Local Sustainability Policies and Programs

A Handbook for Deliberation Support from the Climate Decisions Laboratory at the University of Pennsylvania

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This is a draft, very much a work in progress. Comments and suggestions welcome. kimbrough@wharton.upenn.edu

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Preface

This handbook is, as its subtitle proclaims, meant to serve as a tool to support deliberation with regard to climate change-related programs and policies ("programs" for short). Our focus is on programs that may be implemented at state and local levels of government and administration. The needs of such deliberation are open-ended and in consequence the handbook can never truly be completed. Our plan is to begin by producing something that has some immediate utility and then grow it to become ever more valuable.

Policy making is fraught, vexing, and contentious, especially so in the case of climate policy. The purpose of this handbook is to assist those who would seek to establish effective climate and sustainability policies in the face of great ranges of interests and views by stakeholders. The assistance is in the form of policy and program information, as well as pertinent methodologies, tools, instruction, and results. We appreciate that the methodologies will be unfamiliar to many and their relevance and use not apparent. Indeed, there is no imperative to select everything on the menu this handbook presents. We encourage picking and choosing and we counsel patience and communication with the authors.

We envision several kinds of supports for policy deliberation on sustainability. In brief:

1. A curated repository of information about policies and programs appropriate for state and local adoption. This information constitutes the core of the project, upon which all else builds.
2. Tools, instruction, and eventually results on decision processes for group decision making for climate change policies.
3. Tools, instruction, and eventually results on decision analysis modeling pertaining to climate change policies.
4. Role-play simulations for climate change policy design.

Part I presents a succinct overview for each of these elements.

There are two overarching and distinctive presumptions to this project. (1) There is much to be gained in considering the program alternatives as a group. (2) The analysis will be permanently incomplete, with imprecise and incomplete data present. The trick is to make the most of what we have.

—Steven O. Kimbrough, April 4, 2021, `kimbrough@wharton.upenn.edu`

Part I

Preliminaries

Chapter 1 Overview

By: Steven O. Kimbrough

1.1 Introduction

Transitioning to a sustainable, resilient society is necessary and urgent. It is also dauntingly complex. This great transition requires putting into place a large number of programs and policies. These programs will be selected from a much larger set of possibilities. They will often interact, with vexing consequences that are challenging to foresee.

Organizations of all sizes–civic organizations, state and local governments, small, medium and large commercial firms, national governments, and international treaty organizations—have to grapple with decisions of which programs and policies to implement, and how. They are doing so today and will continue to need to do so at scale.

Focusing on programs and policies apt for selection by municipalities and other local governments, the purpose of this handbook is to facilitate the discussions, the deliberations, and the decisions, that are undertaken to effect the great transition. We are especially concerned with how policies interact with each other and with the preferences and interests of stakeholders. The present chapter overviews concepts for facilitating and supporting these deliberations. It is an introduction to—a brochure for—the larger report that follows and that will be permanently under development.

Throughout and especially in this chapter, we proceed concretely, with examples. We begin with examples of programs and policies that constitute the basis of any deliberation. The deliberations are, after all, about which policies and programs to put into effect and how. It is best, then, to put examples of the objects of deliberation, the policy options, clearly in view and to keep them there.

1.2 A High-Priority Discussion Pool of Sub-National Programs and Policies

This section presents several **kinds** of programs and policies; each has multiple specific variants. Subsequent chapters will expand the scope and specificity of policies in play. Our focus in this chapter is on examples that illustrate the overall approach.

1.2.1 The Short List

The purpose of this section is to present and maintain one or more short lists of policies, suitable to be candidate policies in role play and group discussion exercises. Unless otherwise noted, the presumed context is a county or municipal government.

1. Low embodied carbon concrete
2. Composting
3. GEO: green extension office
4. Building electrification mandates and subventions
5. Electrification of lawn care equipment
6. Electrification of transit buses and utility vehicles
7. Food rescue programs
8. EV charging stations
9. Non-motorized (pedestrian and bicycle) thoroughfares
10. Clean-sourced natural gas
11. Green electricity

2021-08-05: The above 11 are for now meant to be a stable list for decision modeling purposes. Each program has a short draft chapter discussing it, in Part II. The remainder of the material in this section needs editing to reflect this latest version of the short list.

1.2.2 Low Embodied Carbon Concrete

Making cement for concrete is a major GHG emissions source, perhaps seven percent to total global emissions (https://www.iea.org/reports/cement).[1] Fortunately, commercial products are now available at a modest cost premium that provide *low embodied carbon concrete*. In consequence many organizations, both commercial and governmental, have developed policies and practices to encourage or even require the use of low embodied carbon concrete in new construction, including buildings, roads, and sidewalks. The additional cost is a very small percentage of the total cost of the associated projects.

Research the calculation of what it costs to reduce a tonne of CO2 emissions by using low carbon concrete.

Administrative costs (rules and verification procedures) are small for the governing entity and quite incremental to the funder of a project.

The Concrete Center is a good online source, https://www.concretecentre.com/ and especially https://www.concretecentre.com/Publications-Software/Concrete-Compass/Low-Carbon-Concrete.aspx. See chapter 7 for further discussion.

[1]For a news report: https://theconversation.com/bendable-concrete-and-other-co2-infused-cement-mixes-could-dramatically-cut-global-emissions-152544 https://theconversation.com/bendable-concrete-and-other-co2-infused-cement-mixes-could-dramatically-cut-global-emissions-

1.2.3 Composting

Composting is the process of turning organic, carbon-based materials into nutrient-rich fertilizer for soil. It enhances the porosity, stability, water retention, and tillage of soil and improves its resistance to erosion and parasites. As an aerobic process, it decomposes waste materials from yards, kitchens, homes, and other sources in order to manage waste. This diverts the waste from going into a landfill and provides a variety of benefits. There is some benefit from GHG emissions reduction, as the composted materials sequester carbon in the soil.

We need to nail this down more specifically.

Composting programs come in several varieties. The most relevant form for municipalities is *curbside composting*, in which buckets of compostable materials are collected from households much as garbage and recyclables are collected. When run as a typical commercial service, customers are given a fresh five-gallon bucket with each pick up and are changed \$12 (\$18) per month for bi-weekly (weekly) pick up and bucket replacement.

Curbside composting programs may be run in a variety of ways. They may be done in-house or outsourced to a commercial vendor; they may be charged directly to participants or funded as part of general waste collection.

Municipally-sponsored curbside composting programs are common and have existed for several years.

What can be composted is an important issue that arises with all composting programs. Plastics substitute products (table ware, bottles, etc.) on the market are often promoted as compostable but must be treated with high-end industrial composting processes that local vendors often to do provide. Local vendors typically dismiss these compostable claims as greenwashing.

Composting programs require initial and perhaps ongoing educational programs to assure their proper use and flourishing.

See chapter 8 for further information.

1.2.4 Green Financing

Green financing is often instituted through a *green bank* of one kind or another. A green bank is an institution that is created to provide opportunities and funding for green initiatives.

Contrary to the name, a green bank is typically not actually a bank; the institution is often a nonprofit that acts more as an investment vehicle and works to broker deals between investors (clients) and funders. Rather than competing with existing financial institutions, a green bank provides financing with the goal of creating environmental impact, not maximizing profit. The value proposition is that the green bank reduces the cost of capital for green projects, thus incentivizing the change towards a more sustainable future. Some green banks take on many smaller, conventionally unprofitable loans and securitize them for larger banks; this allows the green bank to pursue smaller projects and enables larger banks to partake in financing green projects.

In addition to simple financing, green banks may implement creative or non-traditional methods of allocating capital to customers unable to dedicate sufficient money to green projects. For example, a green bank may choose to co-invest in a project that does not have sufficient funds or resort to on-bill financing (allowing customers to include repayment as a part of their utility bill). However, the function of a green bank does not stop with financing; green banks typically provide ancillary services to customers, ranging from standardized contracts to project-specific consultation.

There are a few dozen stably operating green banks in the U.S. The one for Montgomery County, MD, is notable as a successful green bank operating at the county level (https://mcgreenbank.org).

See chapter 19 for more information.

1.2.5 Electrification of Transit Buses and Utility Vehicles

Policies to replace internal combustion engine (ICE) transit buses and utility vehicles with battery electric-powered vehicles (BEVs) have been put into operation by a number of municipalities. A handful of vendors now supply the market. Many new entrants are anticipated during the next few years.

The basic economic properties of the BEVs are clear: BEVs presently cost much more than ICE vehicles and must also be supported with charging stations. After acquisition, operation and maintenance costs are much lower than with ICE vehicles. It is generally agreed that life-cycle costs of BEVs are now often competitive with ICE vehicles of this class. Further, cost reductions are anticipated in the near future due to competition and falling prices of batteries.

A number of financing and service arrangements are available, including state and federal subsidy programs, and vendors that offer leasing programs.

Reduced air pollution is a significant co-benefit of BEVs, in addition to meaningful reduction in GHG emissions.

We need more numbers here on costs, etc. Just a little.

See chapter 12 for more information.

1.2.6 Internal Carbon Pricing

Internal carbon pricing occurs when an organization—whether public, private or third sector—imposes on itself a price for greenhouse gas (GHG) emissions. The price is normally expressed in dollars per metric tonne of CO_2e (carbon dioxide equivalent) emissions. This can be done in various ways. For present purposes, we focus on pricing by *carbon fee* because it is likely the most important option for local governments and institutions. It works along the following lines:

1. The institution identifies activities to be subject to the fees and quantifies CO_2e emissions for them.

For example, an institution might designate a standard CO_2e emissions rate in tonnes per passenger mile traveled by airplane.

2. The institution sets the internal carbon price in dollars per tonne of CO_2e emitted.
3. When institutional funds are expended for a covered activity a carbon pricing fee is assessed for the activity. Typically, this would be internal carbon price times the standard rate for the activity times the amount of activity, e.g., carbon price $\times$ emissions per mile $\times$ miles traveled.
4. The funds collected are subsequently allocated for broadly "green" purposes, such as purchasing carbon offsets and funding green investments in the organization.

The potential benefit of internal pricing programs is that at small cost to the organization they gently and effectively encourage reduction in GHG emissions and encourage productive investment in that direction. It is also likely that there are positive effects on organizational culture.

See chapter 20 for more information.

1.2.7 Sustainable Living Information and Advice

This family of programs is both informational and educational. As such it belongs in a long tradition of government-sponsored information and advisory programs, such as extension agents and health advisories. This form collates and circulates information about saving money on energy and about living more efficiently, more sustainably, and more healthfuly. Pertinent topics include advice (regarding supporting programs, contractors, etc.) for home energy improvements, information on composting, information on healthy lifestyles, information on indoor air quality, information on carbon footprinting and building thermal efficiency, and so on.

Budget costs can be kept minimal by organizing volunteers or working with NGOs. Co-benefits may include a positive response from the community and gratitude for a service economically rendered.

1.2.8 Building Electrification

Electrification of buildings, especially replacing fossil fuel-based residential heating and cooling systems with electric alternatives, is perhaps the most substantial policy available to municipalities in terms of reduction of GHG emissions.

Building electrification is also perhaps the most fraught and contentious of the available policy options. See https://podcasts.apple.com/us/podcast/the-clash-over-gas-bans-in-b id663379413?i=1000513548635 (https://podcasts.apple.com/us/podcast/the-clash-over-gas-bans-in-buildings/id663379413?i=1000513548635) for a podcast discussion of recent developments (March 18, 2021). See also https://www.motherjones.com/environment/2021/02/how-the-fossil-fuel-industry-convinced-americans-to-love-gas-stoves/

(https://www.motherjones.com/environment/2021/02/how-the-fossil-fuel-industry-convinced-americans-to-love-gas-stoves/) (February 11, 2021).

