

GHGT-11

## Assessment of low carbon energy technologies: fossil fuels and CCS

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### Abstract

This paper presents results that are part of a larger effort driven by the International Resource Panel of the United Nations Environment Program. The reports aims to identify and, when possible, quantify the trade-offs, benefits, and risks of low carbon energy technologies. In order to provide a meaningful comparison a common assessment approach is developed by selecting common environmental indicators, common background data, and common assumptions for inventory construction. The assessment is based on a systematic review of the literature and an extended analysis of life-cycle inventory data in which the global environmental pressure of introducing technologies following widely used scenarios are investigated.

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Selection and/or peer-review under responsibility of GHGT

Keywords: life cycle assesment; environmental assessment; integrated analysis

### 1. Introduction

This paper presents results that are part of a larger effort driven by the International Resource Panel (IRP) of the United Nations Environment Program (UNEP). In collaboration with a large number of experts, IRP is developing a report aiming to provide decision makers with sound information to better understand, from a life cycle perspective, the co-benefits and unintended impacts on the environment and resources of the large-scale deployment of low-carbon energy technologies. The report is driven by the recognition that technologies for emission abatement, whether they are renewable energy, nuclear power or CO<sub>2</sub> capture and storage, throughout their life cycle, require resources and cause various types of environmental impacts, including greenhouse gas emissions.

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The report is titled “The environmental sustainability of low carbon energy technologies” and is composed of two volumes: Energy supply (to be launched in winter 2012) and Energy demand technologies (to be launched in 2013). This paper is embedded in the first volume (the benefits risks and trade-offs of low-carbon technologies for electricity production) which contains an assessment of the potential environmental impacts (alone and combined) of the following technologies: fossil fuels and carbon dioxide capture and storage (CCS); photovoltaics; concentrated solar; solar thermal; wind power; hydropower and geothermal. The technology choice was strongly influenced by the International Energy Agency’s Energy Technology Perspectives report [1].

## 2. Methodology

The reports aims to identify and, to the extent possible, quantify the trade-offs, benefits, and risks of these low carbon energy technologies. In order to provide a meaningful comparison a common assessment approach is needed, that implies, selecting common environmental indicators, common background data, and common assumptions for inventory construction. At the same time, the technology-specific state of knowledge and the technology-specific sustainability concerns need to be addressed. The assessment in the report is based on a systematic review of the literature and an extended analysis of life-cycle inventory data obtained from the literature in which the global environmental pressure of introducing technologies following widely used scenarios are investigated. The assessment method utilized is an extension of existing scenario-based life cycle assessments [2-4].

A schematic representation of the methodology used is depicted in Figure 1. The report contains two main outcomes, a *technology chapter* where each technology is described and knowledge and insights from existing literature are assessed. The second, and more challenging outcome, is the integration of LCA and scenario modeling for the complete portfolio of technologies. This *scenario assessment* will generate information on the risks and trade-offs of low-carbon technologies for electricity production which goes beyond the assessment of one type of technology to the synergies and potential bottlenecks when a complete portfolio of technologies is implemented in large scale.

For the assessment two of the scenarios of the International Energy Agency Technologies Perspectives 2010 report [1] are used, namely: the Baseline and the Blue Map scenario. By combining LCA and the scenarios is possible to estimate the potential impacts, for instance in terms of greenhouse gases, eutrophication, acidification, toxicity potential, of an electricity mix in the future.

The methodology works with a hybrid LCA which combines information of the e.g. emissions of the processes that are directly linked to the functional unit analyzed (1 kWh) with information on the background processes that are further up and downstream through input-output tables. By using this approach, monetary flows between regions (e.g., trade flows) are fully part of the model. In the current report, the model provides results for the global economy as a whole and for nine different world regions. This choice has been driven by the IEA’s energy scenarios and the availability of machining background data from the Exiopool project.

