Emissions Abatement Via Implementation of Electrocaloric Cooling in Residential Air Conditioning

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I. Motivation

Air conditioning (AC) systems negatively affect the environment; their electricity consumption and leakage of the refrigerant required to run them contribute to global warming. As the planet warms and global GDP increases, the demand for these systems will rise world-wide, stressing energy grids beyond capacity and preventing compliance with global refrigerant and emissions reduction goals. This study provides a quantitative assessment of the impact of scaling solid-state electrocaloric (EC) cooling, which is estimated to increase energy efficiency by 25% and eliminate the use of refrigerants [1]. The results presented account for various adoption cases of EC cooling between 2030 and 2050.

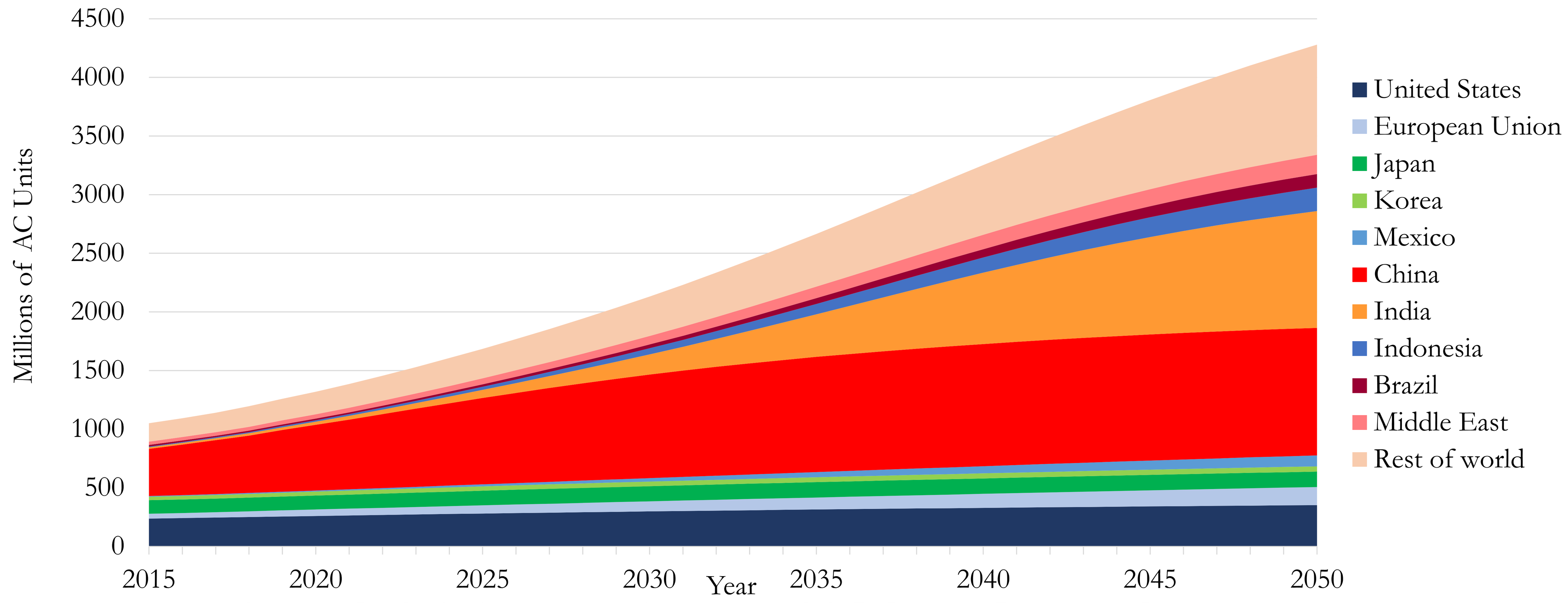

Figure 1: IEA Predicted Residential AC Stock Growth [2]