A number of municipalities have enacted requirements that new building construction after a certain date provide natural gas hookups, thereby in effect requiring electrification of heating and cooling. Alternative policies offer subsidies for electrification.

Vehement opposition from the oil and gas industry is likely.

See chapter 10 for more information.

1.2.9 Behavioral Interventions

There are any number of ideas popping up for gently encouraging people to take beneficial action with regard to climate and sustainability. The very existence of parks and trails encourages outdoor recreation and exercise. Libraries encourage reading. Opt-out instead of opt-in defaults on employment savings plans encourage savings. The ideas are legion.

What might encourage pro-climate action? A recent proposal by Howard Kunreuther and colleagues is for a polity or organization to hold a lottery into which all members of the community are entered. If the winning ticket is drawn by a member who has committed to the preferred action, that member gets a prize. If the member has not previously committed, the prize is not handed out.

To illustrate, a lottery with winning prize of say $500,000 might be instituted with the prize being given out only if the owner of the winning ticket has an operating 10 kilowatt or larger solar installation on their home. The theory is that advance knowledge of the lottery would encourage solar PV. Of course, there are equity considerations present and any such lottery program would need to be carefully designed, but the concept is intriguing.

See chapter 21 for more information.

Chapter 2 Introduction to first-cut analysis

This chapter uses a simple example to introduce first-cut analysis for comparing decision alternatives, in particular the alternatives in the pool described in chapter 1. First-cut analysis is in turn simple and intuitive method for taking an initial towards evaluating a collection alternatives.

We begin with a discussion of the evaluation criteria to be used in the example and how they are to be scored. Then, in §2.2 we discuss and score each program in the pool laid out in chapter 1. The last section, §2.3, discusses the pool of alternatives in light of the scoring in §2.2 and draws out some insights for further deliberation.

2.1 Criteria and Their Scoring

The programs and policies under consideration are to be evaluated by comparing how they perform on the evaluation criteria that are important to the relevant stakeholders and decision makers. In our first-cut analysis we use a maximally simple scale with three points (-1, 0, 1) where a 1 indicates a definite and discernible positive value, -1 a definite and discernible negative value, and 0 an intermediate value, which may be slightly positive or slightly negative. These assessments are, of course, merely a first cut.

We work with a simplified list of evaluation criteria. (Remember, the chapters in part I are not only tutorial in nature, they are introductory. We are giving an overview of the approach.) Our criteria for now are:

BCO Budget expense (cost) to the local government or other organization net of outside grants and program funding such as federal programs. A 1 indicates that the organization actually profits in a meaningful way. A 0 indicates a small profit (rare) or expense, say on the order of funding one employee for a year. A -1 indicates substantial expense to the organization, paid out of its own funds net of outside grants and other funding programs; roughly, these are general revenue dollars raised from the tax payers.

SCO Social expense (cost) to the pertinent body of stakeholders. A -1 indicates a substantial expense. This may occur, for example, due to mandated behavior, such as building improvement, that is not compensated. A 0 indicates a small expense or payment. A 1 indicates a meaningful payment to members of the stakeholders.

GHG Greenhouse gas emission reduction, also called climate mitigation. 1: indicates a definite and discernible positive value. 0: intermediate value, which may be slightly positive or slightly negative. -1: definite and discernible negative value.

HnS Health and safety effects.

CoB Co-benefits, positive consequences other than cost and GHG emissions. Example: a program that creates or improves a recreational area as a side-effect.

DiB Disbenefits, positive consequences other than cost and GHG emissions. Example: a program that destroys or degrades a recreational area as a side-effect.

TRA Transition effects. Are we moving in the right direction? Does it favor something that has to be done eventually? Does it help with adaptation or resilience?

Scores on these criteria can be recorded in tables with the following columns:

BCO	SCO	GHG	HnS	CoB	DiB	TRA

2.2 First-cut scoring

2.2.1 LECC: Low Embodied Carbon Concrete

A policy of requiring use of only low embodied carbon concrete on publicly funded projects has a very modest cost, and so is scored a 0 on BCO, yet would yield a definite benefit in foregone GHG emissions and so is scored a 1 on GHG. The remaining attributes are scores as 0s because any effects are rather minor, expect transition because presumably low carbon concrete in some form or another will be required in the future.

The following, then, is a reasonable first-cut scoring for low carbon concrete.

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
LECC	0	0	1	0	0	0	1

2.2.2 CSCom: Curb Side Composting

A policy of curb side composting, funded as garbage pickup and disposal is funded is here scored as a 0 on BCO because it is expected to be only marginally more expensive than the status quo, net of landfill savings. It is scored a 1 on CoB, co-benefits, because the soil created is environmentally friendly and useful. It is scored a 1 on GHG because it sequesters or reduces some GHG (CO2 and methane) compared to the alternative of landfill disposal. It also scores a 1 on TRA, transition, because it is likely to be required in a highly sustainable society. The remaining criteria come in as 0s.

The following, then, is a reasonable first-cut scoring for curb side composting.

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
CSCom	0	0	1	0	1	0	1

2.2.3 GreF: Green Financing

A successful green financing program, whether or not in the form of a green bank of some kind, would lead to significant GHG emissions reduction by leading to completion of projects that would otherwise not have been undertaken soon, or even at all. Examples include investments in solar PV, replacement of gas with electric appliances, building energy efficiency, and so on. Health and safety benefits (e.g., clearer inside air) and transition benefits would normally ensue. In many cases co-benefits may be realized.

The following, then, is a reasonable first-cut scoring for green financing.

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
GreF	0	0	1	1	1	0	1

2.2.4 EBus: Electrification of Transit Buses and Utility Vehicles

The following is a reasonable first-cut scoring for electrification of transit buses and utility vehicles. HnS scores a 1 on air pollution reduction. CoB = 1 because of noise reduction and comfort improvement. TRA = 1 because ICE vehicles will eventually have to be eliminated. BCO = -1 on the assumption that the life-cycle costs of the vehicles remain a bit higher than for ICE vehicles (but the difference is small and will go the other way, it is believed, within a few years).

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
EBus	-1	0	1	1	1	0	1

2.2.5 InCP: Internal Carbon Pricing

In principle, internal carbon pricing is cost neutral and serves to increase efficiency in the organization. It does assume, however, a prior commitment by the organization to make expenditures in service of climate change mitigation. The positive scores on GHG and other attributes assume that accompanying investments are made that achieve these goals.

The following, then, is a reasonable first-cut scoring for internal carbon pricing.

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
InCP	-1	0	1	1	1	0	1

2.2.6 SusL: Sustainable Living Information and Advice

An effective ongoing informational campaign, funded at minimal cost with volunteer and NGO participation, may foster behavior and community values leading to higher levels of climate and environmentally friendly activity. Mechanisms include reducing barriers to action and encouraging action by imitation of others. This latter impetus is a form of behavioral intervention, §2.2.8.

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
SusL	0	0	1	1	1	0	1

2.2.7 GasB: Building Electrification

A growing number of cities have imposed prohibitions of gas hook ups for new construction. The budget cost of this is low, while the social cost is scored a -1 because it is borne by individuals. The disbenefit score is likewise a -1 because many individuals may prefer gas heating, etc., regardless of cost. On the other hand, banning gas from buildings has a hugely positive effect on GHG emissions, especially as the secular greening of the electric power system advances. Building electrification has positive health and safety aspects as well as co-benefits.

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
GasB	0	-1	1	1	1	-1	1

2.2.8 BHav: Behavioral Interventions

Behavioral interventions constitute a grab bag of policies of great variety, making it problematic to characterize them collectively. We saw one example in §2.2.6: encouraging people to undertake pro-climate and environment actions by informing them of similar actions taken by their neighbors. There is good evidence for this effect.

Many behavioral interventions are informational in nature and can be classed as cases covered by §2.2.6, e.g., for overcoming myopia bias and herding bias. Programs to overcome inertia bias often work by setting up favorable defaults and allowing stakeholders to opt out. There is much evidence supporting the effectiveness of the opt out design.

As an example program, new construction permits might be denied gas hook ups without paying a fee and making a presentation at a public hearing or otherwise making this decision public.

Depending on how onerous the opt out provision is, behavioral interventions can be effective at very small cost, in part because the social cost is judged small because the actor is acting voluntarily, whether opting in or out.

	BCO	SCO	GHG	HnS	CoB	DiB	TRA
Bhav	0	0	1	1	1	0	1

2.3 Discussion of the Scored Pool

Combining these scoring results into one table yields table 2.1.

Program	BCO	SCO	GHG	HnS	CoB	DiB	TRA
LECC	0	0	1	0	0	0	1
CSCom	0	0	1	0	1	0	1
GreF	0	0	1	1	1	0	1
EBus	-1	0	1	1	1	0	1
InCP	-1	0	1	1	1	0	1
SusL	0	0	1	1	1	0	1
GasB	0	-1	1	1	1	-1	1
Bhav	0	0	1	1	1	0	1

Table 2.1: Example First-Cut ACS (alternatives, criteria, scores) table. Alernatives: LECC: Low Embodied Carbon Concrete, CSCom: Curb Side Composting, GreF: Green Financing, EBus: Electrification of Transit Buses and Utility Vehicles, InCP: Internal Carbon Pricing, SusL: Sustainable Living Information and Advice, GasB: Building Electrification, BHav: Behavioral Interventions. Evaluation Criteria: BCO: Budget expense (cost), SCO: Social expense (cost), GHG: Greenhouse gas emission reduction, HnS: Health and safety effects, CoB: Co-benefits, DiB: Disbenefits, TRA: Transition effects.

Table 2.1 is instructive, but hardly dispositive. It constitutes information useful for subsequent deliberation, rather than a decision tool itself. Its main virtues lie in identifying especially strong or weak alternatives and in identifying where more study and finer scoring might be especially rewarding.

On identifying especially strong or weak alternatives:

1. Green financing (GreF), sustainable living advice (SusL) and behavioral interventions (Bhav) have identical scoring signatures and weakly dominate all other policies under the scores and scoring regime in place. That is to say, each of these alternatives is at least as good on all criteria and better on some than each of the other five alternatives.
2. Banning gas in new construction, GasB, is flagged as problematic if only because it is the only alternative with two negative scores.

On identifying were more student and finer scoring might be especially rewarding:

- Curb side composting (CSCom) dominates low embodied carbon concrete (LECC). Both get a 1 on GHG emissions, but are they actually close in this regard and which is better? If LECC reduces GHG emissions very much more than does CSCom, it may well be judged preferable to give LECC a higher priority than CSCom. The point here is that the first-cut ACS table directs us where to look for more information.

Discussion and reflection on a first-cut ACS table, such as table 2.1, are likely to reveal need for two kinds of improvements. The first is improvement in measurement. The table is potentially useful for advising our efforts better to nail down costs, emission levels, and so on. It can do this by identifying where better information is likely to matter and where not.

The second kind of improvement likely to be identified is in the criteria, the columns in the ACS table. Are these the right attributes? What should be added or removed from consideration?

The first-cut ACS table supports deliberation by being modified in response to deliberation with new scores and new kinds of scores, and with new criteria. But this is just a beginning. We turn next to a deeper look at program and policy evaluation criteria, extending the discussion beyond the introductory example of this chapter.