Another characteristic of the report is that it explicitly takes into account that scenario assessment of future energy mixes need to reflect direct improvements or changes of a given technology including background processes. The method employed to modify the background life cycle inventory follows the NEEDs methodology. The scenario assessment uses four data sources (Figure 2):



### 3. Fossil fuels and carbon capture and storage: the technology chapter

Combustion of fossil fuels result on emissions of CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>, particulates, volatile organic compounds and heavy metals such as mercury. The amounts of CO<sub>2</sub> discharged into the atmosphere are mainly dependent on the carbon concentration of the fossil fuel, and to a lesser extent, on the efficiency of the thermodynamic cycle. Emissions of non-CO<sub>2</sub> substances depend not only on fuel characteristics but also on specific conditions such as type of technology, combustion, operating and maintenance conditions, size and age, and emission control policy.

The *technology chapter* aims to provide a broad overview of the status of fossil fuel based power plants. Among the technologies included in the chapter are: pulverized coal fired power plants (sub-critical, supercritical, ultra supercritical); integrated gasification combined cycles; fluidized bed combustion systems; natural gas combined cycles and advice combined cycles (CHAT/SOFT). In terms of fossil fuels, conventional (coal and natural gas) as well as unconventional (oil sands, shale gas, natural gas hydrates) are addressed. Technology options for CO<sub>2</sub> capture included in the chapter are pre-combustion, post-combustion and oxyfuel. A small section dealing with novel concepts (e.g., membranes, hydrate-based technology) has been included. Although CO<sub>2</sub> can be transported by ship and truck, the chapter focuses on CO<sub>2</sub> transport by pipeline as it considers it the most feasible option for large scale implementation. The chapter also addresses CO<sub>2</sub> underground storage both in oil fields and in aquifers.

A main section of the technology chapter focuses on the assessment of the environmental impacts driven by fossil fuels (with and without CCS). The topics are covered at two levels, the power plant (i.e. air emissions, water, waste) and from a life cycle assessment perspective (e.g., global warming potential, acidification, eutrophication, abiotic resource depletion, toxicity). Furthermore, the chapter also provides insights into the environmental impacts from (un)conventional fuel exploitation.

Note that since the chapter deals with data available in the (public) literature, the assessment is mainly based on relatively mature concepts. Given the lack of data available, novel technologies remain relatively uncovered in the assessment. As an example of the type of assessment included in the chapter, Figure 3 provides a comparison of the demand on water resources for several types of cooling systems. The figure distinguishes between water withdrawal (water taken from the source and send back to the same source) and water consumption (loss of water that is not returned to the source). The rates of water withdrawal and consumption depend on the type of cooling strategy used (e.g., an open loop, cooling towers, air cooling systems), the plant size, the energy source used, plant efficiency, type of desulfurization unit used, ambient temperature and whether or not carbon capture technologies are deployed. CO<sub>2</sub> capture technologies increase further demand on water requirements as a consequence of additional fuel use to make up for the energy penalty and the demand of the CO<sub>2</sub> capture system (see table 1).

For instance, coal fired power plants with post combustion (MEA) systems have been reported to have larger cooling water make up requirements, while increased water demand in IGCCs with pre-combustion capture is mainly driven by increased cooling load required to further cool the syngas and steam for the water gas shift reactor and the increase auxiliary load [5, 6]. Dry cooling systems will result in significant lower water requirements, however, they will affect the thermal efficiency of the power plant (see table 1). The impact is larger when CO<sub>2</sub> capture technologies are amplified since they not only affect the power

island but for instance, in the case of MEA, the use of air to cool down the sour gas and the lean solvent leading to an increase of solvent circulation and steam consumption in the regeneration section.

