An Economic Perspective on a Carbon Management Program at the University of Michigan

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Abstract

The recent UN IPCC special report stated that, in order to stay at or below 1.5 degrees of warming, greenhouse gas emissions will need to be reduced by 45 percent below 2010 levels in the next decade, and reach net zero emissions by 2050. These are much steeper cuts than previously estimated and as such, will require immediate collective action considering that global emissions are still rising.

In February 2019, the University of Michigan announced the formation of the UM President's Commission on Carbon Neutrality charged with charting a course to net zero carbon emissions. This report focuses on evaluating the marginal cost and abatement potential of different options available to the university, such as a renewable energy power purchase agreement, the Central Power Plant upgrade, and commoditized emissions reductions like cap-and-trade permits and carbon offsets. Additionally, we examine the feasibility of instituting a carbon tax on campus by performing a simulation on selected schools to illustrate how different tax levels and rebate schemes would affect each schools' budget.

Recommendations:

- **Begin Piloting a Carbon Tax:** Piloting will be a necessary step ahead of implementing a tax university-wide. Given the time delay between piloting and implementing, the university should act quickly to begin piloting a carbon tax with different rebate and revenue schemes so as to not unnecessarily delay implementation.
- **Feedback on Revenue/Rebate Schemes:** Throughout the pilot, they should collect data and elicit feedback from participants to determine which uses of revenue are preferred, how easy it is for units to estimate their yearly charges, and to what level to set the tax.
- **Central Power Plant Upgrade:** The university should continue with the central power plant upgrade if it is a prudent financial investment. They should also adjust their estimated carbon abatement from the upgrade to take into account the declining carbon intensity of the grid, and the methane leakage that occurs from wellhead to power plant.
- **Carbon Neutrality:** The university should set an ambitious carbon neutrality goal. Through the use carbon offsets and cap-and-trade permit retirements, there is no reason why the university can't achieve carbon neutrality by 2020. In the next decade and beyond, cap-and-trade permits or carbon offsets can be seen not as a long-term solution, but as a means of closing the emissions gap to carbon neutrality, while also buying the university time before investing in technological solutions.
- **Technology Investments:** The university should delay any further investments in technology upgrades until the cost curves for those upgrades meet the cost curves for carbon offsets and cap-and-trade permits. With solar PV, wind, and storage prices expected to continue dropping in the coming decades, it would be unwise to invest now as the university would be locked into an above market rate in just a few years' time.

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Background

Global imperative to reduce emissions

The science surrounding climate change is not up for debate. As a society, we are certain that emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gasses, such as carbon dioxide, methane, CFCs, and nitrous oxides. Increases in the concentration of these gases leads to a warming of the Earth's surface as more of the sun's irradiance gets trapped within the atmosphere for a longer duration. While the concentrations might be uniformly distributed across the atmosphere, the impacts of the warming will be most severe in regions already under stress.

Issues surrounding climate change can no longer be pushed off to future decision-makers as many of the natural disasters taking place today are linked to the effects of climate change. Extreme heat, storms, and drought as well as disease, famine and poverty will increase in frequency and severity as the world inches towards 2 degrees Celsius or greater of warming. In order to avoid the worst of those damages, dramatic steps must be undertaken now to curb global emissions.

Intergovernmental Panel on Climate Change: Working group III

The recent UN IPCC report provides recommendations for how countries can cooperate to combat climate change. Due to the fact that a major proportion of emissions affecting the atmosphere at present came from industrialized countries, the report suggests that those countries bear a responsibility to cooperate with developing countries in international action against climate change without standing in the way of the latter's economic development. Cooperation could take the form of financial aid, transfer of technology, or sharing analysis and research. The seriousness of climate change means that, in choosing a strategy, we should look for one that can be justified immediately even in the face of significant uncertainty. Among the other recommendations, the IPCC report suggests that governments set targets for CO_2 emissions, improve energy efficiency measures, use cleaner energy sources, and improve forest management as a possible reservoir of carbon.

A later report published by the same working group underscores that, in order to stay at or below 1.5 degrees of warming, GHG emissions will need to be reduced by 45 percent below 2010 levels in the next decade, and to reach net zero emissions by 2050.[29] These are much steeper cuts than previously estimated and will require immediate collective action considering that current worldwide emissions trajectories are still rising.

The rationale for and the benefits of action by UM

'We are still in' pledge and Carbon Neutrality

The message in the reports by the UN IPCC has been heard and understood around the world. The 'We are still in' pledge, which represents a commitment on the part of cities and organizations to “hold warming to well below 2°C and to accelerate the transition to a clean energy economy that will benefit our security, prosperity, and health,” has been signed by more than 2,800 leaders representing cities, states, companies, and colleges from around the country, including the University of Michigan.[11] In 2018, President Mark Schlissel went even further by committing the University of Michigan to a carbon neutral trajectory and launching an exploratory commission to develop a plan for reaching carbon neutrality. The University of Michigan’s commitment to carbon neutrality is a bold and necessary step at a time when dramatic action is needed, but it also shows recognition that going carbon neutral is both good for the environment as well as the university’s financial position by way of reputational gains.

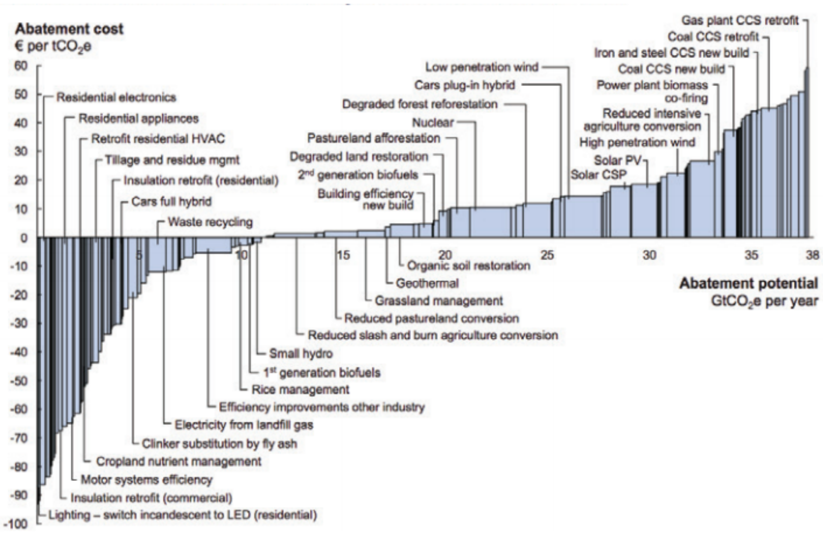
UM compared to other Institutions

Currently, UM lags behind other top universities in the United States in their carbon reduction commitments such as Duke, Yale, Stanford, and MIT (for details on UM electricity consumption and emissions see Appendix A). While these universities are significantly smaller in terms of student population than UM, the University of California system, which has a student population similar to that of UM, has been using a carbon shadow price in their planning and has set a goal of being carbon neutral by 2025. Looking within the Midwest, UM is lagging behind almost all other Big 10 schools in terms of their current carbon abatement commitments, as six schools have set commitments of 100% emissions reductions by 2050.[38] Given the global imperative to reduce emissions at a rate faster than one that would see us be carbon neutral by 2050 and UM’s commitment to a carbon neutral trajectory, this provides an opportunity for the self-proclaimed leaders and best to show leadership on yet another front and commit to full carbon reduction on a timeline more in-line with what is necessary to avert real climate disaster.

Rationale for considering marginal abatement costs

When evaluating abatement options, using marginal abatement cost (MAC) as the primary evaluative criterion and choosing the lowest marginal cost abatement options (\$/MT of CO_2) will minimize overall abatement costs. In their 2009 report, Pathways to a Low-Carbon Economy, McKinsey & Company illustrate the marginal abatement cost and overall abatement potential of over 200 abatement measures across 10 major sectors and 21 world regions between 2009 and 2030.[42] Their results showed that the energy savings of energy efficiency measures could largely pay for the upfront abatement investment costs - in many cases providing a net economic benefit - giving energy efficiency a negative MAC. In other words, these measures are profitable on their own, independent of carbon abatement consideration.

Figure 1
The McKinsey (2009) Marginal Abatement Cost Curve: "Global GHG Abatement Cost Curve Beyond Business-As-Usual-2030"



Source: Global GHG Abatement Cost Curve v2.0. Figure and notes reproduced with permission from McKinsey (2009).
Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

The International Energy Agency's (IEA) market reports confirm this indicating that scenarios with higher energy efficiency penetration show lower overall abatement costs, with an estimated 2.8 trillion dollars in savings from 2015-2030 when comparing energy-efficiency pathways to energy-intensive pathways.[30] In sum, the marginal costs of different abatement measures are not equal and energy efficiency measures are the lowest cost. Both of these studies show that there are a range of ongoing issues that explain why these savings haven't yet been realized, from financial barriers, lack of information, and improperly aligned incentives.

University of Michigan as a test bed for innovation

Developing a carbon tax program at the University of Michigan would not only incentivize abatement in the lowest part of the marginal abatement curve, but it would also be consistent with UM's values in developing leaders who challenge the present and enrich the future. Currently, MCity is working with transportation industry leaders to transition the way we move about the world to a new level of connectivity and automation. Fast Forward and the University Medical system is also working on groundbreaking biomedical research and innovation. The University of Michigan has long been a test bed for innovation, and this innovative spirit should be extended to our carbon management program. We have never waited to follow in the footsteps of who came before; instead we have been trailblazers and leaders. This should be the case when it comes to setting carbon abatement goals, developing strategies to meet those goals, and experimenting with solutions.

A Carbon tax would be consistent with UM values

In a 2014 policy brief published in the Stanford Institute for Economic Policy Research, Professor Frank Wolak reiterates the point that universities should be test beds for carbon tax programs. Seeing as how the primary role of universities is to create and disseminate knowledge, this lends them to be uniquely positioned to address the challenges of pricing greenhouse gases and working out the details before a carbon tax can be effectively implemented on the national scale. Wolak calls for university campuses to implement revenue-neutral carbon taxes on all emissions-producing activities on campus, which would result in business units and individuals paying extra for the activities they undertake that result, directly or indirectly, in emissions.

Implementing a carbon tax at the University of Michigan, similar to the one laid out by Wolak, would be consistent with the mission and vision of the university in every sense. Becoming the first university in the Midwest, and one of the largest universities in the world, to implement a campus-wide carbon tax would make unequivocal UM's position as leaders on the carbon abatement front and challenge the status quo for the benefit of present and future generations.

Carbon tax as institutional innovation

While carbon taxes are being piloted elsewhere, none are being implemented on a campus the size of the University of Michigan. With UM's size, influence, and standing, implementing a carbon tax would be an unprecedented step in carbon management and would begin to create the momentum necessary to hasten society's engagement with climate change mitigation efforts. It would also lead to opportunities to collaborate with peer institutions, businesses, and governments to discuss innovative solutions to global climate change.

Possible Elements of a Carbon Management Program

Cost Effectiveness as an organizing principle

When considering ways of abating carbon emissions, there is no shortage of options. Technological solutions, energy efficiency investments, or carbon sequestration all having the ability to unlock significant abatement potential. When determining which abatement options to select, we propose using marginal abatement cost as the key metric to apply, shifting the fundamental question around abatement from 'can we go carbon neutral' to 'what is the cheapest and fastest way to go carbon neutral'. Below we will outline some of the options currently available when it comes to reducing one's carbon footprint.

Options for carbon abatement

Technological solutions

Technological solutions refer to uses of energy generation technologies to directly met the energy demand of buildings on campus. For our purposes, any technology intervention, in order to be seen as an abatement option, would need to emit less carbon than the energy source it is displacing and would need to directly serve the load generated by the university. Some examples of technological solutions would be solar panels, wind turbines, geothermal plants, and biomass plants. The Central Power Plant (CPP) turbine upgrade, which is set to come online in 2020, would also be included in this category as it is displacing electricity from the DTE grid that is more carbon intensive.

As a supply-side measure, technological solutions have the ability to unlock abatement potential that, otherwise, would be inaccessible to energy efficiency measures. Additionally, there are fewer concerns with additionality. Given that you would be the only beneficiary of the generated energy, you can ensure that the abatement it causes wouldn't have occurred without your investment. Where the efficacy of technological solutions as abatement options comes into question is when considering the installation costs and the implementation time it takes to get them up and running. In a budget constrained world where cost effectiveness is important, breaking ground on a new solar array or geothermal plant might mean foregoing twice as much reduction from energy efficiency projects that never got funded. Additionally, it can take years to get projects to an operational stage, where as those same funds might be used to fund abatement options starting immediately.

Energy Efficiency - Capital investments

The Energy Efficiency 2018 Report published by the International Energy Agency estimates that energy efficiency gains alone could allow the world to extract twice as much economic value from each unit of energy used. Reports like this show why energy efficiency is one of the most effective ways of meeting climate goals, as these investments also often come with a positive net present value in addition to increasing carbon abatement. While these investments make sense on paper as the most prudent carbon abatement options, in reality they often run into problems that inevitably lead to their gains becoming unrealized.

One problem is with funding. Like any collective action problem, even if the overall societal gains from an energy efficiency measure outweigh the costs, if there is no cost-sharing structure in place, the project might end up being unfunded. If each potential beneficiary evaluates their own net benefits as negative, were they to have to face all of the implementation costs, the project would never break ground.

Another problem has to do with incentives. If the individuals making the momentary consumption decisions are not the same people who face the costs of those decisions, then there is no feedback mechanism for them to change their behavior or implement energy efficiency measures. This is commonly seen amongst renters as they do not see their electricity or heating bills and, therefore, don't have any reason to want to change their consumption habits or institute energy efficiency upgrades in their rented homes.

Energy Efficiency - Behavioral interventions

The flip side of implementing energy efficient upgrades like double paned windows, CFLs, and insulation is that this can often lead to the rebound effect, where individuals will feel good about being more energy efficient, and proceed to use more energy as a result. Alongside capital investments, it is important to train people to engage in pro-environmental behaviors with behavioral interventions. Behavioral interventions refer to any measure implemented within a building meant to encourage, nudge, or remind individuals to be more conscious of their decisions as they relate to electricity demand. Examples of this are posters placed on walls reminding people to be conscious of their energy decisions, or stickers on light switches which prime people to think about how flipping that switch will turn on a power plant.