Chapter 3 Evaluation Criteria, Costs and Benefits

The "shopping list"[1] (consideration set) of program alternatives in the rows of the ACS table, table 2.1 page 12, is obviously incomplete. Any realistic situation will have many more programs on the list and up for consideration. See chapter 6 for a more comprehensive list of program alternatives. What should be clear, however, is that no list as in chapter 6 can be complete. Comprehensive, yes; complete, impossible. New ideas are constantly arising and there is no reason at all to think this will end anytime soon. We have to proceed accepting that the situation, and the stock of program ideas, is and will remain in flux.

The same is true of the evaluation criteria, in the columns of table table 2.1 page 12, and for pretty much the same reasons. Making a comprehensive list is possible; making a complete list is not.

For alternatives in the shopping list as well as their evaluation criteria, it is ultimately up to the decision makers to decide which alternatives and which evaluation criteria to consider. The job of handbook such as this is to supply useful information, not to make the decision. Our purpose in the present chapter is to provide useful information about evaluation criteria. Chapter 6 provides a reasonably comprehensive inventory of program and policy alternatives. We take a different tack when it comes to evaluation criteria. This is because evaluation criteria will often be particularized to places and circumstances. While just about every local government can have a curb-side composting program, only Lower Merion Township in Montgomery County, Pennsylvania, can sensibly have an evaluation criterion that takes into account the Cynwyd Heritage Trail (`http://www.cynwydtrail.org/`).

In consequence, discussion of evaluation criteria needs to proceed at a more general level if it is to be useful. That is what we essay to do in this chapter. We begin with discussion of certain fundamental principles that haunt and suffuse climate change policy making.

3.1 Externalities

"Greenhouse gas (GHG) emissions are externalities and represent the biggest market failure the world has seen." Thus begins, famously and correctly, Nicholas Stern's 2008 Richard T. Ely lecture "The Economics of Climate Change" [**?**].[2] Stern's point is central to climate change policy at all levels of decision making, from international agreements to local program development. Therefore, we dwell on it briefly in order to communicate the core of the concept and then we explore the ramifications for our context, policy making at the local level.

[1]Thanks to Michael McElfresh for the term, which we hope communicates effectively.

[2]The lecture summarizes and reflects on the authoritative and highly influential *Stern Review* [**?**], which was commissioned by the British government for the purpose of providing advice on climate change policy.

Externality is a term of art in economics (jargon in other words). The associated concept lies at the core of climate change policy and may be characterized as follows. In a transaction between a buyer and a seller, an externality is said to be present if there is a cost or benefit to a third party not participating in the transaction. Environmental pollution is a standard example. A factory manufactures widgets, dumps waste chemicals into a stream, and sells the widgets to a buyer. The damage done by the waste chemicals is said to be an externality because its cost is not reflected in the price of the widgets. Buyer and seller save money by imposing a cost on a third party, in this case users of the stream.

Greenhouse gas emissions in particular are said to be externalities because when fossil fuels are burned and GHGs are emitted costs are imposed on third parties. Neither the buyer nor the seller of the fossil fuel pays for the damage done by the resulting GHG emissions. In consequence, neither buyer nor seller has, absent policy interventions, any incentive to expend money to reduce their GHG emissions.

Economists generally agree that the case for a market-based economy rests on markets that succeed and in consequence are efficient mechanisms of allocating value. They further agree that significant externalities constitute market failures and lead to inefficient markets, and that such failures should be redeemed by policy interventions, typically by imposing a price on transactions with externalities and using the resulting revenues to compensate for damages. We are safe in making these assumptions and will do so. The idea of imposing compensating costs on GHG emissions shows up in ongoing discussions of putting a price on GHG emissions, thereby encouraging green alternatives and better functioning markets. Imposing a price on GHG emissions, it is agreed, will reduce them and ameliorate the onslaught of global warming. How much it would do so, and whether it would be fast enough to present catastrophe, is another matter, one that not detain us for present purposes.

GHG emissions are an especially vexing externality because in addition to market failure GHG emissions also constitute what is called a *tragedy of the commons* [13]. An example will make the notion clear. In a typical policy case, a particular group of tax payers pays to reduce GHG emissions, but everyone in the world benefits more or less equally and very slightly at that. Put bluntly, why should the citizens of Our Town spend real money to reduce GHG emissions when the overall effect is minuscule and is enjoyed by the entire world? Whatever the cost is, the benefits are less to those who pay. The atmosphere is owned by no one and can be owned by no one, yet is used by everyone. Any individual or business that pays to reduce its GHG emissions is at a comparative cost disadvantage to other individuals and business that forego the payments. In consequence, we can expect ongoing damage from GHG emissions. It pays no single government or other organization to invest in GHG reductions because the benefits will always be less than the costs.

That is the standard story. Of course we do see governments, corporations, individuals, and others paying real money to reduce GHG emissions and it is instructive to inquire why. For the present, the point is that the tragedy of the commons story teaches us that proposals to spend money to save the commons, in this case to reduced GHG emissions, will in all likelihood face serious headwinds from some quarters. That these headwinds might disrupt an election and lead to reversal of a policy is hardly beyond the realm of possibility. In these very politicized times we see people who prefer to spend money to degrade the atmosphere.

As a practical matter, we note that faced with an ACS table as in table 2.1 page 12, many stakeholders will place little if any value on the GHG reduction criterion (column), especially if the associated program has significant costs associated with it. In a nutshell, this is a big part of why programs to ban natural gas in new construction arouse resistance.

The upshot for policy making at the local level (and indeed at all levels) is that effective climate change programs and policies need to find ways to circumvent the tragedy of the commons aspect of GHG emissions. Relying on "doing what is right" is unlikely to garner sustained and overwhelming political support.

What, if anything, can be done in response to this problem? At an abstract level the solution is plain, keeping ACS tables in mind (e.g., table 2.1 page 12). The challenge is to find additional criteria for a program that reduces GHG emissions (or whatever else is in contention) such that the program scores well enough on the additional criteria to overwhelm the costs of GHG reduction from the program.

There are two distinct but related kinds of criteria for doing this: externalities not subject to the tragedy of the commons, and co-benefits.

There are important externalities associated with climate change other than GHG emissions. Among them are the following, all of which involve local effects and so are less exposed than GHG emissions to the tragedy of the commons.

1. Noise

   ICE (internal combustion engine) vehicle traffic and two-cycle lawn care equipment, for example, can disperse significant amounts of noise to third parties, for which they are not compensated. Costs imposed on the buyer and sellers of this equipment for the sake of converting to quieter machines may be justified at least in part by noise reduction to third parties.

2. Health effects

   Air pollution from ICE traffic and from fossil fuel (mainly gas) combustion in residences degrades air quality with multiple health-related effects.

3. Habitat loss

   Habitat loss from new construction, including roads may diminish environmental services, including simple enjoyment, in many ways.

4. Risk imposition or shifting

   Long term commitment to use of natural gas (as in the case of new power plants), shifts the risk of price increases to the customers.

These and other negative externalities of fossil fuel use (no doubt others can be found) can potentially be leveraged to support programs that reduce fossil fuel usage and GHG emisssions.

To be sure, there are negative externalities associated with some climate solutions. Wind turbines for example have often elicited complaints on grounds of noise and esthetics.

3.1.1 Examples

Health effects are perhaps the most salient and documented externalities associated with fossil fuels. They are also much less vulnerable to tragedy of the commons problems than GHG emissions. The following article presents a strong public case in this regard.

"One small idea in Biden's infrastructure plan with big benefits: Electric school buses" (April 6, 2021) https://www.vox.com/future-perfect/2021/4/6/22364385/ one-small-idea-in-bidens-infrastructure-plan-with-big-benefits-electric-schoo (https://www.vox.com/future-perfect/2021/4/6/22364385/one-small-idea-in-bidens-infrastructure-plan-with-big-benefits-electric-school-buses)

3.2 Co-Benefits

The material in this section is drawn from https://riskcenter.wharton.upenn.edu/climate-risk-solutions/recruiting-values [15].

And needs further editing to get the references in.

Action on climate change is often presented—accurately—as costly and difficult, but necessary. The following passage is typical:

> Devising ways to sustain the earth's ability to support diverse life, including a reasonable quality of life for humans, involves making tough decisions under uncertainty, complexity, and substantial biophysical constraints as well as conflicting human values and interests [5]. https://science.sciencemag.org/content/302/5652/1907

This "tough decisions" message, truthful as it is, is in fact a message that many people will not be receptive to, simply because it is tough. Lamentable as this may be, the brute fact is that change will happen faster the more people there are who see an immediate and direct benefit to themselves.

There are things that can be done, including behavioral interventions that circumvent biases and irrationality, effective framing, and research aimed at understanding human decision making. All of this is well and good, and should be vigorously pursued. My purpose here is to draw attention to different approach, one that is entirely complementary.

Consider the following passage appearing in a recent op-ed piece in the Philadelphia Inquirer. The author is discussing a proposal for handling storm water, which proposal she claims:

. . . creates community green space, revitalizes vacant lots, enhances recreational use, and even reduces illegal drug use in public spaces. It can reduce heat stress and energy use while improving air quality and contributing to climate change resiliency. And . . . can stabilize property values and reduce poverty through job creation.

In all, as we can see, she recruits ten values (create community green space; . . . ; reduce poverty through job creation) that she adduces in favor of her proposed policy.

The proposal advocated by Jacquelyn Bonomo in the Inquirer piece is presumably not the cheapest—not the best on direct, immediate costs—of the proposals under consideration. Were it otherwise, she would have argued directly for it on the basis of cost. Instead, she appeals to other values to compensate for comparative weakness on the cost value.

Bonomo's strategy is entirely legitimate, and in fact is routinely and widely used. We may describe it as recruiting values beyond the narrowly economic to support a policy position. Much of what makes complex problems complex is that multiple values are in play. Climate change is a case in point. Here and in general, normatively proper decision making requires that all pertinent values associated with a decision be identified and considered in the deliberation for decision making.

The observation I would to make, the impetus for this blog post, is that recruitment of values beyond the narrowly economic has not been done thoroughly and systematically enough on matters pertaining to the necessary transitions mandated by climate change. There is opportunity for the climate change community to do better. Proposers (Bonomo is an apt example) today must, on a case by case basis, identify and assess the wide range of values associated with policy initiatives.

Imagine instead that an organized, curated, maintained, and accessible body of information on recruitable values were available to help every Jacquelyn Bonomo making a policy proposal for climate change transitions. We might call this tool a climate change values repository.

Note that many, perhaps all, of the ten values Bonomo cites as favoring her proposal (above) are relevant to other transition issues. Knowledge assembled about one value—its benefits, its costs, its main characteristics—can be leveraged in multiple ways and on multiple issues.

Such a tool would bid fair to speed the development of transition policy proposals, and strengthen them in the process. It would also speed the identification of weaker ideas, serving to focus attention on more promising ideas. It could help to assemble policy bundles that would be broadly attractive. Log rolling is an essential, legitimate feature of compromise and accommodation of diverse interests. Also, because the values in play for climate change are wide-ranging, assembling a climate change values repository will serve to draw in and involve a correspondingly wide-ranging collection of people, skills, and interests.

Most important of all, the values recruitment approach, and any tool to support it, would afford ways of reaching people for whom the tough decisions messaging fails to convince. By systematically and thoroughly recruiting values beyond the narrowly economic and beyond a narrow focus on the primary targets of climate change transitions (for example, reducing GHG emissions), we can hope to find values and benefits that make tough decisions easier and even attractive for a wider circle of people.

* * *

Our sense is that in actual deliberations a creative and thorough search for co-benefits will often yield surprising and influential sources of value, favoring climate friendly programs.

3.3 Risk

ACS (alternatives, criteria, scores) tables and the like, such as discussed in chapter 2 and shown in table 2.1 on page 12, are essential and foundational tools for deliberation support. They do not, however, address risk straightforwardly.

