Locational Marginal Carbon Intensity
Definition, Properties and Policy Implications

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"[T]heory [..] becomes a material force as soon as it has gripped the masses." *K. Marx*

"Theory becomes a material force as soon as it has gripped the bosses." *A former colleague*

- **Energy conservation and renewable generating resources reduce emissions of greenhouse gases**
  - Is this always true?
  - Does it matter where or when we reduce electricity demand?
  - Does it matter where we locate renewable generation?
  - And if it matters, what should we do about this knowledge?

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The Question: ***How do renewable resources and demand reduction measures affect CO_2 emissions of the bulk power system?***

- **Take an economist's approach:**
  - Follow the logic that follows the money
  - Money follows prices (LMPs)
  - LMPs are defined as a change in system-wide dispatch costs in response to change in demand
  - LMPs follow marginal generators
  - If we systematically track the change in CO_2 emissions in response to change in demand, it becomes clear that it follows marginal generators in the same way as LMPs

Marginal Carbon Intensity: A Definition

- **Marginal carbon intensity is a change in emissions of CO_2 by the entire grid when we reduce electricity demand by 1 kWh at a given location in a given moment in time and redispatch the system to accommodate that change**

$$MCI_{node} = \frac{\Delta(CO_2)_{system}}{\Delta(Demand)_{node}}$$

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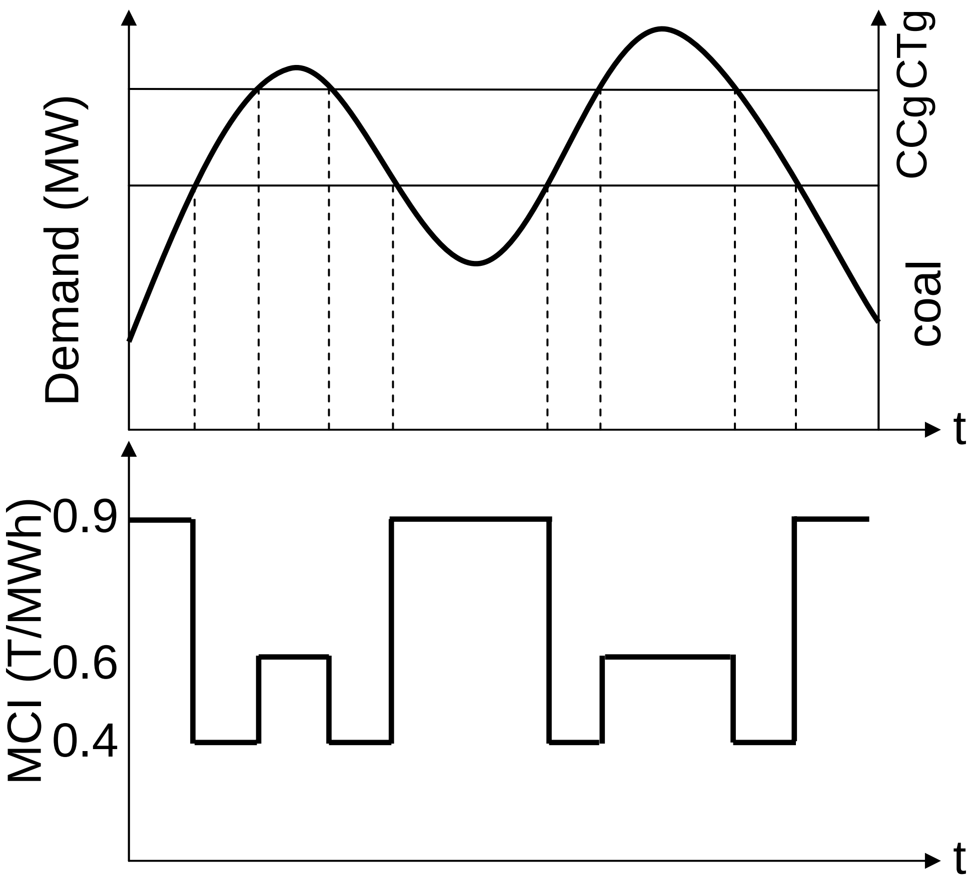
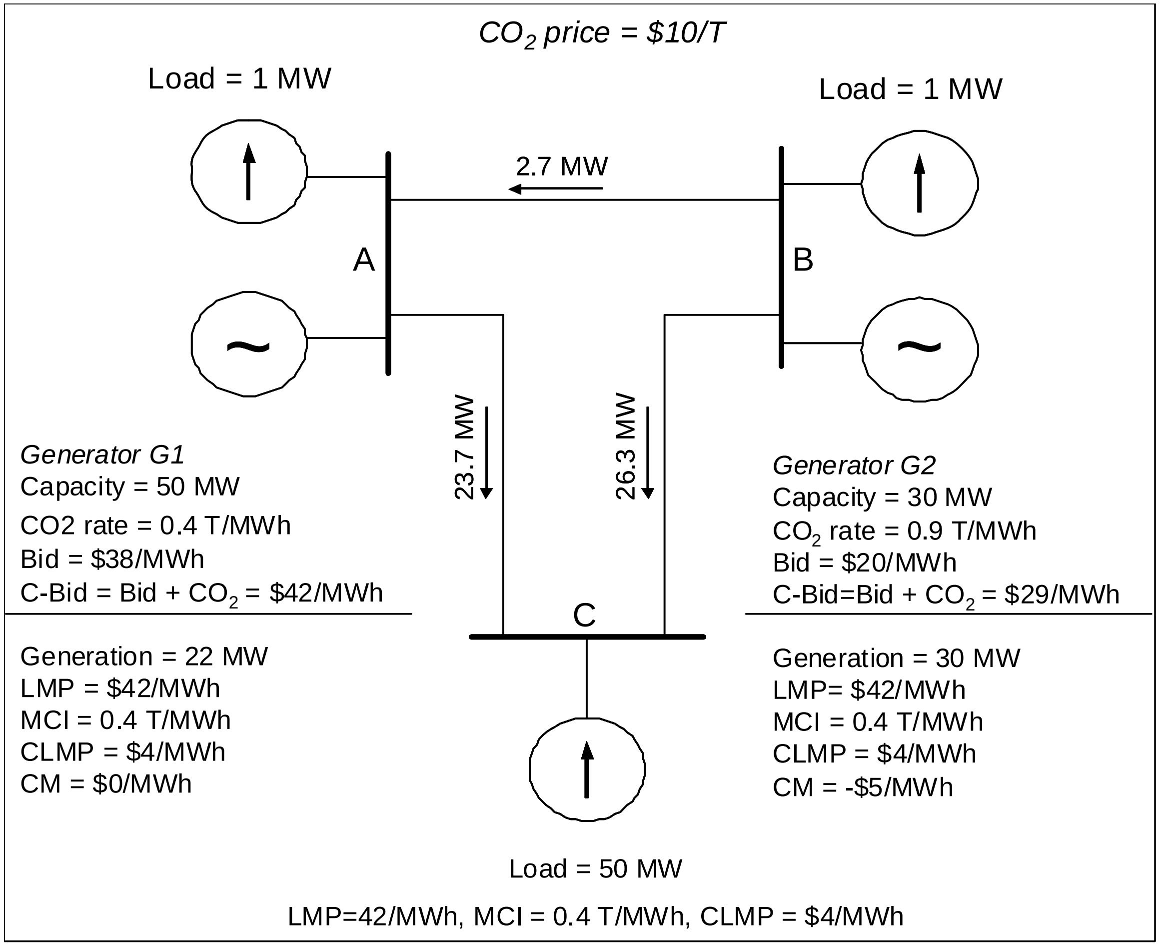
Over time MCI follows the succession of marginal units

Technology	Heat Rate (Btu/kWh)	Fuel Price ($/MMbtu)	VO&M ($/MWh)	CO_2 rate (Ton/MWh)	CO_2 price ($/Ton)	Dispatch cost ($/MWh)
Coal	9500	2.0	1.0	0.9	10	29
CCg	7000	5.0	3.0	0.4	10	42
CTg	11000	5.0	5.0	0.6	10	66