II. Methodology

- Assume commercialization of EC cooling by the end of 2029
- Define Base Case and EC air conditioner system properties (Table 1)
- Apply Life Cycle Climate Performance (LCCP) evaluation for one residential Base Case and EC unit per region (Figure 2)
- Extrapolate per unit results by AC stock (Figure 1) and EC adoption (Figure 3) within each region and sum regional results to arrive at global emissions
- Calculate the difference between scenarios with and without the adoption of EC cooling to determine the emissions abatement (Figure 6)
- Investigate different Base Case refrigerants and EC adoption cases and efficiencies (Table 2)

Table 1: Residential Base Case and EC System Property Assumptions

System Properties	Base Case	EC
Cooling Capacity [tons]	1.5	1.5
Energy Efficiency Ratio (EER) [W/W]	Region Dependent	4.125 or 13
Refrigerant Charge [kg]	1.65	0
Equipment Lifetime [years]	15	15
Annual Leakage Rate [% / year]	4	0
End of Life Leakage [%]	15	0

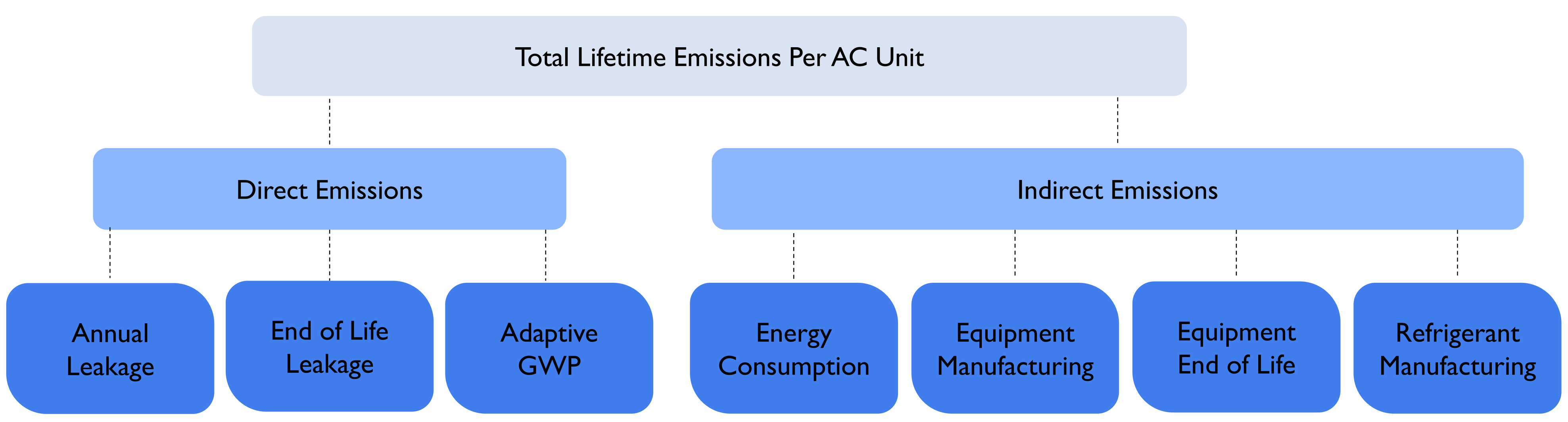

Figure 2: Life Cycle Climate Performance (LCCP) Evaluation Factors [3]