Here at the UM campus, Planet Blue regularly performs energy audits in buildings on campus and implements energy efficiency solutions like setting timers on lights, or reducing air conditioning during non-peak hours. But just as easily as these interventions are implemented, they can be undone as building policy is often subject to change. Additionally, the effectiveness of individual level behavioral interventions, like signage on energy switches or posters around buildings, is hard to measure and can fluctuate over time as there are so many individual decisions being made that will determine the outcome.

Carbon Sequestration - Biological

Biological carbon sequestration (BCS) refers to any biological process, performed by plants or micro-organisms, that sequesters carbon from the atmosphere in biomass or soil. Given that BCS is the environment's way of reducing atmospheric CO_2 levels, increasing BCS efforts would be using the environment's own self-regulation system to self-correct. But while BCS is a promising avenue to increase global abatement potential, the overall capacity of terrestrial ecosystems to sequester carbon is uncertain. Additionally, future abatement derived from replanting forests would require verification, monitoring, and evaluation, to ensure accurate accounting year to year. Decisions to increase biological sequestration measures also come with stark tradeoffs, as devoting cropland to carbon sequestration could lead to a decrease in crop production.

Carbon Sequestration - Industrial

Industrial scale carbon sequestration is commonly referred to as carbon capture and storage (CCS), and refers to the process of capturing CO_2 from large point sources, like coal plants, and is either injected into geological formations for long-term storage or transformed into mineral carbonates. When applied to a modern fossil fuel plant, CCS can reduce carbon emissions by 80-90%.[40] The IPCC estimates that CCS could account for between 10 and 55% of total carbon abatement by 2100.[40] While costs for this technology are decreasing making it a more viable option, it ultimately reduces the overall efficiency of these plants, leading to more fossil fuel combustion than otherwise would have been necessary. Additionally, it is still a relatively new and unproven technology that brings with it logistical and long-run risks.

The role of off-campus carbon abatement

Carbon emissions do not carry with them any deleterious local effects that would preclude concentrating carbon emission or emissions reductions. Regardless of the geographic location of an emission, it will increase CO_2 concentrations in the atmosphere uniformly across the entire world. In short, it doesn't matter *where* carbon reductions occur, just *that* they occur. This principle allows us to broaden the abatement options available to the university as we can decouple energy generation and emissions reductions. While admittedly not ideal, continuing to cause emissions, whether directly through the CPP or through procuring energy from DTE, becomes a viable option if we are responsible for emissions reductions elsewhere. Given this, we should continue to use cost effectiveness as our guiding principle in determining which abatement options to pursue, allowing ourselves to be location agnostic in where those emissions reductions take place. Below we will outline some of the options currently available to procure abatement through market mechanisms.

Offsets

Carbon offsets refer to actions intended to compensate for the emission of carbon dioxide into the atmosphere. These carbon emission offsetting activities are quantified ($/MT of CO_2) and traded. An individual or company buys the offsets and retires them (i.e. does not re-sell them), after which, they can claim that they have reduced their overall carbon footprint by the amount of retired offsets.

Cap-and-trade permits

Cap-and-trade permits are created by cap-and-trade systems, which are designed to cap emissions across carbon intensive industries in a region and allow for market based mechanisms to find the least cost abatement among the participating firms. Each permit represent one metric ton of carbon dioxide that a firm can procure, either through auction or by trading with another firm, that allows them to emit one additional metric ton of CO_2 from their electricity generating or industrial process. In order to be able to use the permits to emit more carbon dioxide, the firm needs to retire the permit, meaning that they can no longer trade it.

Renewable Energy Credits & Power Purchase Agreements

Renewable energy credits (REC) work in a similar way to offsets, but are specific to projects that generate electricity. RECs ($/MWh) are used by large-scale utilities to comply with renewable portfolio standards, set by state governments whereby utilities have to ensure that a proportion of their energy generation is coming from renewable sources. Generally speaking, the transfer of RECs from the renewable energy developer to the utility will be agreed upon in the Power Purchase Agreement (PPA) the two parties sign as a means of proving that the energy procured in the contract is renewable. RECs can also be procured in REC market places, should utilities or any other entity be interested in claiming that a further proportion of their energy consumption is from renewable sources.

Additionality

For carbon offsets and RECs, the biggest unknown is the question of additionality. In the context of carbon abatement, additionality asks if the act of buying that offset or REC actually creates additional abatement that wouldn't have occurred in the case of not buying that offset. This is an important question and one that should be addressed when buying offsets as the goal of carbon abatement is to reduce the quantity of carbon in the atmosphere relative to the counterfactual. To address this concern, organizations like Verra, Gold Standard, and the UN FCCC have developed mechanisms to verify and certify emissions reductions that occur from different projects, after which, those offsets carry with them a standard to ensure the credibility of their emissions reduction. Currently there are a number of markets and brokers that sell offsets varying across project type as well as standard (a list of offsets and prices can be found in Appendix B).

The question of additionality is not a concern when it comes to cap-and-trade permits, as buying and retiring a permit directly leads to one fewer ton of emissions that participants in that marketplace can emit (a list of cap-and-trade prices can be found in Appendix B).

Paramount among the benefits that offsets, permits, and RECs provide is the flexibility they bring in terms of how and where that abatement is achieved. Seeing as how offsets, permits, and RECs commoditize abatement, emitters are no longer constrained by the emissions they themselves can achieve, as they can essentially achieve their abatement goals elsewhere. This allows organizations to reduce their overall emissions at the lowest cost, as a solar farm in Arizona or a tree plantation in Brazil might have a lower cost of carbon abatement than the organization otherwise would have.

Examples of other universities undertaking off-campus carbon abatement

Various universities around the US have recognized the importance of the least cost abatement principle and how it applies to carbon abatement. American University is the first US university to become carbon neutral achieving their goal in 2018, two years ahead of schedule.[8] Their neutrality plan involves a combination of demand reduction techniques to reduce energy use, on-campus renewable energy, as well as REC and carbon offset purchases. Stanford as well has secured a PPA to develop a solar farm in Southern California (300 miles from the Stanford campus) that would offset 100% of their energy use and push them to 80% of their carbon offset by 2021.[20] MIT as well is developing an off-site renewable energy project in North Carolina (about 600 highway miles from Boston) to further their carbon neutrality goals, helping develop a 60 MW solar farm that would offset 40% of their current electricity use.[21]

The role of an on-campus market-based carbon abatement

A report published in 2016 by The Institute for Policy Integrity at the New York University School of Law shows that, among economists, it is widely believed that putting a price on carbon is the most efficient route to reduce emissions to the low enough levels in the required time frame. It went further stating that economists disagreed with this premise that putting a price on carbon would hurt the economy. Instead, they were more concerned with the damage that would be caused by not reducing emissions and continuing with the business-as-usual trajectory, as this will stunt economic growth in the long-run and could lead to catastrophic economic consequences down the road. The two most common types of market based interventions are cap-and-trade and carbon taxation. In this report, we will focus on carbon taxation.

Carbon Tax

A carbon tax aims to price into any transacted good or service the cost imposed by the negative externality of carbon emissions that resulted from that good or service. By pricing in the cost of the externality, the tax is intended to correct an inefficient market outcome that otherwise was being overproduced. In the context of carbon abatement, a carbon tax places a fee on fossil fuel producers for every ton of carbon that enters the economy. While the cap-and-trade program fixes a quantity of emissions allowed in the market and lets the price vary, a carbon tax fixes the price and leaves it up to individual firms to decide how much they want to emit (and abate) based on the tax level.

The context in which a price instrument is preferred over a quantity instrument is when the price of the external damages is, more or less, known. This is not necessarily the case with carbon emissions, as estimates for the damages caused by marginal units of emissions vary widely depending on factors like discount rates and standing. On the benefits side of the ledger, a carbon tax provides price certainty for participants. In a cap-and-trade system, the cost associated with permits can vary from year to year depending on a number of factors, and in a manner that might not be predictable. This makes planning around the future price of permits especially difficult as the price might spike, leading to budgetary problems. A carbon tax avoids this problem as it sets a price schedule for emissions, and lets firms adjust to those prices. Additionally, implementing a carbon tax comes at a lower administrative cost than a cap-and-trade program as it doesn't require any additional infrastructure to maintain and can easily be added onto existing taxes levied on firms.

In light of the program's low administrative burden and overall abatement potential, we recommend that the university seriously consider implementing a carbon tax across different business units on the electricity, natural gas, and steam consumption on campus. A carbon tax will be a necessary tool in the fight to go carbon neutral, as it will make business units think more creatively about their energy consumption habits. It bears noting that, while we believe that a carbon tax program would have the greatest impact for the university in its quest to go carbon neutral, no one of these options should be seen as a silver bullet as achieving carbon neutrality will require a blended solution between policy reform, market based instruments, and energy investments.

Additional carbon tax considerations

Carbon tax feasibility

With talk in recent years of a putting a price on carbon, many companies like Microsoft and Shell have gotten ahead of the curve and placed a price on carbon internal to those companies. This approach has prepared them for when there is a legislated price on carbon, as they will have already factored the price into their procurement and development decisions. Similarly, universities like Yale, Swarthmore, and Duke have done the same, showing a recognition in academia of the importance of pricing carbon and the feasibility of a carbon tax at an institution comprised of units all with distinct goals and budgets.

Can a carbon tax lower emissions

In 2018, the Rhodium Group published a report on the energy and environmental implications of carbon taxation in the US where they showed that a carbon tax can be an effective tool at reducing carbon emissions. In their report, they modeled three different carbon taxes: $14/ton rising at 3% per year, $50 rising at 2% per year, and $73 rising at 1.5% per year. Each was modeled with a range of fairly conservative assumptions about energy prices and technology development during that time period. Among their results, they showed emissions reductions between 39 to 46% below 2005 levels by 2025 under a $50 tax level, which would put the US well ahead of its pledged Paris goal of 26 to 28% by 2025.[37] While none of the taxes considered are likely to achieve the long-term US goal of 80% emissions reductions below 2005 levels by 2050, Rhodium has previously shown that current policy with no carbon tax in place is not nearly enough to even hit the 2025 goals.

The study also found that the carbon tax drove large increases in renewable energy procurement. While business units on campus would not be able to sign their own individual PPAs with power producers or install their own renewable energy, an important takeaway from the study is that when a company felt a large enough impact of the tax, it invested in upgrades that reduced the tax burden. In the context of a university-wide carbon tax, this would come in the form of business units investing in energy efficiency upgrades and behavioral modifications.

How to set a price for carbon

The theory behind a carbon price is that, if the correct price is used, then the economy will respond with the optimal level of carbon reduction. While the term ‘optimal’ is up for debate, the central idea is that setting the price is the first and most important step in the whole process. When determining what price to set, the economic consensus is to use the social cost of carbon, that is, the total cost to society that would come from emitting that ton of carbon. In practice, the social cost of carbon is extremely difficult to determine. Estimates range from $6 a ton to $800 and depend greatly on what discount rate is used to discount future cash flows to present-value terms and which damages are deemed to have standing in the calculation.

But while the range for monetized damages might be wide, the reality in most carbon tax systems is that the price is set toward the lower end of that spectrum, ranging from as little as $1 to $130 with over 33% of carbon tax systems below $15.[47] This is mostly due to political resistance that ranges from opposition from fossil fuel interests, to concerns about distributional impacts and individuals’ willingness to pay the tax rates. That said, as more research is conducted around the world regarding the impacts of temperature on labor and agriculture, models are improving, and so is their estimate of the social cost of carbon.

Distributional impacts of a carbon tax

In the context of a society-wide carbon tax, one major concern is the disproportionate economic impacts across income distributions. Given that households in lower income brackets spend a larger proportion of their income on fuel, a flat tax on fuel would be regressive as it would cause people in low-income brackets to pay a higher proportion of their income towards the tax than people in high-income brackets. Historically, carbon taxes that have not addressed the problem of regressivity have not fared well. In early 1993, the Clinton Administration proposed a British Thermal Unit (BTU) tax, which would have taxed energy production in an effort to combat the emerging threat of climate change. However, opposition quickly grew and the bill was branded as anti-poor. The strong opposition caused the U.S. Congress to drop the proposed carbon tax from the larger economic reform package of which it was a part. More recently, the Yellow Vest protest in France is another example of strong public opposition to a carbon tax when that tax is perceived as unfairly burdening low-income populations. But the evidence of regressive carbon taxation policies does not mean that all carbon taxation policies will be burdened with inequitable distributional impacts. It depends on how the revenues are used.

Carbon tax revenues

In 2014, a report from the National Surveys on Energy and Environment published a report on how the public views a carbon tax. Its finding was that public support for a carbon tax depends highly on the proposed uses of the revenues.[5] Opposition was highest when the revenue use was left unspecified with overall support at 29%. However, support grew to 56% under a revenue-neutral approach where revenues are rebated to households, and to 60% when the revenue was earmarked for research and development for renewable energy. This illustrated how carbon taxation policy lives or dies depending on how the revenues will be used. It also corroborates what is seen in the French carbon tax example, as only one quarter of the 34 billion euros that the policy was expected to raise were earmarked for measures to ease people away from using fossil fuel.[50] In other words, support for the carbon tax hinges on whether or not the public feels that the revenues gained from the tax are going to fund tangible efforts to either reduce inequality or improve the transition to clean energy.

Experience with a carbon tax at other universities

Findings and Recommendations on a Carbon Tax Program at Yale

In August 2014, the president of Yale University commissioned a carbon tax task force to determine whether a carbon tax should be introduced to Yale and, if so, what type of design that tax system would have. The following spring, the task force members reported that they thought a carbon tax was an appropriate tool to create the right incentives for decision makers to reduce emissions while also serving the purpose of expanding Yale’s role as a pioneering institution. They recommended starting with a carbon tax at the social cost of carbon, which they estimated at $40/ton, rising at 3% per year. The tax would initially be levied on carbon emissions strictly from energy use, with a recommendation of continuing with further research into expanding the carbon tax to other types of emissions. Additionally, they recommended that the carbon tax be used as a shadow price in the planning for major capital investments.

In their recommendation, they examined several ways of managing the revenues from the tax: redistributing among units; setting individual targets for units; providing emissions information to each school; and setting aside a portion of funds for investment. For each scheme, they performed a historical simulation of the net tax/rebate for 2010-2014 for selected groupings of buildings. From their analysis, they found that a carbon tax at $40/ton would be large enough to get the attention of management, while not large enough to pose major difficulties for academic programs.