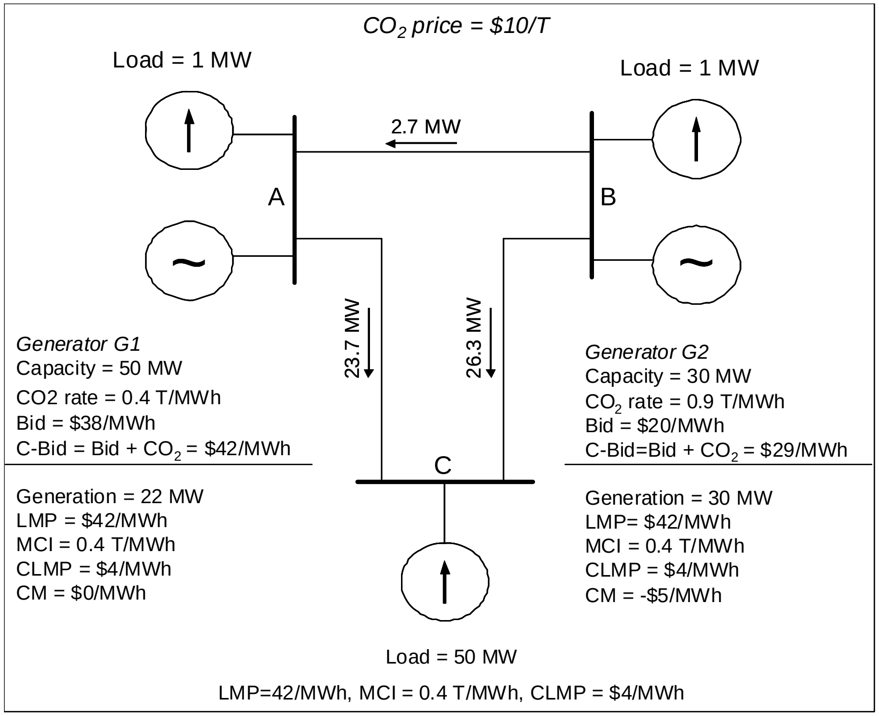
In absence of congestion and losses MCI is the same at all locations