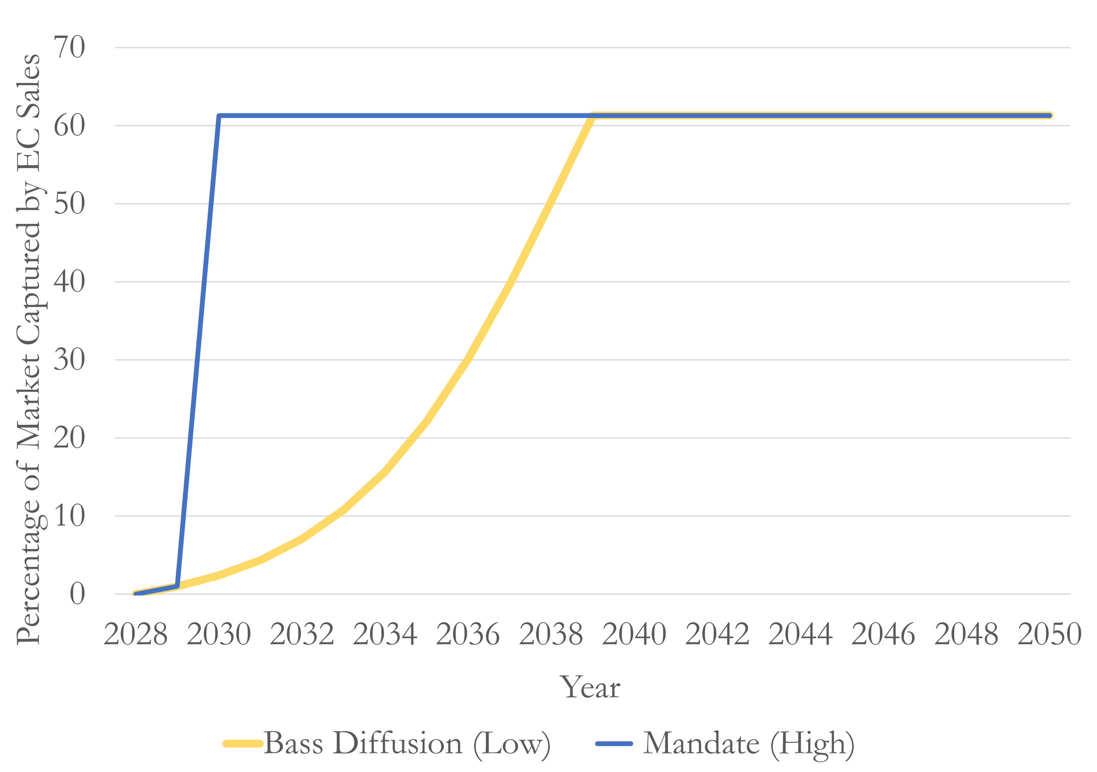

Figure 3: High and Low EC Cooling Adoption Cases [4]

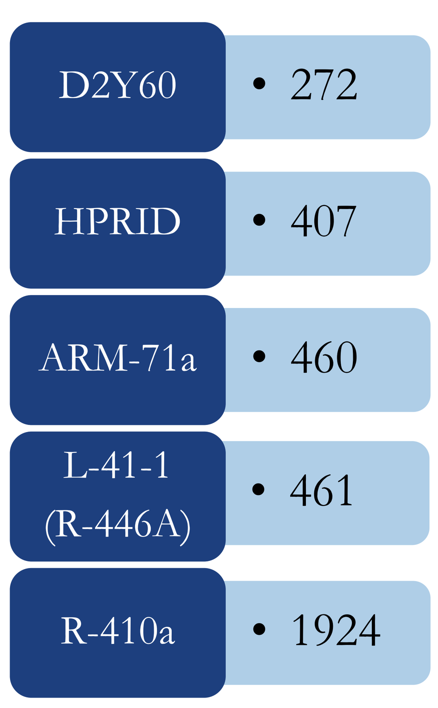

Figure 4: Tested Refrigerants and their Global Warming Potentials (GWPs) [5, 6]

