Evaluating the Use of Bioenergy With Carbon Capture and Storage to Achieve Energy Transition and Decarbonization

Sandrine Selosse
MINES ParisTech, PSL Research University, Centre for Applied Mathematics
Chair Modeling for Sustainable Development

August 28th, 2019
16th IAEE Conference – Ljubljana - Slovenia
Long-term possible low carbon futures of the energy system

- **Climate constraints**
  - 2°C objective (emissions targets [Gt CO₂], radiative forcing [W/m²], atmospheric concentration [ppm])
  - Paris Agreement (NDCs)

How to achieve a sustainable energy transition?
Modelling approach

TIAM-FR: *French version of the TIMES Integrated Assessment Model*

Optimization, linear programming
Minimization of the total discounted cost of the system

Bottom-up
Long-term: *2010*-2100
Multi-regional: 15 regions (+T-ALyC)
Multi-sectors: 6 sectors
42 demands

585 729 data
11 646 commodities (about 770/region)
39 817 technologies (about 2 500/region)

\[
NPV = \sum_{r=1}^{R} \sum_{y \in \text{YEARS}} (1 + d_{r,y})^{\text{REFYR} - y} \times \text{ANNCOST}(r, y)
\]

Where
NPV is the net present value of the total cost for all regions over the projected period;
ANNCOST \( (r, y) \) is the total annual cost in region \( r \) and year \( y \);
d\( r,y \) is the discount rate;
REFYR is the reference year for discounting;
YEARS is the set of years and \( R \) is the set of regions (15 regions)
Long-term possible low carbon futures of the energy system

- **Climate constraints**
  - 2°C objectives (emissions targets [Gt CO₂], radiative forcing [W/m²], atmospheric concentration [ppm])
  - Paris Agreement (NDCs)

Regional contribution to the mitigation effort
Technological choices to a climate stabilization

AR5: 101 of the 116 scenarios with a limited atmospheric concentration at 430-480 ppm rely on BECCS

About 67% of these have a BECCS share in primary energy exceeding 20% in 2100

(Fuss et al. (2014), Nature Climate Change)
World electricity production (PJ)

Increasingly high climate constraint

Paris agreement

2°C Objective

Increasingly high climate constraint
What low carbon and sustainable energy future?

- **Ambitious climate targets achieved if:**
  - Contribution of developing countries
  - Ambitious contribution of emerging countries
  - Early almost total decarbonization of the industrialized countries
  - Major deployment of the CCS
  - Use of negative emissions with BECCS
What low carbon and sustainable energy future?

- **Ambitious climate targets achieved if:**
  - Contribution of developing countries
  - Ambitious contribution of emerging countries
  - Early almost total decarbonization of the industrialized countries
  - Major deployment of the CCS
  - Use of negative emissions with BECCS

- **Technological and resource constraints**
  - Availability of technology
    - Carbon capture and storage (CCS)
    - Availability of onshore storage
  - Resource potential
    - Carbon storage
    - Biomass resources
What low carbon and sustainable energy future?

- Ambitious climate targets achieved if:
  - Contribution of developing countries
  - Ambitious contribution of emerging countries
  - Early almost total decarbonization of the industrialized countries
  - Major deployment of the CCS
  - Use of negative emissions with BECCS

- Technological and resource constraints
  - Availability of technology
    - Carbon capture and storage (CCS)
    - Availability of onshore storage
  - Resource potential
    - Carbon storage
    - Biomass resources

Achieving energy transition with negative emissions: how carbon storage and biomass resource potentials can impact the development of BECCS
The question of carbon storage... (Gt)

Increasingly high climate constraint

Carbon sequestration sites

Paris Agreement 2°C Objective
Analysis of the carbon storage potential

- **Scenario analysis** (under climate constraints)
  - Carbon storage potentials
    - Initial TIAM – 9,392 Gt
    - Collection of various databases, reports, etc. – 10,142 Gt
    - Ref. Dooley – 10,655 Gt
    - Ref. Hendriks – 572 Gt (Low)
      1,706 Gt (Best)
      5,864 Gt (High)
  - Onshore/offshore determination
Carbon storage by year to achieve the 2°C objective (radiative forcing at 2.6 W/m² by 2100)

Sensitivity analyses on carbon storage by site and scenario (Gt CO₂)

