An Economic Perspective on Carbon Neutrality at the University of Michigan

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Executive Summary

The University of Michigan has a stated goal of reaching carbon neutrality. In this *Issue Brief*, we discuss the economics of emissions reduction, estimate the costs of different emissions-reduction projects that are available to the University, and then make recommendations on how the University can cost-effectively set an ambitious time path for becoming carbon neutral.

We begin by emphasizing that carbon neutrality entails net-zero emissions, as opposed to the zero gross emissions of purely local decarbonization. The underlying justification for a carbon-neutrality goal comes from climate science: since greenhouse gas (GHG) emissions mix uniformly in the atmosphere before realizing their impact on the climate, the climate-related effects of emissions reductions do not depend on the location or source of the reduction. Thus, limits on the technical or financial feasibility of campus decarbonization do not constrain the University's ability to mitigate climate change, nor do they justify inaction. Staging carbon neutrality prior to campus decarbonization can resolve the apparent tension between immediate climate action and the complexity of removing all emissions from University activities.

The carbon-neutrality goal allows the University to pursue emissions-reduction projects wherever they are most attractive – whether on the grounds of cost effectiveness, local acceptance, or other relevant criteria. In this brief, we focus on costs. If the University prioritizes projects that reduce emissions at low cost, it will save large amounts of money relative to alternative methods – money that can be used for other valuable actions, such as new educational programming or additional emissions reductions. Since every ton of emissions disproportionately harms the poor, we believe that ambition in emissions reduction is crucial to climate justice. Cost-effectiveness can facilitate such ambition.

The table below presents estimates of the average cost of emissions reduction – in dollars per tonne CO_2 – of five hypothetical projects. It illustrates the large cost disparities that exist between projects in different locations and of different scales and types.

Table 1. Comparison of Selected Projects by Abatement Cost

Project	*Abatement Cost ($/mtCO₂)*
165-MW solar farm – Tucson, AZ	-15
165-MW solar farm – Ann Arbor, MI	+7
Purchase and retire RGGI permits	+10
DTE Power Purchase Agreement (PPA)	+20
On-campus rooftop solar	+105

Note: We assume (i) Projects begin in 2021; (ii) UM receives 50% of the federal investment tax credit on solar projects; (iii) PPA contract length is 15 years.

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The brief describes estimates of average abatement costs for a set of emissions-reduction projects that are feasible for the University, including those in the table above. The full range of potential projects is large, and our analysis is not intended to be comprehensive. Nevertheless, we develop several principles that are relevant to the University's carbon neutrality challenge. We summarize our key findings and recommendations below.

Key findings:

1. The cost of emissions reduction, measured by average cost of abatement (in \$/tonne CO_2), varies widely across different potential actions.
2. The social benefit of emissions reduction exceeds the cost for a wide range of projects.
3. In renewable energy projects, economies of scale allow for significant cost savings.
4. Non-local projects can unlock significant cost savings relative to their local counterparts. We estimate as much as $55 million in savings on a non-local solar project relative to a local solar project, with both scaled at 165-megawatt capacity.
5. The University's power purchase agreement (PPA) with DTE Energy for wind-generated electricity is expensive relative to other potential projects.
6. Purchasing and retiring emissions permits from a carbon cap-and-trade program (such as the Regional Greenhouse Gas Initiative, or RGGI) can be a reasonably low-cost way to credibly, immediately reduce emissions.

Key recommendations:

1. Embrace the concept of net-zero emissions: consider actions in locations beyond UM's physical infrastructure and location as a means to accelerate emissions reduction.
2. Use average abatement cost as a key input to emissions-reduction project selection, in order to achieve carbon neutrality cost-effectively.
3. Post a "Request for Proposal" that is open to both local and non-local large-scale renewable projects. Do this as soon as possible to capture a sizeable but rapidly-declining federal solar subsidy.
4. Choose the shortest length possible for the PPA contract, and substitute in cheaper projects as a replacement.
5. Investigate the purchase and retirement of emissions permits from an existing cap-and-trade program as a strategy for achieving full carbon neutrality in the very short term.
6. Implement an internal carbon price on campus as part of a general program to spur energy conservation and efficiency.

I. Defining the carbon neutrality challenge

An institution achieves carbon neutrality when its total greenhouse gas (GHG) emissions across all activities come into balance with the total emissions reductions for which it is responsible. Carbon neutrality is different from "full decarbonization": achieving the latter requires the total elimination (and/or capture and sequestration) of emissions generated by an institution's activities, while achieving the former requires only that an institution fully cancel out its local emissions with emissions reductions elsewhere. Carbon neutrality is therefore synonymous with "net-zero GHG emissions".

The logic of carbon-neutrality goals – which are quite common today[1] – is based on the science of climate change. GHGs emissions mix uniformly in the atmosphere before realizing their effect on the climate, so the climate-change mitigation effects of emissions reduction do not depend on the location or source of the reduction. However, other attributes of emissions reduction – most notably the costs – vary widely from project to project. Non-local projects thus have the potential to achieve the same climate outcomes as local ones while being more attractive on cost (or other) grounds.

