Reducing Harmful Emissions from Heating, Ventilation, and Air Conditioning Systems

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Social Impact

Heating, ventilation, and air conditioning (HVAC) systems contribute significantly to global warming. The systems contain refrigerants that, if released, are thousands of times more potent than carbon dioxide. Although there are solutions to this problem, it is not economical for companies to make HVAC systems more environmentally friendly; therefore, regulations are needed to bring about the change. There are many possible routes for HVAC regulation, each with varying degrees of effectiveness, feasibility, and cost. The purpose of this research is to perform a policy analysis on possible regulations and make a policy recommendation.

> "Current refrigerants are thousands of times more potent than CO_2 as greenhouse gases"

Biography

Scott Horton is a fourth-year year chemical engineering major with minors in biomedical engineering and computer science. He is originally from Oak Ridge, Tennessee where he attended Oak Ridge High School. At the University of Virginia, he is a Rodman Scholar and helped to found the branch of the chemical engineering honor society, Omega Chi Epsilon. He was also a participant in the Policy Internship Program in 2010 where he worked at the Department of Energy in the Buildings Technologies Program. He conducted research in the area of Heating, Ventilation, and Air Conditioning (HVAC) policy because HVAC systems contribute significantly to global warming. In addition to policy research, he interned at Oak Ridge National Laboratory for four summers in three subject areas: bioinformatics, polymer synthesis, and computational chemistry. He will attend the University of Delaware in the fall for graduate school in chemical engineering in computer modeling and simulation.

Abstract

Current heating, ventilation, and air conditioning (HVAC) systems contribute significantly to global warming. The underlying cause for this problem is that current refrigerants are thousands of times more potent than CO_2 as greenhouse gases. While this problem will likely be solved by a next-generation refrigerant, researchers are developing Not-in-Kind (NiK) technologies which would remove the need for refrigerants. Even with possible solutions, it is not economical for companies to make HVAC systems more environmentally friendly; therefore, regulations are needed to bring about the change. There are a number of policy options to choose from including Hydrofluorocarbon (HFC) containment, phase-outs, taxes on emissions, and cap-and-trade. This paper evaluates these policy alternatives using short-term effectiveness, long-term effectiveness, political feasibility, and cost as criteria. After applying the criteria and reviewing literature, the policy recommendation is to first enact a containment policy, then later pass a cap-and-trade policy, combining the strength of both policies. Containment policies are politically feasible and effective in the short-term, as this strategy simply increases the stringency of regulations and programs currently in place. Though cap-and-trade is currently politically infeasible, it is the best suited policy option for HVAC systems for long-term effectiveness. A secondary recommendation is to separate HVAC regulation from the larger climate change bill. This recommendation is based largely on the political infeasibility of carbon cap-and-trade, a system that is completely independent of HVAC regulations. Ultimately the policy recommendation is twofold: enact a containment bill to reduce emissions in the short-term and pass a cap-and-trade policy to ensure that problem is solved for future generations.

Introduction

Current heating, ventilation, and air conditioning (HVAC) systems contribute significantly to global warming. These vapor-compression systems contain refrigerants that, if released, affect global warming thousands of times more than carbon dioxide (IPCC Second Assessment : Climate Change, 1996; IPCC Third Assessment Report - Climate Change, 2000). There are two sources of greenhouse emissions from HVAC systems: (1) the direct emissions via the release of refrigerants into the environment from leaks and (2) the indirect emissions from the production of electricity used in HVAC operation. In the coming years, the amount of HVAC emissions will escalate as more nations become developed and more people have access to HVAC systems. As shown in Figure 1, if current trends continue, direct emissions from HVAC systems will be responsible for nearly 20% of total impact from greenhouse gas (GHG) emissions by 2050 (Guus J. M. Velders, 2009).