Redistribution: In the Redistribution approach, buildings would be compared to the university as a whole during that year. If a building reduces its carbon emissions more than the university does on average, compared to its historical emissions level, then the building receives funds from the carbon tax pool, while the buildings that perform worse than the university average as a whole pay into the carbon tax pool. One downside of this scheme is the inability of participants to predict the number they are judged against, which could lead to inaccurate investment decisions.

Target: The Target scheme is similar to the Redistribution scheme where rebates are returned based on how the unit performs compared to a target. The difference is in how the target is set. Where the Redistribution scheme would compare units to the average emissions reduction throughout the university, the Target scheme would set a different target for each unit. This change would most likely result in either a surplus or deficit across the university as it is conceivable that each unit could over- or under-perform their specific target. In their analysis, they noted that this scheme might be unpopular as it could appear as a central tax.

Investment: The Investment scheme would simply tax carbon and then return the entire refund at the end of the year to each unit as a lump sum, with a percentage of the refund earmarked specifically for energy efficiency investments.

Information: Under the Information scheme, the piloted buildings receive a monthly energy report with a $40 per ton price signal, but with no actual financial consequences for the units.

Takeaways from piloting different rebate schemes

Shortly after their findings were made public, Yale's president moved forward by conducting a pilot program. From December 2015 to May 2016, Yale piloted a carbon tax on 20 buildings to test the efficacy and feasibility of carbon pricing and different rebate schemes on their campus. They created four treatment groups of five buildings per group, with each group receiving a different rebate option as a treatment. The pilot found statistically significant reductions in emissions across all of the treatment groups relative to the control group, suggesting the potential for a carbon tax to serve as a strategy to enhance energy efficiency and conservation efforts. Each scheme had a lower average reduction than the control by 2.4 to 6.5 percentage points, with the Target and Redistribution schemes having the greatest average reduction at around 10 percent.[57]

Design variations: The Yale example suggests that carbon pricing scheme design matters, but that there are different variations that can work. There were no significant differences in emissions reductions among the carbon pricing schemes, but there were clear differences in their administrative feasibility. They also found that it may be more difficult for larger buildings to reduce emissions, and conversely, that it may be easier for energy intensive buildings to reduce emissions.

Perceived fairness: Their results also showed that a carbon pricing scheme that redistributes funds across units is more effective when it is viewed as fair by all of the entities subject to it. In interviews during the pilot, they found that some units called the redistribution scheme unfair, as it didn't account for the different sizes of buildings and how easy or difficult it would be to reduce emissions. If a scheme is perceived as disadvantaging certain participants, then it can prevent the university population from fully engaging and can cause political will for the program to dwindle.

Clear information and incentives: Clear information can enhance the effectiveness of a carbon pricing tool. At Yale, all of the participants in the pilot found the building energy report as a useful tool for understanding their energy use, carbon emissions, and associated cost. More than half of the units reported a high level of understanding after the six-month pilot term. That said, information alone was not a driving motivational force to reduce carbon emissions.

Cost-effective emissions reduction: The study suggests that the reductions from the pilot came at a marginal abatement cost of around -$100/ MT of CO_2e.[15]

As a result of the pilot, Yale selected the revenue-neutral Redistribution scheme. To go along with the new carbon tax, Yale also committed to being carbon neutral by 2050.

Further examples of carbon taxes

Outside of Yale, a number of colleges have considered implementing a carbon tax on campus, including Swarthmore, Duke, and Berkeley.

Swarthmore: In 2016, Swarthmore established an internal carbon tax ($40/MT of CO_2) with four primary goals: (1) to provide a platform to educate and engage the community with carbon pricing solutions, (2) to incentivize reductions in their emissions, (3) to provide financing for projects that reduce their emissions, and (4) to build momentum for state, national, and global implementation of carbon pricing. The carbon tax is levied campus-wide with the revenues being used to support renewables, efficiency, metering, and educational projects. They also use the carbon tax level as a shadow price to motivate less carbon-intensive construction projects.

Duke: Duke University is committed to being carbon neutral by 2024. In an effort to investigate how a carbon tax can help the university achieve that goal, a team of students set out to mimic Yale's carbon tax task force to find out if a carbon tax was the right mechanism to achieve a greater level of business unit involvement in reducing emissions on campus. After interviewing people associated with Yale's carbon tax program and investigating how a similar program would work on the Duke campus, they identified the energy billing process as a key road block in implementing a carbon tax on their campus. They concluded that the energy billing process should be simplified to allow for carbon taxes to be levied and included as a line item on energy bills. They are also considering a carbon tax pilot.

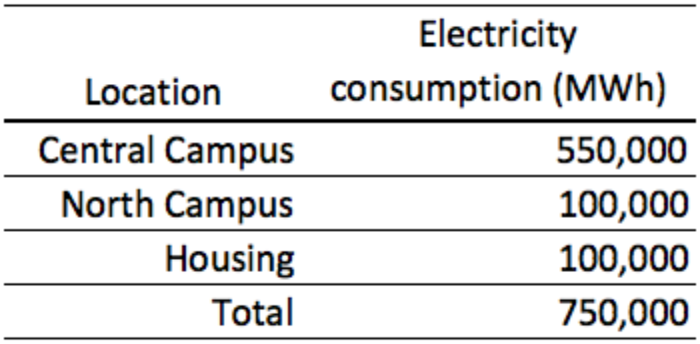
Berkeley: Carbon taxes have also been considered for larger universities such as the University of California system. In their August 2017 report, the University of California's Carbon Neutrality Initiative Finance and Management Task Force recognized that funding concerns would cut across all carbon reduction strategies. Even for programs like energy efficiency retrofits that have a negative marginal abatement cost, they find that those solutions often struggle to find funding due to their large up-front investments. One of the solutions they propose to these funding challenges is to implement an internal carbon tax across the campuses. Recognizing the financial and regulatory risk associated with greenhouse gas emissions, the report recommends setting up a shadow price for carbon, thereby allowing campuses to prioritize funding for actions that reduce carbon emissions without charging an actual carbon tax. Once the shadow price is operationalized, they recommend re-assessing whether or not a carbon tax would be necessary for individual campuses to further fund carbon reduction measures.

University of Michigan Context

Energy Infrastructure

Generation at the University of Michigan

The University of Michigan receives steam and electricity from a variety of sources. The CPP, located on central campus, primarily serves steam demand, the production of which is driven by winter heating demand. In these cases, electricity is a bi-product of the steam production, and it reduces electricity demand otherwise served by the DTE grid. Steam is the binding constraint for electricity production by the CPP, as there needs to be demand for steam in order to produce electricity. In the summer, heating demand is lower, but steam can also be a source of cooling. However, due to the age of the steam cooling equipment, when they break down, they are replaced with newer, electricity driven cooling (AC units), effectively lowering the steam demand in the summer months, while increasing the electricity demand. With the lower steam demand, less electricity is able to be supplied by the CPP at the same time as more is being demanded by the campus, leading to a higher reliance on DTE. On North Campus, electricity load is served by DTE, and steam load is served by a distributed network of 60 to 70 individual boilers fueled by natural gas. A rough breakdown of yearly electricity demand across Central Campus, North Campus and the housing complexes can be seen in Table 1.



Location	Electricity consumption (MWh)
Central Campus	550,000
North Campus	100,000
Housing	100,000
Total	750,000

Table 1. UM yearly energy consumption breakdown by location

UM Sustainability Reporting

Since 2007, the Office of Campus Sustainability has been measuring and reporting on more than 160 environmental metrics around campus in topical areas like energy use and emissions, as well as cross-cutting and emerging sustainability issues. The measurements are taken at the building level, which often doesn’t integrate smoothly with the boundaries for schools, as many units share building space. While the Office of Campus Sustainability creates annual reports for these metrics, they are measured and made available monthly.

Financial Infrastructure

Energy bill administration

Billing for utility services is administered on the school/unit level, while consumption of different services (energy, water, steam) is captured at the building level through meters. The utilities department manages metering and billing throughout campus. For buildings that house multiple units, energy use is allocated base on square footage assigned to the school/unit. Schools are charged on their electricity use ($/kWh) and steam use ($/1000 lbs.), while consumption of air and water are free.

U-M Utility Enterprise Rates:	FY18	FY19	FY20	FY21
Central Power Plant steam (per 1000 lbs)	14.890	15.260	15.640	16.030
CPP, North Campus, Ingalls electric (per kwh)	0.082	0.084	0.086	0.088

Fig. 1. U-M Utility Enterprise Rates from: "Utility Rates." *F&O Utilities*, utilities.fo.umich.edu/services/energy-utilities/business-services/utility-rates/.

Estimating energy costs

When the units submit their five-year budget plan, they also estimate their five-year utility cost, and the Provost's Office takes that estimated amount out of their budget and gives it to the utility department. At end of the fiscal year, each unit receives an adjustment (positive or negative) for the difference between estimated and actual costs. This is based on the price of electricity and the quantity of over/under consumption, but schools don't see the prices and quantities they are being taxed/credited for in that adjustment.

Administrative feasibility of a carbon tax at UM

This robust data collection process of sustainability metrics conducted by the Office of Campus Sustainability adds to the feasibility of implementing a carbon tax, as the university has the capacity to measure how much energy buildings, and even units inside buildings, consume. This goes a long way towards ensuring that a tax on carbon emissions could be levied with a relatively high level of accuracy.

An administrative hurdle in implementing a carbon tax is the lack of administrative infrastructure around reporting out energy usage in a reasonable time frame. Currently, the Provost Office of Budget and Planning only reports out on consumption data on a yearly basis. Monthly reporting would remedy this, as building managers would be able to draw links between what actions in the previous month drove spikes or dips in energy consumption to occur, and then be able to able to make adjustments that improve energy efficiency. At present, monthly data is available online, but building/energy managers would have to take the initiative each month to look up that monthly data.

Difficulty of carbon tax with large campuses

Many of the universities referenced in this report as having implemented a carbon tax are different from the University of Michigan in one key attribute, their size. Yale and Duke, both of which have piloted a carbon tax program, have 12,000 and 16,000 students respectively, while the University of Michigan has roughly three times as many students (45,000) and more than double the carbon footprint.[1, 2, 3, 10, 16, 26] This difference is not inconsequential when it comes to evaluating the merits and feasibility of a campus-wide carbon tax. Timothy Gutowski, a professor of Mechanical Engineering at MIT, writes that carbon taxes on larger universities are a more difficult task, as engineering and science laboratories cause a wider variance in the energy intensity of research activities. What he dubs "industrial-strength" universities are four times more carbon intensive per student than the baccalaureate colleges (28 tons/student compared to 7 tons/student), and they have much higher numbers of students, faculty, and staff.[27] Other issues might arise with the UM Hospital System, as it is a large consumer of electricity, but may not have the flexibility that other units do to reduce its demand.

Proposed actions

Central Power Plant Upgrade

In March of 2017, the Board of Regents approved an $80 million expansion to the CPP, which would include the addition of a 15 MW natural gas turbine to the plant. When it comes online in 2020, the university estimates that the upgrade will reduce the greenhouse gas emissions by 80,000 metric tons per year, but the plant upgrade wasn't decided upon solely for the environmental benefits. Based on the university's estimates, the upgrade is expected to payback within the first decade of its estimated three decade lifetime, making it a prudent financial investment regardless of the environmental benefits.

Renewable Power Purchase Agreement with DTE

The CPP produces around 200 million kWh for central campus each year. With the new plant upgrade, the CPP's generation will increase by 50% to 300 million kWh and the university estimates it will leave just 110,000 MT of emissions reductions to reach our 2025 target of 25% reduction. To meet this shortfall, the university will sign a renewable energy PPA with DTE.

To procure the remaining 450 million kWh of the university's yearly electricity demand that is not provided by the CPP, UM buys power in bulk from DTE through a separate PPA. Currently, the university buys electricity from DTE for around 7.33 cents/kWh as part of that PPA locking them into this rate until the end of 2024.[55] Once that contract has ended, UM has the option to purchase part, or all, of their remaining electricity demand from one of DTE's Voluntary Green Pricing Programs, called MI Green Power. The program sources wind and solar energy projects in Michigan, and allows subscribers to pay a premium between .5 and 3.3 cents per kWh to claim that the energy they consume comes from one of these projects. Notably, while the university will procure 200 million kWh from the MI Green Power program to reach the 25% emissions reduction target, further procurement of renewable energy from DTE past 200 kWh shouldn't be seen as a solution to get much further with emissions reductions. Even if the university were to purchase all of their 450 million kWh of demand from DTE as renewables, that would only reach a 35% reduction in emissions relative to 2006 levels.

Passive gains from Michigan Renewable Portfolio Standard

Michigan's current Renewable Portfolio Standard (RPS) of 15% by 2021 ranks towards the low end when compared to other states with RPS targets.[52] However after coming under pressure from billionaire environmentalist Tom Steyer to reduce their carbon intensity, Consumers Energy and DTE agreed to increase their renewable capacity to 25% by 2030.[15] DTE went further to explain in their 2018 Renewable Energy Plan that they plan to double their renewable capacity by 2022 from 1 to 2 GW. DTE's stated goal in all this is to steadily reduce carbon emissions over the next three decades (50% reduction by 2030 and 80% by 2040), primarily achieved by shutting down coal plants and replacing them with gas-fired plants.[24] Additional pressure may come from the state government as newly-elected governor Gretchen Whitmer has been on record supporting 100% renewable energy by 2050.[44] It remains to be seen whether or not emissions reductions from the power sector in Michigan will proceed as planned. The relative cost of renewables appears to be easing the challenge. As the Michigan Public Service Commission reported in 2018, the cost of renewables is falling much faster than regulators anticipated, and renewables are closing in on cost-parity with natural gas.[7]

Historical and forecasted emissions

A forecast of UM's emissions trajectory through 2030 can be seen in Figure 2. With the CPP upgrade coming online in 2020, and the renewable energy PPA with DTE starting in 2025, the university is expecting to hit their 2025 reduction goal of 25% below 2006 levels. However, if the university is to consider the emissions impact of methane leakage that occurs from wellhead to power plant, an additional and unaccounted for 7,000 MT of CO_2e, will be emitted each year, meaning that we will miss our 2025 target by that same amount.

