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Assessment of the climate commitments and additional mitigation policies of the United States

Jeffery B. Greenblatt* and Max Wei

Current intended nationally determined contributions (INDCs) are insufficient[1] to meet the Paris Agreement goal of limiting temperature change to between 1.5 and 2.0 °C above pre-industrial levels[2], so the effectiveness of existing INDCs will be crucial to further progress. Here we assess the likely range of US greenhouse gas (GHG) emissions in 2025 and whether the US's INDC can be met, on the basis of updated historical and projected estimates. We group US INDC policies into three categories reflecting potential future policies, and model 17 policies across these categories. With all modelled policies included, the upper end of the uncertainty range overlaps with the 2025 INDC target, but the required reductions are not achieved using reference values. Even if all modelled policies are implemented, additional GHG reduction is probably required; we discuss several potential policies.

On 12 December 2015, representatives from 196 countries to the United Nations Framework Convention on Climate Change (UNFCCC)'s 21st Conference of Parties (COP-21) in Paris reached a landmark climate agreement[2] limiting global temperature increase, which will require balancing GHG emissions and sinks after mid-century.

In addition to setting a specific GHG emissions reduction target for 2025 (26–28% below the 2005 level[3]), the US INDC outlined specific steps for achieving these reductions, including existing and planned policies addressing light- and heavy-duty vehicles, appliance and equipment standards, building codes, electricity generation, hydrofluorocarbon (HFC) emissions, methane (CH_4) emissions and federal government operations.

A number of independent entities have examined the US INDC goal and policies to determine their likelihood of success. All conclude that existing federal policy will make it challenging to meet the US INDC, but opinions vary as to the likelihood of achieving the targets with additional federal actions. Eight previous studies are cited and compared with our work in the Supplementary Note.

Unlike most prior studies, our study models the final version of the Clean Power Plan (CPP) and includes a thorough accounting of other policies, including potential policies such as the Montreal Protocol amendment for HFC gases. Our study is also unique in that it estimates uncertainty ranges for historical and projected baseline GHG emissions, updates CH_4 emission estimates to reflect current scientific understanding, estimates GHG savings and uncertainty ranges for each policy, and provides a delineation of policy types spanning three categories. This detailed treatment of US climate policies will be invaluable for policymakers and other stakeholders, as US climate policy progresses toward the 2025 INDC target.

We undertake a comprehensive evaluation of historical and projected baseline US GHG emissions, focusing on key policy years 2005 and 2025. Beginning with the US Department of State's Climate Action Report (CAR)[4] and Second Biennial Report (SBR)[5], we make a number of revisions to both historical and projected emissions using consistent global warming potentials and recent updates to projected energy use, HFC emissions and land CO_2 uptake. Moreover, we make upward revisions to CH_4 emissions based on recent regional, US and global assessments. We also perform a comprehensive uncertainty analysis. See Methods for more information.

Our revised estimates produce a range in 2005 net GHG emissions from 6,323 to 7,403 $MtCO_2e$ (full uncertainty range). For 2025, net GHG emissions range from 0.6% above to 11.8% below the corresponding 2005 level. The change in net GHG emissions relative to the CAR[4] is positive in both 2005 and 2025. See Fig. 1. The largest uncertainty components are due to energy sector emissions, land sink uptake, and CH_4 emissions ($\gtrsim$400 $MtCO_2e$ each in 2005, larger in 2025).

We then estimate GHG emission impacts for a number of policies listed in Table 1, based on the US INDC. In addition, we include some policies not specified in the INDC, including commercial building codes, targets for manure and fertilizer management, and recent California legislation. Reduction estimates and uncertainty ranges are based on published reports by the federal government, independent entities or our own analysis. Some policies mentioned in the INDC, as well as existing state policies, are not modelled as they are included in the 2015 US Department of Energy's Annual Energy Outlook[6] baseline, from which our analysis proceeds.

