Global Mitigation of Non-CO_2 Greenhouse Gases: Marginal abatement costs curves and abatement potential through 2030

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Abstract

Greenhouse gases other than carbon dioxide (CO_2) play an important role in the effort to understand and address global climate change. Approximately 25% of GWP-weighted greenhouse gas (GHG) emissions in the year 2005 comprise the non-CO_2 greenhouse gases (USEPA, 2012). The report, *Global Mitigation of Non-CO_2 Greenhouse Gases: 2010 – 2030*, an update to USEPA (2006), provides a comprehensive global analysis and resulting data set of marginal abatement cost curves (MACs) that illustrate the abatement potential of non-CO_2 GHGs by sector and by region. The basic methodology—a bottom-up, engineering cost approach—builds on the baseline non-CO_2 emissions projections published by EPA (USEPA, 2012), applying abatement options to the emissions baseline in each sector. The results of the analysis are MAC curves that reflect aggregated breakeven prices for implementing abatement options in a given sector and region.

Among the key findings of the report is that significant, cost-effective abatement exists from non-CO_2 sources with abatement options that are available today. Without a price signal (i.e., at \$0/tCO_2e), the global abatement potential is greater than 1,800 million metric tons of CO_2 equivalent (USEPA, 2013). Globally, the energy and agriculture sectors have the greatest potential for abatement. Among the non-CO_2 GHGs, methane has the largest abatement potential. Despite the potential for project level cost savings and environmental benefits, barriers to mitigating non-CO_2 emissions continue to exist. This paper will provide an overview of the methods and key findings of the report.

1 INTRODUCTION

Climate change is influenced by a number of social and environmental factors. The change in our Earth's climate is largely driven by emissions of greenhouse gases (GHGs) to the atmosphere. While some GHG emissions occur through natural processes, the largest share of GHG emissions come from human activities. GHG emissions from anthropogenic sources have increased significantly over a relatively short time frame (~100 years) and are projected to grow appreciably over the next 20 years.

Policy development and planning efforts are underway at all levels of society to identify climate change strategies that effectively reduce future greenhouse gas emissions and prepare communities to adapt to the Earth's changing climate. GHG abatement analysis continues to play an important role in the formation of climate change policy. A large body of research has been dedicated to analyzing ways to reduce carbon dioxide (CO_2) emissions. While this work is critical to developing effective climate policy, other GHG gases can play an important role in the effort to address global climate change. These non-carbon dioxide (non-CO_2) GHGs include methane (CH_4), nitrous oxide (N_2O), and a number of industrial gases such as fluorinated gases.

Non-CO_2 greenhouse gases are more potent than CO_2 (per unit weight) at trapping heat within the atmosphere. Global warming potential (GWP) is the factor that quantifies the heat trapping potential of each GHG relative to that of carbon dioxide. For example, methane has a GWP value of 21[2] which means that each molecule of methane released into the atmosphere is 21 more times effective at trapping heat compared to an equivalent unit of CO_2. Table 1 shows the list of GHG gases with their GWP values that are considered in this report.

Table 1. Global Warming Potentials

Greenhouse Gases	Abbreviation	GWP (100 years)
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	310
Hydro fluorocarbons	HFCs	140 to 11,700
Sulfur Hexafluoride	SF_6	23,900

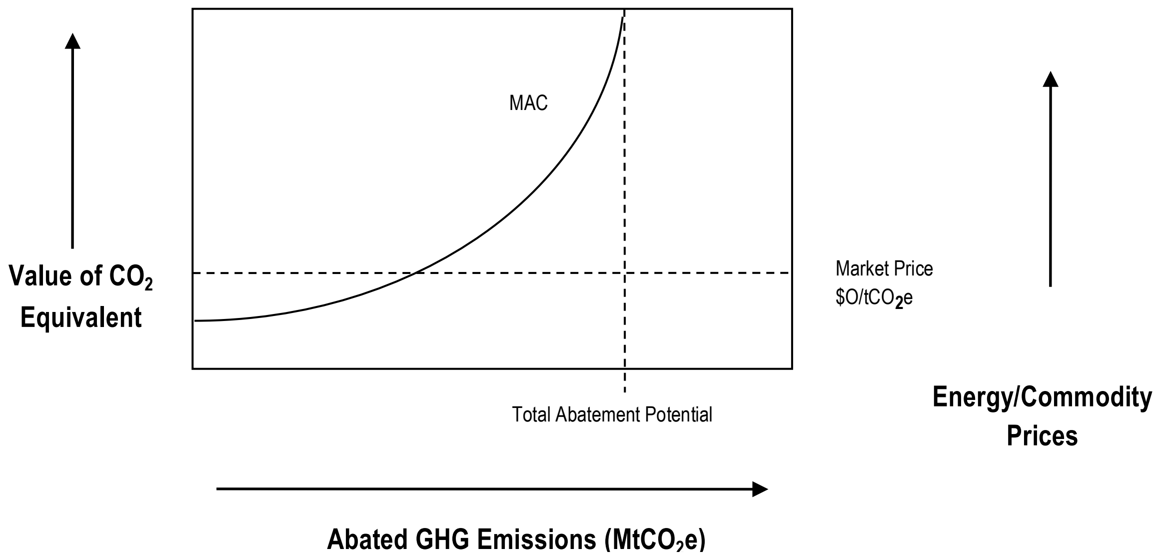
The report, *Global Mitigation of Non-CO_2 Greenhouse Gases: 2010 – 2030* (USEPA, 2013), an update to EPA (2006), provides a comprehensive global analysis and resulting data set of marginal abatement cost curves (MACs) that illustrate the abatement potential of non-CO_2 GHGs by sector and by region. The MAC curves allow for improved understanding of the abatement potential for non-CO_2 sources, as well as inclusion on non-CO_2 greenhouse gas abatement in economic modeling of multigas abatement strategies. This paper presents the methodology, data sources, and key findings of USEPA (2013) and provides comparison of results to previous studies. In this paper we will focus on methane (CH_4) and nitrous oxide (N_2O) from energy, waste, and industrial sources, as well as various fluorinated gases from industrial processes, including sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs).