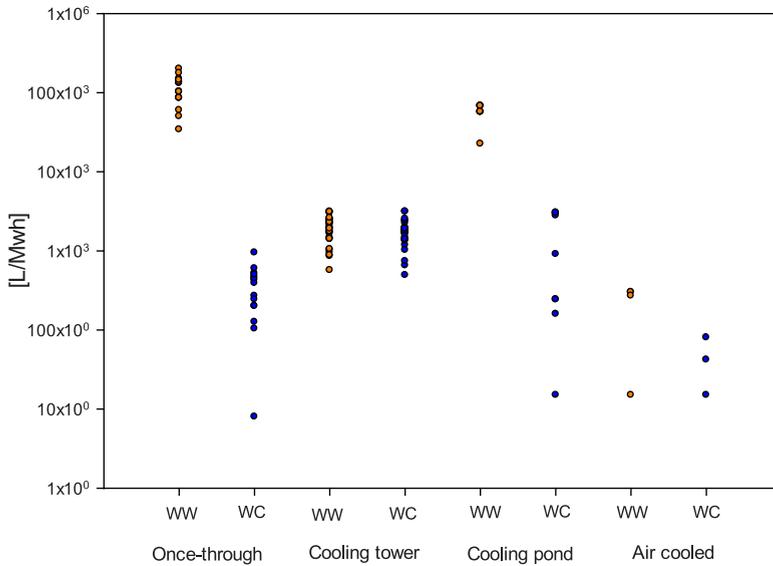


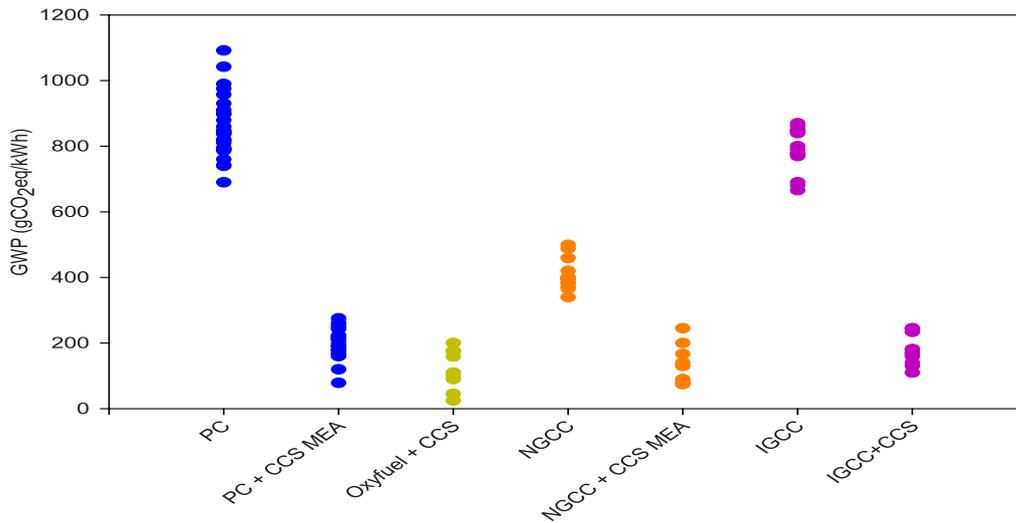
Figure3. Overview of ranges of water withdrawal (WW) and water consumption (WC) found in the literature for different types of cooling systems.

Table 1. Example data found in the literature of water withdrawal (WW) and water consumption (WC) in coal fired power plants with and without CCS