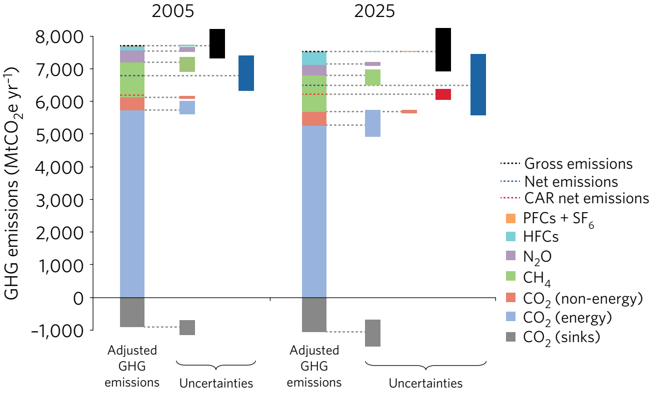

Figure 1 | Baseline 2005 and 2025 greenhouse gas (GHG) emissions with uncertainties shown for each category of emissions. Climate Action Report (CAR)[4] net GHG emissions shown for reference. CO_2, carbon dioxide; CH_4, methane; N_2O, nitrous oxide; HFCs, hydrofluorocarbons; PFCs, perfluorocarbons; SF_6, sulfur hexafluoride; $MtCO_2e$, million tonnes CO_2 equivalent.

Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, MS 90-2002, Berkeley, California 94720, USA. *e-mail: jbgreenblatt@lbl.gov

Table 1 | Summary of estimated greenhouse gas (GHG) emissions reduction in 2025 from policies.

Category	GHG	Policy description	Value range ($MtCO_2e$)			Full uncertainty[†]	
			Reference	Min.	Max.	Min.	Max.
A	CO_2	CPP (final rule)	241	226	255	221	267
		Electricity and buildings (California SB350)[‡,§]	13	13	13	13	14
	N_2O	Fertilizer management (policies in SBR)[‡]	10	10	10	9	13
	HFCs	Phase-out (Final EPA SNAP rule)	59	54	64	54	72
B	All	California 2030 GHG target (Executive Order)[‡,*]	65	65	65	64	68
	CO_2	Appliance standards (2015–2016)	27	27	27	27	29
		Building codes (residential, 2015–2025)[‖]	23	23	23	23	24
		Federal government operations (Executive Order)	26	26	26	25	27
		Heavy-duty vehicles (proposed)[*]	41	36	46	36	48
	CH_4	Oil and gas (proposed)[*]	13	12	14	8	16
		Landfills (proposed)[*]	18	18	18	13	21
C	CO_2	Enhanced CPP (proposed rule)[¶]	407	393	435	384	455
		Appliance standards (2017–2025)	29	29	29	28	30
		Building codes (commercial, 2015–2025)[‡,‖]	29	29	29	29	31
	CH_4	Oil and gas (aspirational target)	121	116	125	85	146
		Manure management (voluntary roadmap)[‡]	21	3	40	2	46
	HFCs	Phase-out (Montreal Protocol amendment)	67	55	79	55	88
Subtotals	All	Category A	323	303	342	306	356
		Category B	214	208	220	196	234
		Category C	674	625	737	596	784
		All	1,211	1,136	1,299	1,099	1,373

Abbreviations: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), Clean Power Plan (CPP), Senate Bill (SB), Second Biennial Report (SBR), US Environmental Protection Agency (EPA), Significant New Alternatives Policy (SNAP), million tonnes CO_2 equivalent ($MtCO_2e$), minimum (min.), maximum (max.), intended nationally determined contribution (INDC). [†]Parameter uncertainties across GHG categories are added in quadrature, except for CH_4, which was not considered to be a Gaussian distribution, but a simple range. As a result, sums of quantities in these columns do not necessarily equal the indicated subtotals. [‡]Not included in INDC. [§]SB350 (50% renewable electricity and doubled rate of building energy efficiency savings by 2030)[14]. [‖]Only residential building codes were specified in the US INDC. Because such codes cannot be mandated federally and are adopted to varying degrees at the state level, we have categorized future residential building codes as a Category B action. For commercial building codes, we have categorized future actions as Category C since no federal targets have been specified. [¶]Reductions shown are incremental to the CPP final rule. [*]See 'Note added in proof'.