Leveraging these facts is vital to reducing emissions at the pace required to limit global average temperature rise to the most commonly discussed levels.[2] In effect, a carbon-neutrality goal allows an institution to pursue the same quantity of emissions reduction as full decarbonization would achieve, without waiting for technical developments to make full decarbonization physically and financially feasible. This means that UM need not wait for the natural-gas fired Central Power Plant to age out of service, for the electricity grid to become cleaner, or for zero-carbon commuting options to become available. Staging carbon neutrality prior to full decarbonization can resolve the tension between immediate climate action and the complexity of removing all emissions from University activities.

In fact, 100% carbon neutrality is technically and financially possible in the very near term (perhaps one to three years), if the University chooses low-cost projects with credible emissions reductions wherever they may be. UM would not be the first institution in higher education to achieve carbon neutrality; American University and Middlebury College, for example, have already done so using a combination of local and non-local actions.

II. The benefits and costs of emissions reduction

To make informed decisions about which emissions-reducing actions to take, the University should consider the benefits and costs of its different options. The benefits of emissions reduction help answer the question of *why* the University should achieve carbon neutrality. The costs of emissions reduction, in contrast, provide insight into the question of *how* to achieve carbon neutrality. The University should pay close attention not just to the overall magnitudes of costs and benefits, but also to their distributions across groups (for example, states, countries, races, and wealth brackets).

The direct benefits of emissions reduction are the avoided damages of climate change to society. These damages include, but are not limited to, the impacts of extreme heat on economic productivity, health,

[1] Many companies (for example, Salesforce and Google), universities (the entire University of California system), and whole countries (Sweden and Norway) have achieved or are committed to achieving net-zero emissions.
[2] 1.5 and 2 degrees Celsius are targets studied by the Intergovernmental Panel on Climate Change (IPCC) due to the forecasted nature and magnitude of climate damages of exceeding these thresholds.

and learning; the effects of more severe natural disasters; and the impacts of ocean acidification and sea-level rise. The *social cost of carbon* (SCC) is the monetized sum of all global damages from an additional unit of carbon dioxide (CO_2) emissions; the U.S. government Interagency Working Group's central estimate of the SCC for 2020 is $50 per tonne CO_2, although some recent studies have estimated a substantially higher SCC. Relatively low-income countries disproportionately bear the burden of these damages, despite having historically contributed far less to global emissions.

There are also a number of potential "co-benefits" of emissions reduction efforts; these accompany climate change mitigation but are not the direct target of the emissions-mitigating activity. They include, for example, the benefits of reduced fossil fuel consumption on local air, water, and soil quality, and the benefits of local economic stimulus from the development of wind or solar farms. These can often be quite large. The University, in particular, may value certain emissions-reduction projects because of increased opportunities they present for teaching, research, and engagement opportunities, or because of positive reputational effects.

Both the size and the distribution of avoided damages provide support for a rapid time path toward carbon neutrality at UM. As shown in Section III below, the social benefit per tonne of emissions reduction (the SCC) exceeds the cost per tonne for most projects considered. That is, it is possible to choose projects such that every unit of emissions reduction up to carbon neutrality produces a positive net benefit to society. A socially-minded institution like UM, therefore, should seek to achieve carbon neutrality as soon as possible. At the same time, the disproportionate burden of climate change borne by lower-income households means that every single unit of emissions reduction up to carbon neutrality would be globally progressive.[3]

In the remainder of this brief, we focus primarily on the costs of emissions reduction ("abatement costs"). In UM's context, a good proxy for total costs is the sum of all financial expenses required to cause emissions to decrease – the monetary costs of construction and operation (e.g., of a solar array), production of energy (e.g., fuel prices), and any other expenses. The social costs of emissions reduction also include the negative effects of any rises in the cost of energy, such as reduced consumption or economic output. We do not attempt to measure these other costs in our ensuing analysis, but they certainly are an important consideration in the development of an emissions-reduction strategy.

As we show in Section III, the average cost per unit emissions reduction varies widely with the type and location of climate action. This fact suggests that there are large savings to be gained from careful selection of emissions-reduction projects. Minimizing the cost of achieving emissions goals ("cost-effective abatement") is truly an imperative for the University because of its simultaneous commitments to education, research, civic engagement, and well-being throughout the state, country, and world. If the University prioritizes projects that reduce emissions at low cost, it will save large amounts of money relative to alternative methods – money that can be used for other valuable actions, such as new educational programming or additional emissions reductions.

III. Estimating the costs of emissions-reduction projects

We estimate the costs of several types of emissions-reduction projects that are feasible for UM. The entire range of potential projects is very large, and our analysis is not meant to be comprehensive.

[3] By "progressive" here, we mean that the relative poor are made better off than the relative rich.

Moreover, our estimates are uncertain and depend on assumptions about evolving electricity systems and market dynamics.[4] Nonetheless, the analysis illustrates several points about emissions reduction that are relevant to the University's carbon neutrality challenge, thereby demonstrating the importance of cost considerations in this context.

We measure costs as the average abatement cost, in dollars per tonne of CO_2 abated. In a typical application, the numerator of this metric is the estimated present-value cost of constructing and operating a project over its lifetime. The denominator is the project's estimated emissions reduction, which we calculate as the avoided emissions of fossil-fuel energy sources displaced by the project.[5] A project with a negative abatement cost is financially attractive on its own, i.e., it yields a positive return on investment even before considering the social benefits of emissions reduction. The metric of dollars per tonne of abatement facilitates a unified analysis across projects and sectors.

