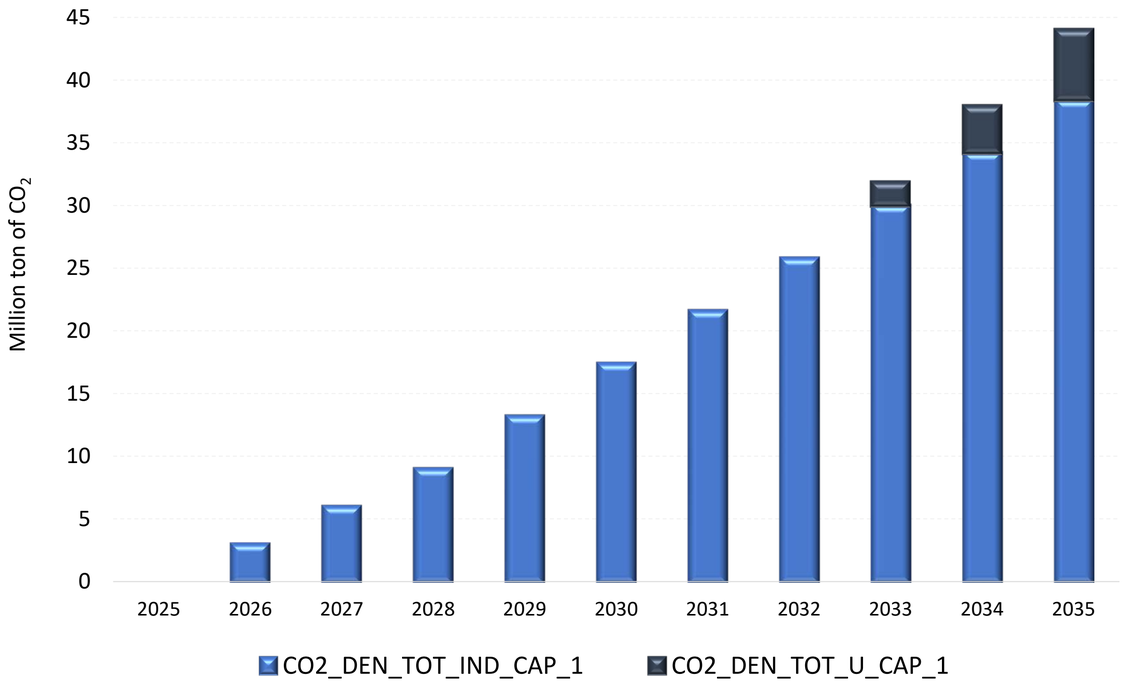


ASSUMPTIONS FOR SCENARIO SIMULATION

- Business as Usual (BaU): no CCS in Saudi Arabia, and the economic-energy-environmental relationships continue as they are in 2025 without any CCS-related changes.
- For other scenarios:
  - Three scenarios assume the policy announcement of a 44 million CO_2 emissions capture target and its allocation between the industrial and utility sectors
  - The levelized costs of CO_2 capture in each sector, along with the associated transport and storage costs.
  - No capture in both sectors in 2025
    - The first capture in industry will occur in 2026, with the amount of 3 million tons, and will increase to the announced capacity of 9 million tons in 2028.
    - The first capture in the utility sector will be realized in 2033, with the amount of 1.87 million tons