There are many types of program risks, including:

1. Efficacy. Will it deliver the promised benefits?
2. Execution. Do we have reliable capability to implement a successful program?
3. Budget overruns. Will its costs balloon unacceptably?
4. Unintended consequences or developments. What is the chance that a favored policy will be undone by new technology or other developments, including policy, regulatory and legal developments? How resilient, how immune to regret is the program in the face of foreseeable developments?
5. Opposition and blow back. Will implementation of the program provoke strong reaction against it?

Classical decision analysis has techniques for modeling and decision making in the face of identifiable risks and they can be useful. The recommendation here, where we focus on practicality above all, is to begin by holding discussions that identify and articulate the risks of concern and then to incorporate them as criteria in expanded ACS tables.

Chapter 4 Interactions

We have noted that the evaluation criteria (the columns) in the ACS table may, and often should, be altered during deliberation. Our purpose in this chapter is to discuss an important source of evaluation criteria in deliberation: interactions among alternatives under consideration and goals and values present in the deliberation. We discuss two kinds of interactions: interactions with goals and objectives and interactions with external considerations.

4.1 Goals and Objectives

As usual, we proceed by example. Figure 4.1 graphs supporting interactions between and among programs and goals.

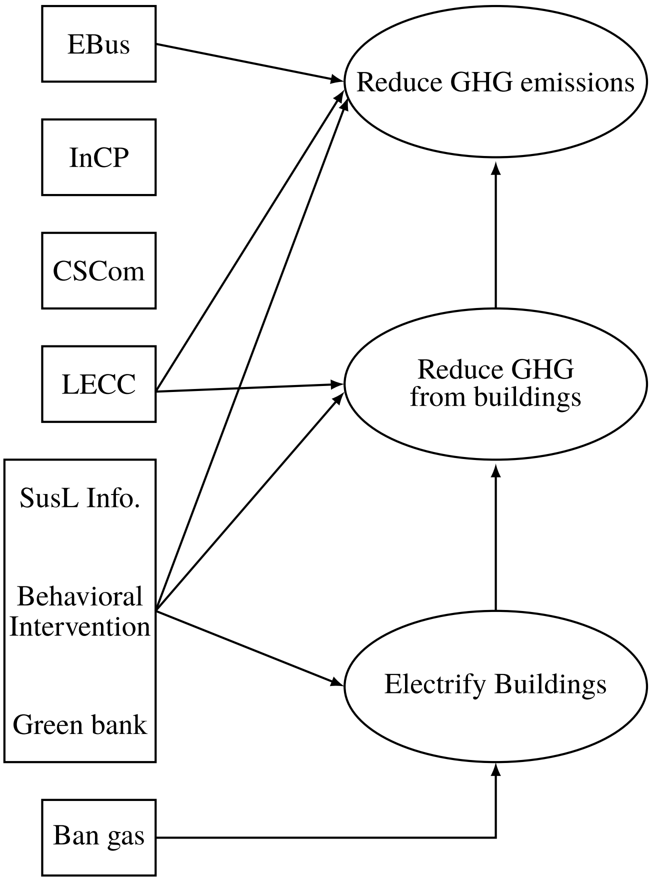

Figure 4.1: Supporting interactions between programs and goals.

Programs are within rectangles; goals and objectives are within ellipses. The diagram states that the overall goal of reducing GHG emissions is supported by the objective of reducing GHG associated with buildings. This objective is in turn supported by the objective of electrifying buildings.

Banning gas hook ups in new construction, "Ban gas," directly affects the objective of electrifying buildings, and indirectly the other two goals and objectives. Electrifying buses and utility vehicles, "EBus," directly affects the goal of reducing GHG emissions, but does nothing for buildings. Green banks, behavioral interventions, and sustainable living information potentially can directly affect all three objectives. Curb side composting and internal carbon pricing are depicted as isolated, without interactions with the objectives because their affects are deemed slight. This is, of course revisable upon receipt of new information.

Not depicted are supporting interactions among the programs, again only because their magnitudes are judged to be small. Sustainable living information, for example, may well motivate someone to make a green investment, perhaps first seeking green financing. Also not depicted is the important goal of reducing fossil fuel consumption, especial petroleum products. This captured through the depicted support by the EBus programs for reducing GHG emissions. Were it desirable to include other displacements of petroleum products (say by electrifying police cruisers) a separate goal for this could be added to the diagram.

The supporting interactions diagram helps reveal important aspects of the candidate programs that are not easily captured by listing evaluation criteria, as in the ACS table, table 2.1. This is because supporting interactions are inherently relational—like "x is longer than y"—rather than monadic—like "x is red"—as are the criteria in table 2.1.

Temporal sequencing is another important aspect of program selection that is relational and not well suited to be represented as one or more criteria in an ACS table.

We will in the sequel discuss methods for deliberating with relational factors arising in pools of alternatives. The reader can go far, however, simply being aware of the matter and exercising good judgment while deliberating.

4.2 External Factors: Logrolling

> Logrolling is the trading of favors, or *quid pro quo,* such as vote trading by legislative members to obtain passage of actions of interest to each legislative member. . . . In organizational analysis, it refers to a practice in which different organizations promote each other's agendas, each in the expectation that the other will reciprocate.
>
> https://en.wikipedia.org/wiki/Logrolling

People who cannot agree on a given collection of options often can and agree when the collection is expanded. In terms of our ACS table, this largely amounts to modifying alternatives (rows) and adding features or conditions to the alternatives that bring additional evaluation criteria. This sort of thing is simply the normal way of doing business, even when the modifications to an alternative have little to do with it, as when a curb-side composting alternative is expanded to include paving a certain street, thereby garnering a key vote.

Logrolling is a normal part of policy making, present more often than not. This has long be understood and is amply documented by political scientists [26]. It is fundamentally why it is not possible to give a comprehensive, let alone complete list of evaluation criteria. Relevant criteria may be just about anything at all, anything that gets the crucial votes.

Creative and diligent search for logrolling opportunities is a central feature of deliberation about climate programs and policies.

Chapter 5 Proceeding

This is the concluding chapter of our quick introduction to deliberation for climate programs. We hope that those who made it this far will find some material of interest and use. We imagine that many groups will be content to survey the chapters in part II, select a consideration set of policies and programs, and then proceed in their wonted fashion to decide what to do. To those in this category, we say "Go for it! Proceed."

To those who would consider additional methods and techniques to support deliberation, what we have to say begins in part III with chapter 24, "Overview of Deliberation Support Methods." There we discuss five deliberation supporting methods that are available and may be useful, depending on circumstances. Briefly:

1. Information about policies and programs.

   This is about communicating to the relevant publics the programs and policies under consideration, and inviting their feedback and participation.

2. Group discussion processes.

   There is good social science behind a number of processes for conducting group policy discussions. The aim is to conduct discussions that are actually informative and rewarding to the participants.

3. Decision processes for group decision making.

   Activists, analysts, and social scientists have devised a number of processes for group decision making. These group decision processes aim to facilitate choice by groups in a way that is judged by the participants to be fair and appropriate. Such processes might be used to make recommendations to decision making bodies, including official committees with responsibility to recommend actions.

   These processes are widely used for such purposes as natural resources management, especially water management. They are under continuing development and often benefit from computational support.

4. Decision analysis modeling.

   Decision analysis modeling produces mathematical models for decision making. Expert participation is necessary, but participants need not be experts. Decision analysis covers a wide range of modeling techniques, which methods have often produced models that yield useful insights for decision makers.

5. Role-play simulations for policy design.

   Role-play simulations have their origin in military war games, which have proved valuable to top military organizations for 200 years.

   A main use of role-play simulations for policy making is as a prelude to negotiation. Much may learned about possibilities and conditions for agreement by having players undertake key roles in practice negotiations.

See chapter 24 for examples and further discussion of role-play simulations for policy making.

5.1 Overriding Principles for Deliberation Support

Must:

1. Maintain flexibility, especially wrt evaluation criteria, which may need to be added at any point, requiring additional scoring to go with them.
   [26].
2. Recognize and be prepared to work with very imprecise quantification, especially scores in ACS tables.

5.2 Meta-Policies

Needs editing, translation into prose. Perhaps, change “policies and programs” to simply “programs” and use “policies” as I have used “meta-policies” here.

1. Identify and implement, ceteris paribus, programs that pay for themselves (in time).
   Example: Conversion to LED lighting.
2. Budget for experimental programs with apparently good cost-benefit characteristics, even if full analysis is not available.
   Example: Information brochures on building electrification.
3. Promote a culture of sustainability.
   Examples: Sponsored walking tours. Bicycle and pedestrian access to recreation and shopping/commercial centers.
4. Be assiduous in identifying and evaluating co-benefits of programs under consideration, with a view to conducting a sufficiently broad cost-benefit analysis.
   Example: Health benefits of building electrification.

Part II

Programs and Policies

Chapter 6 Union Pool of Programs and Policies

6.1 Union List of Local Policies and Programs

These are **kinds** of programs and policies. Each has multiple specific variants. Combinations and consolidations among programs are options as well as implementing parts of individual programs and policies.

1. **Green banks: financing for rooftop solar, for building weatherization, for building electrification**

   A green bank is a program or office that facilitates green financing, e.g., for rooftop solar, building weatherization, building electrification. Green banks typically are not genuine banks. Instead they partner with banks and credit unions to facilitate and reduce the cost of financing green projects. Montgomery County, MD has a successful program.

   Householders then have the prospect near term of saving money on energy bills and, at least during daylight hours, being resilient to power outages.

   See chapter 19.
2. **Curb-side composting**

   See chapter 8.
3. **A climate corps**

   Akin to the CCC and WPA. Participants are trained and deployed for work on broadly environmental projects, improving parks and watersheds, etc. Can work at multiple levels, from national to local.

   Can be as small as a summer jobs and educational program for high school students.
4. **Electrification of lawn care equipment**

   Example: Ban on two-cycle engines for powering lawn care equipment.

   In favor of battery-driven equipment.

   See chapter 11.
5. **Distributed demand response programs**

   Demand response participants are paid to curtail their electricity use during periods of peak demand. Residential participants typically work through an aggregator who holds the primary contract with the utility.

   In principle, municipalities could also be participants in such programs.
6. **Policy support for V2G**

   V2G = vehicle to grid, power: A form of DER (distributed energy resources) that permits EV owners to be compensated for providing electricity to the grid during high demand times.

7. **Policy support for community solar PV**

   This allows renters and homeowners with poor solar prospects to participate in and benefit from renewable energy. Typically a government or NGO organizes the project. Requires state-level authorization and is not yet permitted in Pennsylvania.

8. **Policy support for DER aggregators**

   This is likely the preferred mechanism for effecting DER, demand response, V2G, etc. It's a financial opportunity for households.

9. **Training and education incentives for trades in the energy and sustainability transition**

   Leads to jobs for young people and for mid-career people in sunset industries. Work with NGOs to leverage their assets, e.g., ECA (the Energy Coordinating Agency, https://www.ecasavesenergy.org).

10. **Support for converting to electric buses (and other utility vehicles) by local governments and school districts**

    The economic case is now strong with health and pollution benefits extra. Synergy with own solar panels for cheaper, behind the meter, charging.

11. **Sustainable living information**

    Health and safety information programs serve as precedent. Can be done "in the small" by encouraging volunteer groups and NGOs, or "in the large" through extension agents, item (12.), below.

    One form: **Public awareness programs for electrification and energy efficiency**.

12. **Extension agents**

    Akin to agricultural extension agents for helping businesses and governments run the numbers, etc. to make the energy and sustainability transition.