2 BACKGROUND

MACs provide information on the amount of emissions reductions that can be achieved as well as an estimate of the costs of implementing the GHG abatement measures. Figure 1 shows an illustrative MAC. The x-axis shows the quantity of emissions abatement in $MtCO_2e$, and the y-axis shows the breakeven price in dollars per ton of CO_2 equivalent ($/$tCO_2e$) required to achieve the level of abatement. Therefore, moving along the curve from left to right, the lowest cost abatement options are adopted first.

[2] Based on IPCC Second Assessment Report, 100 year time horizon (IPCC, 1996)

Figure 1. Example MAC Curve



The curve becomes vertical at the point of maximum total abatement potential, which is the sum of all technically feasible abatement options in a sector or region. At this point no additional price signals from GHG credit markets could motivate emissions reductions.

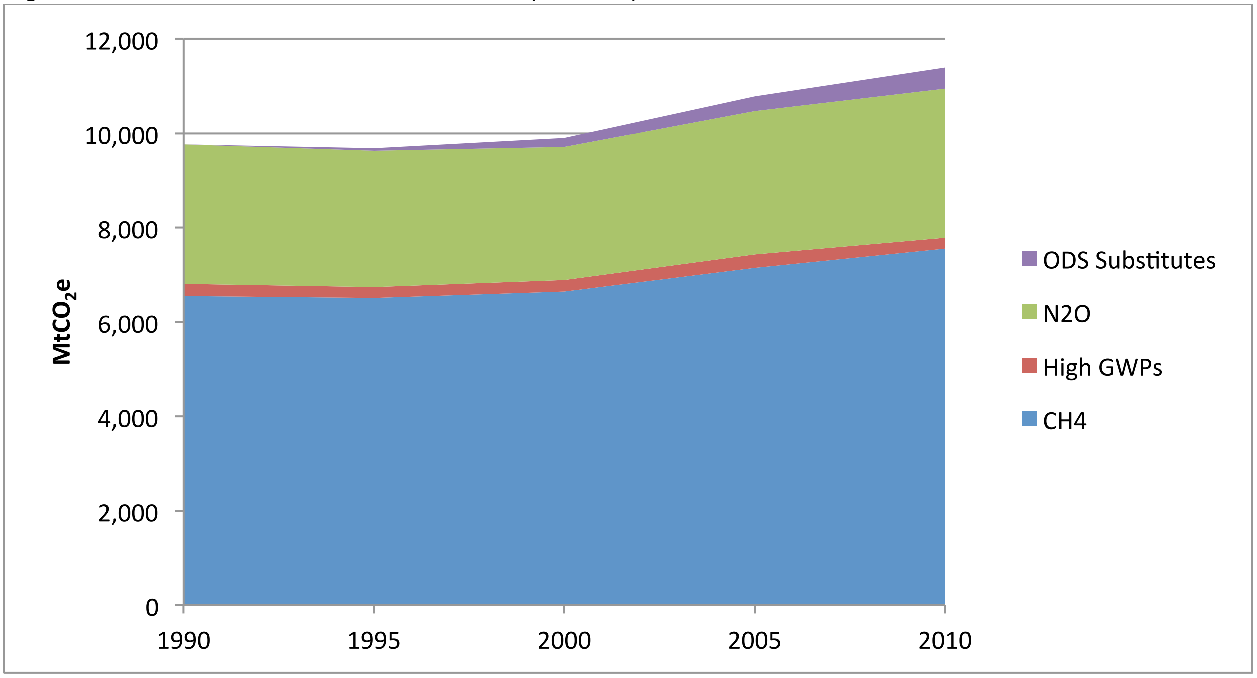
The points on the MAC that appear at or below the zero cost line ($0/t$CO_2$e) illustrate potentially profitable abatement options. These “below-the-line” amounts represent abatement options that are already cost-effective given the costs and benefits considered (and are sometimes referred to as “no-regret” options) yet have not been implemented. However, there may be nonmonetary barriers that are preventing their adoption.

3 BASELINES AND PROJECTIONS

The abatement options represented in the MACs of this analysis are applied to the baselines described here. For consistency across regions and sectors the analysis primarily uses the EPA report, *Global Anthropogenic Non-*CO_2 *Greenhouse Gas Emissions: 1990-2030* for baseline emissions and projections. The Global Emissions Report (GER) was published in December of 2012 (USEPA, 2012), and uses a combination of country-prepared, publicly-available reports (UNFCCC National Communications) and IPCC Tier 1 methodologies to fill in missing or unavailable data. The basis for the U.S. historical emissions in the GER is the U.S. Inventory of Greenhouse Gases and Sinks published in April of 2011 (USEPA, 2011). In some cases, particularly for agricultural emissions, it was necessary to develop separate baselines from which to assess the abatement analyses. For the agricultural sector, the baseline emissions used in this report were based on crop process model simulations and livestock population data combined with projected crop areas and livestock populations, respectively, from the International Food Policy Research Institute International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model.

