Environmental assessment of several 2050 CCS scenarios for France

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Objectives

For each defined scenario of CCS deployment in France in 2050:

- To assess energy requirements
- To assess more precisely avoided CO\textsubscript{2} emissions (CO\textsubscript{2} vented to the atmosphere in the CCS scenarios vs. in a reference scenario without CCS)
- To assess GreenHouse Gas (GHG) emissions, including other main GHG i.e. CH\textsubscript{4} and N\textsubscript{2}O, (GHG vented to the atmosphere in the CCS scenarios vs. in a reference scenario without CCS)
  - Other GHG (HFCs, PFCs, SF\textsubscript{6} etc.) are responsible for only 1% of worldwide GHG emissions
- To assess other pollutant emissions (NOx and SOx) mainly resulting from additional energy consumption of CCS chain + contextualize the increase/decrease of these emissions (when compared to a reference scenario without CCS) by comparing results to the current regional emission level (CITEPA data)

... including indirect impacts (energy consumptions and emissions) corresponding to:

- energy and materials supply activities for each step of CCS chain (CO\textsubscript{2} capture, transportation and storage)
  - e.g. : production and transportation of natural gas, electricity or solvent (MEA)
- building of infrastructures
Systems Boundaries for IFP analysis and BRGM analysis

Analysis focused on the CCS chain, excluding impacts of industrial activities of considered emitters (excepted fumes)

Reference scenarios without CCS:
NO energy consumption
Emissions = Fumes content
Objective and tool used

> **Objective:**
  - Simulation of scenarios at national scale for years 2020 and 2050
    - Scenarios defined by IFP
    - For each scenario: gaseous emission and energy consumption assessment
    - Results transferred to IFP for LCA-type analysis

> **Tool used:**
  - USIMPAC™ (BRGM software):
    - Process simulation software designed for simulators building dedicated to a specific thematic
    - Formerly used by mineral process industries, recently adapted to “waste”
    - During SOCECO2 project: specific models were developed for capture, transport and CO₂ storage
Capture

> **Hypothesis:**
- Post-combustion MEA (Monoethanolamine)
- CO\(_2\) capture system efficiency (prospective),
- With or without capture, taking into account production objectives (kWh for energy production or tons of clinker produced for the cement industry),

> **Modelling:**
- A specific model is built for each industrial CO\(_2\) source, considering specific fuel use for energy supply (coal, natural gas...),
- Based on capture process characteristics and characteristics of considered industries (paper mill…) (cf. literature):
  - Energy requirements for the implementation of capture system
  - CO\(_2\) (+SOx and NOx) capture system efficiencies
  - Emission limit values (NOx, SOx…)
- Reference document: Tzimas, 2007*

Transport

> **Hypothesis:**
  - On-shore and/or offshore Pipeline according to the scenario considered
  - Distance from the CO$_2$ emission source and the storage location

> **Model parameters:**
  - Transported gas mean temperature
  - CO$_2$ pressure at the output of capture process …

> **Modelling:**
  - Model results:
    - Assessment of pipeline diameters
    - Requirements for additional compression along the pipe
    - Emissions and energy consumption
  - Reference document: McCoy, 2008*

Storage

**Hypothesis:**
- Type of geological reservoirs
- Localisation

**Model parameters:**
- Number of injection wells and injection depth
- Leakage rate
- Mean temperature of transported gas
- CO₂ pressure at the output of pipeline and required pressure for storage...

**Modelling:**
- Model results:
  - Required injection pressure
  - Emissions (leakage)
  - Electric consumption (compression)
- Reference document: IPCC, 2005
> Scale definition:
  - For “France” ↔ all industrial sources considered within scenarios, equipped or not with capture systems
  - “CCS” ↔ capture + transport + storage

> CO₂ emission:
  - Capture vs. transport vs. storage:
    - Example, sc.1
    - Same for all scenarios
  - Total CO₂ emissions (CCS)
    - Sc3a et Sc3b < Sc1 et Sc2
    - Related to the number of CO₂ industrials sources equipped by capture system
> **2020 / 2050: increase of CO₂ emission. Two reasons:**

- Increase of industrial sources emission:
  - + 30% (related to hypothesis of economical growth)
- Limited by the effect of the improved capture process efficiency
  - => Focus on industrial sources selected for CO₂ capture implementation:
    - CO₂ emission in 2020: - 66% (scenarios/base-case)
    - CO₂ emission in 2050: - 71% (scenarios/base-case)
CCS for France (example in 2050): SOx, NOx emissions

> Two different trends:

- **NOx** (slight increase)
  - Increase of fuel consumption
  - Partial reaction between NOx matter flows and solvent: 8.5%

- **SOx** (sharp reduction)
  - Increase of fuel consumption
  - Quasi complete reaction between SOx matter flows and solvent: 90%
> **Energy consumption associated to the implementation of a CCS network:**
- Capture: solvent regeneration & compression before transport
- Transport: repressuring if required
- Storage: repressuring at wellhead