<table>
<thead>
<tr>
<th>Year</th>
<th>Site/Scenario</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clim_ini</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clim_Doo</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clim_HenL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clim_HenB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clim_HenH</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clim_Misc</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Deep saline aquifers (offshore)
Depl gas fields (offshore)
Depl oil fields (offshore)
Enhanced Coalbed Meth recov <1000 m
Enhanced Oil Recovery (offshore)
Enhanced Coalbed Meth recov >1000 m
Impact of an onshore storage ban on carbon storage and CCS deployment

**Carbon storage by site (Gt CO₂)**

- **2050**:
  - Deep saline aquifers (offshore) - 6 Gt CO₂
  - Depl gas fields (offshore) - 8 Gt CO₂
  - Enhanced Coalbed Meth recov <1000 m
  - Enhanced Coalbed Meth recov >1000 m
  - Enhanced Oil Recovery (offshore)

- **2100**:
  - Deep saline aquifers (offshore) - 18 Gt CO₂
  - Depl gas fields (offshore) - 16 Gt CO₂
  - Enhanced Coalbed Meth recov <1000 m
  - Enhanced Coalbed Meth recov >1000 m
  - Enhanced Oil Recovery (offshore)
Sensitivity analysis on biomass potential and impact on carbon storage

Carbon storage sites

- Enhanced Coalbed Methane recovery >1000 m
- Enhanced Coalbed Methane recovery <1000 m
- Enhanced Oil Recovery (onshore)
- Depleted oil fields (onshore)
- Depleted gas fields (onshore)
- Deep saline aquifers (onshore)

GtCO₂

- Pot. Bio. HIGH
- Pot. Bio. LOW

W-2050-50_BioHi
W-2050-50_BioLo
W-2050-70_BioHi
W-2050-70_BioLo

--- 50% by 2050 ---
--- 70% by 2050 ---
### Alternatives low carbon pathways:
A joint impact analysis of carbon storage and biomass potentials

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Targeted year</th>
<th>Climate constraint</th>
<th>Carbon storage</th>
<th>Biomass 2050 potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>2050-70-ccsHi-BioMid</td>
<td>2050</td>
<td>70% GHG mitigation</td>
<td>10,142 Gt</td>
<td>215 EJ</td>
</tr>
<tr>
<td>2050-70-ccsHi-BioHi</td>
<td></td>
<td></td>
<td>1,706 Gt</td>
<td>328 EJ</td>
</tr>
<tr>
<td>2050-70-ccsHi-BioLo</td>
<td></td>
<td></td>
<td>572 Gt</td>
<td>70 EJ</td>
</tr>
<tr>
<td>2050-70-ccsMid-BioMid</td>
<td></td>
<td></td>
<td>10,142 Gt</td>
<td>215 EJ</td>
</tr>
<tr>
<td>2050-70-ccsMid-BioHi</td>
<td></td>
<td></td>
<td>1,706 Gt</td>
<td>328 EJ</td>
</tr>
<tr>
<td>2050-70-ccsMid-BioLo</td>
<td></td>
<td></td>
<td>572 Gt</td>
<td>70 EJ</td>
</tr>
<tr>
<td>2050-70-ccsLo-BioMid</td>
<td></td>
<td></td>
<td>10,142 Gt</td>
<td>215 EJ</td>
</tr>
<tr>
<td>2050-70-ccsLo-BioHi</td>
<td></td>
<td></td>
<td>1,706 Gt</td>
<td>328 EJ</td>
</tr>
<tr>
<td>2050-70-ccsLo-BioLo</td>
<td></td>
<td></td>
<td>572 Gt</td>
<td>70 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsHi-BioMid</td>
<td>2100</td>
<td>2°C temperature increase limit</td>
<td>10,142 Gt</td>
<td>215 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsHi-BioHi</td>
<td></td>
<td></td>
<td>1,706 Gt</td>
<td>328 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsHi-BioLo</td>
<td></td>
<td></td>
<td>572 Gt</td>
<td>70 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsMid-BioMid</td>
<td></td>
<td></td>
<td>10,142 Gt</td>
<td>215 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsMid-BioHi</td>
<td></td>
<td></td>
<td>1,706 Gt</td>
<td>328 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsMid-BioLo</td>
<td></td>
<td></td>
<td>572 Gt</td>
<td>70 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsLo-BioMid</td>
<td></td>
<td></td>
<td>10,142 Gt</td>
<td>215 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsLo-BioHi</td>
<td></td>
<td></td>
<td>1,706 Gt</td>
<td>328 EJ</td>
</tr>
<tr>
<td>2100-2D-ccsLo-BioLo</td>
<td></td>
<td></td>
<td>572 Gt</td>
<td>70 EJ</td>
</tr>
</tbody>
</table>
The influence of carbon storage and biomass potentials in the future development of BECCS