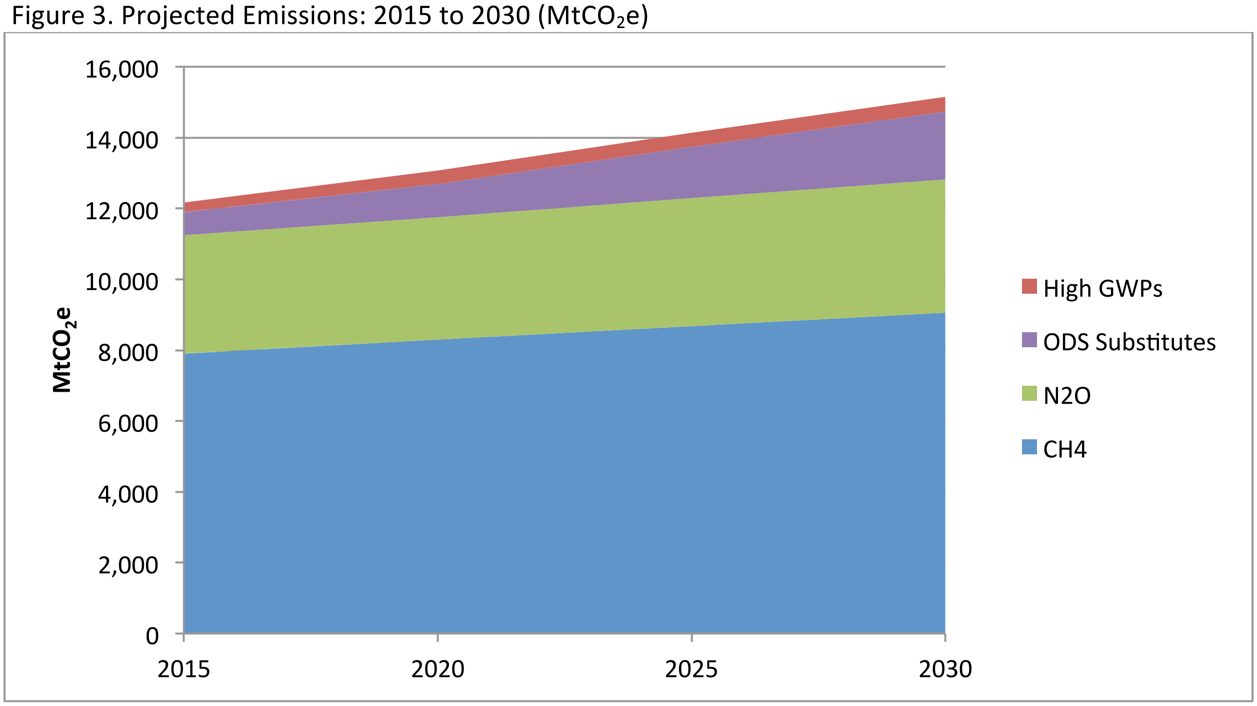
3.1 *Historical Emissions*

Figure 2. Historical Emissions: 1990 to 2010 ($MtCO_2e$)



3.2 *Projected Emissions*

Figure 3. Projected Emissions: 2015 to 2030 ($MtCO_2e$)



3.3 *Baseline Emissions for Agriculture*

Although USEPA (2012) contains estimates of baseline emissions for agricultural sources, alternative baselines were developed for the purposes of the abatement report. The primary rationale was to ensure consistency in the area, number of livestock head, production, and price projections used across the entire agricultural sector. Projections provided by IFPRI from their IMPACT model of global agricultural markets were used to adjust values for agricultural activities and associated emissions over time. In addition, detailed process-based models—Daily Century (DAYCENT) for croplands and DeNitrification–DeComposition (DNDC) for rice cultivation—were used for both the baseline emissions estimates and the greenhouse gas implications of abatement options, thus allowing for a clear identification of baseline management conditions and consistent estimates of changes to those conditions through abatement activities. For emissions associated with livestock, the abatement analysis in this report relies on projections similar to those used in USEPA (2012), but with some differences due to the adjustments made for consistency with IFPRI IMPACT projections across all agricultural sectors. The baseline emissions were also disaggregated by livestock production system and intensity using data provided by the United Nations Food and Agriculture Organization (FAO).

4 METHODOLOGY

MAC curves are developed for each region and sector by estimating the carbon price at which the present value benefits and costs for each abatement option equilibrates. In conjunction with appropriate baseline and projected emissions for a given sector the results are expressed in terms of absolute reductions of carbon dioxide equivalents (million metric tons of CO_2e - $MtCO_2e$). The MACs in this report are constructed from bottom-up average breakeven price calculations. The average breakeven price is calculated for the estimated abatement potential for each abatement option. The options are then ordered in ascending order of breakeven price (cost) and plotted against abatement potential. The resulting MAC is a stepwise function, rather than a smooth curve, as seen in the illustrative MAC below, because each point on the curve represents the breakeven price point for a discrete abatement option (or defined bundle of abatement strategies).

Conceptually, marginal costs are the incremental costs of an additional unit of abatement. However, the abatement cost curves developed here reflect the incremental costs of adopting the next cost-effective abatement option. We estimated the costs and benefits associated with all or nothing adoption of each well-defined abatement practice. However, we did not estimate the marginal costs of incremental changes within each practice (e.g., the net cost associated with an incremental change in paddy rice irrigation). Instead, the MACs developed in this report reflect the average net cost of each option for the achieved reduction – hence the non-continuous, stepwise nature of the curve.

This analysis builds on the approach used in the EMF-21 multigas mitigation study (Weyant and de la Chesnaye, 2006) and USEPA (2006). The non-CO_2 emission sources and gases included in this analysis are:

- Coal mining (CH_4);
- Oil and natural gas systems (CH_4);
- Solid waste management (CH_4);
- Wastewater (CH_4, N_2O);
- Specialized industrial processes (N_2O, PFCs, SF_6, HFCs); and
- Agriculture (CH_4, N_2O).

In addition to updating primary drivers in the model, including baseline emissions projections and energy price paths, we updated capital and operation and maintenance (O&M) costs for individual abatement measures, reduction efficiencies for individual measures by country, and developed international adjustment factors used to construct country specific abatement costs and benefits. Further, in the agriculture sector we updated crop process model simulations of changes in crop yields and emissions associated with rice cultivation and cropland soil management. For more information about additional enhancements to the agriculture sectors and the resulting MACs please see Beach et al., "Marginal abatement cost curves for agriculture non-CO_2 emissions through 2030."

4.1 *Abatement Option Analysis Methodology*

The abatement option analysis throughout this report was conducted using a common methodology and framework. The abatement analysis for all non-CO_2 gases for agriculture, coal mines, natural gas and oil systems, landfills, wastewater treatment, and nitric and adipic acid production are based on USEPA (2006) and improve upon DeAngelo et al. (2006), Beach et al. (2008), Delhotal et al. (2006), and Ottinger et al. (2006). These studies provided estimates of potential CH_4 and N_2O emissions reductions from major emitting sectors and quantified costs and benefits of these reductions. Additional data on abatement options, costs, and market penetration come from partner reported data from USEPA non-CO_2 greenhouse gas voluntary programs, including the Landfill Methane Outreach Program, Natural Gas STAR, AgSTAR, and the Coalbed Methane Outreach Program.

Given the detailed data available for U.S. sectors, the U.S. regional analysis uses representative facility estimates but then applies the estimates to a highly disaggregated and detailed set of emissions sources for all the major sectors and subsectors. For example, the analysis of the natural gas sector is based on more than 100 emissions sources in that industry, including gas well equipment, pipeline compressors and equipment, and system upsets. Thus, the analysis provides significant detail at the sector and subsector levels.