We highlight five main findings with respect to cost.

1. Abatement cost varies widely across different potential actions to reduce emissions.

Table 1 compares average abatement cost across five different projects: four renewable power capacity investments, and the purchase and retirement of emissions permits. The PPA between UM and its electric utility, DTE Energy, has already been chosen. It commits the University to annually paying DTE a 1.5-cent per kilowatt-hour (kWh) premium for production of 200 million kWh of wind-generated electricity in east-central Michigan, administered through a DTE voluntary green pricing program called *MIGreenPower*. Notably, the length of the contract has yet to be determined.

The other three renewable projects are potential solar installations of different types and locations: on-campus rooftop, local utility-scale, and non-local utility-scale. The emissions permit project leverages an existing CO_2 cap-and-trade program for abatement: the multi-state Regional Greenhouse Gas Initiative (RGGI) in the eastern United States. Purchase and retirement of permits from RGGI prevents polluters from using those permits to cover their emissions, so that they instead must make additional emissions reductions. Effectively, this strategy tightens the emissions cap.

The set of projects included below – albeit not comprehensive – is sufficient to illustrate a key point: not all projects are created equal when it comes to cost.

Table 1. Comparison of Selected Projects by Abatement Cost

Project	*Abatement Cost (\$/mtCO_2)*
165-MW solar farm – Tucson, AZ	-15
165-MW solar farm – Ann Arbor, MI	+7
Purchase and retire RGGI permits	+10
DTE PPA	+20
On-campus rooftop solar	+105

Note: We assume (i) Projects begin in 2021; (ii) UM receives 50% of the federal investment tax credit on solar projects; (iii) PPA contract length is 15 years.

[4] Examples of important but uncertain elements include solar installation costs (they have dropped steadily over the past five decades), regional electric grid emissions intensity, and wholesale electricity prices.

[5] We detail our methods for estimating abatement costs in an accompanying appendix.

The University ultimately should assess abatement cost for *all* of its options – such as internal carbon pricing, energy efficiency investments, geothermal power, behavioral interventions, and food-sector emissions-reduction strategies.

2. Economies of scale allow for significant cost savings in renewable project development.

The fixed costs of setup of solar arrays are large. For this reason, building one large solar farm is generally cheaper than building many small solar installations. Table 1 bears out this logic: on-campus rooftop solar has an abatement cost of $105/tonne, while a single utility-scale solar farm in the Ann Arbor area actually has a relatively small cost ($7/tonne).[6] In addition, rooftop solar is severely constrained by available space on campus. Covering every UM property with rooftop solar would achieve reductions of only 1% of University-wide electricity emissions (i.e., emissions from electricity generation) over the 25-year lifetime of the panels.

Large-scale renewable projects are, not surprisingly, becoming increasingly common among institutions of higher education – like Ohio State, Michigan State, Stanford, and Massachusetts Institute of Technology (MIT), to name just a few. Moreover, some institutions have "aggregated" with others for the express purpose of harnessing economies of scale. In 2016, MIT contracted with two non-academic entities to arrange for the construction of a 60-megawatt (MW) solar farm.[7] That same year, George Washington University and American University collaborated on the commission of a 54-MW solar farm.

3. Non-local renewable projects tend to be cheaper than local ones.

As Table 1 shows, we estimate that a 165-MW solar farm in Ann Arbor would have an average abatement cost of +$7/tonne, while the same-sized installation in Tucson, AZ would have an average abatement cost of -$15/tonne. Why is there such cost variation between equally-sized solar farms? Several factors determine the relative merits of solar construction across geographies. First, areas with higher annual solar irradiance retain an advantage in terms of expected electricity generation from photovoltaic panels. Second, costs of engineering, procurement, and construction of solar panels are spatially variable. For instance, building a solar farm in Hawaii—where land rents, sales taxes, and the cost of labor and electrical components are high—would be more expensive than in Oklahoma. Third, the financial value of electricity depends on the wholesale electricity price in the region, and this varies across regions. Finally, a solar farm's emissions reduction depends on the emissions intensity of the electricity generation that it displaces. Replacing a coal power plant, for example, reduces emissions by more than replacing a natural gas power plant.

Table 2 compares the emissions impacts and costs of equally-sized solar farms at various locations. The third column indicates that four of six options have negative estimated costs – that is, they potentially would earn a positive financial return and reduce emissions simultaneously. This is the case because high upfront costs of installation are more than fully recovered through revenues accrued over time from the sale of renewable power. The solar farm in Ann Arbor has the highest cost; for the most part, this fact is explained by the solar resource being relatively stronger outside of Michigan.

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[6] Land use for siting a utility-scale solar farm can be a contentious political issue in some locations.
[7] Through discussions with staff at MIT, we have learned that MIT is working with several other aggregation partners to create a portfolio of large-scale projects to reduce GHG emissions for the next phase of their climate actions.