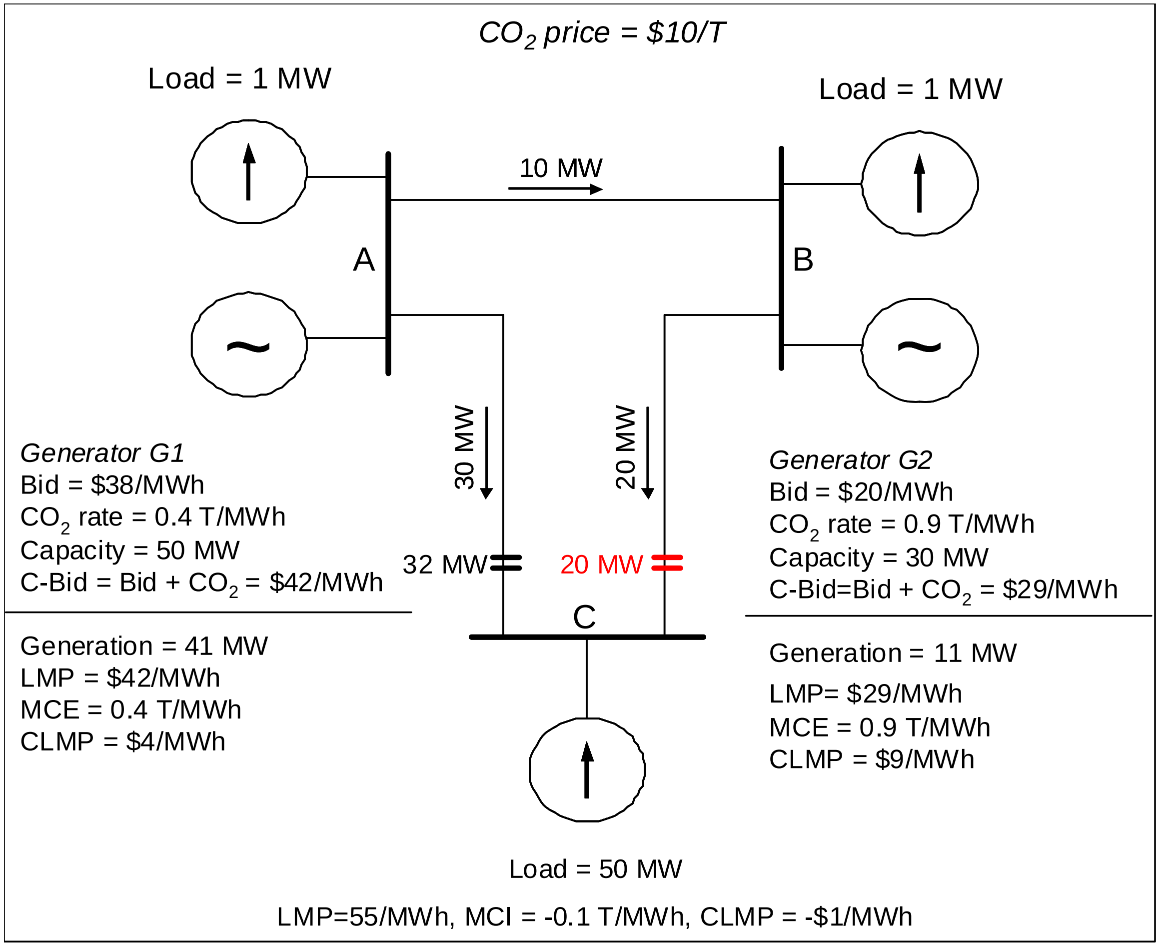
Observations from an unconstrained case

- Generation
  - Gen 1 emits 0.4 T/MWh and marginally displaces itself. Net = 0 T/MWh
  - Gen 2 emits 0.9 T/MWh and marginally displaces Gen 1 with 0.4 T/MWh.

    Net = 0.5 T/MWh
- Loads:
  - at all 3 locations marginally cause 0.4 T/MWh of emissions
- Transmission:
  - unconstrained and has no marginal impact on carbon emissions

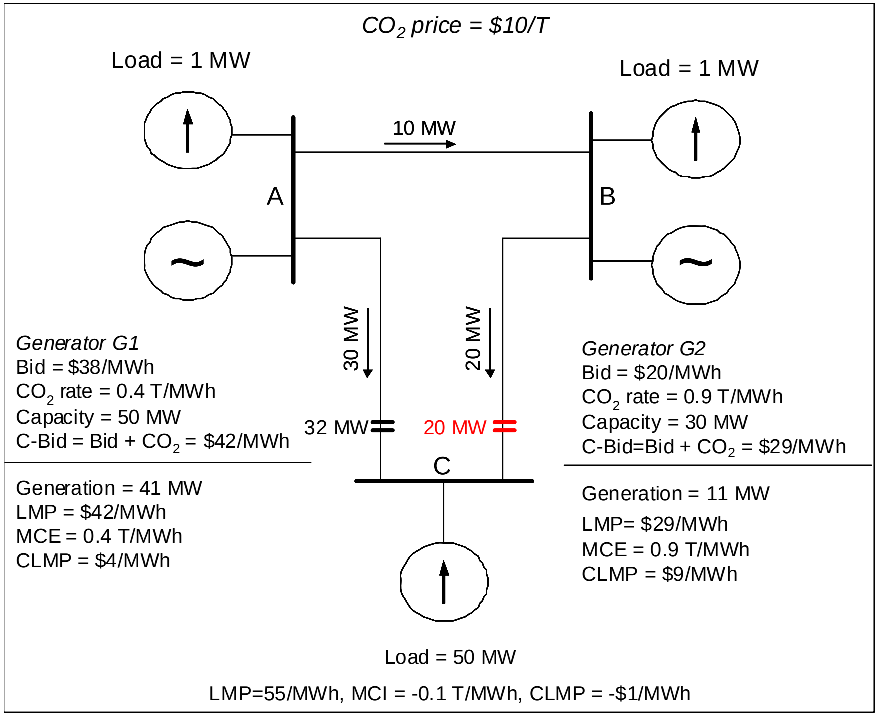


In presence of congestion MCI varies by location. The case of a \$10/T CO_2 price