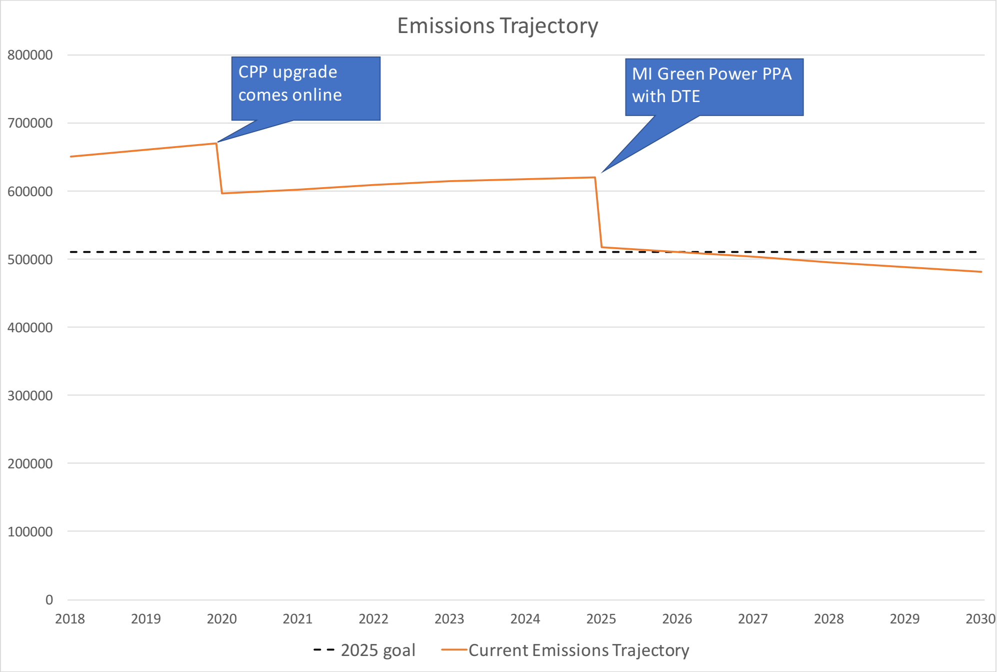


Fig. 2. UM Current emissions trajectory and 2025 emissions reduction goal

Analysis

Modeling a Carbon Tax with Rebate Schemes

Methodology

A carbon tax is one of the most important tools available to the university to help align individual schools' incentives with the university-wide goal of carbon neutrality. In light of this, the first part of our analysis is geared towards estimating and analyzing the effects of a carbon tax on campus. The purpose is not to analyze the behavioral responses of a tax, but rather to see the tax revenues and rebate levels under various tax schemes. To do this, we performed a historical analysis of the budgetary impacts a carbon tax would have on individual schools. In our model, we set 2014 as the base year upon which all of the reduction goals would be based off of, and then administered the hypothesized tax from 2015 through 2017. When selecting schools to include in the case study, we varied our selection across the size of their budget, their quantity of emissions, which campus fund they belong to, and number of buildings they have. The building level emissions data for the analysis are collected by the Office of Campus Sustainability, and the budgetary data is gathered from the Regent-approved University of Michigan campus budget forecast for 2017. Due to the fact that some buildings are shared across departments, we allotted the emissions from buildings to departments based on the Net Assignable Square Footage (NASF) assigned from that building to a given school. The list of schools can be seen in Table 2 along with their 2017 budget forecasts and modeled carbon emissions for 2017. For further detail on the modeling of the carbon tax, see Appendix C.

Modeling a Carbon Tax

The first component of our analysis assessed the impact a carbon tax would have on the budgets of the different schools in the study. We estimated the dollar amounts paid to the carbon tax each year and what that tax represented as a percentage of the school's budget. The estimates were made at two tax levels, \$40 and \$100 per metric ton of CO_2. Results can be seen in Table 2.

Estimated Carbon Tax Expenditure for various U-M Business Units (2017)

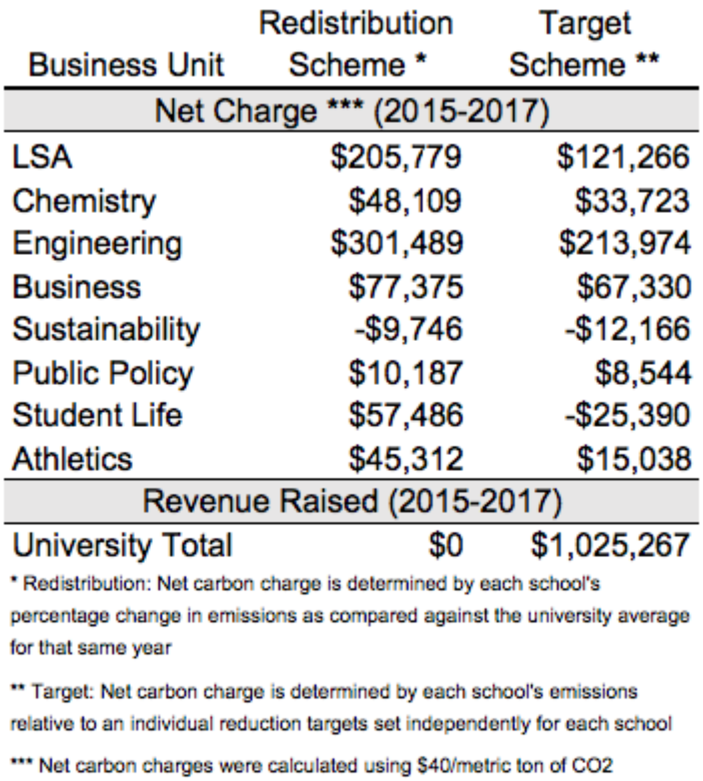
	Budget	Metric tons of CO2	Estimated Tax Expenditures	
			$40 / MT CO2 % of budget	$100 / MT CO2 % of budget
College of Literature, Science, and the Arts	$386,239,472	53,280	$ 2,131,186 0.6%	$ 5,327,965 1.4%
Department of Chemistry	$ 18,040,337	9,339	$ 373,562 2.1%	$ 933,905 5.2%
College of Engineering	$200,863,661	51,554	$ 2,062,156 1.0%	$ 5,155,389 2.6%
Ross School of Business	$ 98,507,112	7,357	$ 294,280 0.3%	$ 735,700 0.7%
School for Environment and Sustainability	$ 10,174,566	1,386	$ 55,435 0.5%	$ 138,587 1.4%
Ford School of Public Policy	$ 12,120,265	902	$ 36,080 0.3%	$ 90,200 0.7%
Student Life (Housing and Dining)	$140,288,000	48,429	$ 1,937,144 1.4%	$ 4,842,860 3.5%
Athletics Department	$172,000,000	18,444	$ 737,768 0.4%	$ 1,844,420 1.1%

Table 2. Estimated carbon tax expenditure for various UM business units (2017)

Table 2 shows that the range of amounts paid to a carbon tax and the percentage of a school's overall budget vary greatly across schools. In the $100 per metric ton scenario, some units pay around 3 to 5% of their overall budget to the carbon tax, while others are close to 1%. While the table only shows data for 2017, the proportion of the overall budget for 2015 and 2016 show similar results. It is also worth pointing out that the two schools representing physical sciences, Engineering and Chemistry, saw two of the three highest overall carbon taxes as a percentage of their budget.

Redistribution and Target rebate schemes

The second component of our analysis focused on rebate schemes and their impact across the university. While rebate schemes are not the only means of using the collected tax revenue, they are a great way to incentivize schools to buy-in to a carbon tax program, and we were interested in understanding how a redistribution and a target scheme would differ in terms of their net tax levied on business units. The redistribution scheme is a revenue neutral approach that compares each school's percentage change in emissions to the overall university-wide emissions percentage change. Schools outperforming the university average are rebated more than they were taxed, resulting in a net rebate, and schools underperforming are rebated less, resulting in a net tax. In essence, the net tax from the schools that underperform are redistributed to the schools that overperform. The target scheme involves comparing units against individualized targets set for each school, instead of comparing them to the university average. Due to the fact that different targets can be set for different schools, this scheme is not revenue neutral, and will often result in a net tax or net rebate across the university. For our case study, we didn't vary the targets across units, instead opting to increase the target reduction for each school by 2% each year. Additionally, the net taxes were calculated as if the carbon tax had been set to $40 per metric ton of CO_2. Results from this analysis can be seen in Table 3.



Business Unit	Redistribution Scheme *	Target Scheme **
Net Charge *** (2015-2017)		
LSA	$205,779	$121,266
Chemistry	$48,109	$33,723
Engineering	$301,489	$213,974
Business	$77,375	$67,330
Sustainability	-$9,746	-$12,166
Public Policy	$10,187	$8,544
Student Life	$57,486	-$25,390
Athletics	$45,312	$15,038
Revenue Raised (2015-2017)		
University Total	$0	$1,025,267

* Redistribution: Net carbon charge is determined by each school's percentage change in emissions as compared against the university average for that same year

** Target: Net carbon charge is determined by each school's emissions relative to an individual reduction targets set independently for each school

*** Net carbon charges were calculated using $40/metric ton of CO2

Table 3. Comparison of net charge and revenue raised between a redistribution and target scheme

Table 3 illustrates the aggregate tax (2015-2017) for the eight schools across the two different schemes. For each school, the net tax decreased significantly from the redistribution to the target scheme. This is due to the fact that the target set in the first year by the university average was a much steeper drop (4.3%) between years than any other step across either scheme. Because of this drop, the College of Engineering would have had to pay $50,000 more in the first year of the redistribution scheme than they would have under the target scheme for the same year. Likewise, the Student Life department would have moved from a net rebate of $4,000 to a net tax of $43,000. This underscores one of the downsides to the redistribution scheme, the uncertainty in where the target will be year to year. This uncertainty around the targeted reductions for each school could lead to economic uncertainty for those schools, as they will have a more difficult time forecasting their expected net tax or rebate. The bottom section, Revenue Raised, bears out how the redistribution scheme is revenue neutral, as there is zero revenue raised, while the target scheme results in a net gain for the university. Overall, rebate schemes are a good way to incentivize buy-in to a carbon tax program on the part of business units, but which rebate scheme will be most successful depends greatly on the perception of how fair and transparent the chosen scheme is perceived to be.

Alternative uses for tax revenue

The schemes modeled above are one way of using the tax revenue, but there are other ways to use the revenue and maintain the incentive to reduce emissions that do not involve rebating the funds back to the schools. One option is to bank the tax revenue year over year, and earmarking it specifically to fund energy efficiency or clean energy investments that are otherwise not undertaken due to being too capital intensive. In this way, the tax revenue is used to fund projects that would benefit multiple schools, but are cost prohibitive for any one school to fund on their own. Alternatively, the tax revenue could be used to offset existing taxes at the university, namely the Provost's tax. The Provost's tax arguably is distortionary, so reducing its impact on campus may be desirable.

Recommendation - Begin carbon tax pilot

The university should begin piloting a carbon tax to subsets of the business units on campus. Across the subsets, they should experiment with different rebate/information schemes to determine which are most effective at encouraging units to reduce their energy consumption. Given that some units are more energy intensive than others or have more inflexible demand, the issue of carbon taxation might be a politically delicate issue. In light of this, the university should solicit feedback from the participating units to better understand their attitudes towards a carbon tax, what rebate/revenue schemes are preferred and viewed as fair, and what level units feel the tax should be set to. Overall, the benefits that a carbon tax brings in aligning emissions reduction incentives throughout the university vastly outweighs any costs that might result, and the university should not waste any time before beginning implementation.

Comparing Average Costs of Abatement

Methodology

As stated previously in this report, we recommend incorporating marginal or average cost of abatement into the means of determining which abatement options the university should pursue. In this section of our analysis, we aim to shed light on the relative costs of different abatement mechanisms through their average cost of abatement, as well as their abatement potential throughout the lifetime of each given option. For more information on the estimation of average abatement cost and abatement potential for the CPP upgrade and the PPA, see Appendix D.

Average abatement cost of the Central Power Plant upgrade

The university states that the CPP upgrade will reduce the university's greenhouse gas emissions by 80,000 per year. The means through which the university can claim abatement while burning natural gas comes from the fact that the university will no longer be procuring as much electricity from the DTE grid, which is more carbon intensive per kilowatt-hour than natural gas. However, to understand the sum total of emissions reductions that the plant would account for, we need to look at the grid intensity across the 30-year expected lifetime of the CPP. To do this, we gathered estimates for the carbon intensity of DTE's portfolio for 2020 to 2030 from DTE, and then extrapolated what the carbon intensity would be from 2030 to 2040 and 2040 to 2050 based on DTE's carbon intensity reduction goals for those decades (50% carbon reduction 2030, 80% carbon reduction by 2040, and an extrapolated 85% reduction by 2050). We calculated the net emissions factor (lbs./MWh) that would result from burning natural gas instead of using the grid. We then estimated the yearly reductions that using the CPP would accrue as a substitute for using the electrical grid. For this step in the analysis, we assumed that the CPP would generate 167,943 MWh of electricity each year. This number was extrapolated by taking UM's reduction goals for the CPP for 2020 (80,000 MT), converting it to lbs., and dividing it by the current emissions factor of the grid (lbs./MWh). The final component in this analysis was to include the leaked natural methane gas that occurs throughout the supply chain. At a 2.3% leakage rate, we found that the university was responsible for an additional 7,000 metric tons of CO_2e per year as a result of the CPP upgrade. With that, we were able to estimate what the total emissions reductions would be from the lifetime of the CPP upgrade.

In order to get the average cost of abatement, we then estimated the total costs of the upgrade. In short, we took the fixed cost of the upgrade, added in the discounted variable costs, and subtracted the discounted avoided cost of procuring that quantity of electricity from the utility. Given the cost of per unit of electricity and the low cost of natural gas, on net, the power plant upgrade has a negative cost over the 30 year lifetime of around -117 million dollars. In other words, the CPP upgrade may be a financially sensible investment regardless of its CO_2 abatement potential.