SCENARIO INPUTS

CO_2 emissions to be captured in the industry and utility

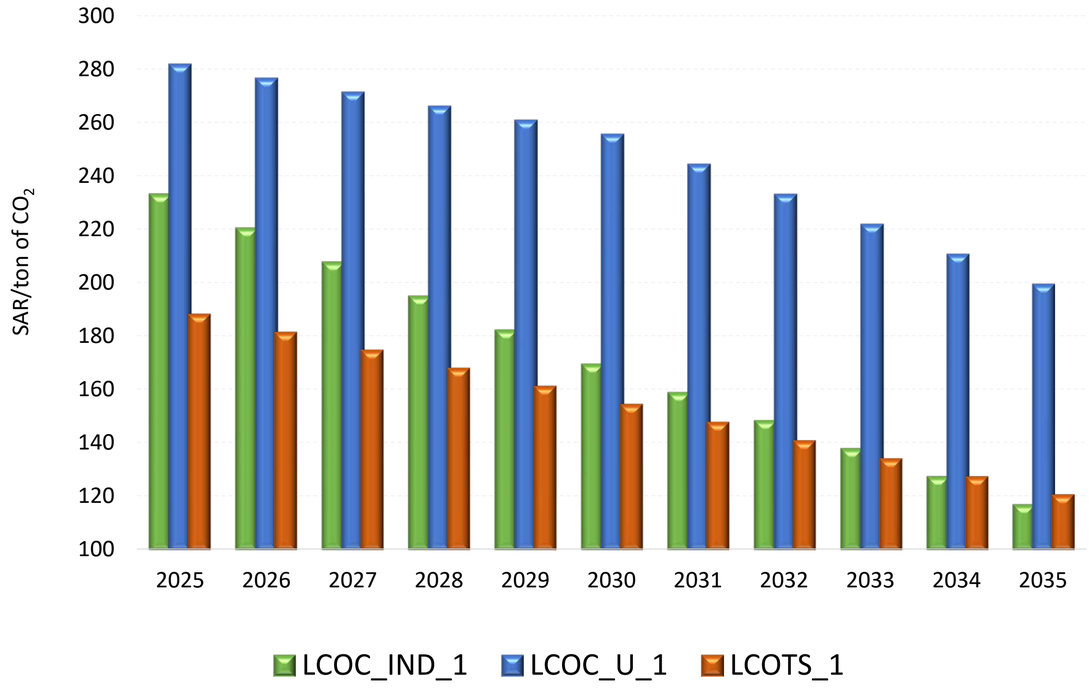


By 2035, to meet the national target of 44 million tons of capture volumes are:

- 38.4 million tons in the industrial sector (blue bar)
- 5.6 million tons in the utility sector (dark blue bar)

SCENARIO INPUTS

Levelized cost of capture in industry, utility, and TS



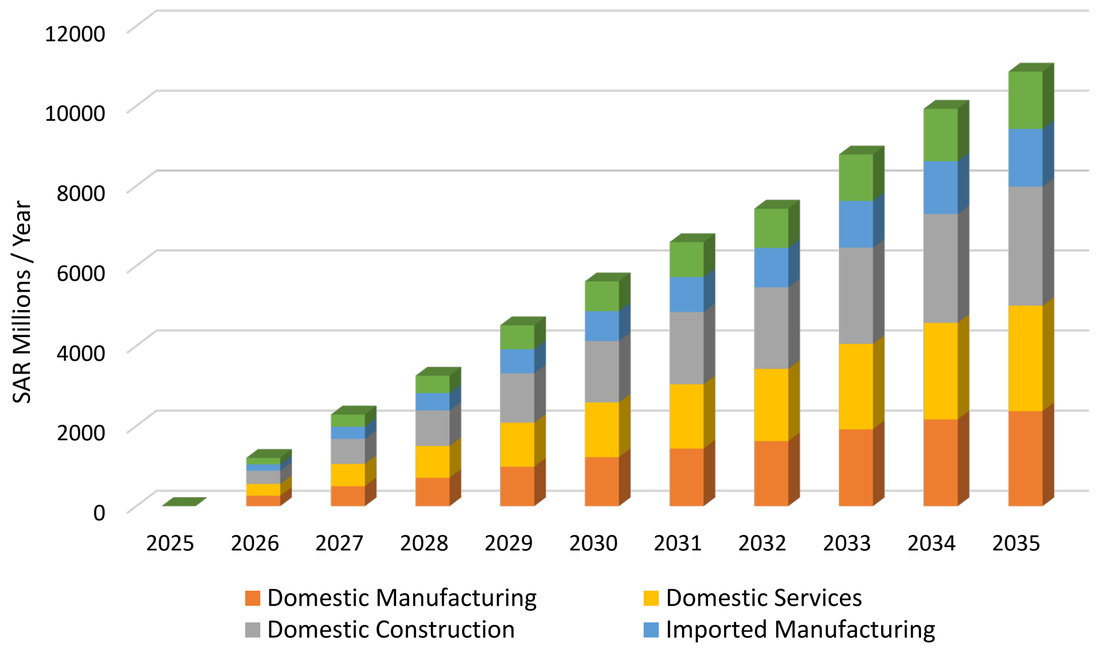
The initial unit costs are estimated:

- SAR 232.5 per ton for industry, SAR 281.25 per ton for utilities, and SAR 187.5 per ton for transport and storage.

These costs are projected to decline over time due to technological learning effects, with an assumed learning rate

SCENARIO INPUTS

Demand for CCS-related Goods and Services.
Domestic vs Foreign Suppliers.



This breakdown is critical for understanding the macroeconomic and sectoral impacts of the modeled scenarios.