4.2 *Technical Characteristics of Abatement Options*

The non-CO_2 abatement options evaluated here are compiled from the studies mentioned above, as well as from the literature relevant for each sector. For each region, either the entire set of sector-specific options or the subset of options determined to be applicable is applied. Options are omitted from individual regions on a case-by-case basis, using either expert knowledge of the region or technical and physical factors (e.g., appropriate climate conditions). In addition, the share or extent of applicability of an option within different regions may vary based on these conditions.

The technical effectiveness of each option is calculated by multiplying the option's technical applicability by its market share by its reduction efficiency. This yields the percentage of baseline emissions that can be reduced at the national or regional level by a given option. This is then applied to the Emissions stream ($MtCO_2e$) to which the option is applied to yield the emissions reductions for the abatement option.

Figure 4. Calculation of Potential Emission Reduction for an Abatement Option

Technical Applicability (%)	X	Market Share[a] (%)	X	Reduction Efficiency (%)	=	Technical Effectiveness (%)				
						Technical Effectiveness (%)	X	Baseline Unit Emissions ($MtCO_2e$)	=	Unit Emission Reduction ($MtCO_2e$)
Percentage of total baseline emissions from a particular emissions source to which a given option can be potentially applied.		Percentage of technically applicable baseline emissions to which a given option is applied; avoids double counting among competing options		Percentage of technically achievable emissions abatement for an option after it is applied to a given emissions stream		Percentage of baseline emissions that can be reduced at the national or regional level by a given option.		Emissions stream to which the option is applied		Unit emission reductions

[a] Implied market share non competing options (i.e., only one options is applicable for an emissions streams) is assumed to add to 100 percent

Technical applicability accounts for the portion of emissions from a facility or region that an abatement option could feasibly reduce based on its application. For example, if an option applies only to the underground portion of emissions from coal mining, then the technical applicability for the option would be the percentage of emissions from underground mining relative to total emissions from coal mining.

The implied market share of an option is a mathematical adjustment for other qualitative factors that may influence the effectiveness or adoption of an abatement option. For certain energy, waste, and agriculture sectors, it was outside the scope of this analysis to account for adoption feasibility, such as social acceptance and alternative permutations in the sequencing of adoption. For example, if n competing (overlapping) abatement options are available for a single emissions stream, the implied market share of each of the n overlapping options is equal to 1/n. This avoids cumulative reductions of greater than 100 percent across options.

While this describes the basic application of the implied adoption rate in the energy, waste, and agriculture sectors, this factor is informed by expert insight into the potential market penetration over time in the industrial processes sector. For sectors such as landfills, where market share assumptions are available, customized shares that sum to one are used instead of 1/n.

4.3 *Economic Characteristics of Abatement Options*

Each abatement option is characterized in terms of its costs and benefits per an abated unit of gas (tCO_2e or tons of emitted gas [e.g., tCH_4]). The benefits include a carbon value/price expressed as

$/tCO_2e$. The carbon price at which an option's benefits equal the costs is referred to as the option's breakeven price. For each abatement option, the carbon price at which that option becomes economically viable is calculated where the present value of the benefits of the option equals the present value of the costs of implementing the option. A present value analysis of each option is used to determine breakeven abatement costs in a given region. Breakeven calculations are independent of the year the abatement option is implemented but are contingent on the life expectancy of the option. The net present value calculation solves for breakeven price, by equating the present value of the benefits with the present value of the costs of the abatement option.

Costs include capital or one-time costs and operation and maintenance (O&M) or recurring costs. Benefits or revenues from employing an abatement option can include (1) the intrinsic value of the recovered gas (e.g., the value of CH_4 either as natural gas or as electricity/heat, the value of HFC-134a as a refrigerant), (2) non-greenhouse gas benefits of abatement options (e.g., compost or digestate for waste diversion options, increases in crop yields), and (3) the value of abating the gas given a greenhouse gas price in terms of dollars per tCO_2e or dollars per metric ton of gas (e.g., $/tCH_4$, $/tHFC-134a). In most cases, there are two price signals for the abatement of CH_4: one price based on CH_4's value as energy (because natural gas is 95 percent CH_4) and one price based on CH_4's value as a greenhouse gas. All cost and benefit values are expressed in constant year 2010 U.S. dollars. This analysis is conducted using a 10 percent discount rate and a 40 percent tax rate, however the MAC model allows for the analysis to be conducted at varying discount and tax rates.

4.4 *Limitations and Uncertainties*

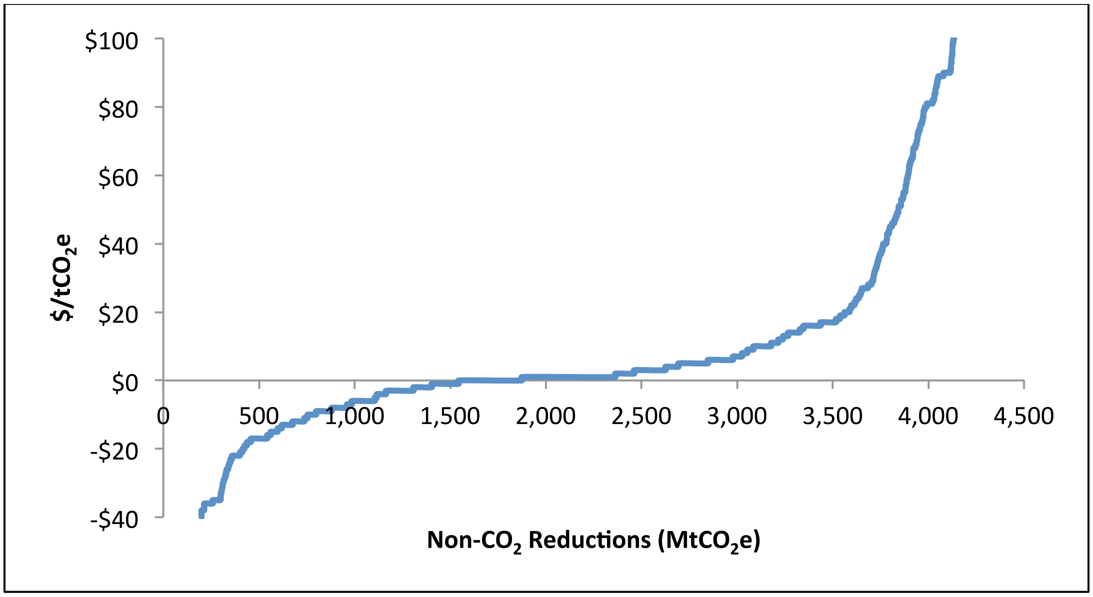
The MACs represent the average economic potential of abatement technologies in that sector. It is assumed that if an abatement technology is technically feasible in a given region then it will be implemented according to the relevant economic conditions. Therefore, the MACs do not represent the market potential or the social acceptance of a technology. In general the analysis takes a static approach to abatement assessment and excludes indirect emissions reductions and transaction costs. The analysis assumes partial equilibrium conditions that do not represent economic feedbacks from the input or output markets. Further, no assumptions are made regarding a policy environment that might encourage the implementation of abatement options.