### Share of CCS in the world production of electricity in 2050

<table>
<thead>
<tr>
<th>Ambitious climate scenario - 70% GHG mitigation target</th>
<th>Biomass potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon storage potential</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>45% (BECCS: 70%)</td>
</tr>
<tr>
<td>Medium</td>
<td>45% (BECCS: 69.8%)</td>
</tr>
<tr>
<td>Low</td>
<td>33% (BECCS: 93.9%)</td>
</tr>
</tbody>
</table>

### Gt of negative emissions (CO2 sequestrated in 2050 from BECCS)

<table>
<thead>
<tr>
<th>Ambitious climate scenario – 70% GHG mitigation target</th>
<th>Biomass potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon storage potential</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>12 Gt</td>
</tr>
<tr>
<td>Medium</td>
<td>12 Gt</td>
</tr>
<tr>
<td>Low</td>
<td>11 Gt</td>
</tr>
</tbody>
</table>
Cost analysis of constraints

Total discounted cost (M€)

- 2°C targets
- NDCs targets

Low biomass potential
## Carbon marginal cost ($/tCO2)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year</th>
<th>Carbon marginal cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDCs_lolo_BioHi</td>
<td>2030</td>
<td>20</td>
</tr>
<tr>
<td>NDCs_lolo_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDCs_upup2_BioHi</td>
<td>2030</td>
<td>25</td>
</tr>
<tr>
<td>NDCs_upup2_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDCs_upup_BioHi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDCs_upup_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-2050-40_BioHi</td>
<td>2030</td>
<td>30</td>
</tr>
<tr>
<td>W-2050-40_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDCs_lolo_BioHi</td>
<td>2050</td>
<td>35</td>
</tr>
<tr>
<td>NDCs_lolo_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-2050-50_BioHi</td>
<td>2030</td>
<td>40</td>
</tr>
<tr>
<td>W-2050-50_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-2050-70_BioLo</td>
<td>2030</td>
<td>40</td>
</tr>
<tr>
<td>W-2050-70_BioHi</td>
<td>2030</td>
<td>50</td>
</tr>
<tr>
<td>NDCs_upup_BioHi</td>
<td>2050</td>
<td>50</td>
</tr>
<tr>
<td>NDCs_upup_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-2050-40_BioHi</td>
<td>2050</td>
<td>75</td>
</tr>
<tr>
<td>W-2050-40_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDCs_upup2_BioHi</td>
<td>2050</td>
<td>90</td>
</tr>
<tr>
<td>W-2050-50_BioHi</td>
<td>2050</td>
<td>95</td>
</tr>
<tr>
<td>NDCs_upup2_BioLo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-2050-70_BioHi</td>
<td>2050</td>
<td>100</td>
</tr>
<tr>
<td>W-2050-70_BioLo</td>
<td>2050</td>
<td>120</td>
</tr>
<tr>
<td>W-2050-50_BioLo</td>
<td>2050</td>
<td>150</td>
</tr>
<tr>
<td>W-2050-70_BioLo</td>
<td>2050</td>
<td>420</td>
</tr>
</tbody>
</table>
To conclude...

- A key measure of success is how far and how fast the Paris Agreement will encourage more ambitious actions.

- Models like TIAM-FR constitute crucial tools to help policymakers as regards long-term low carbon pathways but there is a need for:
  - Position of the envisioned future
  - Connect the proposed trajectories to the real
  - Anticipation and vision, based on short and long term consideration (and without disconnect them)

- Among the low-carbon technology options, CCS technologies are widely presented as a solution for achieving ambitious climate goals, particularly when associated with biomass:
  - Deploying these technologies at this scale for mitigation purposes requires the implementation of incentive and regulation policies
  - Carbon storage capacities and particularly biomass potential can be a limiting factor for (BE)CCS deployment
Thank you for your attention!

sandrine.selosse@mines-paristech.fr
Impact of a contrasted biomass potential on the world electric production (PJ)

Pot. Bio. élevé
Pot. Bio. faible

NDCs

50 % en 2050
70 % en 2050
Regional electricity production (PJ)

INDCs Scenarios: no CCS but electricity from bioplant is more important

UNFCCC-70-NoBECCS: decarbonized electricity system (solar)