Assumptions

It should be noted that there were various assumptions that we made in our analysis that we were unable to confirm with anyone in the utilities department at the university. Broadly, the assumptions we made centered around operation and maintenance, fuel and utility costs, as well as expected lifetime and discount rate. The list of assumptions can be found in Appendix E. Should any of these assumptions change, it is reasonable to expect that our results would change as well.

Average abatement cost of the renewable Power Purchase Agreement with DTE

Similar to how we estimated the average abatement cost of the CPP upgrade, we estimated the average abatement cost for the renewable PPA that the university is considering with DTE. Any emissions reductions that the renewable PPA would take credit for would be determined by the carbon intensity of the counterfactual to signing the PPA, which would involve procuring electricity from DTE. Given that the carbon intensity of the grid is expected to decrease over the lifetime of the PPA, the emissions reductions from the PPA in each successive year are fewer and fewer. For this analysis, we estimated the carbon intensity of the grid in the same manner as for the CPP upgrade. We also estimated that the university would procure around 216,000 MWh per year from the PPA, given that is how much electricity the university would need to procure in 2025 in order to meet their 2025 emissions reduction goal. With this, we calculated the yearly reductions in carbon emissions due to the PPA from 2025 to 2050. Finally, we estimated the abatement cost at different premium levels from the retail rate, a .5 cent premium, a 1 cent premium, and a 3.3 cent premium. Similar to the above analysis, we used a 3.5% discount rate to discount the future abatement costs to net present value.

Results

Figure 3 illustrates the emissions reductions from the CPP upgrade and the renewable PPA over time. From 2020 to 2050, the difference in carbon intensity between the DTE grid and combusted natural methane gas (labeled as Net Emissions Factor) is expected to decrease, and as such, the emissions reductions from the CPP upgrade and the renewable PPA will decrease as well. In 2025, the renewable PPA is expected to offset 110,000 MT of CO_2 which is reduced to just 25,000 MT of CO_2 in 2050. Similarly, accounting for natural methane gas leakage and the reduced carbon intensity of the grid, the CPP upgrade would only abate around 15,000 MT of CO_2 per year over a 30-year lifetime, less than 20% of what the university originally estimated would be the per year abatement (80,000 MT of CO_2). While, the upgrade will result in 73,000 MT of CO_2 abatement in 2020, by 2039, the CPP will be more carbon intensive than the DTE grid. By 2050, operating the CPP instead of procuring that electricity from DTE will result in over 12,000 MT of additional CO_2 emissions per year.

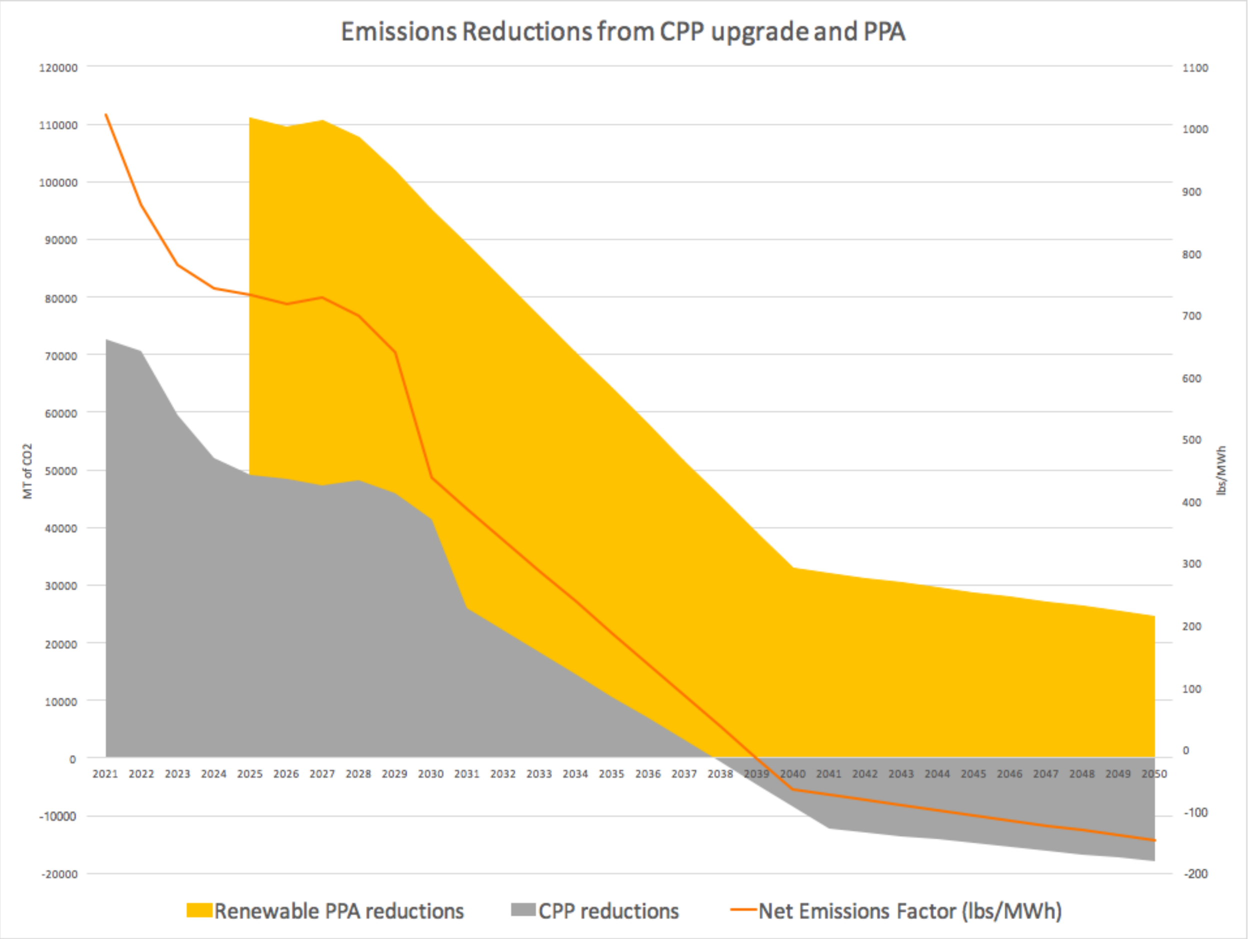
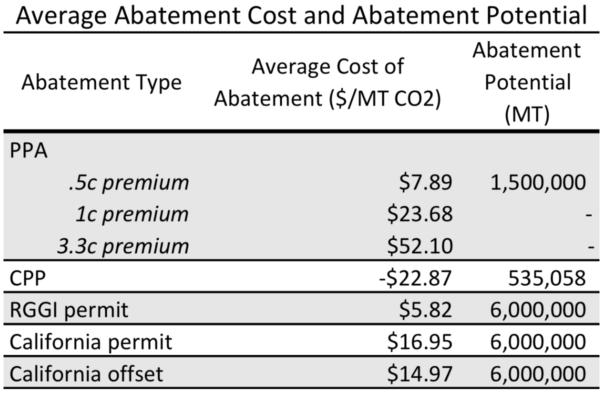


Fig. 3. Emissions reductions over 50 years from the CPP upgrade and PPA

Table 4 highlights the average cost of abatement for the CPP upgrade, the renewable PPA at different premium levels, buying permits from the RGGI and California cap-and-trade markets, as well as buying carbon offsets from the California Offset market. While these numbers are approximate, they clearly show that the CPP upgrade is the most cost effective means of reducing emissions, largely due to the fact that the upgrade has a positive NPV prior to factoring in any benefits from carbon emissions reduction. The other main takeaway is just how much the cost of abatement varies within the PPA depending on how much the university would end up paying as a premium on top of what they otherwise would be paying for electricity. Even at just a half cent premium, the university would be paying almost twice as much per metric ton of abatement compared to buying and retiring permits on the RGGI market. Similarly, at a 1 cent premium, the PPA is almost 50% more expensive per unit as the California cap-and-trade and offset markets.



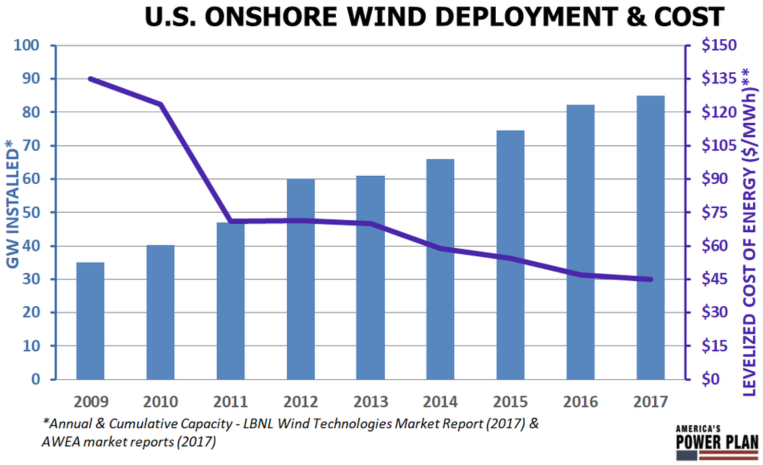
Average Abatement Cost and Abatement Potential

Abatement Type	Average Cost of Abatement ($/MT CO2)	Abatement Potential (MT)
PPA		
.5c premium	$7.89	1,500,000
1c premium	$23.68	-
3.3c premium	$52.10	-
CPP	-$22.87	535,058
RGGI permit	$5.82	6,000,000
California permit	$16.95	6,000,000
California offset	$14.97	6,000,000

Table 4. Average cost and potential across abatement options

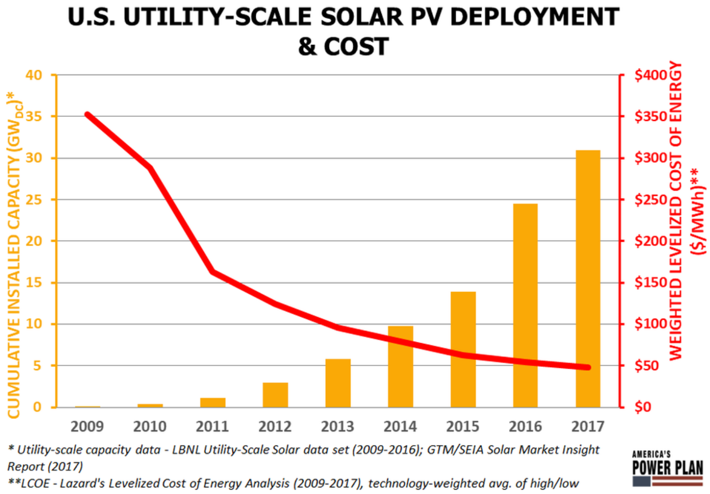
Recommendation - Delay further technology investments

Figures 4 and 5 show how, over the past decade, costs of utility-scale solar and onshore wind have dramatically decreased at the same time as deployments have increased. The National Renewable Energy Laboratory predicts that utility-scale solar costs will decline an additional 60-80% by 2050 with onshore wind prices declining by 30-64% in the same time frame.[6] With prices expected to decrease for the foreseeable future, it might not make sense for the university to begin building or purchasing power from renewable projects now, as it will lock them into a price that will seem high in just a few years' time. Instead, the university should delay large investment decisions until we are further down on the cost curve with those technologies, all while buying time with carbon offsets and cap-and-trade permits. Similarly, with a new administration coming into power in the state of Michigan that has ambitions climate goals, we might see Michigan's grid decarbonize at a faster rate than DTE otherwise predicts. In that case, it would benefit the university to push the renewable PPA and CPP upgrade investment decisions further out, as their overall abatement potential might decrease and cost per unit of abatement might increase faster than we are predicting. But pushing renewable energy projects or PPA decisions out into the future does not change the imperative to be carbon neutral now and therefore, procuring cap-and-trade permits and carbon offsets, at what is already a low price, makes sense as a carbon management technique for the coming decade.



*Annual & Cumulative Capacity - LBNL Wind Technologies Market Report (2017) & AWEA market reports (2017)

Fig. 4. U.S. onshore wind deployment & cost



* Utility-scale capacity data - LBNL Utility-Scale Solar data set (2009-2016); GTM/SEIA Solar Market Insight Report (2017)

**LCOE - Lazard's Levelized Cost of Energy Analysis (2009-2017), technology-weighted avg. of high/low

Fig. 5. U.S. utility-scale solar PV deployment & cost

Carbon Neutral by 2020

Methodology

Given the dire warning set out by the 2018 UN IPCC report showing that society has approximately 12 years to dramatically reduce carbon emissions to avoid climate disaster, we assess a few options for the university to go carbon neutral on an expedited time frame. The final section of our analysis looks at feasible options for the university to achieve carbon neutrality by 2020 and what the financial cost of each option would be. For the purposes of this analysis, we reduced the time frame under which we estimate the cost of going carbon neutral to between 2020 and 2029. In this 10-year period under the university's planned trajectory, we estimate that the university will have a net carbon footprint of 6 million metric tons that would need to be reduced to zero to be carbon neutral.

Given the short time frame between when this report will come out and when 2020 begins, the range of feasible abatement options to get the university to carbon neutrality is limited to cap-and-trade permits and carbon offsets, as neither of these options requires implementation or construction time that would otherwise delay the offsetting of carbon emissions. For each of the three options that we modeled; RGGI cap-and-trade permits; California cap-and-trade permits; and California carbon offsets; we estimated future costs by assuming an annual rate of price increase of 1.4%, and then discounted future costs back to net present value at a 3.5% discount rate.

Cost Comparison

Figure 6 shows the total cost of procuring all 6 million metric tons from these separate markets over the 10-year time frame (details in Appendix F & G). Given the low cost of RGGI cap-and-trade permits relative to the California markets, the total RGGI permit expenditure is much smaller than that of the California markets totaling around $30 million for the decade. But even with the higher cost in the California markets, they are still appealing relative to other abatement options. For reference, buying into the California cap-and-trade market to go carbon neutral from 2020-2029 would cost around $80 million, the same price as the initial fixed cost of the CPP upgrade in the same year. However, spending that $80 million in the California cap-and-trade market would amount to 6 million MT of CO_2 abatement relative to 500 thousand MT of CO_2 abatement in the case of the CPP upgrade for that same decade.