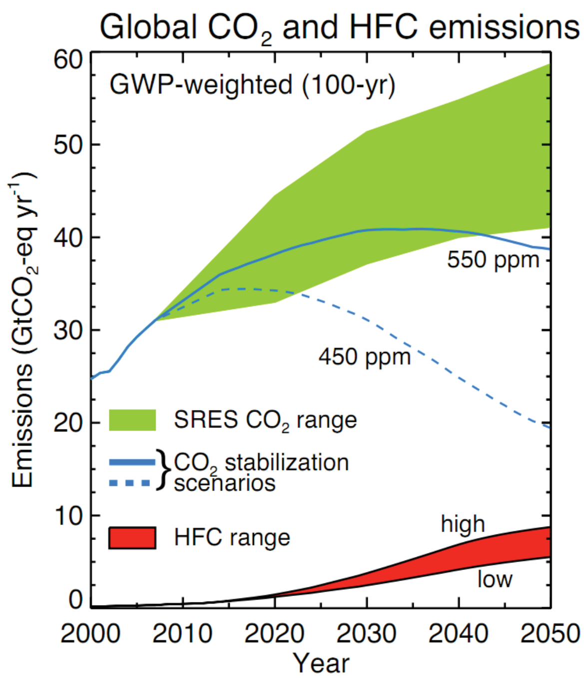

Figure 1. Global CO_2 and HFC (Hydroflorocarbon) Emissions. (Guus J. M. Velders, 2009). The green section indicates the total GHG emissions seen over time. The red section represents the HFC emissions over time. The units on emissions reflect the total impact to global warming. Note that the total HVAC emissions in the form of HFCs is projected to account for 20% of the total impact of greenhouse emissions.

HVAC systems have contributed to other environmental crises in the past. For example, in the 1980s, scientists discovered that the depletion of the ozone layer was largely caused by the emission of CFCs (chloroflorocarbons), the most common refrigerant of the time. The technical solution to this problem was simply to use new refrigerants that did not deplete the ozone layer. This solution involved large implementation costs as changing refrigerants in HVAC systems often requires extensive retrofits or even complete redesign. It is not realistic to believe that industry will front these large expenses at no economic gain without government intervention (Ardehali & Smith, 1996). This intervention appeared globally with the highly-effective Montreal Protocol ("The Beijing Amendment to the Montreal Protocol on Substances that deplete the ozone layer," 1999) which mandated the reduction of CFC emissions. The effectiveness of the protocol was largely due to the enactment of public policy in signing countries. For example, the United States' 1990 Amendments to the Clean Air Act ("Lieberman-Warner Climate Security Act of 2008," 2008) enforced a gradual phase-out of CFCs. Ultimately the international protocol and individual government policies have led to the complete disappearance of ozone-depleting refrigerants from HVAC systems.

To solve the problem of global warming contribution from HVAC, many parallels can be drawn from the ozone-depletion example. The technical solution to the problem will be similar and will again require government intervention. Currently, there are no American regulations in place to combat the HVAC emission problems. All of the recently proposed American climate bills which have addressed this issue use a cap-and-trade strategy ("American Clean Energy and Security Act of 2009," 2009; "The American Power Act," 2010; "Lieberman-Warner Climate Security Act of 2008," 2008). Other countries have begun to implement different policy options, including containment measures, phase-outs of the damaging refrigerants, and taxes on the emissions (Hekkenberg & Schoot Uiterkamp, 2007). This report evaluates four policy options based on short-term effectiveness, long-term effectiveness, cost, and political feasibility:
1) Containment measures
2) Phase-outs
3) Taxes on emissions
4) Cap-and-trade

Technical Solutions

The underlying problem behind the global warming impact of HVAC systems is the set of refrigerants currently in use. These working fluids have global-warming potentials (GWP) that are thousands of times higher than that of carbon dioxide (GWP = 1, CO_2 is used as a basis for this system) (IPCC Second Assessment : Climate Change, 1996; IPCC Third Assessment Report - Climate Change, 2000). A major factor affecting GWP is the infrared (IR) spectrum of the refrigerant, defined by the wavelengths of electromagnetic (EM) radiation absorbed by the compound. It is desirable to release compounds into the atmosphere that absorb EM radiation at wavelengths similar to the existing atmosphere, so that the amount of energy reflected back to the Earth is not increased, thus reducing the global warming effect. (Dickinson & Cicerone, 1986). Another variable affecting GWP is the lifetime of the compound in the atmosphere. Even compounds that have nonideal IR spectra will have a low GWP if they are unstable and degrade rapidly (Eckaus, 1990). Both of these variables are based entirely on the properties of the emitted refrigerant. There are two possible technical solutions: the implementation of next-generation refrigerants or the development of HVAC technologies which do not require refrigerants.