The last column shows the hypothetical cost savings available to the University from building non-local renewable capacity: between $8.8 and $54.9 million.[8]

Table 2. Abatement and Cost of 165-MW Utility-Scale Solar Farms by Location

Location	*Percent of 25-Year UM Electricity Emissions*	*Lifetime Abatement Cost ($/mtCO₂)*	*Break- Even Year (installed in 2021)*	*Initial Investment Cost ($ mil)*	*Total Savings Compared to Ann Arbor Benchmark ($ mil)*
Ann Arbor, MI	42%	+7	N/A	133.1	Benchmark
Tulsa, OK	44%	-3	2043	124.6	24.7
Cambridge, MA	23%	+6	N/A	147.3	8.8
Wilmington, NC	36%	-11	2040	126.0	40.6
Tifton, GA	39%	-15	2038	127.4	49.9
Tucson, AZ	44%	-15	2038	130.3	54.9

Notes: *Electricity Emissions* are emissions from electricity generation. *Initial Investment Cost* assumes (i) construction in 2021 and (ii) UM receives 50% of the federal investment tax credit on solar projects. *Total Savings* are computed as the net cost of the Ann Arbor solar farm minus the net cost of the corresponding non-local solar farm. Net cost is the initial investment cost minus the present-value revenues of a solar farm's electricity sales over time. "N/A" indicates that a project is estimated to not pay for itself over its assumed 25-year lifetime.

4. The University's PPA with DTE for wind-generated electricity, at a cost of +$20/tonne, is expensive relative to estimates of other projects' costs.

The 1.5-cent per kWh premium to which the University agreed in the DTE PPA is more expensive than all six utility-scale projects that we considered.[9] This could be because construction of wind power in east-central Michigan is expensive, or it could be because DTE is charging more than the average cost per kWh it is facing. Either way, Tables 1 and 2 suggest that the University could have saved substantial funds by investing in other projects.

In principle, UM's PPA with DTE could be justified on the grounds of its relative "localness", in spite of its high price tag. But it is important to acknowledge the true geography of the PPA's effects. East-central Michigan may experience positive local economic impacts from the construction of a new utility-scale wind farm. However, the air quality improvements from the farm will accrue to the areas where fossil-fuel intensive power is replaced – which may or may not be in the state of Michigan. Perhaps more importantly, the University will not directly consume the new wind power; the flow of electrons cannot be physically tracked from power producer to final consumer (absent a direct cable connection), and the wind power will simply be transmitted to the regional electricity grid. Thus the PPA, at its core, is a non-local project: it reduces *net* emissions regionally rather than locally decarbonizing UM operations. If the University is going to consider non-local projects – and it should – it ought to seek out cheaper options.

[8] The true costs to UM depend fundamentally on how it shares total costs (or cost savings) with any project partners. For instance, large-scale renewable projects would likely involve collaboration with an entity that builds this type of infrastructure. Ultimately, the cost to UM of such a project depends on the details of a contract with that entity.
[9] A separate, and important, question is whether the renewable capacity being paid for by UM in the PPA is *additional* (i.e., would not have happened if UM had not bought into *MIGreenPower*).

5. Purchasing and retiring emissions permits from the RGGI market is a reasonably low-cost way to reduce emissions.

The total cost of the permit retirement strategy is simply based on the price paid to obtain the permits. This strategy is thus relatively simple, and quick, to put into action. While the overwhelming majority of permits are purchased and submitted to the regulatory agency by regulated entities (that is, the polluters themselves), non-regulated entities may also purchase and retire permits. There is a long tradition of permit retirement on a small scale by environmental organizations and concerned citizens.

Permit prices are readily available from the relevant agency; in RGGI, they are just above \$6/tonne. While each permit represents one tonne of emissions, the effect of a single permit retirement may be somewhat less than a reduction of one tonne; this is because of "leakage" of emissions from inside the program to outside of it.[10] Accounting for leakage based on recent empirical evidence, we estimate that the abatement cost of permit retirement is approximately \$10/tonne for RGGI.

The bottom line is that permit retirement from RGGI appears to be markedly cheaper than the PPA with DTE. Moreover, permits can be purchased at any time from willing sellers in the RGGI market.

IV. Some concrete recommendations for near-term action

We recommend four action items for implementation early in 2020.

1. The University should solicit proposals for large-scale renewable power projects. This is urgent given the declining federal subsidy of large-scale solar projects.

The abatement cost estimates in Table 2 suggest that large-scale renewable projects can be cost-competitive with existing electricity infrastructure. These estimates are, however, highly uncertain. It thus is vital that the University invest in learning what financial terms renewable developers – parties with whom UM would contract for the construction of renewable capacity – are actually offering for different technologies and in different locations.

Moving quickly on large-scale renewables is especially attractive because federal subsidies for solar projects are being phased out over the next three years. In 2019, the federal investment tax credit conveys a reduction in tax liability equal to 30% of a solar installation's initial investment cost. However, the credit level drops to 26% in 2020, 22% in 2021, 10% in 2022, and 0% thereafter. According to our estimates, the abatement cost of the Ann Arbor solar farm rises by \$7 per tonne in the absence of the federal subsidy. The consequences are similar in magnitude for the five non-local solar farms, except for the Massachusetts project; losing the subsidy raises its abatement cost by \$13 per tonne due to a relatively high initial cost.