> **Results:**
- Energy consumption depends on the amount of stored CO₂
- Slight variations related to the number of repressuring stages needed during transport, the number of injection wells and of well depths
Simulator

> CCS simulator: matter & energy balance
  • Possible use at different scales
  • Not limited in terms of number of industrial sources, pipeline and geological reservoirs
    — A flexible tool…

> Results transferred to IFP for further analysis
Approach

Goal: To assess ALL energy consumption and emissions related to CCS deployment

- Direct impacts: BRGM results = basis for IFP analysis
- Indirect impacts: Extracted from reference Life Cycle Analysis databases + IFP calculation from technical data (e.g. impacts of the production of MEA)
- Assumptions and methodology: consistent with previous work (scenario definition) + validation IFP/BRGM for further assumptions

Indirect impacts included in IFP analysis:

- CO₂ capture step:
  - Extraction/production and transportation of fuel used to provide energy
  - Production and transportation of solvent (MEA) (including supply steps corresponding to energy and raw material requirements of this process)
- CO₂ transportation step:
  - Pipelines production and transportation
  - Electricity production (for repressuring if required)
- CO₂ storage step:
  - Wells and platform production and building
  - Electricity production (for repressuring at wellhead if required)
RESULTS: Additional energy consumption related to CCS chain deployment in France

Reminder: No energy consumption for reference scenarios without CCS

2020 vs. 2050:
General increase of energy consumptions corresponding to CCS development

CO₂ transportation
Negligible step when compared to capture and storage steps

CO₂ capture
Scenario 1 = Scenario 2
Higher results for Scenario 3a and 3b because of the additional group (PACA)

CO₂ storage
S2 and S3b: results lower than for S1 et S2, since offshore storage requires fewer wells thanks to a better injectivity

RE: Renewable Energy
RESULTS : GHG emissions related to CCS chain deployment in France

Assessments, expressed in equivalent CO$_2$, include CO$_2$, CH$_4$ and N$_2$O emissions

- $1g$ CO$_2$ = $1g$ eqCO$_2$; $1g$ CH$_4$ = $25g$ eqCO$_2$; $1g$ N$_2$O = $298g$ eqCO$_2$
  (Global Warming Potentials extracted from IPCC 2007)

Several reference values (without CCS) can be used to assess GHG savings associated to CCS, depending on the question:

1. Which is the "GHG efficiency" of the CCS chain?
   - Relevant reference scenario without CCS: Groups of emitters where CCS is deployed

2. Which is the "GHG efficiency" of this CCS scenario?
   - Relevant reference scenario without CCS: All the selected French emitters (i.e. 41 biggest CO$_2$ emitters in 2005)
RESULTS: GHG emissions related to CCS chain deployment in France

3 reference scenarios without CCS (2020 + 2050)

CO₂ transportation and storage
Negligible steps when compared to capture step

CO₂ capture
Responsible for 94% up to 97% of the overall GHG emissions of the CCS scenarios
Scenario 1 = Scenario 2
Higher results for Scenario 3a and 3b because of the additional group (PACA)

GHG emissions corresponding to each CCS deployment scenario (both in 2020 & 2050) and GHG savings when compared to the respective baseline without CCS

- Capture
- Transportation
- Storage

Mt CO₂eq / year

2020 Baseline without CCS
2020 With CCS
2050 Baseline without CCS
2050 With CCS
RESULTS: GHG emissions related to CCS chain deployment in France

GHG savings

1. Efficiency of the CCS chain (where it is deployed)
   - Scenario 1 ~ Scenario 2: 61%
   - Scenario 3a ~ Scenario 3b: 62%

2. Efficiency of the CCS scenario (considering all the 41 biggest French CO₂ emitters in 2005)
   - Scenario 1 ~ Scenario 2: 31% in 2020 and 28% in 2050
   - Scenario 3a ~ Scenario 3b: 50% in 2020 and 47% in 2050

3. Amount of GHG avoided in 2050?
   - Scenario 1 ~ Scenario 2: 26 Mt CO₂eq in 2020 and 30.4 Mt CO₂eq in 2050
   - Scenario 3a ~ Scenario 3b: 41.6 Mt CO₂eq in 2020 and 50.3 Mt CO₂eq in 2050

CO₂ savings (not GHG...) reach a maximum value of 51.9 Mt in 2050 (scenario 3b) to be compared to the French Factor 4 objective for CCS: 60 Mt CO₂ avoided in 2050
RESULTS: NOx emissions related to CCS chain deployment in France

Since NOx and SOx emissions are mainly responsible for local impacts on the environment: Assessments are made at the regional/local scale (more relevant than the national scale)

Without CCS: Selected emitters are respectively responsible for 6% up to 15% of the 2000 NOx regional level (scenarios 2020) and for 8.5% up to 19% of this amount (scenarios 2050)