Technological change in abatement option characteristics including, availability, reduction efficiency, applicability, and costs is not included in the MAC model. For most sectors, the same set of options are applied in 2020 and 2030 and an option's parameters are not changed over the lifetime. Indirect emissions reductions are not accounted for in the analysis due to the requirement for additional assumptions about the carbon intensity of electricity in different regions. While there continues to be ongoing work in the area of abatement option transaction costs (Antinori and Sathaye 2007 and Rose, et al. 2013), given the lack of comprehensive data, this analysis excludes transaction costs.

5 RESULTS AND DISCUSSION

The results of the analysis are presented as MACs by region and by sector and generally focus on the 2010 to 2030 time frame. Figure 5 shows the global total aggregate MAC for all non-CO_2 GHGs in 2030. Worldwide, the potential for cost-effective non-CO_2 GHG abatement is significant. Without a price signal (i.e., at $0/tCO_2e$), the global abatement potential is greater than 1,800 $MtCO_2e$, or 12% of the baseline emissions. As the break-even price rises, the abatement potential grows. Significant abatement opportunities could be realized in the lower range of break-even prices. For example, the abatement potential at a price of \$10/tCO_2e is greater than 3,000 $MtCO_2e$, or 20% of the baseline emissions, and greater than 3,600 $MtCO_2e$ or 24% of the baseline emissions at \$20/tCO_2e. In the higher range of breakeven prices, the MAC becomes steeper, and less abatement potential exists for each additional increase in price.

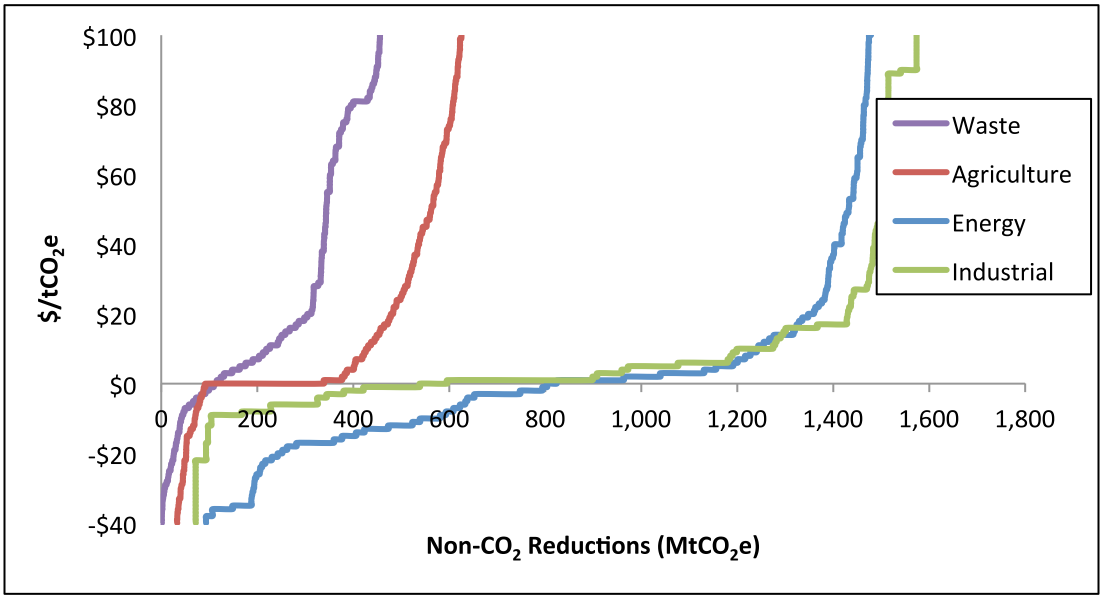
Figure 5. Global Total Aggregate MAC for Non-CO_2 Greenhouse Gases in 2030



As the figure shows, higher levels of emissions reductions are achievable at higher abatement costs expressed in dollars per metric ton of CO_2 equivalent reduced. The quantity of emissions that can be reduced, or the abatement potential, is constrained by the availability and effectiveness of the abatement measures (emission reduction technologies).

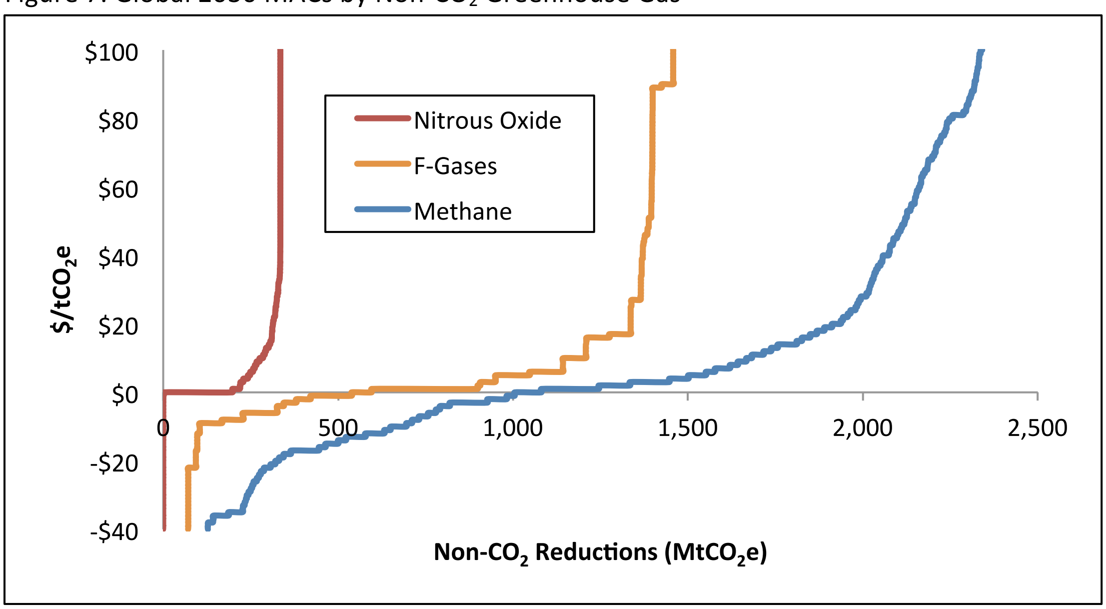
Globally, the sectors with the greatest potential for the abatement of non-CO_2 greenhouse gases are the energy and industrial process sectors, at 1,687 $MtCO_2e$ and 1,597 $MtCO_2e$ of technically feasible reductions in 2030 respectively (Figure 6). While less than that of the energy and industrial process sectors, abatement potential in the agriculture and waste sectors can play an important role, particularly in the absence of a carbon price incentive.