There is ample precedent for higher-ed investment in large-scale renewable power projects. While a few of these projects have been local, most have been non-local. For example, Stanford developed a

[10] Emissions leakage occurs when implementation of a GHG regulatory program causes GHG emissions to increase at pollution sources outside of the program's geographic region or regulated sector(s). This is not to be confused with methane leakage, which is the escape of methane to the atmosphere during the natural gas production process. We account for both types of leakage in this brief; see the Appendix for further details.

solar farm in the Mojave Desert, some 300 miles southeast of Palo Alto, and MIT bought into a solar farm in North Carolina. Both local and non-local projects are justifiable in principle, but it is imperative that institutions do their due diligence in assessing the costs of different options.

MIT's case is particularly instructive. Its solicitation of bids to build renewable energy capacity resulted in 41 proposals, with 11 from the New England region and 30 from outside the region. It ultimately elected to sign a 25-year power purchase agreement with Dominion Energy, which allowed the latter to obtain financing for the construction of a 60-MW solar array in northeastern North Carolina. By retaining (and retiring) renewable energy credits (RECs) from the farm's electricity output, MIT offsets 40% of its annual campus electricity emissions.

2. The University should minimize the length of its PPA with DTE.

The length of the PPA has yet to be finalized. If, as our estimates suggest, the PPA is not cost-competitive with proposals for utility-scale renewables, the University should avoid locking itself into an expensive contract. In fact, as Table 3 below shows, the longer the contract, the more costly per tonne the PPA becomes. This is because the annual cost remains the same every year, while a steadily-decarbonizing grid causes emissions reductions from the PPA to decrease over time.

Table 3. Average Abatement Cost by PPA Contract Length

Contract Length	*Abatement Cost ($/mtCO$_2$)*
5 years	+19
15 years	+20
25 years	+23

3. The University should consider emissions permit retirement as a short-term strategy prior to investment in capital-intensive abatement projects.

The University could undertake permit retirement immediately; the strategy thus offers an abatement option that can be staged ahead of projects that require assessment, planning, and construction of physical infrastructure. At scale, the strategy could achieve carbon neutrality in 2020 with respect to UM Scope 1 and Scope 2 emissions (almost 597,000 tonnes).[11,12] The estimated cost of purchasing RGGI permits for this is $6.2 million.[13] With a social cost of carbon of $50, the corresponding estimated global benefits are almost $30 million.

Permit purchase and retirement can be contrasted with a strategy of purchasing carbon "offsets", i.e., credits for having facilitated emissions reductions beyond the confines of one's own carbon footprint. Paying an entity to reduce emissions by, for instance, altering farming practices or land use choices has the same climate impact as doing so oneself, regardless of location. However, it is extremely

[11] Scope 1 emissions refer to those directly from an institution's owned and controlled sources, including on-site electricity generation, heating and cooling, university-owned vehicles, and refrigeration. Scope 2 emissions refer to those indirectly accrued in the generation of electricity purchased by the institution. Scope 3 emissions are comprised of any other indirect emissions incurred within the institution's supply chain. Scope 3 emissions for UM have not been reported to date.

[12] To put this in context, note that RGGI's total emissions cap in 2020 is almost 71 million tonnes of CO_2.

[13] Planned expenditures at the University for Fiscal Year 2019-2020 are $9.654 billion.

difficult to prove that the offset payment is the true reason for such emissions-reducing behavior change. If the behavior change would have happened anyway – that is, even without the payment – then the offset purchase does not represent an authentic emissions reduction. On these grounds, the purchase of permits is superior to the purchase of offsets. Each permit retirement mechanically and legally tightens the cap, forcing regulated entities to reduce emissions by one tonne. The regulatory framework of the cap-and-trade program ensures that these emissions reductions will happen.

4. The University should implement carbon pricing as part of a general program to spur energy conservation and efficiency on campus.

A carbon price is an important tool for aligning incentives of individual campus units with the university-wide goal of carbon abatement. Consumption of different services (electricity, natural gas, steam, and water) is metered at the building level, and billing for utility services is administered at the school/unit level. A price, in dollars per tonne, could be charged for the CO_2 emissions embodied in energy use. Individual units would pay a carbon charge as part of their normal operating costs. A carbon price would make investments in building energy efficiency more financially attractive, and it could add to the success of behavioral programs targeting conservation.

The effectiveness of carbon pricing at reducing emissions depends on how responsive individuals and campus units are to an increase in the price of energy consumption. It also depends on how revenues raised from carbon pricing are used: they could, for instance, be rebated back to campus units to reduce or eliminate the financial burden of the carbon charge;[14] or they could be used to fund other efforts by the University to reduce emissions. In the preceding analysis, we do not report abatement cost estimates for carbon pricing. However, we note that, conceptually, the dollars per tonne is bounded above by the level of the carbon price set in the program, since consumers would not reduce their energy consumption unless doing so were cheaper than simply paying the carbon price.

Several colleges and universities use an internal carbon price. Beginning in 2016, for example, Swarthmore College initiated department-level carbon charges, and it uses a price of $100/tonne CO_2 equivalent in planning for construction and renovation of buildings. In 2017, Yale University began charging a carbon price of $40/tonne. The program covers 250 buildings and 70 percent of campus emissions. Swarthmore allocates funds from its carbon charge to projects that advance the college's carbon-neutrality mission. Yale rebates 100% of the funds to the units being charged.