III. Results

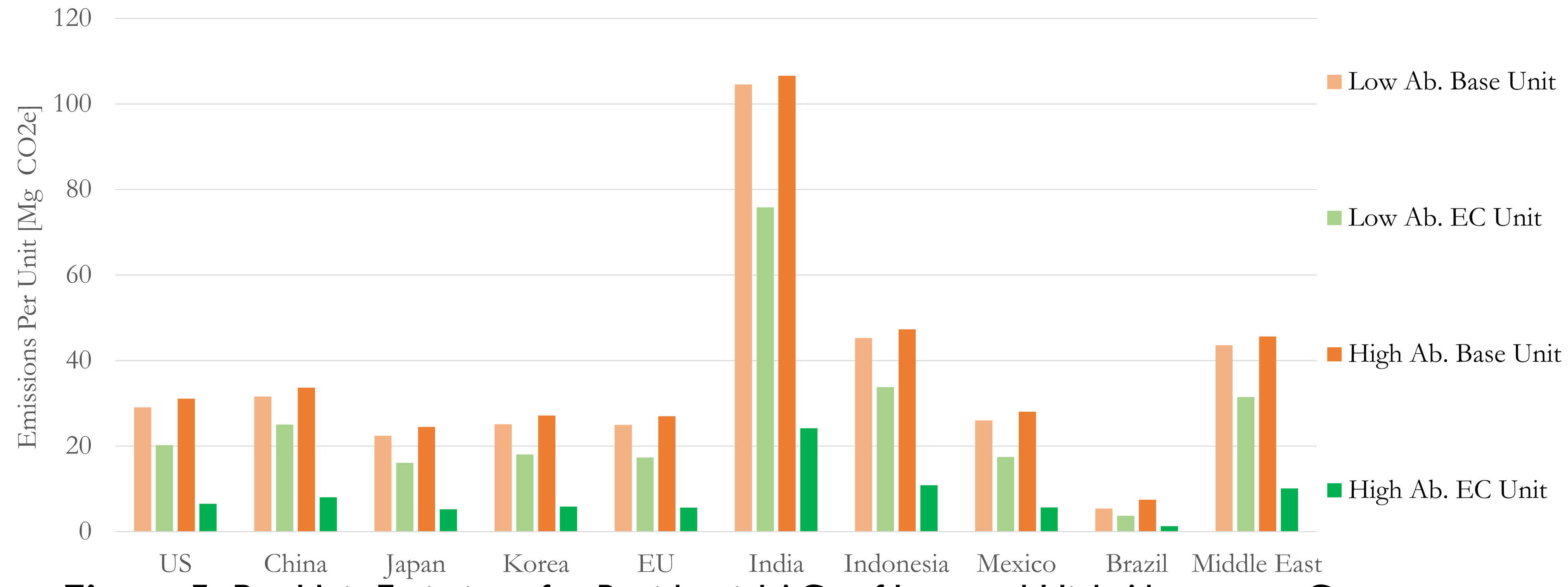

Figure 5: Per Unit Emissions for Residential ACs of Low and High Abatement Cases

Figure 5 represents the total lifetime emissions per residential AC unit in each region. The low abatement Base Unit uses D2Y60 and the EC unit has an efficiency of 4.125 W/W. The high abatement Base Unit uses R-410a and the EC unit has an efficiency of 13 W/W (Table 2).

Table 2: Lowest and Highest Emissions Abatement Cases

Refrigerant	EC Adoption	EC Efficiency [WW]	Abatement [GT CO2e]
D2Y60	Low	4.125 (Low)	57.82
R-410a	High	13 (High)	193.34
D2Y60	100%	4.125 (Low)	76.06
R-410a	100%	13 (High)	230.4