Next-Generation Refrigerants

The first technical solution is the implementation of refrigerants which have much lower GWPs than currently used working fluids. This solution continues to utilize the existing vapor-compression system, therefore saving time and money that would be invested in developing a new type of technology for refrigeration. A major issue for future HVAC systems is that there is no clear next-generation refrigerant. An example of this is seen for mobile air-conditioning (MAC), for which two major contenders for replacement working fluids are carbon dioxide and HFO-1234yf (2,2,2,3-tetrafluoropropene).

Carbon dioxide may seem a paradoxical choice to use as a working fluid as it is commonly associated with being a major contributor to global warming; however, it should be noted that current refrigerants have GWPs of at least 1400 while CO_2 has a GWP of 1 (Calm, 2008). If the current refrigerants were replaced with CO_2, the significant GWP decrease would practically eliminate the HVAC systems' contribution to global warming. Unfortunately, there are many problems associated with the implementation of CO_2 as a working fluid. The major problem is that CO_2 would require a much higher pressure for operation than the current refrigerants, necessitating the complete redesign of many HVAC systems. This higher pressure could also increase the cost of fabricating and maintaining HVAC systems, as leaks would be harder to prevent (International Institute of Refrigeration, 2000).

Another possible replacement refrigerant is HFO-1234yf. There are many potential benefits to using this as a working fluid, including a GWP of 4 due to its short atmospheric lifetime (Calm, 2008). In addition, the physical properties of HFO-1234yf are almost identical to a common current refrigerant, HFC-134a, allowing it to be used in many current systems with minimal retrofits. This physical similarity to HFC-134a also means that the efficiency of the systems would not be affected adversely. Like CO_2, there are barriers to the implementation of this refrigerant. Research on toxicity and flammability has yet to show clear conclusions on whether this refrigerant is safe to use, especially in the MAC market. There are also concerns over the introduction of tri-fluoro acetic acid (TFA) which forms when HFO-1234yf degrades in the atmosphere and ultimately ends up in rainfall. The exact environmental effects of high concentrations of TFA are unknown; however, it is unlikely that the concentrations will be high enough to harm aquatic life (Luecken et al., 2009).

Due to the benefits and drawbacks of both CO_2 and HFO-1234yf, there is no clear technical solution in the MAC market. MAC has drawn international interest because the European Union passed a directive in 2006 which requires automotive producers to use a low-GWP refrigerant in new lines of cars starting in 2011 and in all cars starting in 2017 (European Union, 2006a). In response to these looming deadlines, groups around the world support one of these two refrigerants and strongly oppose the alternative. Germany has supported carbon dioxide as the replacement working fluid by funding much research in this area (Ittershagen, 2008). Alternatively, the chemical companies Dupont and Honeywell are championing HFO-1234yf; a choice supported by US and Japanese automakers. The German environmental agency has spoken out against the use of HFO-1234yf, citing research performed by the German Federal Institute for Materials Research and Testing, BAM (Ittershagen, 2010). In the end, the International Society of Automotive Engineers (SAE) expects that HFO-1234yf will become the next automotive refrigerant. However, chemical producers are hesitant to make large-scale plants as the refrigerant has yet to be approved by the EPA (Weissler, 2010). Groups supporting both of the refrigerants have vested interests and supporting research and neither side has a clearly stronger argument at this point in time. Ultimately further, third-party research is needed to determine what the next refrigerant will be for mobile air conditioning.

