Supplementary Materials for

Carbon Pricing Approaches for Climate Decisions in Higher Education: Proxy Prices for Deep Decarbonization

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Methods

S1.1 Methods for cataloging of carbon pricing policies in higher education

Internal carbon pricing (ICP) policies at U.S. Higher Education Institutions (HEIs) were collected for through a review of entries on the Association for the Advancement of Sustainability in Higher Education (AASHE) Hub,(AASHE Campus Sustainability Hub, 2019) emails and phone calls to AASHE community members, and through the Internal Carbon Pricing in Higher Ed Toolkit Working Group (Second Nature, 2018) led by Yale University and Second Nature. Programs under development/consideration were not included; programs need to be at least at the public pilot stage and publicly reported.

S1.2 Cost estimates of retrofit options (Figure 2)

We estimated life cycle cost (LCC) with and without a carbon price for five energy efficiency improvement options for a dormitory renovation at Smith College in Northampton, Massachusetts in the United States. The options were: insulate the attic to R-49, insulate the basement to R-13, insulate the above grade walls to R-20, air seal the windows and doors, and replace the single pane windows with double pane windows. Unit cost estimates for each option were provided by campus facilities staff. To estimate the specific cost of each insulation option for this building, the unit cost was multiplied by the total surface area of each wall of the attic, basement, and above-grade wall. Surface area was estimated using original blueprints, CAD blueprints, and physical measurements of the building. Initial cost of air sealing was estimated by multiplying the unit cost by the perimeter of each window and door. Attic and basement insulation were treated as a single element for figure purposes.

Modeling the building energy consumption for space heating requires the collection of the following data: building footprint (surface area on which the building stands), total area of occupied and unoccupied spaces, number of floors, shape, substructure, superstructure, exterior walls, roof, windows, exterior doors, interior partitions, interior doors, flooring, ceilings, heating source (such as oil, natural gas, or steam), heating distribution mechanism (such as air ducts or water pipes), and heating end devices (such as standing radiators, radiative floorboards, or registers). These data were collected by viewing archived records and maintenance databases, conducting staff interviews, and completing a site inspection.

To model building energy, we selected the Department of Energy eQuest building energy simulation tool (Crawley et al., 2008). This tool had been used for past studies of building energy consumption on the Smith College campus (Etta Lauren Grover-Silva, 2010). eQuest provides a graphical user interface to the DOE-2 energy simulation modeling software. It is important to note that several versions of the eQuest software have been approved by the California Energy Commission Title 24 as a non-residential Alternative Calculation Method (ACM).

To examine the influence of building parameters on annual heating loads, we constructed a model of Washburn House, a dormitory at Smith College. We used weather data from the Amherst College meteorological station eight miles away. Washburn House was built in 1878, and has a 5000 ft^2 footprint, a total gross occupied area of 19,619 ft^2 on four floors, a predominantly rectangular shape oriented north-south, a load-bearing masonry structure, slate roof (modeled as roof shingles due to the material limitations in eQuest), no wall or roof insulation, a 6 inch concrete slab on grade (earth contact) with no interior finish, and single pane glass windows with 30% net wall surface area coverage. There are no overhangs, blinds, or skylights. We estimated air infiltration rates based on blower door tests on two other load bearing masonry residential buildings of nearly identical in age, construction, layout, and function at Smith College. These results showed air infiltration rates of approximately 6.0 air changes per hour at 50 Pa (ACH50) in the pre-retrofit condition and 3.5 air changes per hour after sealing interventions. When the building is being heated, the indoor core temperature is kept to 70°F while occupied and 64°F while unoccupied. To model the one-pipe steam system with floor radiators, a natural draft steam boiler combusting natural gas was used with an 80% boiler efficiency.

The resulting model showed that we would expect an annual heating load at nominal pre-retrofit conditions of 1160 MMBTU and is within the expected range found by previous research on our campus, specifically Grover Silva et al. (2010), for a load-bearing masonry building.

Energy modeling and energy efficiency improvement costs were combined in a spreadsheet LCC tool (Parker et al., 2018) (see SI_Figure1.xls) which was adapted from the Harvard University tool available online (Harvard University, 2012). Utility escalation rates and prices for water, electricity and natural gas were taken from historical data. All other rates and market prices were adopted from the Energy Information Administration (EIA) (Parker, 2018). A carbon price of $70 per ton, rising at 2.5% per year was applied for the proxy carbon calculations. This value was recently adopted by Smith College (Parker and Barron, 2018) and is roughly in line with the prior U.S. Government social cost of carbon estimates at a 2.5% discount rate (IWG, 2016).