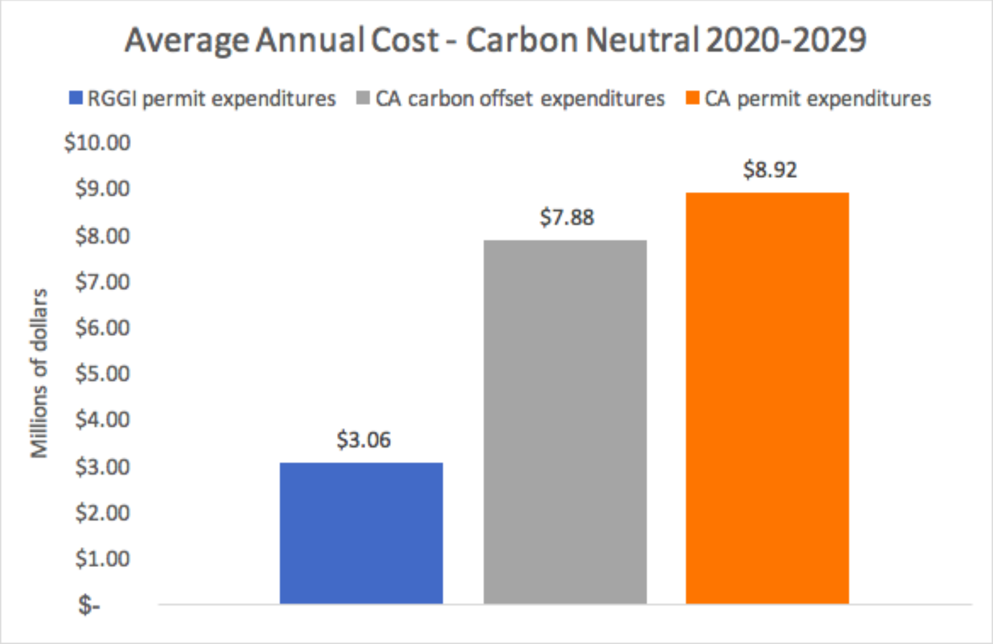


Fig. 6. Average annual cost for going carbon neutral from 2020 - 2029

Emissions Trajectory

The last part of our analysis around carbon neutrality was to visualize how the emissions trajectory for the university would change moving from our current emissions trajectory to one of carbon neutrality by 2020. Figure 7 illustrates these two trajectories side by side with the current emissions trajectory in orange, and the carbon neutral by 2020 emissions trajectory in blue, as well as a dashed line showing the 25% emissions reduction goal set for 2025. In the current emissions trajectory, we assume that the CPP upgrade comes online in 2020, and that the university enters into a PPA with DTE for approximately 216,365 MWh per year that begins in 2025. What the graph immediately illustrates is the stark difference between the two lines, and the area between the orange and the blue, which represents the 6 million tons of carbon that would be abated if the university went carbon neutral in 2020.

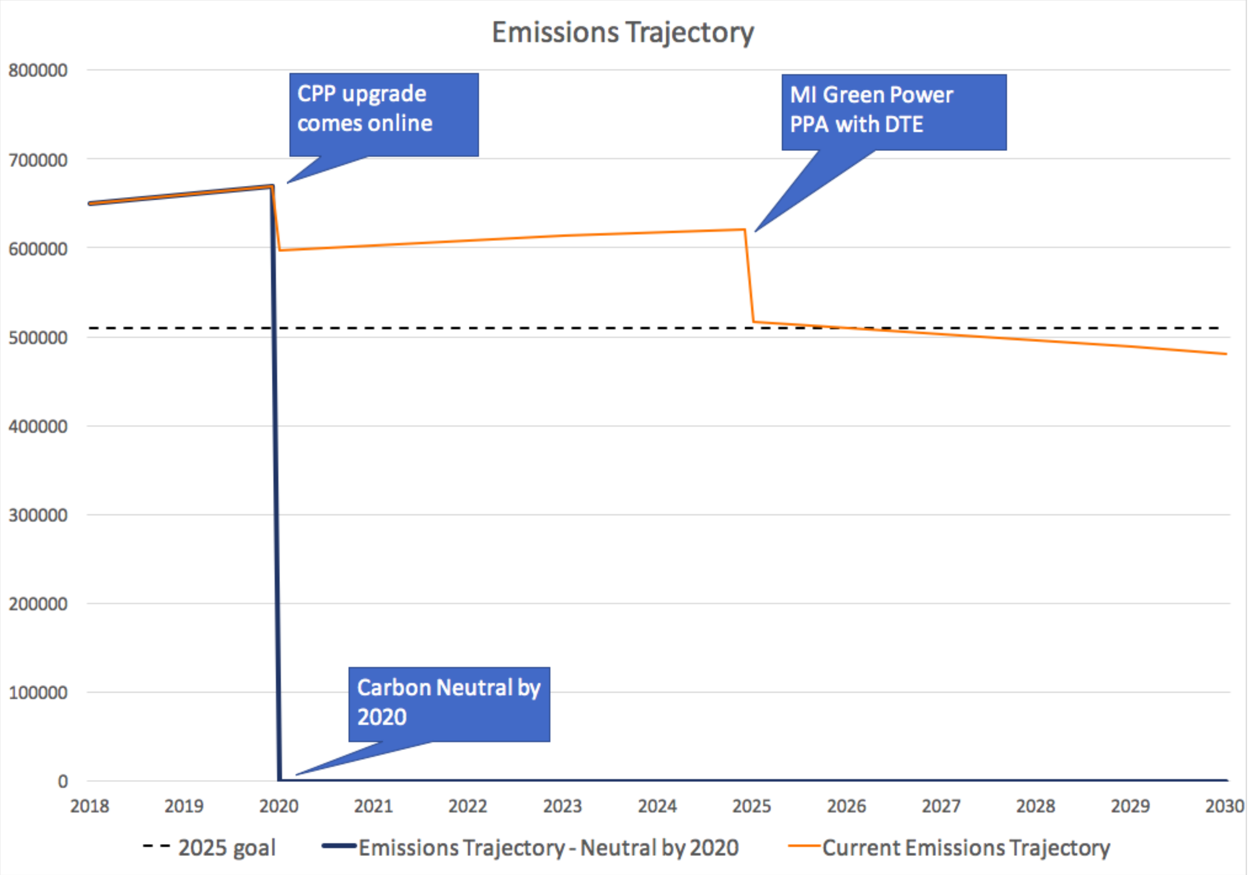


Fig. 7. UM Current emissions trajectory, 2025 emissions reduction goal, and carbon neutral by 2020 trajectory

Recommendation - Set an ambitious carbon neutrality target

The striking nature of the graph illustrates the upside of achieving carbon neutrality by 2020; not only will we abate 6 million more metric tons in the next decade than we otherwise would, but we would make a statement among large research universities showing that carbon neutrality is possible on short timeframes. What is less evident by the graph are the downsides to this approach. Primarily, the university would be spending resources without investing in technology and infrastructure improvements that would either provide clean energy to the university or reduce its overall demand. In that case and beyond the 2020-2029 timeframe, cap-and-trade permits or carbon offsets can be seen not as a long-term solution, but as a means of closing the emissions gap to carbon neutrality, while also buying the university time before investing in technological solutions.

Given the sense of urgency summed up by the UN IPCC, we argue that the 2050 target set by many countries and organizations as a target to achieve carbon neutrality is not ambitious enough. If the University of Michigan truly wants to put itself on a path to carbon neutrality that will have a substantial impact on climate change, it should commit to be carbon neutral by 2020.

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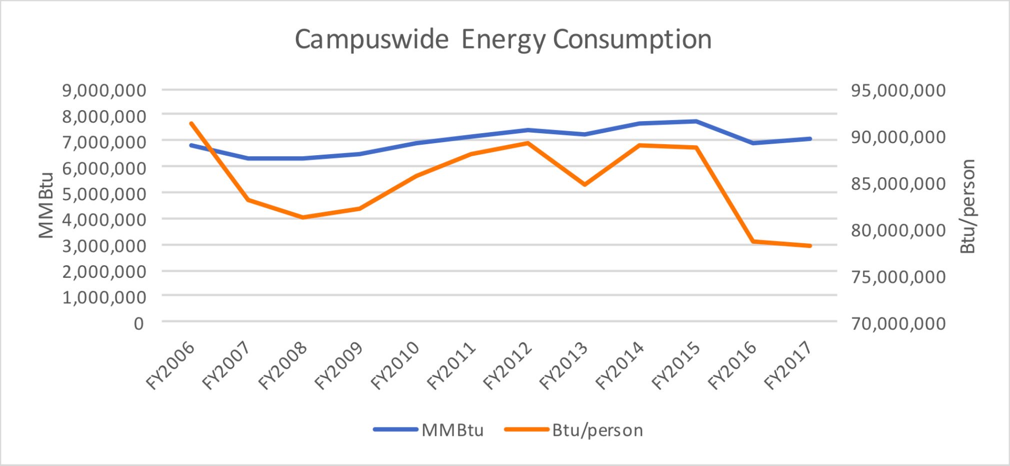
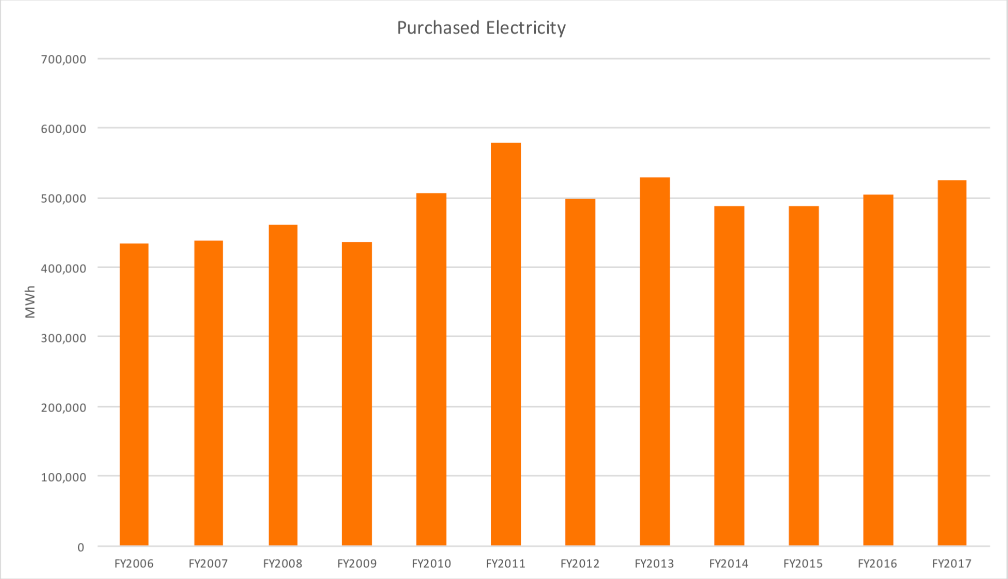
Appendices

APPENDIX A





These charts show UM campus-wide energy consumption and quantity of purchased electricity since 2006. Further detail on the formulation of these charts and other sustainability metrics can be found in "Rego_Benjamin_Supplementary_File1.xlsx"

Data for this analysis was gathered from the following sources:

- "Sustainability Report." *Planet Blue*, 29 May 2018, sustainability.umich.edu/ocs/reports.

APPENDIX B

Offsets

By Type		By Standard	
Project Type	**Average Price ($/tCO2e)**	**Standard**	**Average Price ($/tCO2e)**
REDD+	*$ 4.20*	*Verified Carbon Standard*	*$ 2.30*
Wind	*$ 1.50*	Gold Standard	$ 4.60
Landfill Methane	$ 2.10	VCS+CCB	$ 3.90
Large hydro	$ 0.20	Clean Development Mechanism	$ 1.60
Energy efficiency - community focused	$ 3.70	Climate Action Reserve	$ 3.00
Cleak cookstove distribution	$ 5.10	ISO-14064	$ 0.40
Transportation - private (cars/trucks)	$ 0.30	American Carbon Registry	$ 4.70
Biogas	$ 4.00	Plan Vivo	$ 8.00
Afforestation/reforestation	$ 8.10	Carbon Farming Initiative	$ 10.50
Biomass/biochar	$ 2.00	Other	$ 13.80
Improved forest management	$ 9.50		
Water purification device distribution	$ 5.50		
Run-of-river hydro	$ 1.40		
Solar	$ 3.90		
Energy efficiency - Industrial-focused	$ 1.40		
Geothermal	$ 1.70		
Fuel Switching	$ 3.40		
Grassland/rangeland management	$ 6.90		
Other	$ 4.00		

Emissions Trading

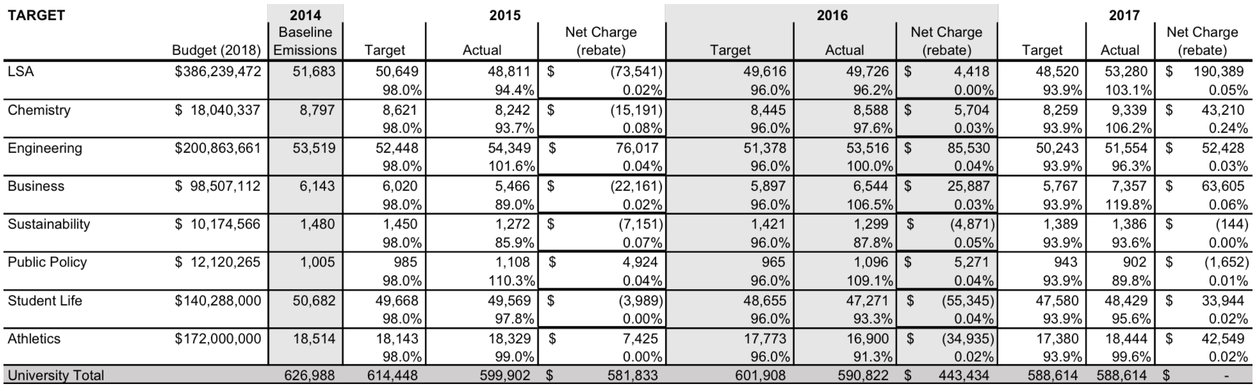
Name of the initiative	Instrument Type	Jurisdiction Covered	Price ($/tCO2e)
Alberta CCIR	ETS	Alberta	$23.11
Beijing pilot ETS	ETS	Beijing	$10.19
California CaT	ETS	California	$15.43
Chongqing pilot ETS	ETS	Chongqing	$1.14
EU ETS	ETS	EU, Norway, Iceland, Liechtenstein	$24.51
Fujian pilot ETS	ETS	Fujian	$2.75
Guangdong pilot ETS	ETS	Guangdong	$1.90
Hubei pilot ETS	ETS	Hubei	$4.01
Korea ETS	ETS	Korea, Republic of	$19.48
New Zealand ETS	ETS	New Zealand	$16.65
Ontario CaT	ETS	Ontario	$15.43
Quebec CaT	ETS	Quebec	$15.43
RGGI	ETS	RGGI	$4.56
Saitama ETS	ETS	Saitama	$5.41
Shanghai pilot ETS	ETS	Shanghai	$4.27
Shenzhen pilot ETS	ETS	Shenzhen	$5.71
Switzerland ETS	ETS	Switzerland	$8.28
Tianjin pilot ETS	ETS	Tianjin	$1.70
Tokyo CaT	ETS	Tokyo	$5.86