Not-in-Kind Technologies

The other set of technical solutions involve using a method other than vapor compression for refrigeration, also referred to as a not-in-kind (NiK) technology. These alternative methods often remove the need for refrigerants entirely, thereby removing direct emissions of GHGs from HVAC systems. Generally these methods are more experimental than next-generation refrigerants and currently none are efficient enough to be competitive with vapor-compression for widespread use. To date, two NiK technologies have been shown to potentially be competitive with vapor-compression: magnetocaloric and thermoacoustic refrigeration (Brown, March 2010). These technologies work in different ways, but both need a source of energy to move heat. For magnetocaloric refrigeration, a magnetic field is applied to a solid which aligns the spin of the electrons, moving them to a higher energy level. When these electrons are allowed to relax, the energy released can be used to move heat against a thermal gradient. Thermoacoustic refrigeration uses the pressure oscillations in sound waves as a source of energy to drive heat against its temperature gradient.

Policy Options

Due to the expensive implementation of technical solutions, government policy is required to catalyze the change to environmentally friendly HVAC systems. Internationally, HVAC emissions are included in the Kyoto protocol, which places limits on total greenhouse gas emissions. To meet this protocol, European countries are implementing three types of policies: improving HFC containment, phasing out HFC use, and taxing HFC use (Hekkenberg & Schoot Uiterkamp, 2007). Although the United States is not bound by the Kyoto Protocol, it has submitted a number of bills to Congress that promote the regulation of HFC use via cap-and-trade. As no regulation has yet passed in the United States, a policy recommendation will be made after evaluating the short and long term effectiveness, costs, and political feasibility of each option.

Improving HFC Containment

Containment strategies are based on the fact that refrigerants do not harm the environment unless they are released. Therefore, even without a change in refrigerant, the HVAC contribution to global warming can be insignificant if emissions are greatly reduced from both the operating systems and the refrigerant disposal process. Figure 2 shows that the only sources of emissions are from operating systems (HFC Stocks) and refrigerant disposal. Containment strategies vary greatly in stringency and can range from simply regulating intentional venting of refrigerants to forcing the repair of leaks on almost all HVAC systems. Although containment polices are implemented to some degree in many countries,

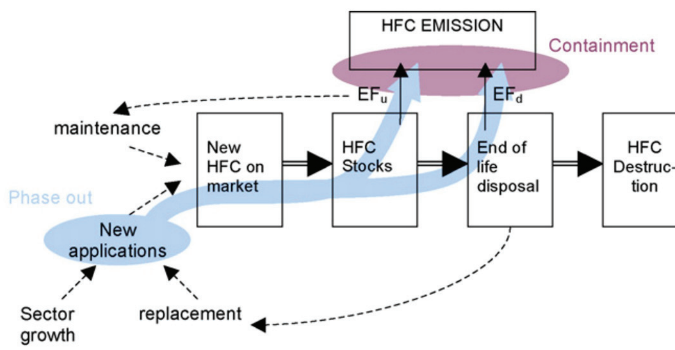

Figure 2. Refrigerant Lifecycle. (Hekkenberg & Uiterkamp, 2007). Shown in blue is how a phase-out affects this lifecycle. Purple shows how containment strategies affect the lifecycle. An explanation of how each policy affects this figure is described in the respective sections below.

the Netherlands, with a particularly strict policy, has been by far the most successful in reducing emissions(Hekkenberg & Uiterkamp, 2007). The Dutch first implemented containment strategies in 1992 to meet the goals laid out by the Montreal Protocol in the form of a regulation called STEK. Over the last 15 years, the Netherlands have led the world in reducing the emission rate from refrigeration systems. Of all the refrigerants within Dutch systems, 5% are emitted into the atmosphere annually, compared to global averages of 30%. Due to this huge success, the EU has formulated its own regulations on stationary HVAC largely based on

STEK (European Union, 2006b). The Netherlands' policy has been in place for long enough that it has been used as a case study (Freezing HFC emissions, 2008). It should be noted that there was a large amount of cooperation between the industry and the government in forming the regulations. Overall, the program is viewed as a success through a wide variety of interviews conducted on those in industry, recorded in the case study. These interviews concluded that the major drawback of the policy was the extra administrative effort in industry to ensure that regulations were followed.