| Fuel          | Cooling system    | Type boiler | Water use   |            |            |            | Efficiency power plant |          | Source |
|---------------|-------------------|-------------|-------------|------------|------------|------------|------------------------|----------|--------|
|               |                   |             | Without CCS |            | With CCS   |            | Without CCS            | With CCS |        |
|               |                   |             | WW [l/kWh]  | WC [l/kWh] | WW [l/kWh] | WC [l/kWh] | [%]                    | [%]      |        |
| Coal          | once-through      | USC         | 139927      | 104        | 240495     | 410        | 44                     | 34,8     | [6]    |
|               | wet-cooling tower | SC          | 2400        | 1685       | 4379       | 3085       | 38,3                   | 26,4     | [7]    |
|               |                   |             |             | 1900       |            | 2700       | 42                     | 32       | [8]    |
|               |                   |             | 2168        | 1721       | 4091       | 3152       | 39,3                   | 28,4     | [9]    |
|               | air cooled        | SC          | 0           | 0          | 0          | 0          | 42,1                   | 32,6     | [6]    |
|               |                   |             |             | 100        |            | 800        | 40                     | 29       | [8]    |
|               |                   |             | 313         |            | 2660       |            |                        |          | [9]    |
| hybrid system | SC                | 480         | 236         | 2715       | 1820       | NS         | NS                     | [7]      |        |

USC: Ultra supercritical; SC: super critical; NS: no specified

Besides air emissions, water and waste the chapter also examined the potential impacts from a LCA perspective as described in the methodology. For illustration purposes figures 4A and 4B depict ranges found in the literature for the environmental categories Global Warming Potential and Euthrophication. In the figures ranges for power plants with and without CCS are distinguished.



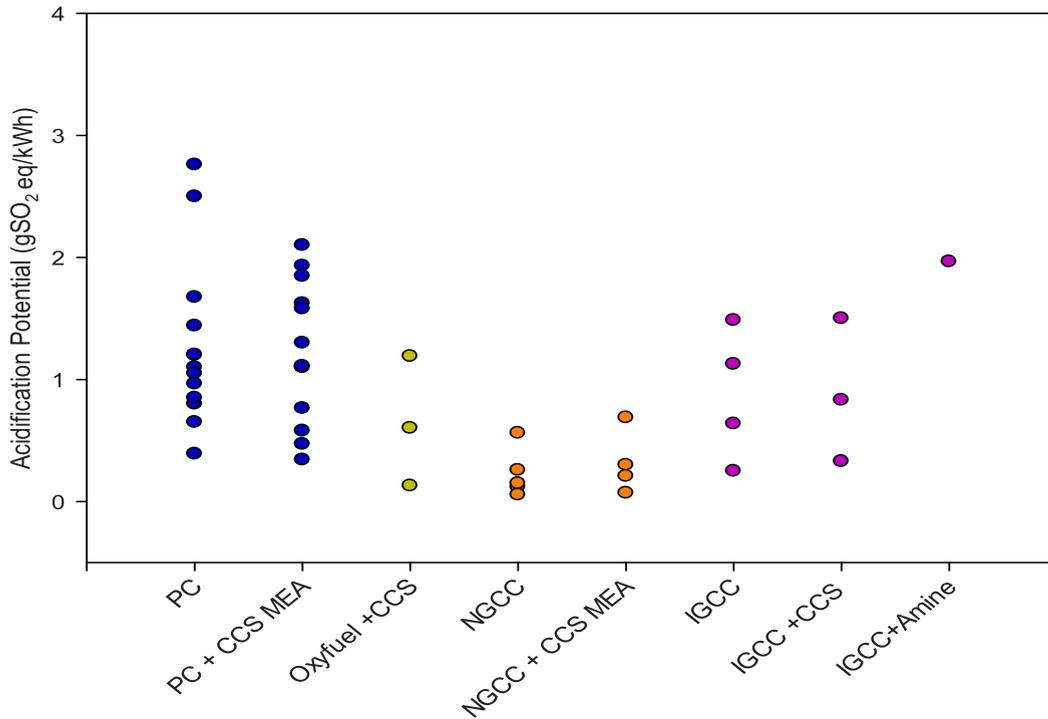


Figure 4 . Global warming and acidification potentials reported in life cycle assessment for fossil fuel power plants with and without CCS.

In the coming months results of the integrated assessment will be produced which will allow to assess the impact and potential cobenefits of deploying a large portfolio of low carbon generation technologies, of which CCS is one of the technologies. The report with the complete assessment and background information will be publicly available from the UNEP website.

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