Policies are divided into three categories depending on current status:

- Category A: Passed legislation or final rule (finalized by late 2015).
- Category B: Proposed legislation, proposed rule, or executive order.
- Category C: Announced target, potential policy or voluntary measure.

The rationale for categorizing different types of policy is discussed in Supplementary Methods, 'Modelled policies.' Implied in this categorization is a decreasing likelihood of policy impact in 2025 in moving from Category A to C.

Combining all of our 2025 estimates together, including uncertainties arising both from the inherent range of impacts as well as parameter uncertainty, results in GHG emission reduction ranges shown in Table 1 and Fig. 2.

The CPP contributes the most to GHG emissions reductions. Two versions are modelled: the final rule, and an enhanced version based on the proposed rule. The final rule, published in October 2015[7], is included in Category A, with estimated reductions from 221 to 267 $MtCO_2e$ in 2025. These estimates do not include some additional reductions that may have been assumed to take place elsewhere in the energy system. However, the earlier proposed rule is much more ambitious[8], with total savings that are more than twice as large; therefore, this policy is included in Category C as something that the US might later pursue.

Five other policies—CH_4 oil and gas aspirational target[9], California's 2030 GHG target[10], two HFC policies (the US Environmental Protection Agency (EPA)'s Significant New Alternatives Policy (SNAP)[11] and Montreal Protocol amendment[12]), and the heavy-duty vehicle efficiency proposed rule[13]—each have impacts of between 36 and 146 $MtCO_2e$, or 3.2 to 10.7% of total reductions. Of these, only SNAP is a Category A policy. We estimate that the remaining 10 policies, which span Categories A, B and C, collectively reduce emissions between 177 and 251 $MtCO_2e$ (16.1 to 18.3% of total reductions).

The US INDC pledges a 26 to 28% reduction below the 2005 GHG emission level in 2025. Considering the uncertainties discussed above, this produces a 2025 target ranging from 4,553 to 5,478 $MtCO_2e$. The difference between this target and the estimated 2025 emissions without INDC policies results in an 'emissions gap' ranging from 896 to 2,121 $MtCO_2e$, with a reference value of 1,510 $MtCO_2e$ corresponding to a 4.8% reduction below the 2005 level.

Including policies that the US has actively adopted (Category A) results in remaining emissions between 5,230 and 7,135 $MtCO_2e$. While it would appear that there is some overlap with the target emissions range, as the high end of the 2025 target is higher than the low end of remaining emissions, this is not the case. Because of the way these ranges are correlated with common assumptions about energy-related CO_2 emissions, land sinks, and CH_4 emissions, the estimated emissions gap after including Category A reductions is 551 to 1,805 $MtCO_2e$, or 8.7 to 24.4% of the 2005 level. See Fig. 3.

Including Category B policies results in an emissions gap of 340 to 1,586 $MtCO_2e$, while including Category C policies as well lowers the gap to between −356 and 924 $MtCO_2e$. While the low end of this latter range is indeed negative, indicating emissions 5.6% lower than the maximum 2025 target (26% below the 2005 level), it corresponds to favourable assumptions for all parameters, and implementation of all policies. The upper end, corresponding to less favourable parameter assumptions, is 12.5% above the minimum 2025 target (28% below the 2005 level), indicating that further reductions will be necessary to close this gap with confidence. We briefly discuss policy options below; for more information, see Supplementary Discussion.

