Environmental implications of carbon limits on market penetration of combined heat and power with the U.S. energy sector

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Overview

Combined heat and power (CHP) is promoted as an economical, energy-efficient option for combating climate change. To fully examine the viability of CHP as a clean-technology solution, its market potential and impacts need to be analyzed as part of scenarios of the future energy system, particularly those with policies limiting greenhouse gas (GHG) emissions. This paper develops and analyzes scenarios using a bottom-up, technology rich optimization model of the U.S. energy system. Two distinct carbon reduction goals were set up for analysis. In Target 1, carbon emission reduction goals were only included for the electric sector. In Target 2, carbon emission reduction goals were set across the entire energy system with the target patterned after the U.S.'s commitment to reducing GHG emissions as part of the Paris Agreement reached at the COP21 summit. From a system-wide carbon reduction standpoint, Target 2 is significantly more stringent. In addition, these scenarios examine the implications of various CHP capacity expansion and contraction assumptions and energy prices. The largest CHP capacity expansion are observed in scenarios that included Target 1, but investments were scaled back in scenarios that incorporated Target 2. The latter scenario spurred rapid development of zero-emissions technologies within the electric sector, and purchased electricity increased dramatically in many end-use sectors. The results suggest that CHP may play a role in a carbon-constrained world, but that role diminishes as carbon policies become more stringent.

Methods

This study utilizes the MARKet ALlocation (MARKAL) model to analyze energy system wide impacts of various CHP capacity expansion and contraction scenarios under technology, energy price and emissions policy sensitivities with a particular focus on the manufacturing and commercial sector. MARKAL is an engineering-economic mixed-integer linear programming model that solves for the least-cost system-wide solution for meeting end-use energy service demands given resource supply assumptions on primary energy sources, conversion technology assumptions, and additional constraints such as air quality regulations and vehicle efficiency standards over a modeling time horizon (Loulou et al., 2004). U.S. EPA's Office of Research and Development has developed a database representing the entire U.S. energy system at the nine Census Division resolution, herafter referred to as EPAUS9r, for use with the MARKAL modeling framework to explore scenarios of the evolution of the energy system through 2055 (Lenox et al., 2013). Data are derived primarily from the U.S. Department of Energy's Energy Information Administration (EIA)'s NEMS model, and 2014 EPAUS9r database which is calibrated to the Annual Energy Outlook (AEO) (EIA, 2014). Researchers in academia, non-govermental organizations, and national laboratories apply and use EPAUS9r in a wide range of applications, e.g., Dodder et al. (2015), Nichols et al. (2015), and Bistline (2015). The database includes end-use demands for energy services (e.g., vehicle miles traveled, lumens of lighting, process heat for the industrial sector) and supply curves for coal, natural gas, crude oil, biomass feedstocks, and other non-biomass renewable resources. Energy technologies (e.g., light duty vehicles, electric power plants) are then specified based on their cost (e.g., capital, variable and fixed operation and maintenance) and performance (capacity, efficiency, and availability). The database is calibrated to 2005 and 2010 actuals in terms of fuel use, demands and electricity generation, and the period between 2015 and 2055 corresponds to the modeling years.

BASE case refers to the scenario in the 2014 EPAUS9r database, which includes upper limits on CHP capacity expansion as dictated by AEO 2014. In the reference (REF) scenarios, we do not impose any growth constraints on CHP investments. The no investment (NI) scenarios disallow new investments in CHP capacity. The natural gas (NG) scenarios simulate a doubling of natural gas costs. Next, carbon reduction targets were incorporated on top of the technology scenarios. In Target 1, the CO_2 emissions from Electric Generating Units (EGUs) are reduced by 33% by 2030 from 2005 levels. A more stringent Target 2 implements a combination of CO_2 and CH_4 emission reductions from the U.S. energy system patterned after the Paris Aggrement. In Target 2, we assumed a reduction of 28% by 2025 from 2005 levels to be reached, and also the CO_2e emissions are to be decreased by 1% annually starting in 2025 until 2055.

Results and Preliminary Insights

In 2010, the total installed CHP capacity is 67 GW of which 63 GW is in the manufacturing sector. The investment in CHP technologies was largest when CHP growth was unbounded (REF cases), and Target 1 was implemented. The CHP expansion peaked at 105 GW of installed capacity in 2055 where almost half of the capacity was installed in the commercial sector. The lowest investments were seen in scenarios where growth was bounded, natural gas prices were high, and Target 2 was implemented. For all scenarios, natural gas was the preferred fuel whereas biomass replaced natural gas with more investments in scenarios that incorporated Target 2 and high natural gas prices. Target 1 helped to increase investments in industrial CHP, but Target 2 did not.

The most significant contributors to CHP growth within the industrial sector were the food and chemicals industries. Investments in food CHP were highest (11 GW additional capacity) in scenarios where growth was unbounded, and Target 2 was incorporated. The highest CHP expansion was observed in the chemicals industry under Target 1 and low natural gas price scenarios. Technology selections within the chemicals industry were varied but typically included moderate investments in natural gas engines, steam turbines, and microturbines. Natural gas turbines were heavily favored in the Target 1 scenarios, and moderate capacity expansion in biomass turbines were seen in the Target 2 scenarios.

In the commercial sector, we observed the largest investments in the Target 1 scenarios, with a maximum installed capacity of 58 GW in 2055. In general, higher natural gas prices led to lower CHP investments within this sector. Natural gas microturbines were the technology of choice within the Target 1 scenarios.

Both Target 1 and Target 2 scenarios resulted in CO_2 emissions reductions compared to cases with no carbon limit, however the system wide reductions were moderate in Target 1 scenarios. The increase in CHP investments in industrial and commercial sectors has increased sectoral NOx emissions. However this increase was very small compared to overall system-wide NOx emissions where the majority of the NOx emissions are from the transportation sector. When considering CHP technologies as options for dealing with climate change, it is important to consider any potential local air quality trade-offs that may occur as a result of its increased use within the context of a changing energy system along with greenhouse gas implications. The scenarios that had the largest investments in CHP technologies also saw slight increases in cumulative NOx emissions with respect to the BASE scenario due to the reliance of the manufacturing sector on on-site electricity generation under Target 1 scenarios. The scenarios that have the largest reductions in NOx emissions, have moderate investments in CHP technologies. The scenarios with Target 2 implemented resulted in decarbonization of the EGUs along with electricification of the end use sectors including manufacturing sectors. These scenarios allow for moderate investments in CHP technologies as well as a slight improvement in air quality.

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