Figure 6. Global 2030 MACs for Non-CO_2 Greenhouse Gases by Major Sector



Methane offers the largest potential for abatement across of all of the non-CO_2 greenhouse gases with over 2,300 $MtCO_2e$ of technically feasible reductions available in 2030 (Figure 7). The fluorinated industrial gases and N_2O combined offer over 1,500 $MtCO_2e$ of technically feasible reductions in the same time period. Figure 8 depicts the abatement potential by gas in 2030. In addition to the technically feasible reductions, it is worth noting the large volume of cost-effective reductions (reductions at $0/tCO2e) which could be undertaken without the benefit of a carbon price to make the abatement option economically feasible.

Figure 7. Global 2030 MACs by Non-CO_2 Greenhouse Gas



As shown in figure 8 and 9, China and the U.S. are the top two contributors to global abatement potential with cost-effective ($0/$tCO_2e$) abatement of 249 $MtCO_2e$ and 165 $MtCO_2e$ respectively. Total technically feasible abatement for these two regions is 560 $MtCO_2e$ and 928 $MtCO_2e$ for China and the U.S. respectively. Taking a closer look at the largest sources of abatement potential in these regions, this analysis shows that Oil/Gas, Refrigeration/AC, Livestock, and Coal offer the greatest opportunities, as shown in figures 10 and 11.

Figure 8. Global 2030 MACs for Non-CO_2 Greenhouse Gases by Major Emitting Regions