S1.3 Analysis of life-cycle costs studies (Figure 3)

We analyzed several LCC studies conducted with ICPs at three different institutions: Princeton University (Princeton NJ, U.S.A), Smith College (Northampton MA, U.S.A) and Cornell University (Ithaca NY, U.S.A). Data from Princeton University were analyzed under a data confidentiality agreement with Princeton University. Data from Smith College were taken from the example shown in Figure 1 and an additional case study on off-road electric vehicles e.g. golf carts (available upon request, significantly adapted from Howarth and Moonitz (2018)) (n=6 in total). Cornell University analyses were reported publicly (Cornell Senior Leaders Climate Action Working Group, 2016).

The largest share of analyses come from Princeton University where we began with 31 LCC analyses with 69 individual project cases were collected from the study period (2008-2018) after excluding projects with no energy component (e.g. aesthetic features like flooring). These data were originally collected for operational rather than research purposes; some projects had incomplete data (initial costs for alternatives or ICP cost as a component cost were not reported). We were able to extract a final set of 19 analyzed project baseline-alternative pairs (from 36 cases). These were selected because they included sufficiently complete records of energy and carbon costs. Some records required cleaning which included correcting bad spreadsheet references and calculating some missing entries (e.g. present value cost reported, annual value interpolated). For the purposes of this paper, multiple analyses of similar decisions but with different key assumptions were plotted independently and multiple alternatives to the same baseline technology were plotted independently. Institutional assumptions about discount rate and carbon price were not standardized in order to reflect the analysis as it was actually conducted at the time. Baseline options were defined based on labeling and project documentation wherever possible. In cases where the baseline was undefined, the lowest initial cost option was selected. Data spanned 2008-2018 with initial project costs from a few thousand dollars to \$1.4M (median cost \$500,000).

Each project involves making an upfront investment to reduce energy and/or carbon costs by some percentage over the lifetime of the project. An LCC analysis will indicate that a project is financially justified if the up-front investment is lower than the reduction in discounted lifetime energy costs, e.g. if the ratio of investment to lifetime energy costs is smaller than the percentage reduction in energy costs (Figure 2a). Each pair of points on the graph represents the comparison of an alternative (i) with a baseline scenario (b). For Fig. 2a, data from the Smith College case study LCCs and from Princeton University's archive of LCCs were used to compute: (1) the present value of lifetime energy related expenses (denoted $energy_i$ and $energy_b$) and (2) the present value of investment and lifetime non-energy operation and maintenance expenditures (denoted $invest_i$, $invest_b$, om_i, and om_b). A project is financially justified if the energy cost savings are larger than the increase in investment and operation & maintenance expenditures, e.g. if $energy_b - energy_i > invest_i + om_i - (invest_b + om_b)$. To facilitate comparison across projects of widely varying size, we scale by the baseline energy cost implying that a project is financially justified if $1 - \frac{energy_i}{energy_b} > \frac{invest_i + om_i - (invest_b + om_b)}{energy_b}$. For each point in Figure 3, the vertical coordinate is the left-hand side of this inequality and the horizontal coordinate is the right-hand side. A project is financially justified if the vertical coordinate exceeds the horizontal coordinate, e.g. if the point lies above the breakeven line. In each pair of connected points, the circular endpoint includes only actually incurred costs in computing $energy_i$ and $energy_b$, while the triangular endpoints add the proxy carbon price in these computations.

We separately analyzed date from Cornell University's Options for Achieving a Carbon Neutral Campus by 2035: Analysis of Solutions (2016). Due to the way Cornell reported information in this study, there are two computational changes in panel (b). First, energy and operation & maintenance expenditures were reported jointly so the coordinates of each point are given by $(\frac{invest_i - invest_b}{energy_b + om_b}, 1 - \frac{energy_i + om_i}{energy_b + om_b})$. Second, Cornell computed the carbon costs in two ways. The triangular points include only carbon costs for emissions associated with direct combustion of natural gas, while the square points also include greenhouse gas costs associated with methane leakage in the extraction and distribution of the natural gas. Cornell assumed a relatively high upstream leakage rate of 12% and used a 20-year global warming potential. Recent work (Zavala-Araiza et al., 2015), suggests much lower leakage rates.

S1.4 Estimating carbon share of energy costs (Figure 4)

Energy market prices were drawn from EIA data and emissions intensities from Environmental Protection Agency(U.S. EPA, 2018). CO2e intensity for electricity in the northeast was estimated using data from the Independent System Operator New England (ISO-NE) which publicly reports emissions from marginal generation(ISO New England Inc., 2018). CO2e intensity for electricity in the Southeastern U.S. (SERC-Midwest) was taken from U.S. EPA’s eGRID dataset(US EPA, 2020). On campus electrical generation costs (via co-generation) were estimated by Smith College (Northampton MA, U.S.A)(Parker, 2018). These are likely to vary relative to other institutions with unique on-site generation infrastructure. Details in SI_Figure_3 Energy Price with ICP.