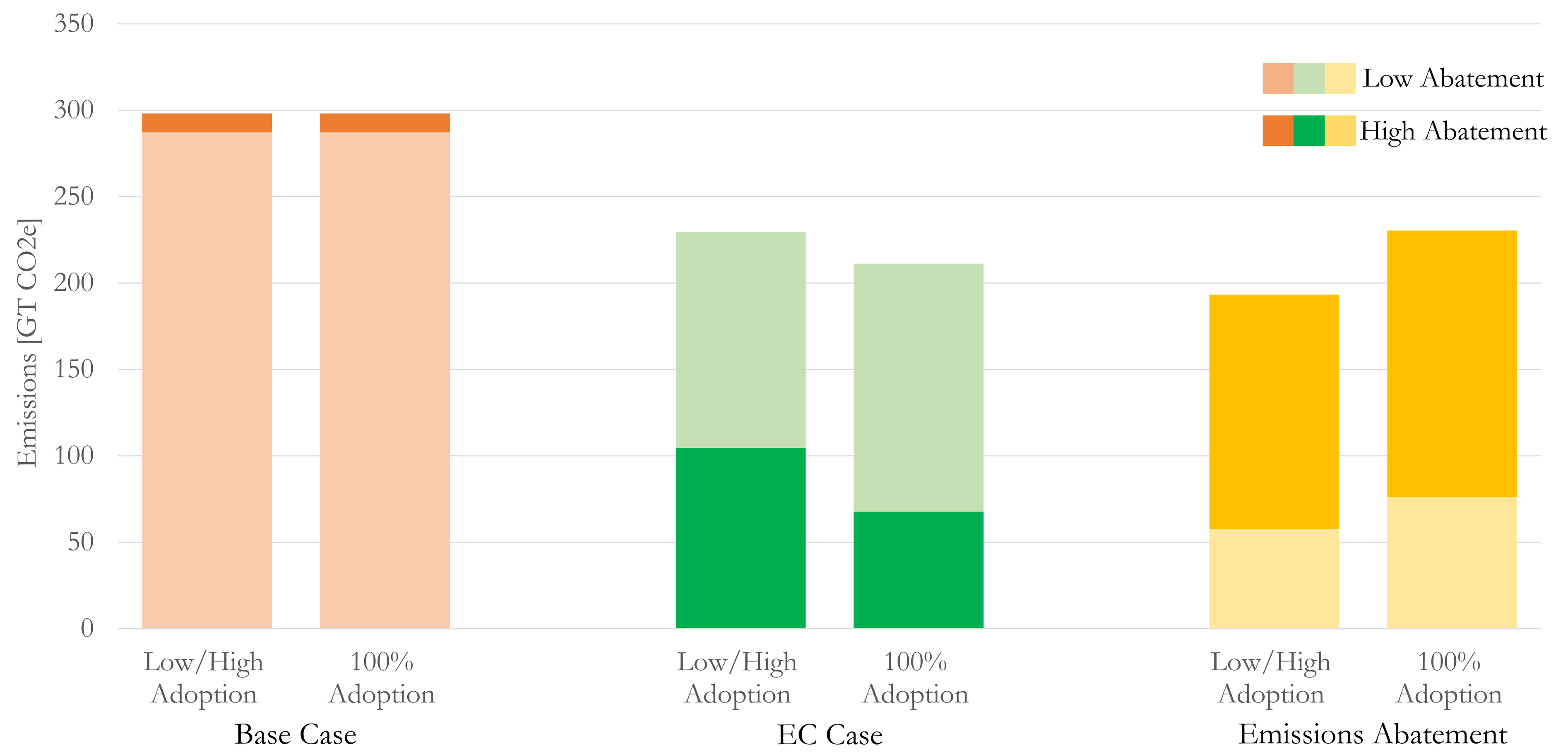

Figure 6: Modeled Emissions Scenarios by Adoption of EC Cooling

The Base Case and EC Case bars in Figure 6 represent the total lifetime emissions of all the units implemented in the modeled scenarios between 2030 and 2050. The emissions abatement is the difference between the two cases. The highest and lowest emission abatement for each adoption scenario are presented. The phase-out of all refrigerants in the residential AC model accounts for an estimated mitigation of the leakage of 12% of global refrigerants [7].

IV. Conclusions and Key Findings

- Residential EC units produce 20.8% – 82.5% less lifetime emissions than Base Case units
- The adoption of residential EC cooling can prevent warming of 0.07 – 0.29 °C in the modeled scenarios
- EC cooling adoption in commercial air conditioning can mitigate up to 265.5 GT CO2e

V. Model Limitations and Next Steps

- Improve energy demand predictions due to Base Case system assumptions
- Incorporate the transition of electrical grids to green energy
- Consider regional building envelopes
- Investigate emissions savings and applications of EC cooling for mobile vehicles, data centers, and vaccine transportation and storage

VI. Acknowledgements and References

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