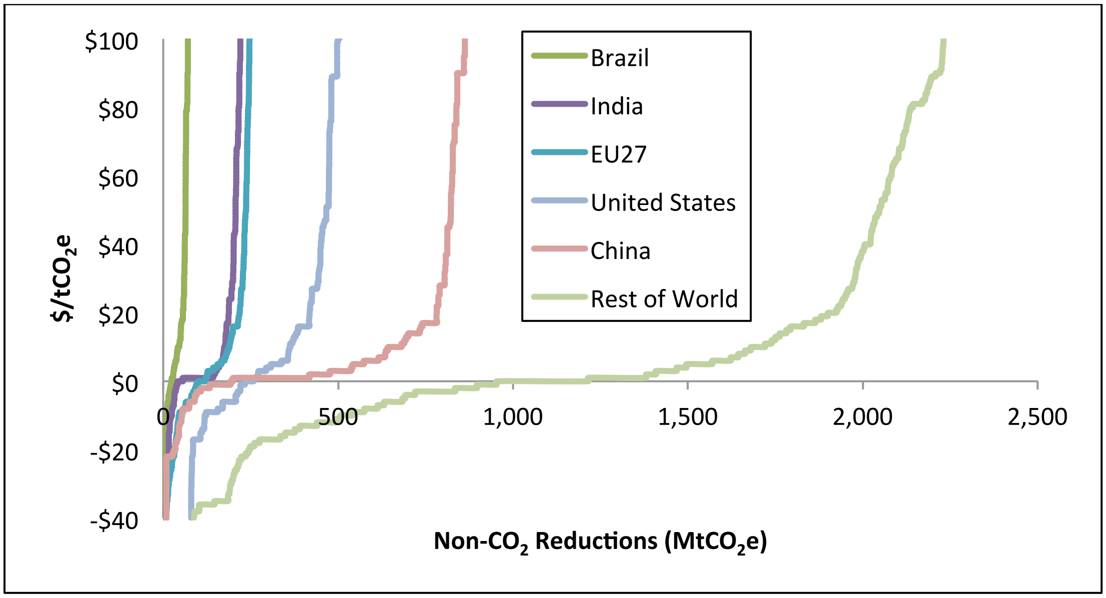


Figure 9. 2030 MAC for Non-CO_2 Greenhouse Gases for China and the United States

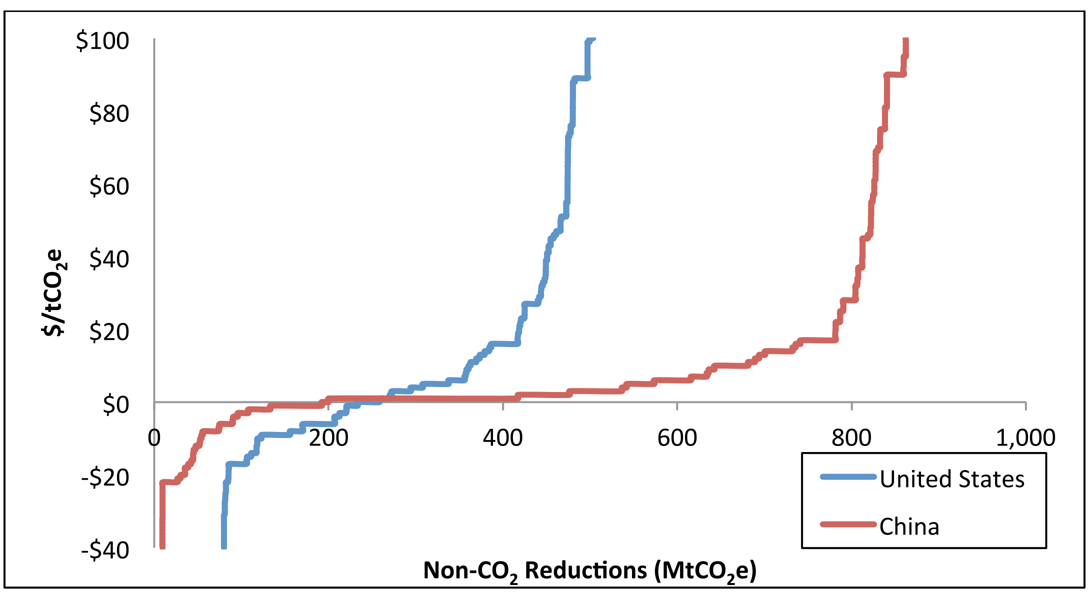


Figure 10. 2030 MACs for United States

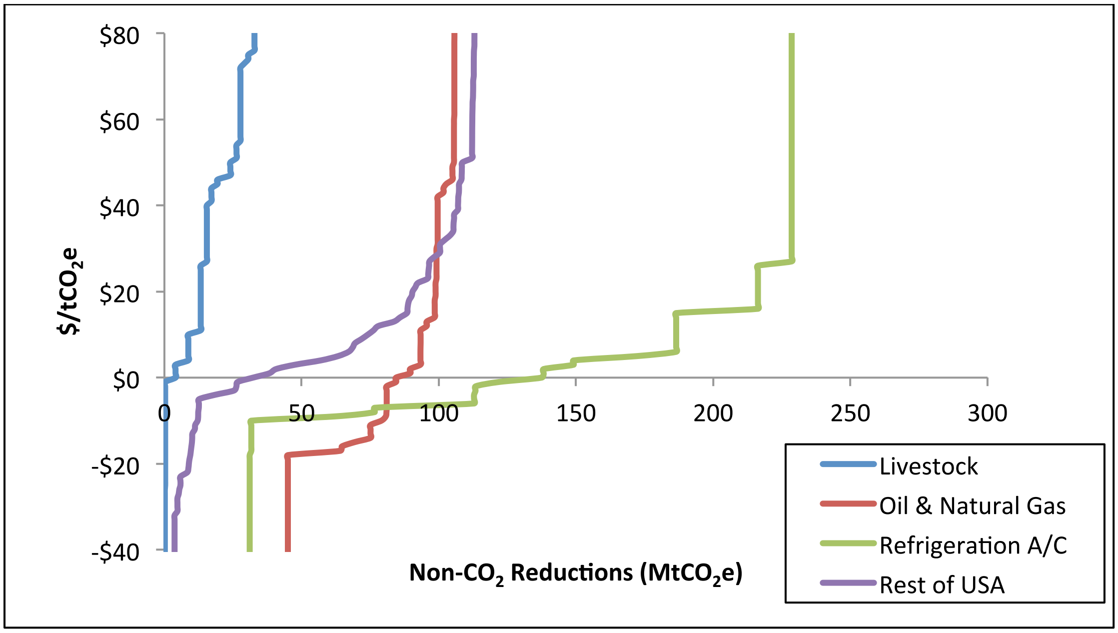
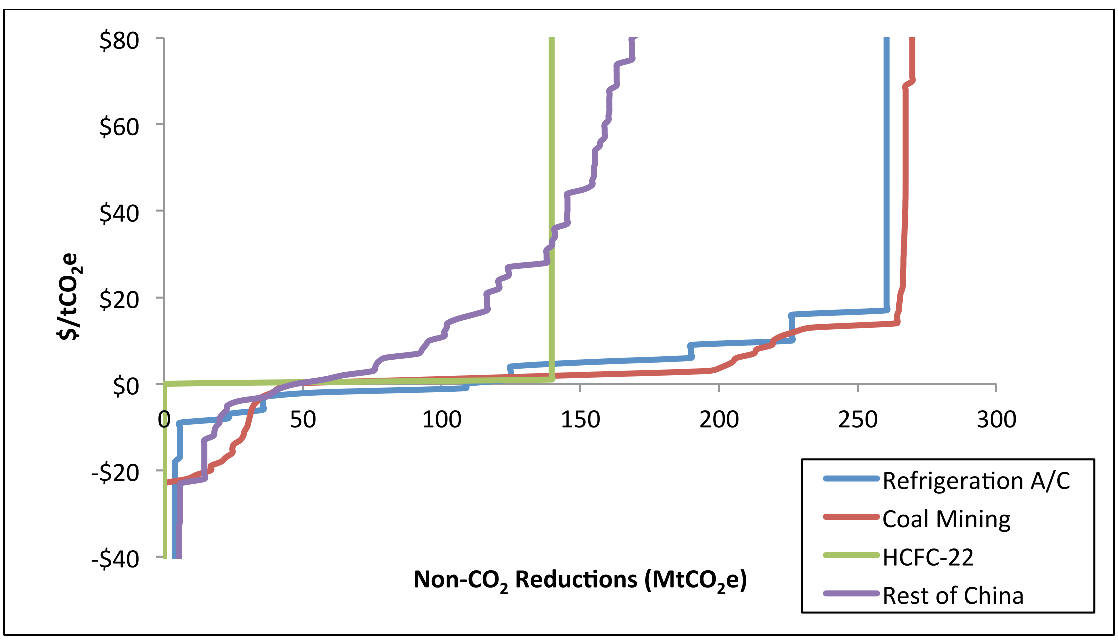