Text S2

Supplementary Text on Higher Education Institution Internal Carbon Prices

Summary of Existing Internal Carbon Prices

We have summarized additional details about existing internal carbon prices in U.S. Higher Education below. For several schools, a longer case study and other documentation can be found on the Internal Carbon Pricing in Higher Ed Toolkit website (www.secondnature.org/carbon-pricing). If your U.S. HEI has developed an internal carbon price and is not listed here, please submit a case study to the toolkit.

Princeton University has been using a proxy carbon price in capital construction decisions within facilities planning since 2008.(Princeton University, 2008) They began by using a fixed price at \$25/MTCO2e (metric ton carbon dioxide equivalent), based on European Union carbon markets. In 2016, the price was raised to \$45/MTCO2e. More recently (2019), Princeton has shifted to using a much higher price (\$268/MTCO2e), and will continue to evaluate its effectiveness as a decision-making tool. Princeton has also begun to explore using its proxy price in procurement decisions around concrete. More detail can be found in the case study on the Toolkit website.

After experimenting with a proxy carbon price in 2009, **Yale University** piloted its carbon charge with four approaches in 2015, and then launched the Yale Carbon Charge Project in 2016 to experiment with a revenue neutral carbon fee applied to administrative units on campus.(Gillingham et al., 2017) The Yale Carbon Charge operates by measuring the carbon emissions from each administrative unit (e.g. School of Law, Central Library) and levying a carbon fee on those emissions. Based on performance relative to a baseline, each administrative unit receives a proportional rebate. The charge applies to operational energy consumption in more than 250 buildings owned by Yale University, which represents roughly half of the university's buildings but 70% of energy consumption. Yale uses a fixed carbon price of $40/ MTCO2e, based on the Social Cost of Carbon at 3% developed by the Obama Administration (Interagency Working Group on the Social Cost of Carbon (IWG-SCC) and Office of Management and Budget, 2013) Participating units have responded with a range of steps including energy conservation checklists, energy literacy campaigns, changing heating and cooling set points, occupancy sensors, and equipment efficiency upgrades. More detail can be found in the case study on the Toolkit website and in case studies and student projects from a range of disciplines on the carbon charge website (Yale University, 2018).

Swarthmore College developed a hybrid approach in 2016, with a carbon fund and a proxy carbon price. A Carbon Charge Committee set the proxy carbon price value of $\$100/MTCO_2e$, which is applied to construction, renovation, and campus utilities projects. The carbon fund, which began as a carbon price of $\$23/MTCO_2e$ implemented as 1.25% of department budgets, also includes voluntary donations by departments and raised $333,000 in the first year to be used for GHG emission reduction projects and sustainability education projects(Swarthmore College, 2017). The price was later adjusted to $\$26/ MTCO_2e$. To date (FY17-FY20), the carbon fund has collected $1,338,294 – with $902,467 going towards a green revolving fund (remainder of funds are used for strategic planning, analysis, and outreach). Swarthmore projects lifetime emissions reductions of 12,761 $MTCO_2e$ (roughly equivalent to 80% of current annual emissions from Scope 1, 2 and air travel) from revolving fund projects for a savings of $1,705,008 (or -$134/ $MTCO_2e$) (E. Drake, personal communication). More detail can be found in the case study on the Toolkit website.

Cornell University used a one-time application of a proxy carbon price in a technical and financial analysis of viable options for carbon neutral power and heat for Cornell's Ithaca, NY campus. The analysis used a rising carbon price that tracked the Obama Administration social cost of carbon, starting at $38/MTCO2e and rising at 1.75% per year.(Cornell Senior Leaders Climate Action Working Group, 2016) Unique among the schools we examined, they explicitly applied the price to upstream methane leakage associated with natural gas use, which impacted which projects broke even with the carbon price.

Arizona State University (ASU) is implementing a proxy price for life cycle cost analysis of campus facilities decisions ($10/MTCO2e). ASU has also adopted a carbon charge for all ASU-sponsored air travel (~24,000 trips/yr), including research, athletics and student-paid study abroad. Air travel paid by another institution or individual is not included. The charge was initially set at $8 per round trip flight (~ $4/MTCO2e)—based on futures prices for offsets—and goes to fund offsets.(Dalrymple, 2018) The price has risen every year for five years, and is now at $10/trip. More detail can be found in the case study on the Toolkit website.