Modeling a policy after the Dutch system could work well in the United States, as there is a current annual leakage rate of 13-22% of refrigerant in HVAC. Current US regulations prevent intentional venting of refrigerants into the environment and require the repair of leaks which emit greater than 35% of the total refrigerant volume from a system containing 50 lbs of refrigerant or more (EPA, 1995). This policy is not very stringent, as it only targets substantial leaks out of the largest commercial and industrial systems. In comparison, the Dutch system includes even minor leaks in all but the smallest residential systems (more than 6.6 lbs of refrigerant). In terms of the policy metrics, short-term effectiveness is high for containment strategies(Hekkenberg & Schoot Uiterkamp, 2007). This policy is less effective in the long term because, ultimately, emissions are only reduced by a factor of 4 at most; in comparison, a policy leading to a change in refrigerant would need to drop emissions by more than a hundred-fold. Political feasibility should be comparatively high for containment, as it requires no extensive retrofits or redesign of systems and, therefore, is a minimal cost to companies. Political feasibility is also high for this option because the EPA can change regulations without a bill going through Congress, albeit the process still includes input from those affected. In this case, likely opposition would arise from those who have not been under leakage regulation before, such as owners of middle-sized refrigeration systems. Costs to the government would be minimal, seen only in regulation enforcement.

Phase Out Strategies

Phasing out environmentally damaging refrigerants is, historically speaking, the most popular public policy. During the ozone depletion crisis, the United States successfully employed phase-outs of refrigerants. Currently, Austria and Denmark have implemented a similar strategy to address the problem of high GWP refrigerants (Hekkenberg & Schoot Uiterkamp, 2007). Specifically, the Denmark regulation required all new HVAC systems to no longer use HFCs as of January 1st 2006 ("Commission Decision," 2006). This is different than a ban, because old systems are still allowed to use HFCs. Over time, as old systems are replaced, HFCs will gradually phase-out and be replaced by more environmentally friendly refrigerants. The major advantage to this form of a phase-out is seen in long-term effectiveness where there are no more HFC emissions. Short-term effectiveness will be lower than containment because the ban on HFCs is only on new systems (Ardehali & Smith, 1996). The poor short-term effectiveness can be illustrated by Figure 2. The new refrigerant would enter the market but would take time to become incorporated into systems actually in use (HFC stocks). As emissions only occur from HFC stocks and end-of-life disposal, the policy would be ineffective at first. The political feasibility is low for this policy option because changing practices would not be optional and all HVAC systems would be affected. A problem with a strict phase-out on HFCs is that efficient technical options might not be available for all applications. Phase-outs do well in terms of cost to the government, as most costs are fronted by the companies. The one cost to the tax-payer is the implementation of regulation, which would be cheap and only require the verification of the refrigerant in each new product line.

Tax on HFCs

Both Denmark and Norway currently have a tax on HFCs, which is similar to a containment strategy because the consumer is only taxed on what is leaked into the environment. Consumers pay a tax when buying the refrigerant, but this tax is refunded when the refrigerant is properly destroyed. The tax is relative to the GWP of the purchased refrigerant, encouraging the use of more eco-friendly refrigerants (Hekkenberg & Schoot Uiterkamp, 2007). Specifically looking at the Norwegian tax, the first year of taxing HFCs resulted in a reduction in HFC imports from the business-as-usual scenario, but still recorded increases over the previous year (due to the phase-out of ozone-depleting refrigerants) (SenterNovem, 2007). Ultimately, more time is needed to determine all of the effects of a tax on HFC emission changes over time.

The short and long effectiveness of a tax will vary from industry to industry. Companies are incentivized to reduce emissions because they will get larger refunds, but if an HVAC system has inherent leakage problems, then it might be more economical to switch to a lower-GWP refrigerant. Companies are likely to choose whichever route (containment or new refrigerants) is better suited for the particular system involved. This would lead to some companies reducing emissions a small degree in the short term, while other companies would reduce emissions by a large degree in the long term. The short-term and long-term effectiveness of this strategy would both have moderate success; it should be noted that ultimately a tax is not as effective as containment or bans because there is no legally binding requirement to change practices. In terms of Figure 2, a tax would affect all stages in the life cycle of the refrigerant. The costs to the government would be low and leaky systems would lead to monetary gains for the government. Regulation would be cheap, as taxes are easy to implement and refunds would be given based on how much of a refrigerant is sent to the disposal plant. The political feasibility of this option would be especially high because there is no actual requirement to change strategies. Although opposition would arise from those with large systems that would have to front huge fees initially, the amount of refrigerant in residential and mobile air conditioners would not lead to a high enough tax to cause strong opposition from the general public.