V. Conclusion

The findings and recommendations presented in this brief are by no means sufficient, on their own, to determine UM's best course of action. Rather, our intent is to contribute an economic perspective to the University's pursuit of carbon neutrality, by clarifying the meaning and scope of the carbon-neutrality goal, and by providing a sense of the costs of different ways to reach that goal. With that intent in mind, we add two broader recommendations to the four concrete ones listed in the preceding section. First, we recommend that the University embrace the meaning of carbon neutrality by pursuing emissions reductions *wherever* they are most attractive. Local decarbonization has many virtues, but the difficulty of decarbonizing certain processes does not preclude the University from

[14] Note that the incentive to reduce emissions is preserved even when revenues are returned to campus units: while units experience little or no change in their financial standing, the cost of energy has still risen.

undertaking ambitious emissions reductions. Second, we recommend that the University use average abatement cost as a key input into its decision-making process for emissions reduction. Our analysis suggests that "high costs" are not a valid reason for inaction.

There are many paths to carbon neutrality, and we do not endorse one specific path. But by following the recommendations laid out here, we believe that the University would achieve its goal of net-zero emissions faster and at lower cost. This would make the University a climate leader in higher education, the state of Michigan, and beyond. More importantly, it would make a significant difference in combating climate change, an existential threat whose dire impacts are already being felt today.

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Appendix:
Methods for estimating abatement cost and baseline emissions

The appendix describes methods for estimating average abatement cost for four cases: utility-scale solar energy installations; on-campus rooftop solar; the power purchase agreement between DTE Energy and the University of Michigan; and emission permits in the RGGI market. It also describes methods for estimating the University's baseline emissions. Our spreadsheet containing all of these analyses is available upon request.

Case 1. Utility-scale solar energy installations

We estimate the average abatement cost of 165-MW solar arrays at six different locations: Ann Arbor, MI; Cambridge, MA; Tifton, GA; Tucson, AZ; Tulsa, OK; and Wilmington, NC. We chose Arizona because of the quality of its solar resource. We chose Cambridge, Massachusetts and Wilmington, North Carolina because MIT is physically located in the former city and chose a solar energy project near the latter. We chose Oklahoma because of its emissions-intensive power generation portfolio. And we chose Georgia for its combination of good solar resource quality and emissions-intensive power portfolio.

To arrive at our abatement cost estimates, we first must estimate total costs and total emissions reductions for each solar array. We describe each of these calculations in turn.

<u>Total costs</u>

Total costs of solar installations depend on both upfront costs of construction and revenues over time from electricity sales. To obtain estimates of upfront costs, we rely on the National Renewable Energy Laboratory's (NREL) engineering, procurement, and construction (EPC) cost tables. These tables record costs per direct-current watt of installed solar in each U.S. state, accounting for location and capacity, and including transmission line construction costs.[15,16]

To produce estimates of revenues from electricity sales, we require estimates of electricity generation by each solar array. We obtain these using NREL's PVWatts Calculator.[17] This tool yields estimates of annual energy production of grid-connected PV installations that account for the uneven distribution of solar irradiance across the U.S.[18] The estimates depend on location, capacity, and a set of parameters that includes module type, directional orientation of panels, panel axis tilt, and system losses. We use a capacity of 165 MW and default options for all other parameters. From the generation

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[15] Fu, Ran, David Feldman, and Robert Margolis. "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018." Golden, CO: National Renewable Energy Laboratory, 2018. NREL/TP-6A20-72399. <www.nrel.gov/docs/fy19osti/72399.pdf.>

[16] The price of land is a very small share of renewable capacity upfront costs. However, there may be political constraints on the construction of new renewable capacity in certain locations.

[17] Dobos, Aron P. "PVWatts Version 5 Manual Technical Report." Golden, CO: National Renewable Energy Laboratory, 4 Sept. 2014, doi:10.2172/1158421.

[18] Sengupta, Manajit, et al. "The National Solar Radiation Data Base (NSRDB) for CSP Applications." *Renewable and Sustainable Energy Reviews*, vol. 89, June 2018, pp. 51–60., doi:10.1063/1.511771.

estimates, we deduct electricity transmission and distribution (T&D) losses based on a loss factor from the U.S. Energy Information Administration (EIA).[19,20]

To translate annual generation into annual revenues, we multiply the former by the wholesale price of electricity in the relevant wholesale power market, which we obtain from the EIA.[21] To calculate the total present value of revenues, we sum discounted annual revenues over the lifetime of the array, which we assume to be 25 years (2021-2045).[22] We subtract the total present value of revenues from upfront costs to yield a total cost estimate (in 2020 dollars). This is the numerator in our average abatement cost metric.

Total emissions reductions

The emissions impact of a solar installation depends fundamentally on what electricity source(s) it replaces. Since electricity grids are regional and interconnected, and since electrons cannot be physically tracked from source to end consumer, the emissions avoided through operation of a solar farm in any given location is an empirical question. The conceptually correct measure of a solar installation's emissions impact is the "marginal emissions factor", i.e., the emissions intensity (in tonnes CO_2/kWh) of the electricity generation that is avoided due to the new solar electricity generation.[23] The marginal emissions factor is different from the average emissions factor: the latter captures the average emissions intensity of the entire regional grid, rather than specifically of the sources that are affected.