Smith College developed a proxy carbon price in 2018, based on recommendations from a campus-wide Study Group on Climate Change. An undergraduate honors thesis designed the approach based on models at Swarthmore College, Princeton University, and Harvard University. The Committee on Sustainability selected a starting range of $60–75/MTCO2e, which was implemented as a proxy carbon price of $70/MTCO2e, which rises at 2.5% per year. This price was prioritized as consistent with a broader trajectory towards keeping global temperatures below 2°C and estimating the social cost carbon in a way that places a higher value on impacts on future generations (i.e. a lower discount rate). The price has been applied to HVAC budget analyses as well as in planning decisions about heating plant fuels and geothermal heating. The ICP has also been used by students in Environmental Science and Policy capstones (Chiang et al., 2020) and in an economics honors thesis (Li, 2019), but there is likely limited awareness of the ICP among the broader campus community. More detail can be found in the case study on the Toolkit website.

Weber State University adopted a carbon fund for air travel in 2012. The fee is assessed on VP-level administrative units as a share of the total flight miles at the start of the fund (2012) (Utah State University, 2020a). It has been assessed as $0.01 per flight mile (approximating ~ 1 lb CO_2e per mile or ~$22/MT CO2e). As flight miles have increased over time, the total funds collected has increased from $20,000 in 2012 to $100,000 in 2016 at which point the total amount of fee was capped. Air travel has stayed relatively stable in the 8-10 million miles range in recent years (Jennifer Bodine, Weber State University, personal communication). We note that this program has been run internally, with no public-facing components.

Whitman College is unique in that the student government voted to voluntarily apply a carbon charge to a student travel fund. The tax varies with mode of transport and time zones crossed. Proceeds are used for a student green fund(Ezarik, 2016).

The **University of Maryland** developed a carbon charge for air travel in 2017. It applies a charge of $5 per domestic round trip which is used to fund offsets (Colella, 2017).

The **University of California Los Angeles** adopted a carbon charge for air travel in 2018 as a 3-year pilot. It applies a charge of $9 per domestic flight and $25 per international flight. Proceeds go to fund on-campus emissions reductions projects such as energy efficiency and/or renewable energy. Grant-funded, study-abroad, and charter flights for athletics teams are exempt (UCLA, 2018).

Utah State University recently adopted a $10/flight carbon charge for air travel. The university is covering all of the fees in the first year of the program, phasing in payments by academic departments over time (Utah State University, 2020a; Utah State University, 2020b).

Note: Southern Oregon University also levies a 1% fee on air travel and uses it to fund a Climate Action Fund (CAF) which supports conservation projects on campus, including lighting retrofits, building envelope upgrades, and other projects (Beigel-Coryell, 2016). However, they do not consider this a carbon price so we have not included it in our official tally.

In table S2.1 (below) we list information on two other climate action areas (carbon neutrality and fossil fuel divestment) for each school with an ICP.

Non-governmental organizations (NGOs) share many features with U.S. HEIs. The U.S. NGO the World Resources Institute has a carbon charge of $50/ton for their staff's air travel, electricity consumption, and employee commuting, with the bulk of the proceeds going to metrics collection, policy development and implementation(Kamins et al., 2018).

Data Availability

The data for figures 2 and 4 are located in the associated SI data files with additional details available upon request. Information for Figure 3(b) can be found on the website for Cornell University's Options for Achieving a Carbon Neutral Campus by 2035: Analysis of Solutions (2016). The processed version of the data used in figure 3a are stored in "SI_Figure3a_graph_data.csv". Requests for the original data under a data confidentiality agreement should be directed to Shana Weber (shanaw@princeton.edu).

Code Availability

R code (R v4.0.0, R Studio v1.3.959) used to generate the figures is located as SI_Code_BarronInternalCarbonPricing.Rmd at https://github.com/barronlab/proxycarbon

Institution	**Carbon Neutrality Commitment Date**	**Fossil Fuel Divestment Announcements (if any)**
Arizona State University	2020	
Cornell	2035	Direct and indirect (2020)
Princeton University	2046*	
Smith College	2030	Direct and indirect (2019)
Swarthmore College	2035	
University of California Los Angeles	2025	Direct and indirect (2019)
University of Maryland	2050	Direct (2016)
Utah State University	2050	
Yale University	2050*	Coal and oil sands only (2016)
Weber State University	2050	
Whitman College	2050*	Direct and indirect (2018)

Table S2.1 Carbon neutrality dates and fossil fuel divestment status for institutions with ICPs. Carbon neutrality commitments are generally under the Second Nature framework (Second Nature, 2019) (but not for all schools, *=outside SN framework (Yale Sustainability, 2005; Whitman College, 2016; Princeton University, 2019)). Endowment divestment announcements reflect divestment from coal, oil and fossil gas unless otherwise noted (Smith College, 2018; GoFossilFree, 2020; Stamm, 2020). Dates reflect year of announcement as divestment may play out over time. Direct refers to investments held individually. Indirect refers to collections of investments (mutual funds and venture capital).

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