13. **Building electrification mandates and encouragement**

    Such as require new construction to be fully electrified, require electrification upon sale of an existing building, provide technical and other information to facilitate electrification, and so on.

    Could be combined with green financing, (1.).

    The Energy Gang podcast of April 15, 2021, "Unlocking Home Electrification With Heat Pumps"

    Excellent discussion of operating characteristics and policy.

    `https://podcasts.apple.com/us/podcast/unlocking-home-electrification-with`
    `id663379413?i=1000517299281`

    https://podcasts.apple.com/us/podcast/unlocking-home-electrification-with-heat-pumps/id663379413?i=10005

14. **Food rescue programs**

    Feed the hungry with what would otherwise be wasted food from restaurants and grocery stores. Many examples exist of successful programs. Typically they are run by volunteers and NGOs.

See chapter 13.

15. **EV charging stations**

    Construction of; mandates for; "right to charge" laws.

16. **Transition municipal buildings to high-grade efficiency standards**

17. **Expand public transit**

    Study and assess the costs and benefits of increasing frequency and of adding new routes.

18. **Expand bicycle and pedestrian thoroughfares**

    Often described as "low stress" bike routes and "last mile design." Study and assess the costs and benefits of adding and improving routes and connectors.

    See chapter 15.

19. **Amenities for public transit and bicycles**

    Study and assess the opportunities costs and benefits of making making public transit and bicycle commuting more attractive to use. Look at parking near transit hubs.

    See chapter 15.

20. **Support for compostable food utensils and containers**

    Including water/liquid bottles. The issue here is that in many cases bottles and tableware advertised as compostable require industrial processing (to grind them up) cannot be handled by local outfits as they are presently configured.

    Were a municipality to arrange for this extension to acceptable compost, the range of composting programs and benefits to landfill would be greatly extended.

    See chapter 8.

21. Waste regulation, including ban on single-use plastics, bottle deposits, etc.
22. EV incentives, including charging stations, HOV lane access, parking benefits, etc.
23. Soil management for carbon capture, etc.
24. Transitioning municipal buildings to sustainable standards (weatherization, efficiency; net-zero buildings?)
25. research on green building codes
26. **Low Embodied Carbon Concrete**

    See chapter 7.

27. Internal Carbon Pricing
28. **Behavioral Interventions**

    See chapter 21.

29. **Municipal Vehicle Electrification**

    See chapter 12.

30. **Municipal building electrification**

    See chapter 10.

31. **Municipal work rules reform**

Aimed at reduction of GHG emissions. One proposal being tried is for a 4-day (32 hour) work week (https://www.treehugger.com/spain-to-try-4-day-workweek-5120478). Other ideas include mixing on-site and distal work, extending practices from the Covid-19 pandemic.

32. Environmental and Sustainability Dashboard
In part a form of behavioral intervention. In part an opportunity for citizen science. Valuable contributions can be had from students, as well as citizen hobbyists. Has educational and cultural value for the entire community. Moves towards the higher levels of environmental monitoring and management that will be needed with climate changes.

33. TOD: Transit-oriented development

> TOD, or transit-oriented development, means integrated urban places designed to bring people, activities, buildings, and public space together, with easy walking and cycling connection between them and near-excellent transit service to the rest of the city. It means inclusive access for all to local and citywide opportunities and resources by the most efficient and healthful combination of mobility modes, at the lowest financial and environmental cost, and with the highest resilience to disruptive events. Inclusive TOD is a necessary foundation for long-term sustainability, equity, shared prosperity, and civil peace in cities.
> https://www.itdp.org/library/standards-and-guides/tod3-0/what-is-tod/ (https://www.itdp.org/library/standards-and-guides/tod3-0/what-is-tod/)

There is a good discussion in [**?**].

34. Promote a culture of walking
And bicycling, and being out and about as a pedestrian. Orient the built environment as much as is practicable towards pedestrians (bicycles, etc.). Create new walkways and upgrade existing walkways to make them more useful (e.g., connected with car parks, with public transit) and more pleasant (greenery, sound barriers.)
Contributions: Reduced vehicle miles traveled (VMT) reduces GHG emissions. Walking promotes health and well-being. Greenery and sound barriers are pleasant and reduce stress. Greenery is beautiful.

35. Green walls, living walls
Green walls, aka living walls, e.g., https://architizer.com/blog/product-guides/product-guide/eantka-green-walls/.
Green Engine Coffee in Haverford, PA:
http://www.greenenginecoffee.com/
https://www.yelp.com/biz/green-engine-coffee-haverford-2
Contributions: Encourages walking (which reduces VMT and promotes health), cleans

Figure 6.1: Green wall on administrative building of the Musée du Quai Branly in Paris.

the air, reduces stress. Greenery is beautiful.

See figure 6.1.

American vendor, Nedlaw Living Walls, http://nedlawlivingwalls.com/.

36. Sound barriers

    Contributions: Encourages walking (which reduces VMT and promotes health), reduces stress. See figure 6.2.

37. Green, planted areas for storm and flood buffering

    Convert areas prone to flooding to marshland and parkland that can quickly recover from flooding. Landscape for use for parks and recreation.

    Contributions: Mitigation of storm damage, expected to increase with climate change. Promotes health and well-being, beauty, and stress reduction.

38. Biochar

    An important form of carbon dioxide removal (CDR).

    Good discussion and references in https://cdrprimer.org.

39. Power purchase agreement (PPA) for renewable energy

    Just do it.

    https://foreignpolicy.com/2021/04/13/solar-community-owned-projects-green

    https://foreignpolicy.com/2021/04/13/solar-community-owned-projects-green-transition/

40. **Commit the governmental unit to 24/7 carbon-free energy**

    This is a much stronger commitment than net-zero energy. Under 24/7 carbon-free energy, **all** energy used is green or from carbon-free sources of generation (marginally carbon-free).

Figure 6.2: Glass wall facing street in the garden of the Musée du Quai Branly in Paris.

https://blog.google/outreach-initiatives/sustainability/our-third-decade-

https://blog.google/outreach-initiatives/sustainability/our-third-decade-climate-action-realizing-carbon-free-future

41. Community microgrids

    Come in many forms. A good search term.

42. Buy green electricity

    See Chapter 17.

43. Buy/consume natural gas that is certified to have been produced with minimal environmental leakage.

    See Chapter 16.

44. A transition fund to cover projects that come close to paying for themselves, but do not and that reduce GHG emissions effectively.

45. A green brokerage agency, generalizing the notion of a green bank and modeling itself on extension agencies.

    Information and know-how (e.g., about state and federal support programs) directed at businesses, contractors, designers, who can use the information and possibly support to encourage electrification.

46. Tree planing and maintenance

    Resilience and quality of life; cooling.

47. Infrastructure for living with challenging weather conditions

    Heat waves, heavy rains, etc.

48. Heat gap management and remediation

    See "Charting a Course to Shrink the Heat Gap Between New York City Neighborhoods"

Community organizers and New York residents hope high-resolution maps of hot spots in the Bronx and Manhattan will result in more equitable development.
By Delger Erdenesanaa
August 18, 2021
[?]
NYC heat map [?]: https://council.nyc.gov/data/heat/

49. Geographically-based census studies.
For example, "Mapping the Best and Worst Bus Stops in San Francisco" For transit users, amenities like seating, shelter and good signage can be hard to come by, according to a census of Bay Area bus stops.
By Laura Bliss, August 3, 2021,
Link
The underlying study, "Are Shelters in Place?: Mapping the Distribution of Transit Amenities via a Bus-Stop Census of San Francisco" [?]
Census or accounting models more generally:
"The Big Moment for Carbon Accounting" August 13, 2021, The Interchange podcast, [?].
50. Encourage and promote low carbon alternative activities by individuals (walking, bicycling, gardening, local recreational games and sports, etc.)
51. Green planting. Vegetative swales, green parking lot borders and internal islands with well designed shade tress, rain gardens, planted highway medians
52. High albedo surfaces. Paint rooftops white. Color streets and highways white.
53. Home certification for ecological soundness.
54. Refrigerant management policy
55. Ban on single-use plastic
Think180. (n.d.). Banning Single-Use Plastics—What are the Pros and Cons? Think180. Retrieved February 22, 2022, from https://think-180.com/lifestyle/single-use-plastic
56. Renewable Energy Certificates (RECs)
57. District geothermal
https://heet.org/ and
St. John, J. (2022, March 1). A net-zero future for gas utilities? Switching to underground thermal. . . . Canary Media. Link [?]
Volts podcast on GeoGrid: Audrey Schulman and Zeyneb Magavi on how to replace natural gas with renewable heat Ground-source heat pump district heating everywhere! https://www.volts.wtf/p/volts-podcast-audrey-schulman-and?s=r

6.2 Links

- United States Climate Alliance http://www.usclimatealliance.org/ Alliance Policies
- ICLEI https://iclei.org/en/Home.html and USA office: https://icleiusa.org/

  > Achieve your Sustainability & Climate Ambitions. For more than three decades, we have provided the tools, technical assistance, frameworks and network to advance sustainability and climate action.

- Database of State Incentives for Renewables & Efficiency (DSIRE) https://www.dsireusa.org/

File: local-pool.tex

Chapter 7 LECC: Low Embodied Carbon Concrete

Gabriela Garity

2021-07-31; 2021-08-10

7.1 FAQs

7.1.1 What is Low Embodied Carbon Concrete?

Low embodied carbon concrete (LECC) generates less carbon emissions in its production than conventional concrete. Cement, the "glue" that holds concrete together, comprises only 7-15% of concrete's volume, but is responsible for 95% of the emissions.[1] Cement is responsible for approximately 8% of all global greenhouse gas emissions, which would make it the third largest emitter behind the US and China if it were a country.[2] Cement is made by roasting limestone at 2,600°F. Approximately half the emissions come from the fuel used to heat the ovens, and the other half is released in a chemical reaction in which carbonaceous limestone becomes calcium oxide. Therefore, reducing overall embodied carbon in concrete can be achieved through three primary strategies: reducing the amount of cement in concrete mixes, using renewable energy for cement production, and and storing CO2 within cement.

7.1.2 Reducing Cement Use in Concrete

Using less cement is the most effective way to reduce the carbon footprint of concrete.[3]s Portland cement, the most common type of cement, can be replaced with other materials, called Supplementary Cementing Materials (SCMs). Fly ash from coal-fired power plants and slag from steel-blast furnaces are industrial wastes, often called geopolymers, that are typically used as SCMs. However, as these industries decarbonize, the supply of their byproducts is expected to decrease. Non-fossil fuel based SCMs include glass pozzolan, made from post-consumer recycled glass, as well as rice husk ash, made from the agricultural byproducts of rice production. Limestone can also be added to mixes to reduce the amount of cement in concrete. A variety of other lab-based and naturally occurring SCMs are currently being researched and published.[4] Some examples of companies bringing lower-carbon SCMs to market are introduced below.

[1] https://stok.com/insights/embodied-carbon-deep-dive-low-carbon-concrete/

[2] https://www.bbc.com/news/science-environment-46455844

[3] https://materialspalette.org/concrete/

[4] Stok insights

- Geopolymer Solutions

  Geopolymer Solutions combines recycled industrial wastes of fly ash and ground granulated blast-furnace slag as well as other naturally occurring minerals to create a heat-free cement with a carbon footprint approximately 10% that of Portland cement. It also offers added benefits including a higher quality, more durable, acid-resistant, longer lasting product that requires less water to produce. It can easily replace Portland cement at standard ready-mix concrete facilities.[5]

  Studies show that for higher grade concrete, the production costs of geopolymer cement are lower than conventional Portland cement. For lower grade cement, the costs are approximately the same.[6] However, the cost of geopolymer concrete varies significantly depending on geographical location, especially according to the availability of industrial wastes from heavy industry. As steel and power industries decarbonize, these sources of waste are likely to become more scarce.