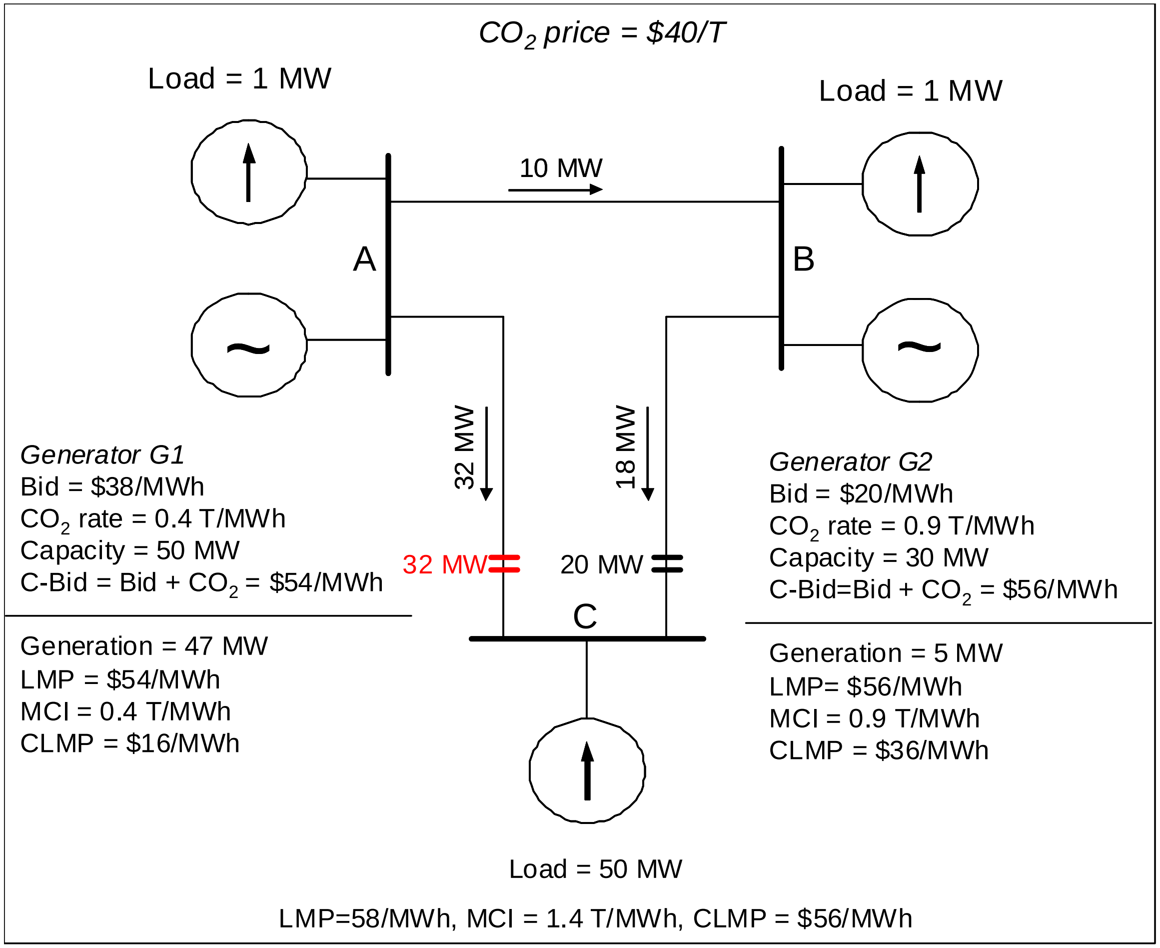


Observations from a constrained case with \$10/T CO_2 price

- Generation:
  - Gen 1 emits 0.4 T/MWh and marginally displaces itself. Net = 0 T/MWh
  - Gen 2 emits 0.9 T/MWh and marginally displaces itself. Net = 0 T/MWh
  - Adding 1 MWh of wind at bus C will increase emissions by 0.1 T
- Load:
  - Bus A: increases emission by 0.4 T/MWh
  - Bus B: increases emission by 0.9 T/MWh
  - Bus C: decreases emission by 0.1 T/MWh
- Transmission:
  - B → C line is congested
  - Helps to reduce emissions: relieving 1 MW of congestion increases emissions by 1.5 T/MWh