Marginal emissions factors are difficult to estimate and are not guaranteed to be valid outside the context of their measurement. We do not attempt to estimate them here, nor do we borrow them from elsewhere.[24] Instead, we use average emissions factors among non-baseload power sources in the relevant geographic region to calculate emissions impacts. These numbers are published by the Environmental Protection Agency (in pounds CO_2/Megawatt-hour [MWh]).[25] "Baseload" refers generally to power sources that are normally always generating, so "non-baseload" averages capture the emissions intensity of the sources that are much more likely to stop generating when new renewable capacity comes online.

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19 The EIA recommends a loss factor of 4.7% <https://www.eia.gov/tools/faqs/faq.php?id=105&t=3>.

20 Since the electricity generator is paid for power produced, not power delivered, we do not expect UM to bear the cost of T&D losses. We nonetheless include these costs in our calculation, because we are interested in the social cost of emissions-reduction projects, rather than the private cost to UM.

21 Hodge, Tyler. "Wholesale Power Prices in 2017 Were Stable in the East, but Increased in Texas, California—Today in Energy" *U.S. Energy Information Administration (EIA) - Independent Statistics and Analysis,* 18 Jan. 2018, <www.eia.gov/todayinenergy/detail.php?id=34552>.

22 We use a real discount rate of 3.7% for computing present value from a 25-year stream of power revenues. We obtain this rate by taking the prime rate of 5.5% and subtracting the inflation rate of 1.8%. This treats the discount rate solely as a reflection of borrowing cost, without any consideration of social concerns (such as the social rate of time preference).

23 For utility-scale solar projects, we omit T&D losses in our emissions-reduction calculations, because these are common to both proposed projects and the baseline electricity generation that such projects would replace. They thus cancel each other out in our analysis.

24 We strongly recommend that the University incorporate marginal emissions factors in its abatement cost calculations before making any decisions about emissions-reduction projects. Indeed, accurate carbon accounting depends on this.

25 United States Environmental Protection Agency, Center for Corporate Climate Leadership (2018). "Emission Factors for Greenhouse Gas Inventories." Pp. 1–5. <www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf>.

We assign emissions factors to each solar array under consideration by matching its location to a geographic region. We then adjust these factors in each future year to account for future changes to electric power generation. To do this, we estimate a future time path of DTE's decarbonization rate and assume that non-baseload, regional average emission factors at all six of our chosen locations drop at the same rate. DTE has an official decarbonization target – described as "X% reduction by year Y, relative to 2005" – for the years 2024, 2030, 2040, and 2050.[26] We use DTE's reported 2005 average emissions factor to translate these future targets into average emissions factors in those years. Then, using DTE's forecasted 2020 emissions factor, we linearly interpolate annual average emissions factors between target years.[27] Finally, we adjust EPA regional emissions factors so that they decrease at the same percentage rate as DTE's emissions factor.[28] The product of annual emissions factor and annual generation is our estimate of annual emissions from combustion for electric power.

We additionally account for methane leakage in the natural gas supply chain. To do this, we first interpolate natural gas generation fractions from DTE's forecasts for the years 2018, 2024, 2030, and 2040. From these fractions, we impute estimates of annual natural gas generation from the grid. We multiply generation by a natural gas emissions factor from the EIA to recover emissions from natural gas generation.[29] We then multiply this number by a leakage factor from a UM analysis of methane leakage,[30] resulting in an estimate of the CO_2-equivalent emissions from leakage that are avoided through construction of solar capacity.

The sum of emissions from grid combustion and emissions from methane leakage is our estimate of total emissions reductions. This forms the denominator in our average abatement cost metric. Average abatement cost at each location is equal to total cost divided by total emissions reduction.

Case 2. Rooftop solar on the University of Michigan campus

We estimate the average abatement cost of constructing solar arrays on all on-campus roofs. To do so, we take advantage of the "GeoPlanner Assessment of Ann Arbor Campus Solar Potential", a tool created by UM's Professor Adam Simon. This tool includes an ArcGIS base map of UM's campus with information on all building footprints. We use the tool's built-in function for translating usable rooftop area into expected annual generation from fixed-panel rooftop solar PV. The function itself is based on numbers from PVWatts, with minor differences in the underlying parameter choices relative to the choices we make in using PVWatts to estimate utility-scale generation (Case 1 above).[31]

We use this annual generation number as an input into PVWatts and back-calculate the total direct-current capacity of all rooftops. We multiply total capacity by the cost of residential solar (in dollars

[26] DTE Energy. "2019 Integrated Resource Plan Summary."
[27] DTE Energy. "Voluntary Green Pricing Programs: University of Michigan." September 14, 2018.
[28] EPA's latest regional emissions factors pertain to 2016. Lacking 2020 estimates of non-local emissions factors, we assume that emissions factors have not changed between 2016 and 2020 and only begin to drop in 2021.
[29] The emissions factor is a 2018 national average computed from emissions and generation data available at <www.eia.gov/electricity/data/state/>.
[30] The factor 0.27 is based on a 100-year global warming potential. For consistency with a 20-year global warming potential, the appropriate factor is 0.68. See Raimi, Daniel, Eric Kort, and Austin Glass. "Methane Emissions and the University of Michigan." August 2019.
[31] We use a panel tilt of 42 degrees in our own PVWatts calculations, while the GeoPlanner function uses a panel tilt of 34 degrees.

per direct-current Watt [$/W]) in Michigan, as reported in NREL's EPC tables, to obtain an estimate of upfront project cost.