- Pozzotive

  Pozzotive processes recycled glass into pozzolan that improves concrete performance. By increasing compressive strength and avoiding a chemical reaction that causes cracking, glass pozzolan reduces the amount of cement needed in concrete mixtures and saves maintenance costs. It is also more workable, pumpable and longer lasting. According to Pozzotive, their product reduces the embodied carbon in concrete by up to 50%. As environmental regulations are forcing the closure of coal-fired plants, fly ash, a once abundant source of pozzolan for concrete making, is becoming more and more scarce. This has allowed recycled glass to compete better in the pozzolan market. Concrete made with Pozzotive has been used for high-visibility projects in New York City including the United Nations Plaza, City Point, and the Second Avenue Subway station. According to Pozzotive, the price of concrete made with their products is on par ordinary Portland cement and can replace up to 40% of it.[7] In addition, salvaging recycled glass saves governments money by sending less glass to landfills, which are costly. The greatest barrier to widespread adoption of this SCM is lack of awareness. Changing industry standards will require engineers, contractors, subcontractors, and ready-mix suppliers to understand and implement the replacement. The recently published ASTM Standard Specification for Recycled Ground-Glass Pozzolan for Use in Concrete will make it easier for building teams to specify this material.[8]

- Lafarge Holcim's OneCem® Portland Limestone Cement

  Portland-limestone cement (PLC) is the most widely used SCM today, already beginning

[5] https://www.geopolymertech.com/green-concrete/

[6] https://iopscience.iop.org/article/10.1088/1757-899X/998/1/012051/pdf

[7] Link

[8] https://cleantechnica.com/2021/03/02/low-carbon-concrete-starting-from-the-ground-up/

to be accepted by the construction community and readily available through existing supply chains. This blended cement is made of 5-15% limestone, reducing the amount of cement required in concrete and reducing its carbon footprint by approximately 10%.[9] Lafarge Holcim, the largest cement manufacturer in the United States, is one of the many suppliers promoting this SCM with their OneCem® Portland Limestone Cement.[10] The OneCem® branding is intended to represent that this is the "one cement" that can be used for nearly all applications, serving as an equivalent or better replacement for standard Portland cement. The price of PLC is equal to or in some cases cheaper than regular Portland cement.[11] Lafarge Holcim says that limestone is still an underutilized carbon solution for the construction industry and that it is working to accelerate its adoption.

7.1.3 Renewable Energy in Cement Production

The energy required to heat cement ovens constitutes about 40% of emissions from concrete production.[12] Fossil fuels are currently the primary energy source since they are the cheapest option, but they can be can be replaced with renewable sources such as solar power, biomass, municipal waste, and green hydrogen. The European Cement Association says it already gets 44% of its energy from non-coal sources including industrial waste, mineral oil and used tires. A California-based startup called Heliogen is developing a way to cost-effectively use solar energy to power cement ovens using arrays of mirrors connected to advanced computer vision software. Capturing sunlight to produce a consistent stream of energy concentrated enough to power enormous cement kilns has been an ongoing challenge, and it will be up to Heliogen to demonstrate an economically-competitive way to do so. Hanson, a subsidiary of the global building materials giant HeidelbergCement, is collaborating with researchers to use green hydrogen produced through on-site solar- and wind-powered electrolysis to partially power their cement plant. LaFarge Holcim, another building materials giant, currently gets 45% of fuel used to heat cement kilns from waste, biomass, and other low carbon sources, and it seeks to increase that to 65% by 2022. LaFarge Holcim expects that stricter building regulations and carbon taxes, especially in the EU, will increase customers' willingness to pay a premium for low-carbon concrete.[13] However, until renewable energy becomes competitive with fossil fuels worldwide, this method of reducing the carbon footprint of concrete is likely to be the least popular.

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[9] https://www.cement.org/sustainability/portland-limestone-cement

[10] Link

[11] https://precast.org/2014/06/portland-limestone-cement/

[12] https://cleantechnica.com/2019/11/26/cements-co2-emissions-are-solved-technically-but-not-eco

[13] Link

7.1.4 Carbon Capture in Cement Production

Carbon emissions themselves can be captured and reused in the cement making process to generate value-added cement products. As carbon policies become more stringent, carbon storage technologies like these can present additional economic advantages for the construction industry. Existing options for concrete made with carbon capture, utilization, and storage technologies include:

• CarbonCure Technologies

CarbonCure seeks to store greenhouse gases in the pores of concrete by using CO2 instead of water to cure it. By retrofitting existing concrete plants, this companies expects to commercialize its technologies quickly. Although products like carbon-cured concrete could earn a "green premium" among environmentally-conscious buyers, CarbonCure claims that the costs of concrete made using their technologies are on par with conventional concrete. CO2 delivery and equipment costs are offset with a stronger product, which means lower quantities of concrete required as compared to conventional concrete1.[14] So far, CarbonCure achieves a net carbon reduction of about 5-7%.[15] Concrete made with CarbonCure's technology has been used in a variety of public and private projects around the US and Canada, from the Georgia Aquarium to the Linkedin Middlefield Campus in California.

• Blue Planet

Blue Planet uses carbon dioxide captured from the exhaust stacks of power plants to create carbonate rocks, replacing natural limestone rock, which is the main component in concrete. Flue gas used to make the synthetic carbonate aggregate does not require purification, making it an extremely energy-efficient and low-cost process. The resulting concrete is just as strong as regular concrete, Blue Planet's CO2-sequestered synthetic limestone aggregate is 44% CO2 by mass, allowing concrete to become carbon-negative. Blue Planet markets its products as an economically sustainable carbon capture alternative for builders. Its materials have been used in public projects such as the San Francisco International Airport.[16]

• Solidia

Solidia Technologies uses lower temperature and less energy during cement manufacturing and uses CO2 instead of water for concrete curing, resulting in up to 70% overall reduction in emissions compared to standard precast blocks and massive water savings.[17] Solidia claims that their products use the same equipment and raw materials, cost less to produce, and cure in 24 hours rather than the conventional 28 days.[18] LaFarge Holcim helped bring Solidia to market in 2019 by supplying its low embodied carbon cement to EP Henry's paver and block plant in New

[14] https://livingbuilding.kendedafund.org/2019/07/16/carboncure/

[15] https://www.environmentalleader.com/2021/06/new-york-passes-low-carbon-concrete-bill/

[16] http://www.blueplanet-ltd.com/

[17] Link

[18] Link

Jersey.[19]

7.2 Software tools

Tracking the embedded carbon content of construction materials using energy modeling software has the potential to significantly reduce emissions. Online tools currently available include the Athena Impact Estimator, the Bath Inventory of Carbon and Energy (ICE), Tally One Click LCA,[20] and most recently the Embodied Carbon in Construction Calculator (EC3).[21] The open-source EC3 database includes more than 16,000 materials, which democratizes access to information about the environmental impact of construction choices. This information was previously locked away in hard-to-find and inconsistently formatted PDFs, which reduced builders' ability to compare materials directly. Projects that used EC3 during their pilot period reduced carbon emissions by 30% without significant financial impact, just by making more informed, data-driven decisions.[22] Software programs like EC3 can also help drive demand for low-carbon construction solutions and provide useful data to policymakers.[23]

7.3 Low Embodied-Carbon Concrete Options in the Greater Philadelphia Area

- US Concrete

US Concrete is a national concrete supplier that uses several methods to lower the embodied carbon of its products, from using supplementary cementitious materials to incorporating CarbonCure technology.[24] Action Supply Co is the US Concrete supplier that services the Philadelphia area.[25]

- Conewago Ready Mix

Conewago Ready Mix is a locally owned and operated concrete supplier serving the South-Central Philadelphia region that has partnered with CarbonCure to incorporate CO2 injection technology into their concrete production facilities.[26] According to Conewago, there is "not much difference in price" between traditional concrete and their carbon-cured concrete, since Portland cement content is reduced. A longer list of producers supplying concrete made with CarbonCure technology can be found here.

[19] Link
[20] https://www.oneclicklca.com/
[21] Link
[22] https://www.dezeen.com/2020/02/21/embodied-carbon-in-construction-calculator/
[23] https://carbonleadershipforum.org/what-we-do/initiatives/ec3/
[24] https://www.environmentalleader.com/2021/06/new-york-passes-low-carbon-concrete-bill/
[25] https://www.us-concrete.com/locations
[26] https://philadelphia.citybizlist.com/article/641770/conewago-ready-mix-brings-greener-concrete

• Nexii Building Solutions

Canadian green construction company Nexii Buildings Solutions Inc. is producing Nexiite, a low-carbon alternative to concrete. Buildings made with Nexiite are also more thermally efficient, requiring 33% less energy to heat, and are built faster and at lower cost.[27] Nexii is currently on track to open Pennsylvania's first green building manufacturing plant, which will serve the Philadelphia area.[28] Nexii's CEO says that using Nexiite will save customers money, as not only will the price be equivalent to traditional building materials, but also the 75% increase in building speed will reduce overall construction costs.[29]

7.4 Current barriers to adoption of LECC

• Lack of demand

When it comes to implementing LECC in construction, science is not the problem. With a wide variety of solutions already being developed in labs around the world, the greatest barrier will be getting the construction industry to adopt them. Demand will have to originate from customers themselves, who must specify low carbon concrete during new construction design. Builders tend to focus on the heat and electricity requirements of buildings that have already been constructed rather than construction materials. Action from policymakers, such as municipal LECC requirements and incentives for green construction, can help increase green cement's priority for developers and construction companies.

7.5 Policy Proposals

7.5.1 EPD Price Bids

This policy proposal gives concrete producers access to a tax rebate that will help fund the creation of Environmental Product Declarations (EPDs) for their products. Concrete producers bidding on public projects (or the projects of a sizeable academic or other institution) will be ranked based on the GWP of their concrete, in addition to cost. An artificial 5% discount will be applied to the bid prices of producers with the lowest GWPs, potentially making their bids more competitive. An additional 3% discount will be applied to producers that use any carbon capture, utilization, or storage technology to manufacture their concrete.

The intention of this policy proposal is to ensure that producers with the lowest-carbon concrete are in the best position to win public sector business. By leveraging public purchasing power, the bill hopes to catalyze the development and widespread deployment of low carbon

[27] Link
[28] Link
[29] Link

concrete.[30] This proposal is modelled off of New York State's proposed Low Embodied Concrete Leadership Act (LECLA). This policy was developed with input from academia and industry, including Columbia University's Center on Global Energy Policy. The full text of the proposed Senate bill can be found here.

EPDs report the global warming potential (GWP) value of products and materials. GWP is an independent, consistent metric for measuring and reporting the carbon content of materials that can be used to compare materials based on their environmental impact.[31] Reducing the GWP of materials can be achieved by reducing the embodied carbon content of concrete, which could involve any of the three methods outlined in the document above. Since the public sector consumes approximately 37% of all concrete produced according to a 2019 study, focusing on reducing emissions from concrete in public projects could be highly impactful.[32]

7.5.2 Mandating Construction with LECC

This policy proposal provides guidelines for construction with low-embodied carbon concrete, which can be achieved either through reduced use of cement or through replacement of ordinary cement with low-carbon materials, such as supplementary cementitious materials (SCMs) or carbon-cured concrete. There are four methods for compliance:

i. Cement Limit Method - Mix: limiting the cement content of a particular concrete mix to the value shown in the table below.
ii. Cement Limit Method - Project: limiting cement usage of all concrete designs within the same project to the value calculated using the equation below.
iii. Embodied Carbon Method - Mix: limiting the embodied carbon content of a particular concrete mix to the value shown in the table below.
iv. Embodied Carbon Method - Project: limiting cement usage of all concrete designs within the same project, wherein total embodied carbon (EC^{proj}) of all concrete mix designs within the same project shall not exceed the project limit ($EC_{allowed}$), determined using the table in Figure 7.1 and the equations in Figure 7.2.