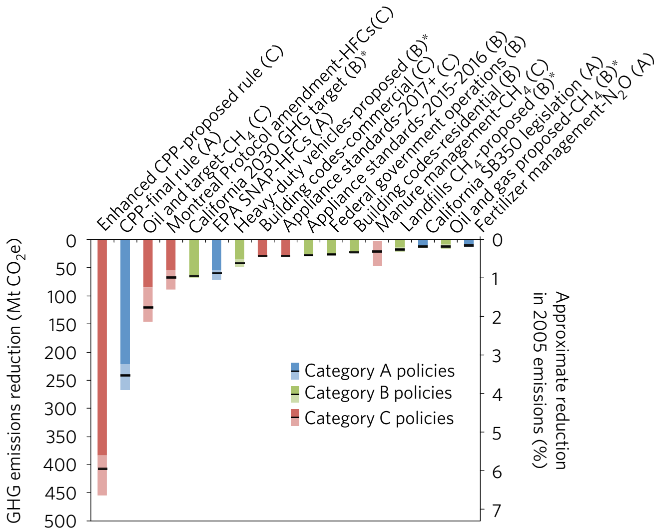

Figure 2 | Rank-ordered greenhouse gas (GHG) reduction estimates in 2025 by policy. Lighter coloured bars indicate full uncertainty ranges. Black horizontal lines denote reference values. CO_2, carbon dioxide; CH_4, methane; N_2O, nitrous oxide; HFCs, hydrofluorocarbons; $MtCO_2e$, million tonnes CO_2 equivalent; EPA, US Environmental Protection Agency; SNAP, Significant New Alternatives Policy. *See 'Note added in proof'.

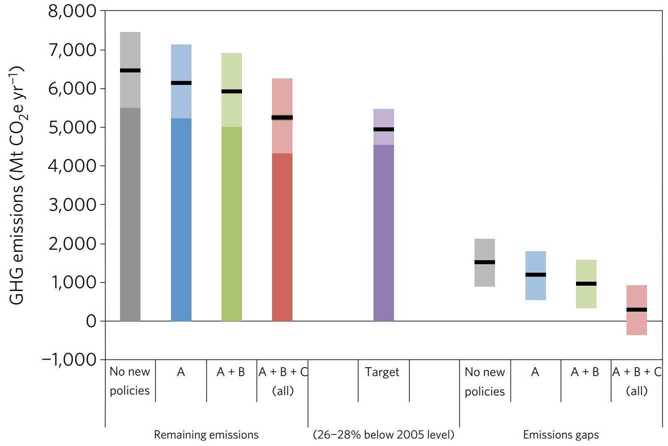

Figure 3 | Estimated remaining 2025 greenhouse gas (GHG) emissions, target and emissions gaps by policy category. Lighter coloured bars indicate full uncertainty ranges. Black horizontal lines denote reference values. Colour code: No new policies (grey); Category A (blue); Categories A + B (green); Categories A + B + C (red); Target (purple). $MtCO_2e$, million tonnes carbon dioxide equivalent.

In the electricity sector, an aggressive phase-out of coal and natural gas generation, with accompanying increases in renewables, energy efficiency and possibly nuclear generation could be enacted. As an example, California plans to meet a 33% renewable electricity target in 2020, and 50% in 2030[14], as well as phase-out coal generation by 2030[15]. Several other states[16] are also actively reducing electricity-sector GHG emissions. Together, these strategies could even exceed proposed rule CPP reductions (see Supplementary Discussion, 'Extensions of the CPP').

Vehicle electrification represents an important GHG emission reduction strategy in the transportation sector, due to the lower GHG intensity of electricity- versus petroleum-powered vehicles. California and seven other states[17] have a 2025 target of 3.3 million zero net emission vehicles; if scaled to the US, it would encompass 16 million vehicles, 6% of projected stock. Such a target could save more than 50 $MtCO_2e$ and also reduce air pollution.

Policies that shift mobility use from private vehicles to lower GHG modes (public transit, non-motorized mobility, and on-demand shared-ride vehicles), such as in California[18], could be strengthened. Moreover, vehicle automation could significantly lower GHG emissions[19], although increased usage might undermine some savings.

Current biofuels targets have been reduced from 36 billion gallons of ethanol-equivalent originally proposed for 2022[20]. However, there may be more than 1 billion tonnes of US biomass available by 2030, sufficient for 70 billion gallons[21], with significant GHG savings.