From this number, we subtract the avoided cost over time of DTE electricity (again using a 25-year lifetime beginning in 2021). It is important to note here that there is a difference between private and social measures of avoided financial cost in this context. Private avoided cost is calculated as the product of expected rooftop solar generation and the retail electricity rate (in $/kWh) that UM would have paid for this amount of grid power. Social avoided cost, however, is the product of generation and the variable cost of that generation. The retail electricity rate is higher than the variable cost because it is set – through regulatory proceedings – so as to allow the utility to recover *all* of its costs, including fixed costs of construction and maintenance. As a result, private savings are larger than social savings.

In this brief, we calculate the avoided *social* cost of rooftop generation. Were we to use the private measure of avoided cost, we would be ignoring the high likelihood that retail rates would be raised for the rest of DTE's Michigan customers, so that the University benefits at the expense of the rest of the DTE service area. We measure social cost with the Michigan-average wholesale electricity price (in $/kWh). We multiply annual expected generation by this price and discount to convert annual costs into present-value terms. Finally, we subtract the sum of these annual present-value costs from our upfront cost estimate to yield a total cost estimate.

We obtain an estimate of total emissions reductions from rooftop solar capacity in the same way as described in Case 1, with one exception: we account for T&D losses from DTE generation while setting T&D losses from rooftop solar to zero. Average abatement cost is equal to total cost divided by total emissions reductions.

Case 3. University of Michigan power purchase agreement with DTE Energy

We estimate the average abatement cost of the University's PPA with DTE. We calculate average cost starting in 2021 (the contract start date) and with three different contract lengths: 5, 15, and 25 years (contract length has yet to be determined, according to UM's Office of Campus Sustainability). The only cost to the University is the premium (1.5 cents/kWh) it pays DTE. To estimate the total cost of this premium, we multiply it by expected annual generation (200 million kWh), discount to recover present values from each year, and sum these annual present values. To estimate total emissions reductions, we follow the procedure described in Case 1.

Case 4. RGGI emission permits

We estimate the average abatement cost of emission permit purchase and retirement from the Regional Greenhouse Gas Initiative, a 9-state CO_2 cap-and-trade program in the New England and Mid-Atlantic regions of the U.S. We consult results from the quarterly RGGI auction held on December 4, 2019 to find permit price in dollars per short ton; we then convert these to dollars per metric tonne.

These numbers are not accurate estimates of abatement cost because of leakage – that is, rises in emissions outside of the cap-and-trade program's geographic coverage as a direct consequence of the program. To account for leakage, we multiply the RGGI permit price by a factor of 2.04, which is consistent with a published empirical estimate of 51 percent leakage.[32]

Baseline emissions calculation

While a complete accounting of the University's greenhouse gas emissions is beyond the scope of this brief, we do require an estimate of total emissions from the University's electricity consumption in order to compute percentages of 25-year electricity emissions to which each utility-scale solar farm is equivalent (column 1 of Table 2). Our estimate includes an accounting for methane leakage in the natural gas production process, as well as in the University's 15-MW Central Power Plant (CPP) expansion and the PPA with DTE.

We begin with an estimate of annual electricity consumption on Central and North Campuses and in University housing.[33] From correspondence with the University's Plant Operations office, we obtain an estimate of annual generation from the CPP (prior to its expansion), from which we also back out the annual generation that comes from the regional electricity grid. We use our time path of Michigan non-baseload average emissions factors to calculate total emissions due to grid power generation, accounting for methane leakage (see Case 1 above). We calculate emissions from the CPP similarly, using a natural gas, combined heat and power emissions factor reported by the U.S. Department of Energy.[34]

The sum of annual emissions from grid combustion, CPP combustion, grid leakage, and CPP leakage yields an estimate of annual total emissions from electricity consumption at UM. From this total, we subtract estimated emissions reductions from the CPP expansion and the PPA.

The CPP expansion involves the construction of 15 MW of new cogeneration capacity. We obtained expected annual generation from this new capacity through correspondence with UM's Office of Sustainability. We multiplied this number by the "net" emissions factor implied by the CPP – that is, the difference between the grid's emissions factor and the CPP's emissions factor – to estimate the emission reductions from combustion attributable to the CPP. We then added back an estimate of emissions leakage – the product of total emissions from new capacity and our leakage factor of 0.27.

Emissions reductions from the PPA come directly from the procedure outlined above in Case 3. We assume a lifetime of fifteen years for the PPA.

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32 Fell, Harrison, and Peter Maniloff. "Leakage in regional environmental policy: The case of the Regional Greenhouse Gas Initiative." *Journal of Environmental Economics and Management*, vol. 87 (2018): 1-23.

33 We assume that electricity consumption is constant over time. In fact, electricity consumption will likely rise over time, but we do not attempt to forecast such increases here.

34 United States Department of Energy. "Combined Heat and Power Technology Fact Sheet Series." July 2016. <https://www.energy.gov/sites/prod/files/2016/09/f33/CHP-Steam%20Turbine.pdf>.