In presence of congestion MCI varies by location. The case of a $40/T CO_2 price



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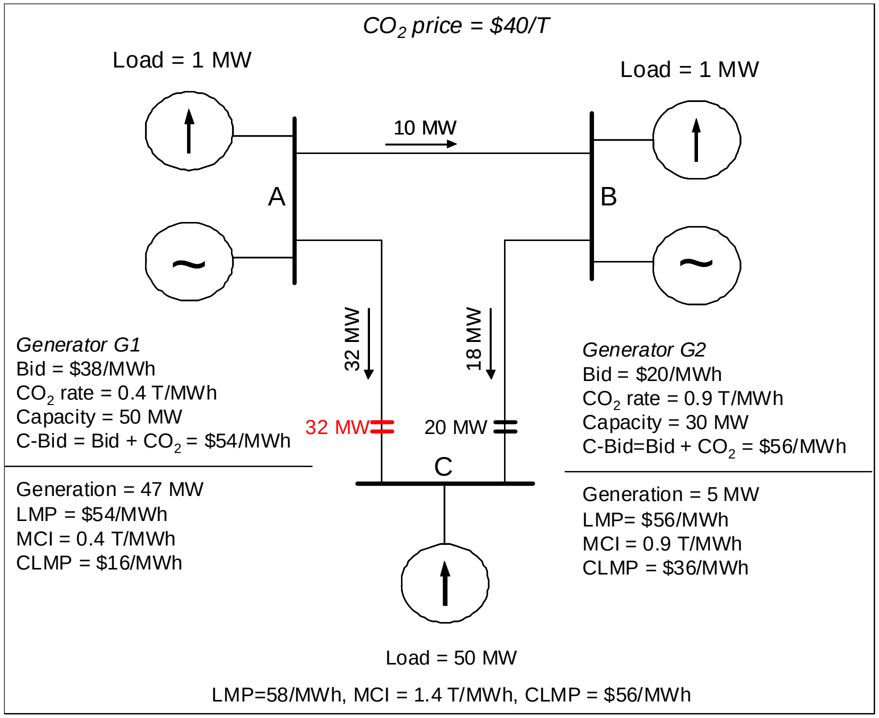
Observations from a constrained case with $40/T CO_2 price

- Generation:
  - Gen 1 emits 0.4 T/MWh and marginally displaces itself. Net = 0 T/MWh
  - Gen 2 emits 0.9 T/MWh and marginally displaces itself. Net = 0 T/MWh
  - Adding 1 MWh of wind at bus C will decrease emissions by 1.4 T
- Load:
  - Bus A: increases emission by 0.4 T/MWh
  - Bus B: increases emission by 0.9 T/MWh
  - Bus C: increases emission by 1.4 T/MWh
- Transmission:
  - A → C line is congested
  - Helps to increase emissions: relieving 1 MW of congestion decreases emissions by 1.5 T/MWh



Policy Implications

- **If CO_2 prices embed all policy initiatives and are simply percolated through the environmental dispatch, the above discussion is useful and helps to assess the impact of policy on carbon reduction**
- **If other policy measures are:**
  - introduced via additional incentives, i.e. subsidized demand reduction programs or renewable portfolio standards and
  - justified to the public as measures targeting reduction of CO_2 emissions,
  - Then the above discussion is highly relevant for the design and implementation of these and similar measures
- **Underlying mathematics is fully scalable for real life systems[1].**
- **System operators in organized markets and regulated utilities using SCUC/SCD software should experience little difficulty with reporting locational marginal carbon intensity on a forward and real time basis**

[1] Aleksandr Rudkevich, "Economics of CO_2 Emissions in Power Systems." Submitted to Energy Journal, February 2009.

Pablo A. Ruiz and Aleksandr Rudkevich, "Marginal Locational Carbon Intensities in Power Networks." Submitted to IEEE Transactions on Power Systems, March 2009

When and where locational MCI information will be essential

- **When CO_2 emission reduction is claimed as a benefit we should make sure that reduction will in fact occur and that the subsidy is equitably distributed with respect to the goal**
  - Transmission planning: must be relieving congestion which increases emissions, not otherwise.
  - Demand reduction: at locations with positive MCI makes sense, otherwise – does not. Paying the same subsidy per MWh or MW of demand reduction at locations with different MCIs is not equitable. The same dollar amount buys different CO_2 emission reduction.
  - Renewable Portfolio Standards: siting renewables at locations with positive MCI makes sense, otherwise – does not. Issuing RECs on a per MWh or MW basis at locations with different MCIs is not equitable. The same dollar amount buys different CO_2 emission reduction.
- **The policy makers, market participants and the public should be provided with adequate and verifiable information to be able to make informed decisions on the design and implementation of emission reduction policies**

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