These tables show the prices of different offsets and emissions trading schemes. Carbon offsets are broken down by project type and standard. Emissions trading is broken down by initiative. Further detail can be found in "Rego_Benjamin_Supplementary_File2.xlsx"

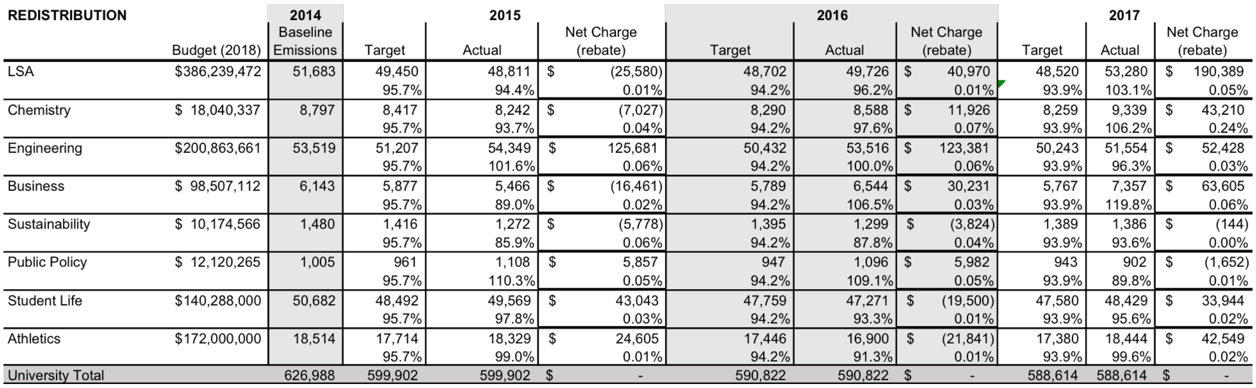
Data for this analysis was gathered from the following sources:

- Hamrick, K., & Gallant, M. (2017). *Unlocking potential: State of the voluntary carbon markets 2017*. Washington, DC: Ecosystem Marketplace, Forest Trends.
- "Map & Data." *Carbon Pricing Dashboard | Up-to-Date Overview of Carbon Pricing Initiatives*, carbonpricingdashboard.worldbank.org/map_data.

APPENDIX C



TARGET		2014	2015			2016			2017		
	Budget (2018)	Baseline Emissions	Target	Actual	Net Charge (rebate)	Target	Actual	Net Charge (rebate)	Target	Actual	Net Charge (rebate)
LSA	$386,239,472	51,683	50,649	48,811	$ (73,541)	49,616	49,726	$ 4,418	48,520	53,280	$ 190,389
			98.0%	94.4%	0.02%	96.0%	96.2%	0.00%	93.9%	103.1%	0.05%
Chemistry	$ 18,040,337	8,797	8,621	8,242	$ (15,191)	8,445	8,588	$ 5,704	8,259	9,339	$ 43,210
			98.0%	93.7%	0.08%	96.0%	97.6%	0.03%	93.9%	106.2%	0.24%
Engineering	$200,863,661	53,519	52,448	54,349	$ 76,017	51,378	53,516	$ 85,530	50,243	51,554	$ 52,428
			98.0%	101.6%	0.04%	96.0%	100.0%	0.04%	93.9%	96.3%	0.03%
Business	$ 98,507,112	6,143	6,020	5,466	$ (22,161)	5,897	6,544	$ 25,887	5,767	7,357	$ 63,605
			98.0%	89.0%	0.02%	96.0%	106.5%	0.03%	93.9%	119.8%	0.06%
Sustainability	$ 10,174,566	1,480	1,450	1,272	$ (7,151)	1,421	1,299	$ (4,871)	1,389	1,386	$ (144)
			98.0%	85.9%	0.07%	96.0%	87.8%	0.05%	93.9%	93.6%	0.00%
Public Policy	$ 12,120,265	1,005	985	1,108	$ 4,924	965	1,096	$ 5,271	943	902	$ (1,652)
			98.0%	110.3%	0.04%	96.0%	109.1%	0.04%	93.9%	89.8%	0.01%
Student Life	$140,288,000	50,682	49,668	49,569	$ (3,989)	48,655	47,271	$ (55,345)	47,580	48,429	$ 33,944
			98.0%	97.8%	0.00%	96.0%	93.3%	0.04%	93.9%	95.6%	0.02%
Athletics	$172,000,000	18,514	18,143	18,329	$ 7,425	17,773	16,900	$ (34,935)	17,380	18,444	$ 42,549
			98.0%	99.0%	0.00%	96.0%	91.3%	0.02%	93.9%	99.6%	0.02%
University Total		626,988	614,448	599,902	$ 581,833	601,908	590,822	$ 443,434	588,614	588,614	$ -



REDISTRIBUTION		2014	2015			2016			2017		
	Budget (2018)	Baseline Emissions	Target	Actual	Net Charge (rebate)	Target	Actual	Net Charge (rebate)	Target	Actual	Net Charge (rebate)
LSA	$386,239,472	51,683	49,450	48,811	$ (25,580)	48,702	49,726	$ 40,970	48,520	53,280	$ 190,389
			95.7%	94.4%	0.01%	94.2%	96.2%	0.01%	93.9%	103.1%	0.05%
Chemistry	$ 18,040,337	8,797	8,417	8,242	$ (7,027)	8,290	8,588	$ 11,926	8,259	9,339	$ 43,210
			95.7%	93.7%	0.04%	94.2%	97.6%	0.07%	93.9%	106.2%	0.24%
Engineering	$200,863,661	53,519	51,207	54,349	$ 125,681	50,432	53,516	$ 123,381	50,243	51,554	$ 52,428
			95.7%	101.6%	0.06%	94.2%	100.0%	0.06%	93.9%	96.3%	0.03%
Business	$ 98,507,112	6,143	5,877	5,466	$ (16,461)	5,789	6,544	$ 30,231	5,767	7,357	$ 63,605
			95.7%	89.0%	0.02%	94.2%	106.5%	0.03%	93.9%	119.8%	0.06%
Sustainability	$ 10,174,566	1,480	1,416	1,272	$ (5,778)	1,395	1,299	$ (3,824)	1,389	1,386	$ (144)
			95.7%	85.9%	0.06%	94.2%	87.8%	0.04%	93.9%	93.6%	0.00%
Public Policy	$ 12,120,265	1,005	961	1,108	$ 5,857	947	1,096	$ 5,982	943	902	$ (1,652)
			95.7%	110.3%	0.05%	94.2%	109.1%	0.05%	93.9%	89.8%	0.01%
Student Life	$140,288,000	50,682	48,492	49,569	$ 43,043	47,759	47,271	$ (19,500)	47,580	48,429	$ 33,944
			95.7%	97.8%	0.03%	94.2%	93.3%	0.01%	93.9%	95.6%	0.02%
Athletics	$172,000,000	18,514	17,714	18,329	$ 24,605	17,446	16,900	$ (21,841)	17,380	18,444	$ 42,549
			95.7%	99.0%	0.01%	94.2%	91.3%	0.01%	93.9%	99.6%	0.02%
University Total		626,988	599,902	599,902	$ -	590,822	590,822	$ -	588,614	588,614	$ -

These tables show how the individual net charges were calculated for the different business units in the carbon tax case study for both the Redistribution and Target Schemes. Further detail on the formulas used in the calculations can be found in "Rego_Benjamin_Supplementary_File3.xlsx"

Data for this analysis was gathered from the following sources:

- *2016-2017 Budget Detail*. The University of Michigan, June 2016.
- Kunselman, Steve & Ken Keeler. Personal interview. 21 Aug. 2018.
- "Sustainability Report." *Planet Blue*, 29 May 2018, sustainability.umich.edu/ocs/reports.
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APPENDIX D

Table 1

Year	DTE Grid Emissions Factor	Net Emissions	DTE grid carbon	CPP reductions	CPP Electricity	Variable Costs	Utility Rate
2020	1449	1050	0.13	72672	167943	9.49	73.30
2021	1421	1022	0.15	70539	167943	9.17	70.82
2022	1276	877	0.24	59493	167943	8.86	68.43
2023	1179	780	0.30	52104	167943	8.56	66.11
2024	1141	742	0.32	49209	167943	8.27	63.88
2025	1131	732	0.32	48448	167943	7.99	61.72
2026	1115	716	0.33	47229	167943	7.72	59.63
2027	1127	728	0.33	48143	167943	7.46	57.61
2028	1097	698	0.34	45858	167943	7.21	55.66
2029	1038	639	0.38	41363	167943	6.97	53.78
2030	836.5	438	0.50	26013	167943	6.73	51.96
2031	786	387	0.53	22190	167943	6.50	50.21
2032	736	337	0.56	18366	167943	6.28	48.51
2033	686	287	0.59	14543	167943	6.07	46.87
2034	636	237	0.62	10719	167943	5.87	45.28
2035	586	187	0.65	6896	167943	5.67	43.75
2036	535	137	0.68	3073	167943	5.48	42.27
2037	485	86	0.71	-751	167943	5.29	40.84
2038	435	36	0.74	-4574	167943	5.11	39.46
2039	385	-14	0.77	-8398	167943	4.94	38.13
2040	335	-64	0.80	-12221	167943	4.77	36.84
2041	326	-73	0.81	-12858	167943	4.61	35.59
2042	318	-81	0.81	-13495	167943	4.45	34.39
2043	310	-89	0.82	-14133	167943	4.30	33.23
2044	301	-98	0.82	-14770	167943	4.16	32.10
2045	293	-106	0.83	-15407	167943	4.02	31.02
2046	284	-114	0.83	-16044	167943	3.88	29.97
2047	276	-123	0.84	-16682	167943	3.75	28.95
2048	268	-131	0.84	-17319	167943	3.62	27.98
2049	259	-140	0.85	-17956	167943	3.50	27.03
2050	251	-148	0.85	-18593	167943	3.38	26.12

Parameters	
capital costs ($)	80000000
CRF	0.054
Fixed O & M ($)	0
Discount Rate	0.035
lifetime (years)	30
Variable O&M ($)	0
Fuel ($/Mmbtu)	2.73
Fuel ($/MWh)	9.31
Fuel Price Escalation Rate	0.02
Utility Rate ($/MWh)	73.3
Utility Price Escalation Rate	0.02
Natural Gas CO2 Emission	398.83
Base (2005)	1673
Natural gas	
kg/mmBtu	53.06
lbs/kg	2.20
mmBtu/MWh	3.41
lbs/MWh	398.83

SL 2030-2040	50.19
SL 2040-2050	8.36

LCOE	$ 35.21
Total Abatement (MT)	453,657.28
Total Cost	$ (127,800,537.30)
Average Cost	
Electricity ($/MWh)	21.70
Premium ($/MWh)	-23.24
Abatement ($/MT)	(281.71)

Table 2

Year	lbs/MWh	DTE grid carbon intensity	renewable PPA reductions (MT)	Renewable PPA	Utility Rate ($/MWh)	Abatement cost - .5 c premium per kWh ($/MT)	Abatement cost - 1.5 c premium per kWh ($/MT)	Abatement cost - 3.3 c premium per kWh ($/MT)
2020	1449	0.13	-	-	73.30	-	-	-
2021	1421	0.15	-	-	74.03	-	-	-
2022	1276	0.24	-	-	74.77	-	-	-
2023	1179	0.30	-	-	75.52	-	-	-
2024	1141	0.32	-	-	76.28	-	-	-
2025	1131	0.32	110999	216365	77.04	8.21	24.62	54.16
2026	1115	0.33	109429	216365	77.81	8.04	24.13	53.08
2027	1127	0.33	110607	216365	78.59	7.69	23.06	50.74
2028	1097	0.34	107662	216365	79.37	7.63	22.89	50.36
2029	1038	0.38	101872	216365	80.17	7.79	23.38	51.43
2030	971	0.50	95296	216365	80.97	8.05	24.14	53.12
2031	907.4	0.53	89051	216365	81.78	8.32	24.96	54.92
2032	843.7	0.56	82805	216365	82.60	8.65	25.94	57.06
2033	780.1	0.59	76559	216365	83.42	9.04	27.11	59.63
2034	716.4	0.62	70313	216365	84.26	9.51	28.52	62.73
2035	652.8	0.65	64067	216365	85.10	10.08	30.24	66.52
2036	589.2	0.68	57822	216365	85.95	10.79	32.37	71.21
2037	525.5	0.71	51576	216365	86.81	11.69	35.06	77.14
2038	461.9	0.74	45330	216365	87.68	12.85	38.54	84.80
2039	398.2	0.77	39084	216365	88.55	14.40	43.19	95.02
2040	334.6	0.80	32838	216365	89.44	16.56	49.67	109.27
2041	326.2	0.81	32018	216365	90.33	16.41	49.22	108.28
2042	317.9	0.81	31197	216365	91.24	16.27	48.81	107.38
2043	309.5	0.82	30376	216365	92.15	16.14	48.43	106.55
2044	301.1	0.82	29555	216365	93.07	16.03	48.09	105.81
2045	292.8	0.83	28734	216365	94.00	15.93	47.79	105.15
2046	284.4	0.83	27913	216365	94.94	15.85	47.54	104.58
2047	276.0	0.84	27092	216365	95.89	15.77	47.32	104.11
2048	267.7	0.84	26271	216365	96.85	15.72	47.15	103.73
2049	259.3	0.85	25450	216365	97.82	15.67	47.02	103.45
2050	250.95	0.85	24629	216365	98.80	15.65	46.95	103.29