Hydrogen can be produced from many sources and could reduce GHG emissions across multiple sectors. Federal spending of ~*US*\$100 million annually supports ambitious hydrogen production, storage and fuel cell goals, but more could be done to realize them, such as increased commercialization and infrastructure efforts[22].

Electrifying building and industrial heating can reduce emissions when electricity has a lower GHG emissions intensity than fossil sources[23]. Electric heat pumps are far more efficient than combustion, and high-temperature industrial approaches can provide higher throughput, space savings and improved quality[24].

The majority of oil and gas sector CH_4 leaks probably come from a minority of 'super-emitters' that, if identified and addressed, could reduce sector emissions 65 to 87%[25]. Moreover, landfill CH_4 emissions could be reduced by 90% in new facilities, and up to 60% in older ones[26].

The use of slow-release fertilizers has been shown to reduce N_2O emissions by 35%, without a corresponding increase in labour[27]. With the majority of the 345 $MtCO_2e$ of estimated 2025 N_2O emissions due to agriculture, such an application would result in much larger reductions than assumed under current federal policy[5].

Additional HFC reductions of ~33% or 82 $MtCO_2e\,yr^{-1}$ in 2025 could come from more aggressive Montreal Protocol amendments[28].

A variety of land management practices could enhance carbon storage, reducing 2030 CO_2 emissions by >40 $MtCO_2e\,yr^{-1}$ in California (The Nature Conservancy, unpublished data, 2015), with greater potential nationally.

Finally, GHG emissions trading now being pursued in a handful of US states[10,29] as well as internationally[30] could unlock low-cost GHG reduction strategies, lowering total emissions while saving money.

In conclusion, updated estimates of 2005 and 2025 US GHG emissions, along with estimates of the impacts of US INDC policies, indicate that additional mitigation measures will probably be required to reduce US GHG emissions to the 2025 INDC target (26–28% below the 2005 level). Promising strategies exist spanning multiple sectors and technologies. Time is short, so it is vital for the US to develop achievable plans to maintain pressure on other nations to support the Paris Agreement.

Note added in proof: The recent passage of California SB 32 on 25 August 2016 codifies the statewide GHG emissions reduction target (Executive Order B-30-15) in law[31]. Furthermore, the US Environmental Protection Agency and the US Department of Transportation's National Highway Traffic Safety Administration jointly finalized the heavy-duty vehicle standards on 16 August 2016[32], and the US Environmental Protection Agency finalized its CH_4 emissions standards for oil/gas and landfill sectors on June 3, 2016 and July 15, 2016, respectively[33,34]. All these changes elevate the corresponding policies from Category B to A. However, this Letter was resubmitted before these changes occurred, so they were not incorporated in the analysis.

Methods

Methods and any associated references are available in the online version of the paper.

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Author contributions

M.W. performed HFC policy analysis and comparison to prior studies; J.B.G. performed all other calculations and analysis. J.B.G. and M.W. wrote the manuscript and addressed reviewer concerns.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to J.B.G.

Competing financial interests

The authors declare no competing financial interests.

Methods

Historical US GHG emissions were obtained from the US Environmental Protection Agency (EPA)'s 2015 GHG emissions inventory[35], which provided annual historical estimates from 1990 to 2013. We also examined emissions data from EPA's 2014 GHG emissions inventory[36], which provided annual historical estimates from 1990 to 2012, for additional information about HFC and perfluorocarbon (PFC) emissions. EPA's 2016 draft inventory[37] reported emissions to 2014, and makes important revisions to prior year estimates, suggesting that historical (including 2005) net emissions were higher by >300 $MtCO_2e\ yr^{-1}$. However, as the data were not finalized, we did not utilize them in our analysis.