A significant share of the projected demand is directed toward the **construction sector**, followed by **services and manufacturing**, with **domestic suppliers** accounting for the majority of this activity.

SCENARIO DESIGN OF FINANCING OPTIONS

Four scenarios were simulated using KGEMM in addition to the baseline in the horizon 2026–2035

Scenario 1:

Fully financed by foreign reserves.

Scenario 2:

50% reserves and 50% government budget.

Scenario 3:

50% government and 50% private sector.

Business-as-Usual (BaU): No CCS deployment

MACROECONOMIC IMPACTS OF THE TARGETED CCS DEPLOYMENT UNDER ALTERNATIVE FINANCING OPTIONS

% deviation from BaU, average 2026-2035

Indicator	CCS Costs Financing Options		
	Fully Financed by Reserves	50% Reserves & 50% Government	50% Government & 50% Private
	Scenario 1	Scenario 2	Scenario 3
Output & Labour			
GDP	0.60	0.55	0.50
Non-oil GDP	0.83	0.76	0.69
Non-oil Employment	0.29	0.26	0.24
Capital Formation and Fiscal Revenues			
Non-oil Investment	3.35	2.99	2.55
Non-oil Government Revenues	0.22	0.20	0.18
Domestic Demand & Households			
Domestic Demand	1.10	0.98	0.84
Household Consumption	0.15	0.13	0.12
Household Disposable Income	0.16	0.14	0.13
Prices, Money & Exports			
Consumer Price Index	0.01	0.01	0.02
Broad Money	0.36	0.32	0.30
Non-oil Goods Export	0.71	0.67	0.63

Note: All the output indicators in the table are in SAR millions at 2010 prices, while employment is in thousands. The broad money is in SAR million, and CPI is in the base year of 2010.

- CCS investments raise GDP by 0.5–0.6% vs. BaU, mainly through non-oil sectors (0.7–0.8%), extra construction and equipment purchases, the pipes, capture units, monitoring systems, engineering, and services activity is outside hydrocarbons.
- Non-oil jobs increase by 0.2–0.3%, reflecting growth in labor-intensive industries.
- Investment & Public Finances: Non-oil capital formation jumps 2–3%, boosting non-oil revenues by 0.2% through higher payrolls and profits.
- Domestic demand grows 0.8–1.1%, driven by investments; household income and consumption rise modestly.
- Supply-chain capacity keeps inflation muted: the CPI ticks up by only 0.01–0.02 % vs. BaU despite the demand expansion and some cost push, such as wage raises. broad money expands ~0.3% with GDP growth.
- Non-oil exports rise ~0.63–0.71% across scenarios.

SECTORAL ECONOMIC IMPACTS OF THE TARGETED CCS DEPLOYMENT UNDER ALTERNATIVE FINANCING OPTIONS

% deviation from BaU, average 2026-2035

Indicator	CCS Costs Financing Options		
	Fully Financed by Reserves	50% Reserves & 50% Government	50% Government & 50% Private
	Scenario 1	Scenario 2	Scenario 3
Output			
Industrial GVA	0.66	0.60	0.41
Service GVA	0.56	0.50	0.45
Labour			
Industrial Employment	1.07	0.96	0.90
Service Employment	0.825	0.818	0.815

Note: All the output indicators in the table are in SAR millions at 2010 prices, while employment is in thousands. The broad money is in SAR million, and CPI is in the base year of 2010.

- Industry benefits most: Reserve-financed CCS (Scenario 1) boosts industrial GVA by **0.55%** over BaU, driven by higher demand for steel, cement, machinery, and construction activities.
- Services follow closely, led by engineering, transport, ICT, and other CCS-related business services.
- Employment rises in the same order - industry (+1%) and services (+0.8%). Excluding construction, industrial jobs increase by 0.3%, reflecting lower labor intensity than services.

CONCLUSION AND FUTURE WORK

- CCS integration into KGEMM enables quantification of macro-sectoral trade-offs
- Overall, the Saudi target of 44 $MtCO_2$ capture by 2035 yields CCS delivers *broad-based positive effects*, strongest when *reserve-financed;* shared financing slightly softens but does not negate the gains.
- Industry and services see the largest gains in *value added and jobs* due to their central role in building and operating CCS facilities.

Policy Insights:

1. Financing: Using *foreign reserves* yields the strongest stimulus and avoids crowding out. If fiscal funding is needed, defer low-payoff projects while protecting *education, digital infrastructure, and renewables*.
2. Domestic Spillovers*: Link CCS procurement to local supply chains* to amplify industrial and employment benefits.

