Bottom-up approaches to estimate life cycle GHG emissions of fossil fuel production, transport, energy production, CO$_2$ capture and storage

Outline

- Imperial College’s Life cycle assessment (LCA) model
- LCA boundaries of CCS system
- Life cycle inventory (LCI) modelling
  - example LCI models for coal and gas
- Case study: Middle East natural gas production, LNG transport and power generation in the UK
- Limitations of current bottom-up studies used to inform emission factors
- Challenges of evaluating GHGs emissions across the value chain
Life Cycle Assessment (LCA) is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements.

Imperial College’s LCA model (ICLCA) of fossil fuel production, transport, power generation value chains

- **Natural resources**
- **Extraction of fossil fuel**
- **Processing of fossil fuel**
- **Consumables Production**
- **Raw Material Production**
- **Fossil fuel transportation**
- **Consumables transportation**
- **Power Generation with CO₂ Capture**
- **CO₂ Conditioning**
- **CO₂ Transportation**
- **CO₂ Storage**
- **Upstream processes infrastructure**
- **Power plant and CO₂ capture facility infrastructure**
- **CO₂ pipeline infrastructure**
- **CO₂ injection infrastructure**
Imperial College’s LCA model of fossil fuel production, transport, power generation value chains

Key advantages

- Covers conventional / unconventional fossil fuel value chains for coal and natural gas
- Accurate accounting of fuel/materials supply requirements and emissions (air, water, solid waste) per unit process/subsystem
- Modular structure allows combination of component processes to represent the specifics of any given value chain

Current developments

- Life cycle cost model development
- CCS network evolution optimisation and real options assessment

Approaches for life cycle inventory analysis

<table>
<thead>
<tr>
<th>Published emission factors</th>
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</thead>
<tbody>
<tr>
<td>Equipment manufacturer emission factors</td>
</tr>
<tr>
<td>Engineering calculations*</td>
</tr>
<tr>
<td>Process simulation or other computer modelling</td>
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<tr>
<td>Emissions monitoring over a range of conditions and deriving emission factors</td>
</tr>
<tr>
<td>Periodic or continuous monitoring of emissions or parameters for calculating emissions</td>
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</tbody>
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Improved accuracy
Additional data requirements
Higher cost

*: Engineering calculations are based on basic chemical or physical principles of a process, considering operational parameters.
LCA model of the natural gas supply chain and power generation options

Unit processes in the offshore natural gas production LCI model

- **Platform drilling and production**
  - Reciprocating engine operation for HVAC
  - Drilling power generation
  - Produced gas compression
  - Emergency diesel engine operation
  - Firewater pump operation
  - Crane engine operation
  - Emergency drilling
  - Routine fairing
  - Emergency fairing

- **Support vessels and transportation**
  - Standby vessel operation
  - Supply vessel operation
  - Helicopter use

- **Routine maintenance**
  - Production separator depressurisation (or blowdown)
  - Gas pig launching
  - Condensate pig launching
  - Compressor blowdown
  - Compressor starts
  - Gas well workovers (tubing maintenance)
  - Gathering gas pipeline blowdown

- **Non-routine maintenance**
  - Emergency platform shutdown
  - Pressure relief valves release

- **Other operations**
  - Offshore gas well
  - Completion
  - Mud cuttings roll-off bins

- **Equipment leaks**
  - Valve leakage
  - Connector leakage
  - Open end pipelines (OLEs) leakage
  - Other leakage
### Unit processes included in the gas processing plant LCI model