This proposal is modeled off of the Low Carbon Concrete requirements found in the municipal code of Marin County in California. The full text of the code amendments can be found here.

[30] https://www.carboncure.com/concrete-corner/new-yorks-proposed-low-carbon-concrete-policy/
[31] Link
[32] https://www.ibisworld.com/united-states/market-research-reports/ready-mix-concrete-manufacturing-industry/

Table 19.07.050 Cement and Embodied Carbon Limit Pathways

	Cement limits for use with any compliance method 19.07.050.2 through 19.07.050.5	**Embodied Carbon limits** for use with any compliance method 19.07.050.2 through 19.07.050.5
Minimum specified compressive strength f'_c, psi (1)	Maximum ordinary Portland cement content, lbs/yd³ (2)	Maximum embodied carbon kg CO_2e/m^3, per EPD
up to 2500	362	260
3000	410	289
4000	456	313
5000	503	338
6000	531	356
7000	594	394
7001 and higher	657	433
up to 3000 light weight	512	578
4000 light weight	571	626
5000 light weight	629	675

Notes
(1) For concrete strengths between the stated values, use linear interpolation to determine cement and/or embodied carbon limits.
(2) Portland cement of any type per ASTM C150.

Figure 7.1: Cement and Embodied Carbon Limit Pathways

Equation 19.07.050.3:

$Cem_{proj} < Cem_{allowed}$

where

$Cem_{proj} = \Sigma Cem_n \, v_n$ *and* $Cem_{allowed} = \Sigma Cem_{lim} \, v_n$

and

n = the total number of concrete mixtures for the project

Cem_n = the cement content for mixture $_n$, kg/m³ or lb/yd³

Cem_{lim} = the maximum cement content for mixture $_n$ per Table 19.07.050, kg/m³ or lb/yd³

v_n = the volume of mixture $_n$ concrete to be placed, yd³ or m³

Applicant can use yd³ or m³ for calculation, but must keep same units throughout

Figure 7.2: LECC equation

7.6 Links and further information

1. "Pathways to transforming heavy industry," The Interchange podcast on April 29, 2021. Link
2. "Bendable concrete and other CO2-infused cement mixes could dramatically cut global emissions" February 14, 2021 Link

    > Local governments are taking the first steps. "Low embodied carbon concrete" rules and projects to reduce the amount of cement in concrete have cropped up around the country, including in Marin County, California; Hastings-on-Hudson, New York; and a sidewalk pilot in Portland, Oregon.

3. https://www.concretecentre.com/Publications-Software/Concrete-Compass/Low-Carbon-Concrete.aspx
4. https://www.carboncure.com/about/

File: concrete.tex

Chapter 8 CSCom: Composting

By: Shan Shan (Christine) Liang

2021-07-27

8.1 FAQs

1. What is composting?

   Composting is the process of turning organic, carbon-based materials into a nutrient-rich fertilizer for soil. It enhances the porosity, stability, water retention, and tillage of soil and improves its resistance to erosion and parasites. As an aerobic process, it decomposes trash from your yard, kitchen, home, or community in order to manage waste. This diverts the waste from going into a landfill and provides a variety of benefits.

2. What can be composted?

   The best compost includes a variety of materials in order to get a richer result with more micro-nutrients and diverse, beneficial microbial life. Generally, compost should have approximately 25–30 parts of carbon to 1 part of nitrogen. If there is too much carbon, decomposition slows down. If there's not enough carbon and too much nitrogen, the compost will give off an odor.

   Many random things from yards and kitchens can actually be composted because they are organic and carbon-based. Some materials like paper, cloth, wood, and string can also be composed but take more time because they need to be decomposed further. However, animal products and synthetic materials generally cannot be composted.

   https://www.planetnatural.com/composting-101/making/what-to-use/

3. What is compost used for?

   - Agriculture: crops and sod farms
   - Landscapers: industrial and commercial properties, golf courses, athletic fields, landfill covers, and damaged soils
   - Plant Nurseries: seedling crops and reforestation projects
   - Public Agencies: highway median strips, parks, recreational areas, other public property
   - Residents: home landscaping and gardening

4. What are the benefits of composting?

   Without composting, most of this waste would go into a landfill. This is detrimental to our health and environment because of the toxic methane emissions released there. Instead, composing turns waste into a rich nutrient that improves soil health by preventing soil erosion and adding more nutrients. Since waste is diverted from landfills, cities

Yes	No
Leaves	Raspberry & blackberry brambles
Grass clippings	Long twigs or big branches
Brush trimmings	Pet droppings, especially dogs & cats
Manure (preferably organic) & Animal products—meat, bones, dairy, fish skins, fat	Coal ash
Any non-animal food scraps: fruits, vegetables, peelings, bread, cereal, coffee grounds and filters, tea leaves and tea bags	Colored paper
Old wine	Diseased plants
Pet bedding from herbivores ONLY—rabbits, hamsters, etc.	Inorganic materials
Dry cat or dog food	Synthetic chemicals
Dust from sweeping and vacuuming	
Dryer lint	
Old herbs and spices	

Table 8.1: Examples of compostable and non-compostable materials.

and governments can also save money by reducing landfill capacity and avoiding landfill tipping costs. Moreover, composting improves plant growth and carbon sequestration and reduces soil contamination. This also creates opportunity to strengthen communities and boost local employment as people come together to protect their environment.

5. What are composting programs that can be implemented? See `https://repository.wellesley.edu/object/ir893`.

Curbside Collection	Drop-off Collection	Compost Bin Distribution
• Food waste is picked up by waste haulers every week and sent to a composting site. • Different bins are provided to people to encourage waste separation. • Appropriate for: urban communities.	• Individuals store and drop off food waste at designated locations. • Waste is transported to another location to be composted. • Appropriate for: rural communities.	• People receive their own compost bins at a subsidized cost. • Composting happens at residents' own homes. • Requires thorough education to teach residents about composting techniques. • Appropriate for: rural or urban.

Table 8.2: Composting program types.

6. How can composting programs become successful?

   See "Composting in America" PIRG Report.

   Convenience: Residents and businesses contribute more organic material to composting programs if that material is picked up "curbside," as is most trash and recycling. Some communities, such as San Francisco, have also encouraged residents to participate in composting programs by making the bins for organic waste larger and trash bins smaller.

Affordability: Municipalities can incentivize residents and businesses to participate in composting programs by making them more affordable than trash disposal. This can be achieved through systems like Save Money and Reduce Trash (SMART) in which residents pay less if they throw out less trash. Systems like this create a direct financial incentive for residents to toss their organic waste into the composting bin instead of the trash. Local governments can also combine the cost of organic waste pickup with trash and recycling, so that participants do not pay an extra fee, which is a barrier to participation.

Frequency: Organic waste should be collected as regularly and frequently as trash. Portland, Oregon, picks up organic waste more frequently than trash, encouraging residents and businesses to put their organics into the compost bin for quicker service.

Education: If people throw out materials that do not belong in compost, the compost can become contaminated. Sorting contaminants out of organic waste is resource-intensive, so it is more efficient and effective for residents and businesses to throw out the appropriate materials from the start. Education and outreach initiatives like public service announcements, media stories, community meetings and on-site training can inform residents and businesses about what to throw in the compost bin and can also encourage participation.

7. What composting services are on the market and who does them?

Figure 8.1: Composting types.

- Residential/home composting (food scraps and yard waste)
- Industrial/commercial composting (waste from schools, businesses, restaurants and markets)

Composting services can be divided into residential and industrial with 3 main differences: scale, management, and temperature.

See Plastics industry report.

- Scale: Industrial composting is done by the truckload, and compost windrows (long rows of piled compost) can weigh thousands of pounds. In contrast, home composters may have a small pile or barrel
- Management: Industrial composting is much more actively managed.
- Temperature: In industrial composting, the compost mound is very hot due to the composted materials being shredded, turned frequently and handled with more rigor than in home composting, which is done in much cooler temperatures.

Types of Industrial Composting:

See RTS report.

- Windrow composting, a method of commercial composting that piles waste into long rows (windrows) between 4 to 8 feet high and 14 to 16 feet wide; waste is periodically turned to introduce oxygen, and high temperatures created by large piles can break down problematic materials.
- Static pile, similar to residential composting; Waste is loosely piled and then layered with bulking agents to allow oxygen to permeate the pile. In larger facilities, a network of pipes will also blow air from the underside of the pile
- In-vessel, uses anaerobic reactions to break down waste; organics are placed in a drum or large silo and hermetically sealed, with mechanical mixing taking place periodically. In this carefully controlled environment, organics such as meat and bones can be processed.

8. How can we increase the scope of compostable material?

Organizations can consider using grinders to breakdown and process waste because they are a better option than macerators or single-shafted machines. Grinders (also known as shredders) ground up solid waste to a small size, which increases the efficiency of composting systems. Depending on the volume of waste material, organizations can look into grinders from JWC Monster or CBI Terex to learn more. It's very important to make sure the size of the grinder matches the volume of the waste because large grinders are very expensive but can be a worthwhile investment. Overall, organizations should consider the end market (selling the compost or using it), volume, tipping fees, and goals.

JWC Monster (residential):

Contact Info: ElizabethQ@jwce.com // 949-254-6487

Cost: $18,000-$130,000

Appropriate for: college campus, small town, single organizations.

CBI Terex (industrial):

Contact Info: joe.gallagher@terex.com // (603) 382-0556

Cost: $400,000- $600,000

Appropriate for: zoo, large city, collection of small towns, multiple organizations.

See How to Compost.

Another option to increase the range of compostable material is industrial composting, which heats waste to a high enough temperature for microbes to break it down in a timely manner. In this environment, even biodegradable plastics can be composted; unlike traditional plastic, biodegradable plastic is made from plants. Without industrial composting, biodegradable plastic would take years to compost in your backyard. This may seem like a long time, but traditional plastic would take 400 years to break down.

9. Good Practices for Composting

   See PIRG report.

   (a). Make composting cheaper than trash disposal

   • charge residents and businesses less if they throw out less trash to incentivize people to throw organic material into compost bin

   • embed the cost of organics collection into the overall cost of trash and recycling services to remove the disincentive of paying an additional fee

   (b). Educate residents and businesses

   • Educational and public outreach campaigns

   • Social marketing such as advertisements, public announcements and social media to help promote the concept of composting

   • Peer-to-peer education and volunteers who teach gardening/composting classes

   (c). Create demand and markets for compost

   • buy back locally-produced compost for use in public projects

   • Distribute compost to residents, community gardens, or other local projects

   • require residents and businesses to use compost in landscaping renovations or large projects

10. Potential Steps Forward

   See PIRG report.

   (a). Require commercial producers of organic waste to divert it to composting facilities.

   (b). Require government projects to use compost

   (c). Incentivize backyard and community composting.

   (d). Subsidize the creation of composting facilities and programs through grants, loans and other financial mechanisms.

   (e). Fund programs to develop and test municipal composting programs.

   (f). Use locally-produced compost in public projects and spaces

   (g). Ban organic material from landfills.

11. Successful Municipal Ongoing Programs

   San Francisco Fantastic Three: EPA report.