Other data sources provided both historical and projected emissions. The US Department of State's 2014 US Climate Action Report (CAR)[4] and 2016 Second Biennial Report (SBR)[5] provided five-year estimates for all GHGs from 2000 to 2030 (plus some years between 2010 and 2015). The US Energy Information Administration's 2015 and 2016 Annual Energy Outlook (AEO) reports[6,38] provided annual energy-related CO_2 emissions to 2040, and the EPA's 2015 Significant New Alternatives Policy (SNAP) report[11] provided HFC emissions in 5-year intervals from 2010 to 2030.

The SBR was released after our initial analysis was completed, and its projected baseline GHG emissions included some, but not all, policies we modelled in our analysis. As a result, it was not possible to use the SBR projections to represent future emissions in the absence of federal actions in support of the US INDC. Therefore, we have retained the CAR projections with some important modifications.

For energy-related CO_2 emissions, we used 2015 AEO projections[6] modified to subtract bunker fuel emissions (in accordance with Intergovernmental Panel on Climate Change (IPCC) inventory reporting guidelines[4]), and included projected emissions from US territories estimated from historical EPA data[35]. We also subtracted some industrial CO_2 emissions reported by the CAR as non-energy emissions. (The 2016 AEO, which included projections with and without the CPP, was released too recently to be incorporated into this analysis. However, we did utilize a small additional GHG saving arising from outside the electricity sector as a result of the CPP that was not included in the EPA analysis[8]; see Supplementary Methods, 'Historical and projected baseline US GHG emissions' for details.)

For non-energy CO_2 emissions, we retained the CAR projections (none were separately provided in the SBR). For land use CO_2, we used SBR projections, as they reflected important recent revisions in estimated future land use practices and resulting CO_2 absorption. Emissions of non-CO_2 GHGs were expressed in CO_2 equivalent units using 100-year global warming potentials (GWPs) from either the IPCC Second Assessment Report (SAR)[39] or Fourth Assessment Report (AR4)[40]. The AR4 GWPs were used in the US INDC and all data sets except the EPA's 2014 GHG inventory and the CAR, which used SAR GWPs. For consistency, we converted non-CO_2 emissions from SAR to AR4 GWPs, as described in Supplementary Methods, 'Global warming potentials (GWPs).' We retained these adjusted CAR emission projections for N_2O, PFCs and SF_6. For HFCs, however, the EPA recently made significant upward revisions to projected baseline emissions in its 2015 SNAP report[11], so we used those projections instead.

A number of recent studies point toward important differences between CH_4 emission estimates from EPA, and those based on measurements obtained from towers, aeroplanes and satellites[41–47]. As a result, we used a correction factor of $1.50^{+0.25}_{-0.40}$ times the EPA's GHG values for historical CH_4 emissions and the CAR's AR4-adjusted projected emissions, resulting in increases in estimated CH_4 emissions of 354^{+177}_{-283} $MtCO_2e$ in 2005 and 368^{+184}_{-295} $MtCO_2e$ in 2025. While these upward revisions represent the latest scientific understanding, considerable uncertainty remains. More detail about these corrections can be found in Supplementary Methods, 'CH_4 adjustments.'

To characterize uncertainty in energy-related CO_2 projections, we examined the 2015 AEO reference case along with 13 side cases[6]. We found that total CO_2 emissions in 2025 varied by approximately $\pm4\%$, and used this range to characterize future uncertainty. The additional uncertainty arising from our modifications to the AEO projections were found to be negligible. See Supplementary Methods, 'Uncertainty estimates,' for details. For CH_4, as noted above, we used a correction factor with uncertainty bounds.

In addition to the above uncertainties, we used EPA's own uncertainty estimates[35] for GHG emissions in 2013 to estimate intrinsic uncertainty. We used separate 95% uncertainty interval estimates for each GHG except for CO_2, where we used separate uncertainty estimates for energy, non-energy and land sink emissions. We assumed that the relative uncertainty in each GHG category would remain the same in other years, including 2005 and 2025, and applied these estimates to all adjusted emissions estimates except CH_4 (since our own estimate of uncertainty was far larger than what EPA assumed).