<table>
<thead>
<tr>
<th>Combustion equipment operation</th>
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<tbody>
<tr>
<td>Auxilary boilers (natural gas fired)</td>
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<tr>
<td>Hot oil heaters (natural gas fired)</td>
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<tr>
<td>Gas turbines for recompression (natural gas fired)</td>
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<tr>
<td>Gas turbines for electrical generation (natural gas fired)</td>
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<tr>
<td>Flaring, pilot flaring (dry gas, low sulphur)</td>
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<tr>
<td>Emergency flaring (acid gas, low pressure)</td>
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<tr>
<td>Emergency flaring (acid gas, high pressure)</td>
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<tr>
<td>Tail gas incineration (acid gas)</td>
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<tr>
<td>Emergency fire water pump IC engines (diesel fired)</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Venting equipment operation</th>
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<tbody>
<tr>
<td>Dehydration vents (including Kimray pump emissions)</td>
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<tr>
<td>Gas processing /sour gas treatment</td>
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<tr>
<td>Condensate storage tank operation</td>
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<tr>
<td>Compressor starts</td>
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<tr>
<td>Compressor blowdowns</td>
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<tr>
<td>Processing maintenance blowdowns</td>
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<tr>
<td>Fire incidents</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Operation of equipment releasing fugitive emissions</th>
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<tbody>
<tr>
<td>Valves</td>
</tr>
<tr>
<td>Pump seals</td>
</tr>
<tr>
<td>Flanges</td>
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<tr>
<td>Compressor seals</td>
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</tbody>
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### Unit processes included in the LNG Plant LCI model

<table>
<thead>
<tr>
<th>Combustion and venting equipment operation</th>
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<tbody>
<tr>
<td>Refrigeration compressor turbines</td>
</tr>
<tr>
<td>LNG facility power</td>
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<tr>
<td>Hot oil heater</td>
</tr>
<tr>
<td>Additional power for ship at berth</td>
</tr>
<tr>
<td>Acid gas venting (H₂S removal and CO₂ knock out) with incinerator</td>
</tr>
<tr>
<td>Methane in nitrogen purge</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation of equipment releasing fugitive emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valves, flanges, seals and connectors</td>
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</table>

<table>
<thead>
<tr>
<th>Routine flaring</th>
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<tbody>
<tr>
<td>Purge gas flaring (dry gas, wet gas and marine faring)/Pilot flaring</td>
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<tr>
<td>Ship loading</td>
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<tr>
<td>Flash gas flaring</td>
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</tbody>
</table>

<table>
<thead>
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<th>Non-routine flaring</th>
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<tbody>
<tr>
<td>Dry flaring</td>
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<tr>
<td>Wet flaring</td>
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<tr>
<td>Marine flaring</td>
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</table>
Life Cycle Model for CO$_2$ Capture and Geological Storage

Component LCI Models: Post-combustion CCS system

Coal combustion Life Cycle Inventory model

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Coal combustion process LCI Model results

Normalised LCIA results of alternative coal and coal combustion technology options based on World 1995 normalisation scores
Sensitivity analysis: Plant level effect of coal type on life cycle impact indicator scores (post-combustion CO₂ capture with MEA, transport and injection)

The baseline case represents a 500 MW plant using a US Appalachian low sulphur bituminous coal.

Case study: full chain analysis of Middle East natural gas to a UK power plant without/with CCS

Qatar North Field offshore production (1,730 MMscf/day) → undersea pipeline (80 km) → Gas processing and LNG plant at Ras Laffan (2×7.8MTPA) → LNG shipping (Q-Max & Q-Flex) from Qatar to the UK via Suez Canal (11,281 km) → Receiving terminal at South Hook (2×7.8MTPA) → onshore gas pipeline to power plant (100 km) → Alternative gas power generation with/without CO₂ capture → CO₂ pipeline transportation (300 km) → CO₂ injection into saline aquifer (161t/hr)
Case study: full chain analysis of Middle East natural gas to a UK power plant without/with CCS

GHG emissions from the gas supply chain

Comparison of GHG emissions for different gas supply options to the UK market
Case study: full chain analysis of Middle East natural gas to a UK power plant without/with CCS

Life cycle of GHG emissions for alternative power plant configurations with gas supplied from Middle East

Comparison of GHG emissions for alternative coal and natural gas fired power plant configurations