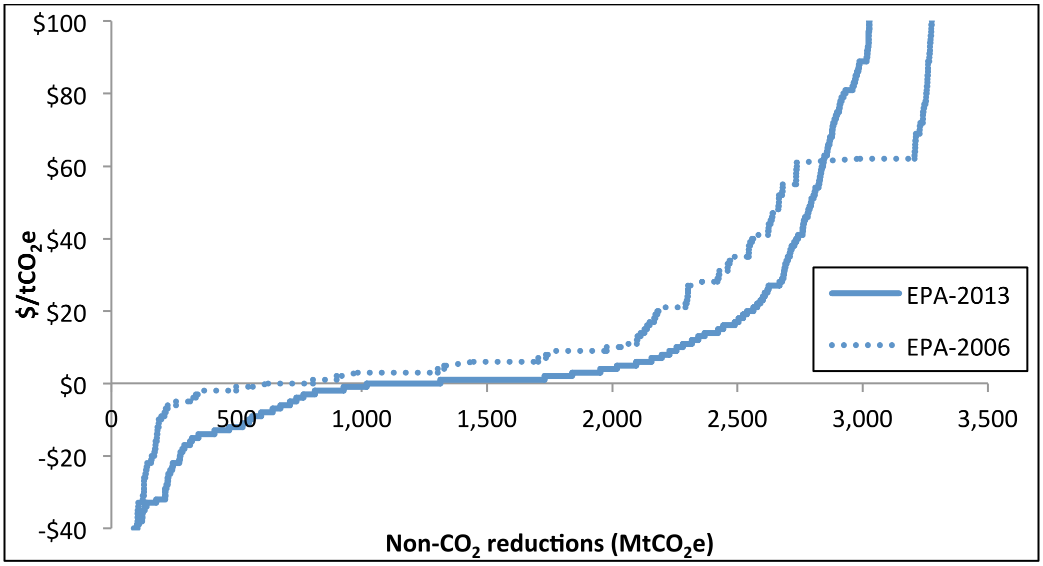
Figure 11. 2030 MAC for China



5.1 *Comparison to previous studies*

The previous USEPA (2006) non-CO_2 greenhouse gas marginal abatement cost curve study only evaluated abatement potential out through 2020. Comparing 2020 abatement potentials (figure 12) we find that the 2013 analysis shows 3,581 $MtCO_2e$ of technically feasible abatement potential globally, where EPA (2006) showed 3,401 $MtCO_2e$, a difference of 5%.

Figure 12. 2030 MAC for Non-CO_2 Greenhouse Gases for China and the United States



As shown in figure 13, below, the sectors driving this difference are Agriculture and Waste. In addition, the industrial sector has expanded to include photovoltaic and flat panel display manufacturing.

Figure 13. Comparison of Global Non-CO_2 MACs in 2020

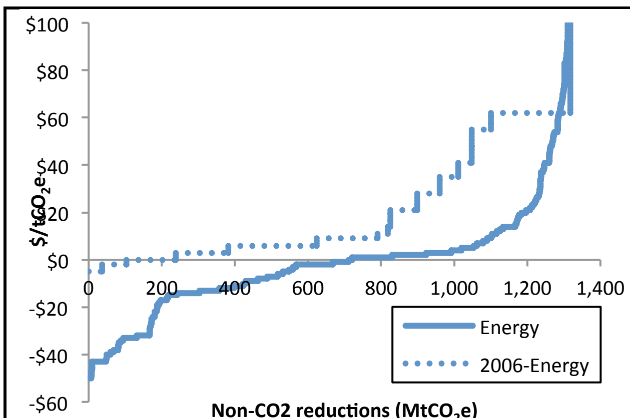


Figure 13a. Energy Sector MACs for 2020

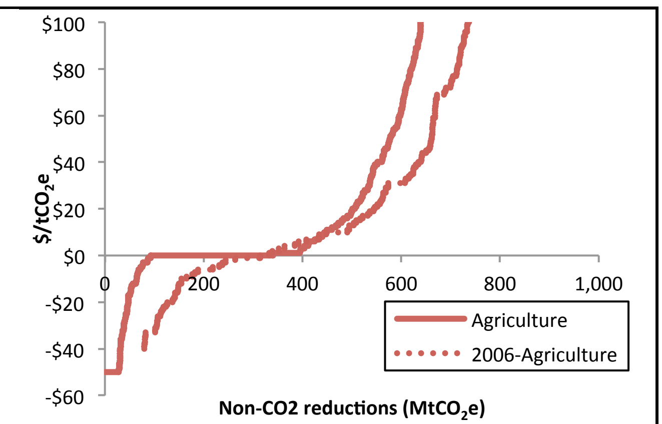


Figure 13b. Agricultural Sector MACs for 2020

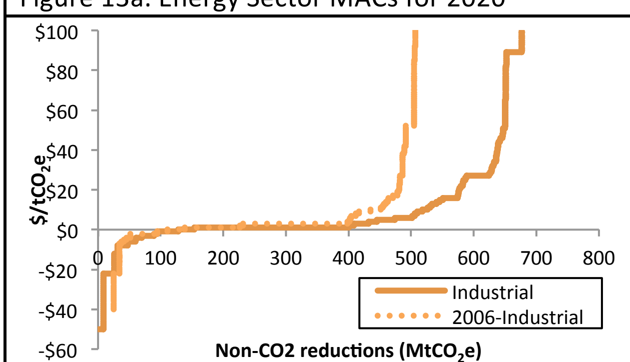


Figure 13c. Industrial Sector MACs for 2020

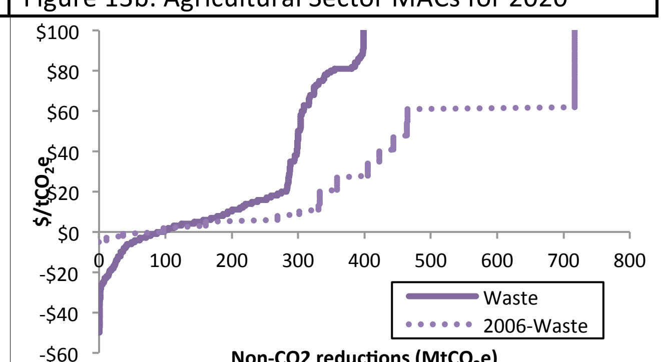


Figure 13d. Waste Sector MACs for 2020

Additional drivers of differences in the abatement potentials shown in these analyses include updated energy prices, and updated capital and O&M costs for abatement measures. Other key model improvements incorporated since the 2006 have also contributed to the difference between the two reports. These model changes include incorporation of more detailed facility level information in the energy, waste, and industrial sectors; the addition of new abatement options in several sectors; updated reduction efficiencies for existing mitigation options; addition of new industrial and waste sub-sectors.

6 CONCULSIONS

This study, which incorporates new data on mitigation technologies, costs, and emissions baselines, alongside a new modeling approach, provides updated and more detailed marginal abatement cost curves disaggregated globally for all non-CO_2 greenhouse gases and sectors. The resulting comprehensive data set of MAC curves allow for improved understanding of the mitigation potential for non-CO_2 sources, as well as inclusion of non-CO_2 greenhouse gas mitigation in economic modeling of multigas mitigation strategies. The level of disaggregation provided by this analysis allows end users, including modelers, policy makers, and analysts, flexibility in the way in which the data can be aggregated and incorporated in to models and analysis. Future research on technological change of abatement option characteristics, as well as inquiry in to appropriate transaction costs associated with the implementation of abatement options will result in additional improvements to the MAC analysis and data sets.

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