Impact of CCS deployment on NOx emissions

1. Significant INCREASE of NOx emissions when compared to reference scenarios (same emitters without CCS) because of additional energy and materials consumptions and even if a slight part of NOx emissions are captured and stored

2. HOWEVER, NOx emissions of CCS scenario are responsible for "only" 7% up to 22% of the 2000 NOx regional emissions level

... this question should be addressed locally in order to check if this increase is problematic or not
RESULTS: SOx emissions related to CCS chain deployment in France

Without CCS: Selected emitters are respectively responsible for 6% up to 15% of the 2000 SOx regional level (scenarios 2020) and for 9% up to 17% of this amount (scenarios 2050).

Impact of CCS deployment on SOx emissions:
Significant DECREASE of SOx emissions when compared to reference scenarios (same emitters without CCS) because of the quasi complete reaction of SOx with the solvent (CO2 capture step) and even if additional energy and materials consumptions are required (inducing more SOx emissions).

SOx emissions in each area (or group of area) in 2020 and 2050:
Comparison of emissions corresponding to the selected emitters (both with and without CCS) with the total SOx emitted in the same area in 2000.
Conclusion

> CCS chain enables to achieve significant GHG emissions reduction even considering both direct and indirect impacts (62% GHG emission reduction in 2050 when compared to the same emitters without CCS)

> Maximum avoided CO₂ emissions in 2050 amount to 51.9 Mt (scenario 3b) to be compared to the French Factor 4 objective for CCS (60 Mt CO₂ avoided in 2050)

> However, CCS deployment requires significant additional energy: from 250 up to 410 PJ/yr in 2050 (respectively corresponding to scenarios 2 and 3a) i.e. 6.0 up to 9.8 Mtoe in 2050...

> Sharp GHG emission reduction is achieved BUT other pollutant emissions can increase (local pollutant such as NOx). However, NOx emissions corresponding to selected emitters in CCS scenarios are responsible for less than 22% of the 2000 NOx regional emissions level
   • Positive and negative effects should always be compared and weighed up
   • This question should be addressed at the regional scale

> Further work
   • Other capture technologies could also be studied (oxycombustion, precombustion)
   • Such an analysis could be extended to other pollutant emissions (e.g. NH3)
BACK UP
Hypothèses et données générales

> Scénarios de mix de production électrique
  • 2020: vision centrale RTE pour la France
  • 2050: scénario volontariste du CAS, simulation Markal

> Scénario de mix d'approvisionnement en gaz naturel pour la France
  • identique pour 2020 et 2050 : données CEDIGAZ (2020)

> Filière d'approvisionnement en gazole
  • base de données ACV DEAM
Hypothèses et données sur le captage

• Production de la MEA
  — Source : Nexant, CHEMSYSTEMS, PERP REPORT, *Process evaluation/Research Planning, Ethanolamines 01/02S2*
  — Procédé "Scientific Design" et distribution "Light" (ie 60% en masse de MEA, 30% de DEA et 10% de TEA)
  — Limites :
    Imputations à la MEA des consommations d'utilités et réactifs ramenées au prorata massique,
    Pas de prise en compte du traitement des déchets éventuels, faute d'informations permettant de traiter ces aspects.
  — Site de production supposé être à Lavéra

• Utilisation de la MEA
  — Solvant contenant 30% en masse de MEA (le reste étant de l'eau)
  — Consommation de MEA totale = Masse de MEA pour faire fonctionner les unités de captage + Taux de dégradation de la MEA*Masse de CO₂ à capter
  — Même consommation de MEA quelque soit le secteur d'activité
Hypothèses et données sur le transport

Prise en compte des impacts liés à la recompression du CO₂ lors de son transport et à la construction des pipelines

> Pression en entrée de pipeline: 100 bar, pression en sortie de pipeline: 80 bar

> Même infrastructure de transport en 2020 et 2050 (donc dimensionnée sur les plus gros débits)

> Calcul de pertes de charge afin d'évaluer la dépense énergétique nécessaire à la re-compression du CO₂

> Données retenues pour la construction des pipelines : données ACV de l'International Iron and Steel Institute (IISI), ne tenant pas compte de la fin de vie des pipelines et d'un éventuel recyclage des matériaux

> Durée de vie des pipelines: 50 ans
Hypothèses et données sur le stockage

Prise en compte des impacts liés à la recompression du CO₂ en tête de puits (injection) et à la construction des infrastructures de stockage

> Données tirées de la base de données Ecoinvent
  - Forage de puits onshore
  - Forage de puits offshore
  - Construction de plateformes offshore

> Durée de vie d'un puit
  - Structure de forage (casings, plateformes...) : durée d'exploitation
  - Matériel soumis à la corrosion à renouveler tous les 15 ans
  - Prise en compte de la fin de vie des puits (rebouchage)