Cap-and-Trade

With cap-and-trade policies, it becomes more expensive over time for companies to continue to use environmentally-damaging refrigerants. The idea behind cap-and-trade is that companies are allotted allowances for HFC usage which can be sold from one company to another. The total allotted usage decreases over time and the remainder is auctioned by the US government to companies needing more allowances. In the past, cap-and-trade was used to combat acid rain via reducing SO_2 and NO_x emissions as part of the Clean Air Act ("Lieberman-Warner Climate Security Act of 2008," 2008). This program has been very successful, with a 40:1 benefit to cost ratio (EPA, 2004). A novelty to HVAC cap-and-trade is that it targets the production of HFCs rather than emissions. This means that allowances for companies are consumed upon the production of refrigerants or the import of goods containing refrigerants. From Figure 2, cap-and-trade would affect the same stages of the refrigerant life-cycle as a phase-out strategy.

In terms of the policy metrics, cap-and-trade has some surprising results. Nominally, this method should be more politically feasible than a phase-out because, while it provides economic incentive for new practices, nothing is strictly required. However, no bill containing HVAC cap-and-trade has passed through Congress. This could be because the HVAC regulation is part of a larger climate bill which hopes to regulate the entire carbon market. Political opposition to this bill is largely due to the carbon cap-and-trade system. Carbon cap-and-trade is based on emissions rather than production, and is completely separate from the proposed HVAC cap-and-trade. Unless the bill is separated, the issues around carbon cap-and-trade will also reduce the political feasibility of HVAC regulation.

In terms of effectiveness, cap-and-trade should have good long-term effectiveness and poor short-term effectiveness. As mentioned before, technical issues existent in HVAC are not universal to all applications (this was a major problem in phase-out mechanisms). This supports cap-and-trade, which would allow companies that can cheaply switch practices to sell their allowances to those that cannot drop HFC usage. Despite the lack of stringent regulations, the monetary incentive is an effective way to encourage companies to reduce their long-term refrigerant emissions. Ultimately, the short-term effectiveness of cap-and-trade is poor as it does not target HFCs currently within systems. Costs to the government for this regulation should be low; some of the enforcement systems and methods are currently in place for the NO_x and SO_2 programs.

Conclusion

The policy options were evaluated using short-term effectiveness, long-term effectiveness, political feasibility, and cost. For long-term reductions, a cap-and-trade is the most appropriate. The only other option that is effective in the long-term is phase-outs, which are currently not suitable for the HVAC market. Cap-and-trade does have problems in terms of political feasibility, as the climate bills have been in Congress for years without being approved. It would be ideal to separate the cap-and-trade policy for HVAC from the larger bill to increase the political feasibility; however, this might still take years to pass. For the time being, it makes sense to enact the more politically feasible option of a containment strategy. This option excels in the area of short-term effectiveness and reduces emissions from the current systems. Containment is also inexpensive for the government to implement, as it simply expands on systems already in place. Ultimately the policy recommendation is twofold: enact a containment bill to reduce emissions in the short-term and pass a cap-and-trade policy to ensure that problem is solved for future generations.

Acknowledgements

First I would like to thank the Policy Internship Program at the University of Virginia for the opportunity to perform this research. Within this program I would like to thank Michael Rodemeyer and Jim Turner for their guidance throughout the internship process. Mr. Joe Hagerman and The Building Technologies Program in the Office of Energy Efficiency and Renewable Energy at the Department of Energy for hosting my internship this summer. Specifically within the program I would like to thank Mr. Antonio Bouza for mentoring me on the technical issues throughout the summer. On the policy-side of my internship, I would like to thank Dr. Collin McCormick for being my mentor.

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