Future Research Directions:

- Integrate **CCS with carbon pricing and renewables** in KGEMM for least-cost net-zero pathways.
- Assess **carbon pricing** or **market loans** as financing options.
- Simulate varying **learning rates, capture and penetration rates, and cost parameters** to model endogenous capture and compare **alternative mitigation strategies**.

THANK YOU
FOR YOUR ATTENTION!

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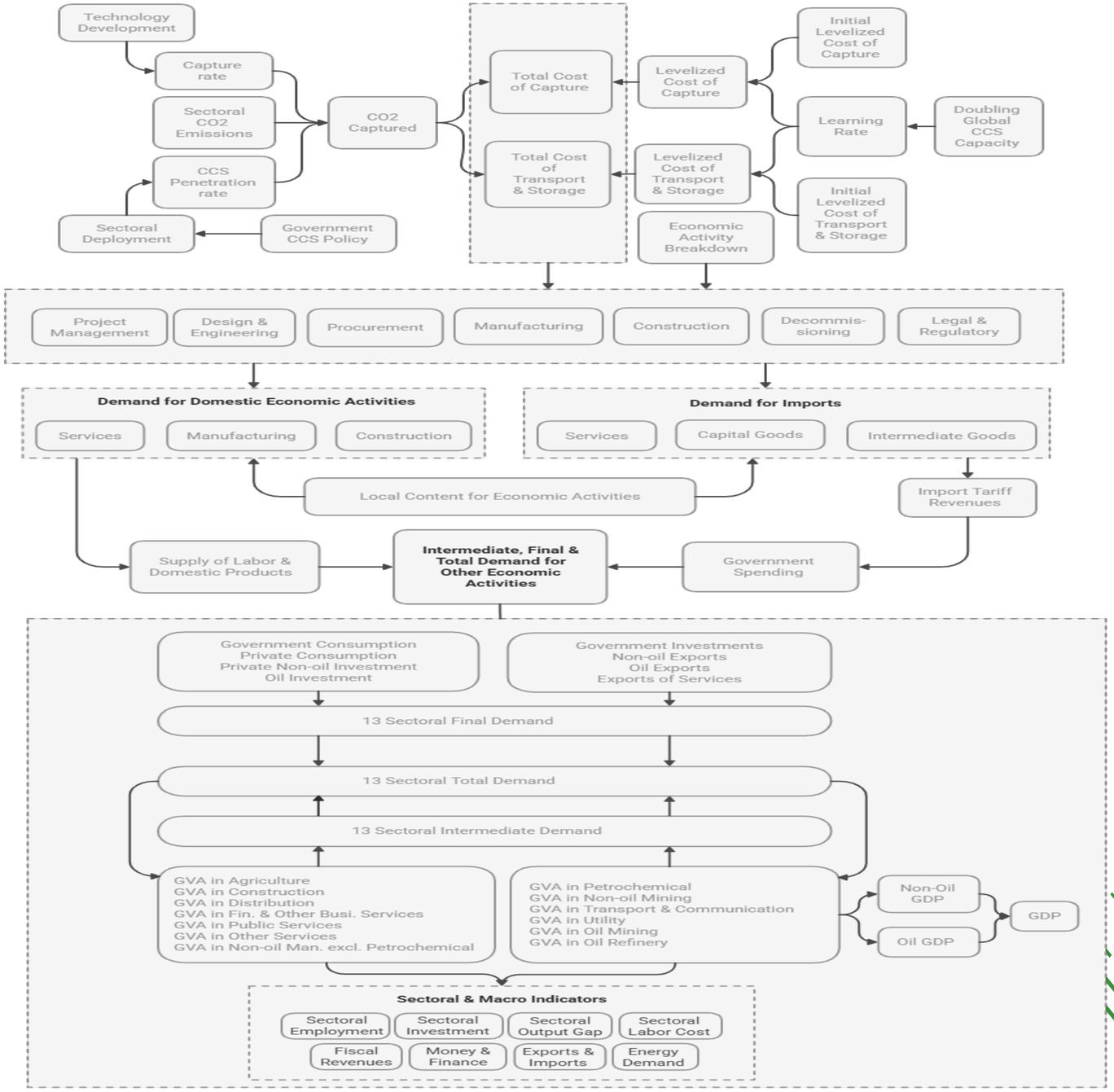
BACK UP

CCS Flowchart in the KGEMM



Source: Authors' own construction.
Note: GVA=Gross Value Added.