Parameters	
capital costs	0
CRF	0.000
Fixed O & M	0
discount rate	0.035
lifetime	0
Variable O&M	0
Fuel ($/Mmbtu)	2.73
Fuel ($/MWh)	9.307935
Fuel Price Escalation	0.02
Utility Rate ($/MWh)	73.3
Rate with 0.5c Premium ($/MWh)	78.30
Rate with 1c Premium ($/MWh)	83.30
Rate with 1.5c Premium ($/MWh)	88.30
Utility Price Escalation	0.01
Base (2005)	1673
SL depreciation (2030-2040)	63.64
SL depreciation (2040-2050)	8.365

Total Abatement	
MT	1,528,543

Average Cost - 30 years	
.5c	$ 10.42
1.5c	$ 31.25
3.3c	$ 68.75

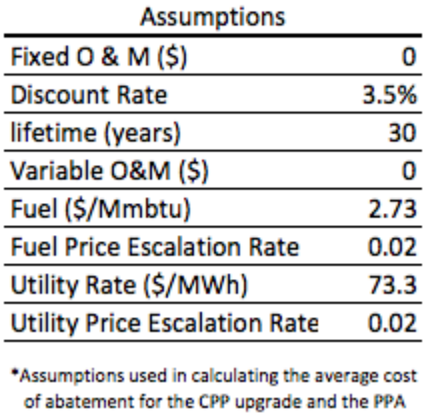
Average Cost - 10 years	
.5c	$ 7.89
1.5c	$ 23.68
3.3c	$ 52.10

These tables illustrate how the declining carbon intensity of the grid impact the average abatement cost and abatement potential of the CPP upgrade (Table 1) and the PPA (Table 2). Further detail on the formulas used in the calculations can be found in "Rego_Benjamin_Supplementary_File4.xlsx"

Data for this analysis was gathered from the following sources:

- Adams, James & Malcolm Bambling. Personal interview. 18 Dec. 2018.
- The PPA Task Force. *An Investigation of Power Purchase Agreements for the University of Michigan: A Path to Carbon Neutrality*. Students for Clean Energy, 2018, energy.umich.edu/wp-content/uploads/2018/06/ppas_for_u-m_final_report_0.pdf.
- "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *Today in Energy - Daily Prices - Prices - U.S. Energy Information Administration (EIA)*, www.eia.gov/todayinenergy/prices.php.
- *Voluntary Green Pricing Programs University of Michigan*. DTE Energy, 14 Sept. 2018.

APPENDIX E



Assumptions

Fixed O & M ($)	0
Discount Rate	3.5%
lifetime (years)	30
Variable O&M ($)	0
Fuel ($/Mmbtu)	2.73
Fuel Price Escalation Rate	0.02
Utility Rate ($/MWh)	73.3
Utility Price Escalation Rate	0.02

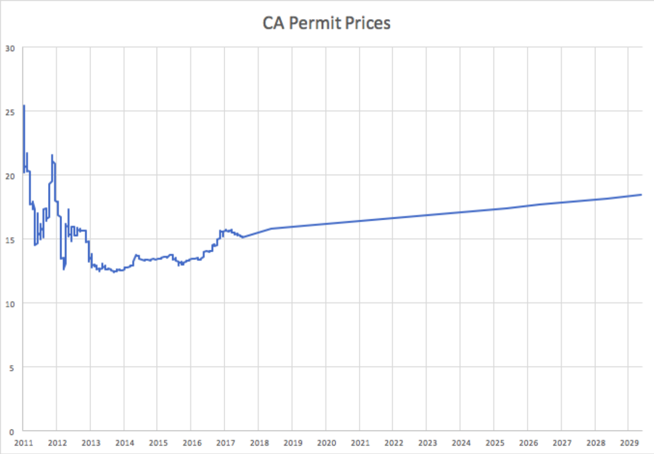
*Assumptions used in calculating the average cost of abatement for the CPP upgrade and the PPA

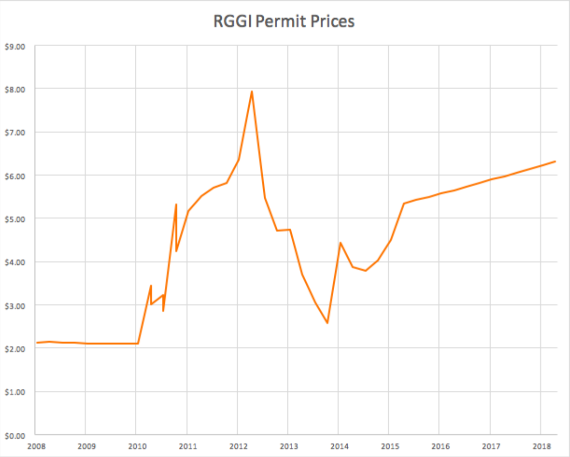
This table lists the assumptions used in the CPP upgrade and PPA analysis.

Data for the assumptions was gathered from the following sources:

- Adams, James & Malcolm Bambling. Personal interview. 18 Dec. 2018.
- The PPA Task Force. *An Investigation of Power Purchase Agreements for the University of Michigan: A Path to Carbon Neutrality*. Students for Clean Energy, 2018, energy.umich.edu/wp-content/uploads/2018/06/ppas_for_u-m_final_report_0.pdf.
- “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” *Today in Energy - Daily Prices - Prices - U.S. Energy Information Administration (EIA)*, www.eia.gov/todayinenergy/prices.php.

APPENDIX F



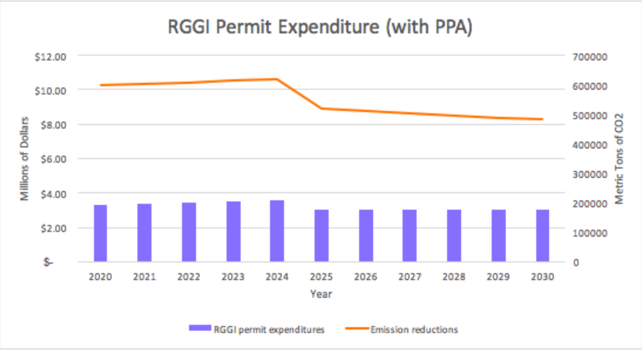


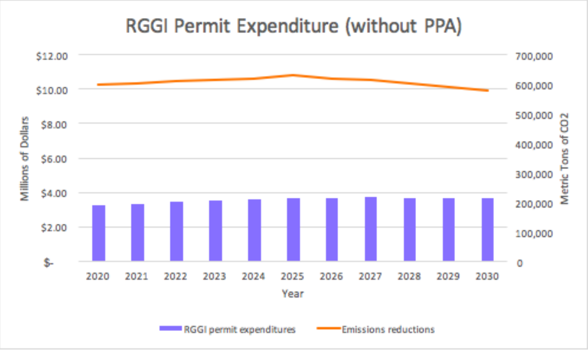
Tables representing past cap-and-trade permit prices, and estimates for future prices. Further detail on the formulas used in the calculations can be found in "Rego_Benjamin_Supplementary_File4.xlsx"

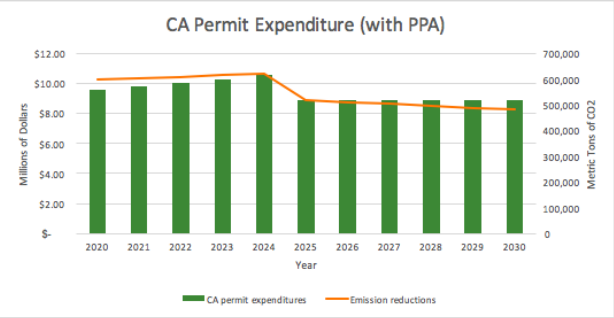
Data for these graphs was gathered from the following sources:

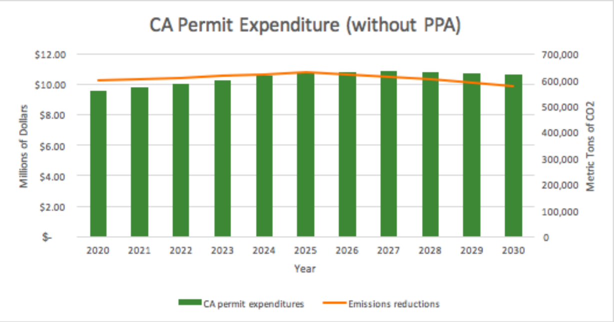
- "Allowance Prices and Volumes." *Allowance Prices and Volumes | RGGI, Inc.*, www.rggi.org/auctions/auction-results/prices-volumes.
- "California Carbon Dashboard." *California Carbon Dashboard: Carbon Prices, the Latest News, and California Policy*, calcarbondash.org/.

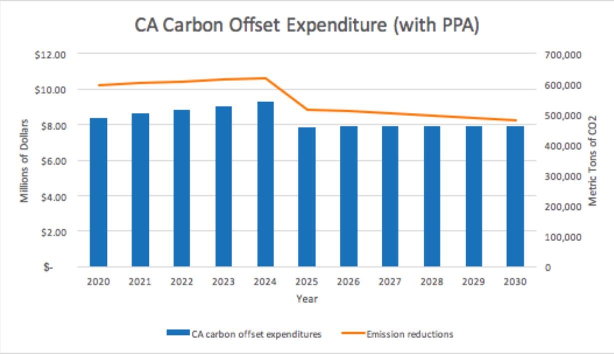
APPENDIX G

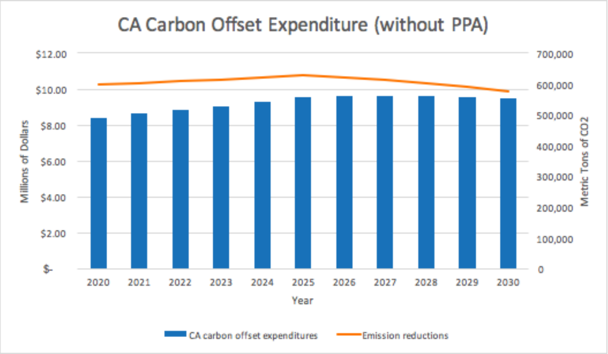

RGGI Permit Expenditure (with PPA)


RGGI Permit Expenditure (without PPA)


CA Permit Expenditure (with PPA)


CA Permit Expenditure (without PPA)


CA Carbon Offset Expenditure (with PPA)


CA Carbon Offset Expenditure (without PPA)

	With PPA	RGGI Permits		CA Carbon Offsets		CA Permits	
Year	Emissions reductions (MT of CO2)	Price (dollars/MT)	Expenditures (millions of dollars)	Price (dollars/MT)	Expenditures (millions of dollars)	Price (dollars/MT)	Expenditures (millions of dollars)
2020	596,885	$ 5.50	$ 3.28	$ 14.07	$ 8.40	$ 16.05	$ 9.58
2021	602,685	$ 5.58	$ 3.36	$ 14.30	$ 8.62	$ 16.28	$ 9.81
2022	608,485	$ 5.66	$ 3.44	$ 14.52	$ 8.84	$ 16.50	$ 10.04
2023	614,285	$ 5.74	$ 3.52	$ 14.76	$ 9.06	$ 16.74	$ 10.28
2024	620,085	$ 5.82	$ 3.61	$ 14.99	$ 9.29	$ 16.97	$ 10.52
2025	517,328	$ 5.90	$ 3.05	$ 15.23	$ 7.88	$ 17.21	$ 8.90
2026	510,128	$ 5.98	$ 3.05	$ 15.47	$ 7.89	$ 17.45	$ 8.90
2027	502,928	$ 6.06	$ 3.05	$ 15.71	$ 7.90	$ 17.69	$ 8.90
2028	495,728	$ 6.15	$ 3.05	$ 15.96	$ 7.91	$ 17.94	$ 8.89
2029	488,528	$ 6.23	$ 3.05	$ 16.21	$ 7.92	$ 18.19	$ 8.89
2030	481,328	$ 6.32	$ 3.04	$ 16.47	$ 7.93	$ 18.45	$ 8.88

	Without PPA	RGGI Permits		CA Carbon Offsets		CA Permits	
Year	Emissions reductions (MT of CO2)	Price (dollars/MT)	Expenditures (millions of dollars)	Price (dollars/MT)	Expenditures (millions of dollars)	Price (dollars/MT)	Expenditures (millions of dollars)
2020	596,885	$ 5.50	$ 3.28	$ 14.07	$ 8.40	$ 16.05	$ 9.58
2021	602,685	$ 5.58	$ 3.36	$ 14.30	$ 8.62	$ 16.28	$ 9.81
2022	608,485	$ 5.66	$ 3.44	$ 14.52	$ 8.84	$ 16.50	$ 10.04
2023	614,285	$ 5.74	$ 3.52	$ 14.76	$ 9.06	$ 16.74	$ 10.28
2024	620,085	$ 5.82	$ 3.61	$ 14.99	$ 9.29	$ 16.97	$ 10.52
2025	628,327	$ 5.90	$ 3.71	$ 15.23	$ 9.57	$ 17.21	$ 10.81
2026	619,557	$ 5.98	$ 3.70	$ 15.47	$ 9.58	$ 17.45	$ 10.81
2027	613,534	$ 6.06	$ 3.72	$ 15.71	$ 9.64	$ 17.69	$ 10.85
2028	603,390	$ 6.15	$ 3.71	$ 15.96	$ 9.63	$ 17.94	$ 10.82
2029	590,400	$ 6.23	$ 3.68	$ 16.21	$ 9.57	$ 18.19	$ 10.74
2030	576,624	$ 6.32	$ 3.65	$ 16.47	$ 9.49	$ 18.45	$ 10.64

Graphs and tables showing the cost per year over the next decade of going carbon neutral. The six graphs show how cost differs depending on what market you buy the offsets/cap-and-trade permits, and whether or not the university signs the PPA. These graphs and tables can be found in "Rego_Benjamin_Supplementary_File4.xlsx"

Data for these tables and graphs was gathered from the following sources:

- "Allowance Prices and Volumes." *Allowance Prices and Volumes | RGGI, Inc.*, www.rggi.org/auctions/auction-results/prices-volumes.
- "California Carbon Dashboard." *California Carbon Dashboard: Carbon Prices, the Latest News, and California Policy*, calcarbondash.org/.