EPA parameter uncertainty estimates were combined in quadrature as per standard error propagation methods. Other sources of uncertainty, which had minimum/maximum ranges but no formal confidence intervals, were linearly combined (that is, without quadrature) to obtain a maximum uncertainty range, which we refer to as 'full uncertainties.'

For each INDC policy listed in Table 1, we developed GHG reduction estimates based on federal government analyses, extrapolations from independent analyses, and synthesis from scientific literature. 'High' and 'low' bracketing uncertainty estimates were developed for most policies; others utilized single-point values. To these ranges we added intrinsic uncertainties described above to arrive at full uncertainty estimates. When subtracting GHG emissions policy reductions from baseline emissions, care was taken to include intrinsic uncertainties only afterward, to avoid overestimating the uncertainty.

More details are given in Supplementary Methods, 'Modelled policies,' but in brief, we estimated 2025 policy impacts as follows:

(1) Clean power plan. We used EPA's analysis of its final rule (Category A, despite a current legal challenge[48]) to obtain a range of GHG savings[8]. For the enhanced version of the CPP (Category C), we used EIA's analysis[49] of the proposed rule to estimate a range of GHG savings across scenario variants, and subtracted this range from estimated final rule savings.

(2) Appliance and equipment standards. We performed trend analysis on historical estimates in ref. 50 to estimate future savings in electricity and natural gas, converting to GHG emissions via data from ref. 51 and EIA[6]. Category B represented savings from standards finalized through 2016, whereas Category C included savings from potential new standards through 2025.

(3) Building codes. We based our estimates for future residential (Category B) and commercial (Category C) building code energy savings on state-by-state projections of ref. 52, converting to GHG emissions in a similar manner as for appliance and equipment standards (see above).

(4) Heavy-duty vehicles. We used estimates from EPA and US Department of Transportation of their proposed rule[13] (Category B; see 'Note added in proof') policy for medium- and heavy-duty vehicles spanning multiple scenarios and calculation methods to provide a range of GHG savings.

(5) Federal government operations. We used the Administration's own estimate[53] of GHG savings from clean electric and thermal energy sources, reduced energy use in federal buildings and federal vehicle fleets, and similar savings from major federal suppliers for this Category B executive order.

(6) CH_4 mitigation. Using our revised higher emissions rates of CH_4 from US sources, we adjust percentage savings estimates for certain CH_4 reduction policies:

Oil and gas. We used the Administration's estimate of its proposed rule[54] (Category B; see 'Note added in proof') GHG savings range. We also used the Administration's aspirational target (Category C) of a 40 to 45% sector reduction from the 2012 level by 2025[55].

Landfills. Category B (see 'Note added in proof') savings are based on an EPA proposed rule analysis[56].

Manure management. We base savings on the Administration's voluntary biogas roadmap[57] (Category C) savings estimates.

No other federal policies exist with quantitative reduction targets for CH_4, so none were included.

(7) N_2O mitigation. We used the difference between adjusted CAR[4] and SBR[5] N_2O emissions as a proxy for current federal policy (Category A) fertilizer management N_2O savings discussed in the SBR.

(8) HFC mitigation. We used estimated reductions from EPA's 2015 SNAP[58] regulations (Category A), while larger reductions are based on compliance with a proposed Montreal Protocol amendment (Category C)[59].

(9) California policies. California has the most aggressive GHG emissions reductions policy of any state in the US[60]. We used the CALGAPS model[61] to simulate recently passed California renewable portfolio standard and building efficiency legislation (SB350, Category A) and the statewide GHG emissions reduction target (Executive Order B-30-15, Category B; see 'Note added in proof'). These policies are additional to the federal CPP, because California is expected to meet its CPP obligations with existing policies 'years ahead of schedule'[62] and projects its own GHG emissions in 2030 to be 34% below the CPP target[63], or 15 $MtCO_2e$, higher than our estimated savings from SB350. The statewide GHG emissions reduction target is estimated from the difference between the 2030 target of 40% below the 1990 level[10] and expected emissions from all other existing policies[61].

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