<table>
<thead>
<tr>
<th></th>
<th>lowest case</th>
<th>difference between lowest and highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal: Oxyfuel-combustion with CCS</td>
<td>72</td>
<td>217</td>
</tr>
<tr>
<td>Coal: Post-combustion with CCS</td>
<td>227</td>
<td></td>
</tr>
<tr>
<td>Coal: Conventional power plant</td>
<td>781</td>
<td>180</td>
</tr>
<tr>
<td>Gas: CCGT</td>
<td>240</td>
<td>89</td>
</tr>
<tr>
<td>Gas: SMR+membrane</td>
<td>42</td>
<td>102</td>
</tr>
<tr>
<td>Gas: ATR+adsorption</td>
<td>69</td>
<td>121</td>
</tr>
<tr>
<td>Gas: CCGT with MEA capture</td>
<td>45</td>
<td>106</td>
</tr>
</tbody>
</table>
Comparison of GHG emissions for different natural gas power generation value chains around the world and with CCS implementation.
Limitations of current bottom-up studies used to inform emission factors

- Current GHGs emissions factors and emission database are developed mainly considering North American conditions. There are limitations in applying these emission factors to operations outside these regions.
- GHGs emissions along the gas value chain are mainly from:
  - **Combustion sources**: mainly the use of fossil fuel to power the gas transport and gas processing. These emissions are not affected by emission factors and can be calculated or estimated.
  - **Vented methane**: emissions depend on the operational options and regional regulations (North American emission factors may not be appropriate);
  - **Fugitive methane emissions**: emissions depend on the type of equipment used, operational options and regional regulations (same limitations as above for North American studies)
- The ICLCA life cycle bottom-up approach can help overcome these limitations through a combination of monitoring and modelling and accounting for operational options, equipment used and regional regulations.

ICLCA approach compared to other approaches in literature

**IPCC Tier 1, 2 and 3**: emission factor approach which can generate average emissions with a range; covers key processes in the value chain; good at generating GDP related GHGs emissions.

Not suitable to evaluate emissions for a specific reservoir or a production chain.

**API 2009 and 2004**: bottom-up approach; emission factors based on unit process or equipment level; cover all the processes in the value chain; emission factors developed from measurements data and literature.

It is a database, not a model!

**US EPA emission factors**: emission factor approach, can generate average emissions with a range; cover key processes in the value chain; emission factors statistically summarised from measurements or monitoring data and industry emission reporting data for different years across US.

Focusing onshore emissions, not suitable to evaluate emissions for a specific reservoir or a production chain.
ICLCA approach compared to other approaches in literature

**Industry emissions reporting**: estimation and measurements for the company as a whole in a specific year. Based on a combination of emission factors, monitoring and own estimation tools; may be considered biased by environmental groups/NGOs in particular.

Majority of **literature studies in the public domain**:

- use average values or emission factors;
- focus on a given natural gas production method (CBM for example) or specific value chain sub-systems (LNG for example);
- variable boundary conditions and assumptions
- Site specific, can be fast outdated
- do not link the characteristics of the reservoir to GHGs emissions
- Do not consider the whole life of operations (lack of temporal representation)

ICLCA model: Life-cycle bottom-up approach

**Model characteristics**

- Emissions are accounted from a resource/reservoir’s life cycle perspective, do not rely on not a single time/period snapshot or measurement
- Considers resource characteristics
- Allows to investigate the effect of operational choices (production methods, production rates, emission control methods etc)
- Uses simulation and engineering calculations at unit process level
- Methane, GHG and other environmental emissions can be traced back to equipment level
- Available monitoring data can be used to update/validate individual equipment or process emissions, update models currently used
- Allows to analyse reliably emissions from operations around the world
- Can be parameterised to the specifics of individual operations
- Compatible with main stream emission factors (API, 2009; EPA emission factors, 2012 and 2013) and latest emission regulations (US NSPS, 2012)
How bottom-up approaches can help address the challenges of evaluating GHGs emissions across the natural gas value chain

Life cycle bottom-up emissions analysis is needed to:

- quantify the relative uncertainty of emissions from combustion sources, vented gas, fugitive emissions
- Assess the impact of the following factors in methane/GHG emissions
  - geological conditions of production reservoir;
  - geographical location of the reservoir;
  - the operational options/requirements;
  - regional regulations;
  - monitoring/measurement methods;
  - emission modelling/estimation approaches;
  - different emission factors used;
- Relate emissions to specific equipment/processes, so targeted control can be implemented (this may differ from site to site and will also vary over time for the same operation)
- Assess emission reduction and cost for different emission control options

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