Methodology for calculating electricity and heat marginal abatement cost curves (MACC) in the IEA World Energy Outlook 2009

CO_2 Emission Savings

The total CO_2 emission savings in the Power Generation (PG) sector for a given year is simply the difference of emissions between the Reference (RS) and 450 Scenarios. These savings are broken into two main components; the savings from reduced demand, and the savings due to the change of the fuel mix.

CO_2 savings from reduced electricity & heat demand are calculated based on the average CO_2 content of fossil fuel-based plants in the Reference Scenario. Everything else being equal, in fact, nuclear and renewable power plants would continue to generate the same amount of electricity, while fossil-fuel ones would see a decrease in generation. This is calculated as:

$$CO_2\ Savings\ due\ to\ lower\ electricity\ and\ heat\ demand$$
$$= \Big((Total\ Energy\ Output_{RS} - \sum Energy\ Output_{Nuclear\ RS,\ Renewables\ RS}) - (Total\ Energy\ Output_{450} - \sum Energy\ Output_{Nuclear\ RS,\ Renewables\ RS}) \Big) \times \left(\frac{CO_2\ Emissions_{RS}}{(Total\ Energy\ Output_{RS} - \sum Energy\ Output_{Nuclear\ RS,\ Renewables\ RS})} \right)$$

Therefore, savings from technology switching is the difference between total CO_2 savings in the PG sector and CO_2 savings from reduced electricity and heat demand.

Savings from technology switching are allocated as follows:

- Fossil fuel-based generation with reduced average CO_2 content. We assume that the difference comes from two sources: more efficient plants that use the same fuel in both scenarios, and using existing or building new additional gas to displace coal plant[1]. The combined savings are based on the difference in CO_2 content through technologies in the first case and through fuels in the second case.

    - More efficient plant (excluding CCS). The average CO_2 content of each type of fossil fuel in the 450 Scenario is lower than in the RS because of newer technologies (e.g. supercritical, ultrasupercritical, IGCC) which replace older and less efficient plants. This replacement takes place for both coal and gas plants, although the order of magnitude of the savings in gas plants is much smaller than for coal plants.
      The savings due to more efficient coal plants are calculated as the difference between the average CO_2 content of coal-fired generation (excluding CCS) for the Reference Scenario and the 450 Scenario multiplied by the electricity generation from coal plants in the 450 Scenario for the given year[2]. In this case:

[1] This displacement is negligible for oil-fired plants and has therefore not been included.
[2] By comparing against the same year for Reference and 450 Scenarios (as opposed to the base year) we are inherently excluding the annual CO_2 reduction seen in the Reference Scenario.

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$$CO_2 \text{ savings due to more efficient coal plants} = Energy\ Output_{Coal\ 450} \times (\alpha_{Coal\ RS} - \alpha_{Coal\ 450})$$

$$where\ \propto = emission\ content\ per\ unit\ of\ energy\ produced$$

$$\text{Note: } All\ figures\ exclude\ CCS - fitted\ plants$$

An analogous methodology is employed to estimate the CO_2 savings due to more efficient gas plants.

- Building and using existing spare and new gas capacity to displace coal-fired generation. Emission savings are calculated as the difference between the average CO_2 content of coal- and gas-fired generation (excluding CCS) for the Reference Scenario multiplied by the difference between the 450 and RS gas-fired generation (when greater than zero), but bounded such that it is not larger than the reduction in coal-fired generation between the two scenarios.

$$CO_2 \text{ savings due to coal to gas switch} = Min\ (\text{Max}(Energy_{Gas\ 450} - Energy_{Gas\ RS}, 0),\ \text{Max}(Energy_{Coal\ RS} - Energy_{Coal\ 450}, 0)) \times (\alpha_{Coal\ RS} - \alpha_{Gas\ RS})$$

$$where\ \propto = emission\ content\ per\ unit\ of\ energy\ produced$$

$$\text{Note: } All\ figures\ exclude\ CCS - fitted\ plants$$

- The emission savings from plants fitted with CCS are currently set to be equal to the CO_2 captured, and are determined directly from the model output as the actual emissions from these type of plants are available. Given a specific carbon capture rate (we assume 90%), the savings from CCS-fitted plants may be calculated as follows:

$$CO_2 \text{ savings due to CCS fitted plants} = \frac{(Emissions_{CCS\ 450} - Emissions_{CCS\ RS})}{1 - Carbon\ Capture\ Rate}$$

Alternatively, the CO_2 savings from CCS-fitted plants could be calculated alongside nuclear and renewables in a proportionate manner (as indicated in the next point), once taken into account the CO_2 emitted in CCS-fitted plants. Both methods provide quite similar results.

- The remainder is allocated proportionally to nuclear and renewables based on electricity and heat generation output.

Abatement Costs per Unit

The abatement costs from technology switching (as defined in the previous section) are essentially calculated using the long-run marginal costs (LRMC) of the new plant (for that category and region) and its associated emissions per unit (gCO_2/kWh) relative to a reference plant that it would effectively displace.

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In other words this can be thought of as:

$$Abatement\ cost\ per\ tonne\ of\ CO_2 = \frac{\left(LRMC_{New\ Plant} - LRMC_{Ref\ Plant}\right)}{\left(Emissions\ Per\ Unit_{Ref\ Plant} - Emissions\ Per\ Unit_{New\ Plant}\right)}$$

Where for renewables and nuclear with assumed zero emissions this becomes simply:

$$\frac{\left(LRMC_{New\ Plant} - LRMC_{Ref\ Plant}\right)}{Emissions\ Per\ Unit_{Ref\ Plant}}$$

So for each technology switching category we calculate as follows:

Technology Switching Category	New Plant	Reference Plant
More Efficient Coal	Coal Ultrasupercritical	Coal Supercritical
More Efficient Gas	Gas CCGT	Region Default
Additional Gas*	Gas CCGT	Coal Subcritical
CCS-fitted plants†	Coal Oxyfuel with CCS, Coal IGCC with CCS, Gas CCGT with CCS	Region Default
Nuclear	Nuclear	Region Default
Renewables†	Hydro, Bioenergy, Wind Onshore, Wind Offshore, Geothermal, Solar Thermal, Solar PV, Tide/Wave	Region Default

* *Calculated using short-run marginal cost (SRMC) when utilising existing spare gas capacity and CO_2 content based on default efficiency*

† *Computed separately for each new plant type listed*

Arguably, determining the default reference plant is the most contentious part, but we have attempted to make this more representative by adjusting the reference plant by region and by period (defined as current to 2020, and 2021 to 2030).

For example, in one region the reference plant might be a supercritical coal-fired plant in 2020, but by 2030 this may be an ultrasupercritical plant. In a developing region it may be a subcritical plant in 2020, going to a supercritical plant by 2030. Also, depending on the technology mix of the individual region we may use a simple average of two competing technologies (e.g. 50% coal supercritical and 50% CCGT).

Abatement Costs

Once the abatement costs per tonne of CO_2 have been determined, the abatement costs are simply a function of the abatement costs per unit (e.g. \$/tCO_2) multiplied by the corresponding CO_2 emission savings (tCO_2) for each technology switching category.

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