   In 2002, San Francisco set a goal of 75% diversion by 2010 and in 2003 Zero Waste by 2020, meaning the city would no longer need landfills. The city's comprehensive Environment

Code, created in 2003, is based on the Precautionary Principle. The city's Mandatory Recycling and Composting Ordinance, passed in 2009, requires all of San Francisco to separate recyclable materials, compostable materials and landfilled trash. Although the city has yet to reach this goal, the city's 3 bin system, policies, financial incentives, and extensive outreach to residents and businesses, helped San Francisco achieve the highest recovery rate of any major city in North America.

See Fantastic Three report.

San Francisco implemented an innovative “Fantastic Three" three stream citywide residential and commercial curbside collection program that includes separate collection of commingled recyclables; compostable materials, including all food scraps, food-soiled paper and yard trimmings; and any remaining trash in three separate bins with various size and rate options. The name refers to San Francisco's easy-to-use three bin system. Each resident and business has three bins:

• Blue bin for recyclables

• Green bin for compostables

• Black bin for landfill-bound material

To encourage recycling, composting, and other waste reduction, The Department of the Environment prioritizes education and outreach to encourage compliance, rather than impose fines. Face-to-face outreach has proven effective in helping residents and businesses become compliant with laws. However, the City can impose fines to repeat offenders. The Environment Now team conducts extensive, multilingual and door-to-door outreach to residents and businesses and also checks residential curbside bins throughout the city. If materials are found in the incorrect bin, a tag is posted on the resident's bin that indicates the correct bin. The team returns the following week to ensure that the error was corrected. The team also visits residents to answer questions about recycling and composting.

The Department of the Environment staff work with Recology, the city's hauler, to ensure that businesses have composting and recycling bins. If they do not, the Department sends them a letter advising them to order composting and recycling service. The Department of the Environment then follows up in person to ensure compliance.

In addition, the Department of the Environment launched RecycleWhere, a recycling database for residents and businesses to find information on how to recycle almost anything in San Francisco. The Signmaker tool is another resource for residents and businesses to make their own recycle, compost, and landfill signs. SFRecycles was created to help residents and businesses with what goes where.

The Department of the Environment, which works with businesses and residents all over San Francisco, has found that the community continues to be very positive and supportive of the City's zero waste goals. San Francisco residents take great pride in their city and are passionate about taking care of it. This attitude has helped integrate sustainability into

San Francisco's culture.

San Francisco's zero waste program is funded solely from revenue generated through refuse rates charged to customers. This revenue sustains material collection, processing, disposal, hazardous waste collections, all outreach and marketing materials, as well as some programs within the Department of the Environment and the Department of Public Works. The cost of collecting compostables, recyclables, and landfill-bound materials is about the same. While maybe more expensive to process, recyclables are baled and sold to their respective markets and the compostables are processed and transformed into nutrient-rich compost, which is sold to local farms. Landfill-bound materials are processed less but are charged by weight and dumped in the landfill with no return on investment.

Philly's Community Composting Network:

See Philadelphia Citizen article.

Philadelphia sought designs for composting infrastructure that were neighborhood-scale, enclosed, easy to build and maintain and could be used by schools and community organizations. The Philadelphia Food Policy Advisory Council (FPAC) started a compost bin design competition, but the contest didn't turn up any models the city thought were foolproof, so they turned to the tried and true three-bin model, according to former FPAC manager Hannah Chatterjee. The three-bin system—the industry standard for small-scale urban composting—allows you to have compost in different stages of decomposition simultaneously; after the first bin is full, you move the material to the second and start the cycle over.

Funded by grants from Comcast and the Pennsylvania Department of Agriculture, the program is headed up by the city's Office of Sustainability and Department of Parks and Recreation. They provide the 12x4x4-foot, three-compartment compost bin, training and ongoing support for each site as it gets set up.

The idea is this: neighbors bring their food and yard scraps to a nearby site and share the responsibility of turning the piles and maintaining the bin. The resulting fertilizer is available to all participants for use in garden beds, window boxes, potted plants at home, or even trees lining streets nearby.

DC Composting for Community:

See DC report.

The DC Parks and Recreation (DPR) Community Compost Cooperative Network uses new critter proof and smell proof compost bins designed by Urban Farm Plans to allow trained community members to compost food scraps with garden waste from DPR and partner DPR gardens to responsibly create high quality compost. To join, each member must take an hour of training and help process compost 1-hour a month.

Each cooperative can handle around 100 active composters or about 1 ton of material a month. DPR currently has 50 cooperative compost sites with a capacity of 5000 people actively composting or 50 tons of material a month with no operating costs and no carbon footprint. Currently there are more than 1000 people composting around 20 tons a month in this network.

Requirements for Cooperative:

1-3 Co-op Managers (Can't start a co-op without at least 1 manager. About 3 hours of work a month) Responsibilities

1. Train future co-op members (will be trained to do this)
2. Organize once a month work day
3. Quality control

Co-op Members Responsibilities

1. Take a 1-hour training
2. Help process compost 1-hour a month
3. Provide an active form of communication

Curbside Compost in Connecticut:

See http://www.curbcompost.org/

Serving the Fairfield and Westchester County communities, Curbside Compost collects food scraps from homes, schools, offices, markets, restaurants and events. Owners Nick and Erica Skeadas started their compost businesses in 2015. Skeadas transports your food scraps to New England Compost in Danbury, charging $32 a month for residential pickup. He then sells compost to customers for $17 per 1 cubic foot bag of compost. "Every household is different, but we collect about 13 pounds per household per week," Nick Skeadas said. The team currently services 150 households per month, and hopes to expand to more towns in the future.

Residential Food Scrap Pick up: $32 /month. Commercial Pick up: $352 /year

$17 per 1 cubic foot bag of compost

$175 for 1 yard of compost

$235 for 2 yards of compost

$375 for 3 yards of compost

$435 for 4 yards of compost

$495 for 5 yards of compost

$555 for 6 yards of compost

Backyard compost at Prince William county in Virginia:

See PIRG report.

In 2015, Prince William county in Virginia wanted to expand the capacity and operations of its local composting facility. Since the 1990s, the county had been processing yard waste at its facility but wanted to upgrade its technology and add food waste to the program. Instead of financing the project themselves, the county partnered with Freestate Farms which took over operations and installed new equipment. Through the contract, Freestate

Farms handles and finances the upgrades, while the county now pays a price per ton of organic material delivered to the facility – similar to how trash and recycling programs often work. The new fees are comparable to what it previously cost the county to operate the facility. By 2020, the facility will be operating at double its original processing capacity, composting over 80,000 tons of organic waste per year.

The Solid Waste Division sells Presto Geobin compost bins for $30 each (limit three per household). Special features of the bin include:

• Lightweight plastic hoop-style bin

• 36" in height and adjustable to three feet in diameter

• 17.6 cubic feet (0.65 yards) capacity

• Easy to assemble

• Provides instructions for composting

• Holds compost neatly in place

• Ventilating holes admit air and moisture

<u>Successful Ongoing Academic Programs</u>:

Harvard University:

https://green.harvard.edu/topics/waste/composting

Harvard offers composting in all freshman dorms. All students have to do is line their compost bin with their provided Biobag, discard waste into the bin, bring dorm compost to the compost bin, and grab another biobag to repeat the process. In 2012, Harvard Campus Services also installed a BioGreen 360 in-vessel composter at Harvard Law School. The unit receives 1,000 pounds of food scraps daily and through microbial activity and electric heat, evaporates and breaks down the scraps to about 100 pounds of sterile pellets. To date, Harvard has been experimenting with adding the pellets to horticultural refuse to augment organic nutrients for use on campus soils.

UT Dallas:

https://sustainability.utdallas.edu/operations/composting/

Comet Composting is a program for UT Dallas students, staff, and faculty to compost organic material easily and efficiently on campus. Using supplies provided by the UT Dallas Student Government, participants will be trained in composting, provided with a composting caddy, and given access to the large composting bins located across campus. Students can participate in the Comet Composting program by watching the training video and completing a short knowledge assessment. In August 2017, a partnership with Organix Recycling formed and enhanced the overall composting program at UT Dallas. With the transition, specialized compost containers were installed near kitchen locations, therefore simplifying the pre-consumer food waste collection process. With this new partnership, additional food items became acceptable in the waste stream that were not previously accepted (for example, meat and dairy products), increasing the amount of food waste that is recycled.

Cornell University:

Composting bins are located in every All You Care to Eat Dining Rooms on campus managed by Cornell Dining, and many other dining facilities on campus. All of Cornell Dining's pre-consumer food waste is collected in every Dining unit and composted by one of the Cornell University Agricultural Experiment Station (CUAES) farms, Farm Services. As of 2018, composting is also available in all Cornell's on-campus residential communities. Student Residential Compost Managers oversee compost bins in residential community kitchens and provide peer-to-peer education on composting. Students can find bins in their halls or join the program as a volunteer!

University of Texas Arlington:

See News report.

The university tries to make recycling fun for students through a competition called Recyclemania. The university residence halls and apartments participate in a competition, called Recyclemania, among one another to promote recycling within the living area. There are 13 different departments to the committee. The composting program at UTA is a part of the Landscaping and Habitat department. The university collects all of the compostable campus waste, such as kitchen waste and coffee grounds, from the campus groundskeepers and composts the raw materials into mulch, which is then used for landscaping around the campus.

8.1.1 What do you need to compost?

Food, Paper wrapping, Paper napkins (colored vs white)- backyard composting

Necessary:

• Compost bin- homemade or purchased bin for your compost pile

Helpful Tools:

• kitchen compost bin or biodegradable bags- any open bin to collect kitchen food scraps and garbage waste in your house before you toss them into the outdoor compost bin

• Clippers, trimmers, etc.: Most gardeners find they need a variety of clippers and trimmers. All of them help you produce material for the compost bin; some may help you cut it up so it decomposes more quickly.

• Wheelbarrow or garden cart: You'll need to transport piles of refuse to the bin, and these make it doable. A deep, high-sided wheelbarrow is also the best possible receptacle for sifting compost.

• Rake: An old-fashioned leaf rake brings it all together.

• Hoes, hatchet, leaf-shredder- preps the compost material by chopping it into smaller pieces

• Fork: to move compost material either into or out of a bin and/or turn piles

• Aerator: An aerobic pile will need to be turned, but with an aerator the job needs to be done less frequently. Aerators are designed to penetrate dense material easily; when they're pulled back up, they bring to the surface some of the material that was at the bottom. There are two basic types of aerators, those with screws, and those with wings.

• Compost thermometer- very helpful if you intend to heat the compost.

• Screen- sifts the compost

PAPER TYPE	REUSE	RECYCLE	COMPOST	GARBAGE
Glossy	X	X		
Metallic	X			X
Wax-Coated	X			X
Plain/Non-Glossy, Non-AstroBright	X	X	X	
Tissue	X	X	X	
Paper Tube	X	X	X	
Paper Boxes	X	X	(some)	

Figure 8.2: Paper and composting.

Paper Cups- not compostable due to plastic lining Bottles

Compostable Items

• Cutlery

• Packaging

• Sheet labels

• Roll labels

• Takeaway packaging

• Deli papers

• Food safety stickers

• Menus and displays

• Cups/lids

• Pots/bowls

• Catering Bags

8.1.2 Vendors in the Philadelphia, PA region

1. Mother Compost

   https://mothercompost.com/

   610-509-9700

   info@mothercompost.com

   You Can Compost:

   - FOOD

     Coffee Grounds/Filters

     Cooked/Fried Food

     Dairy

     Egg Shells

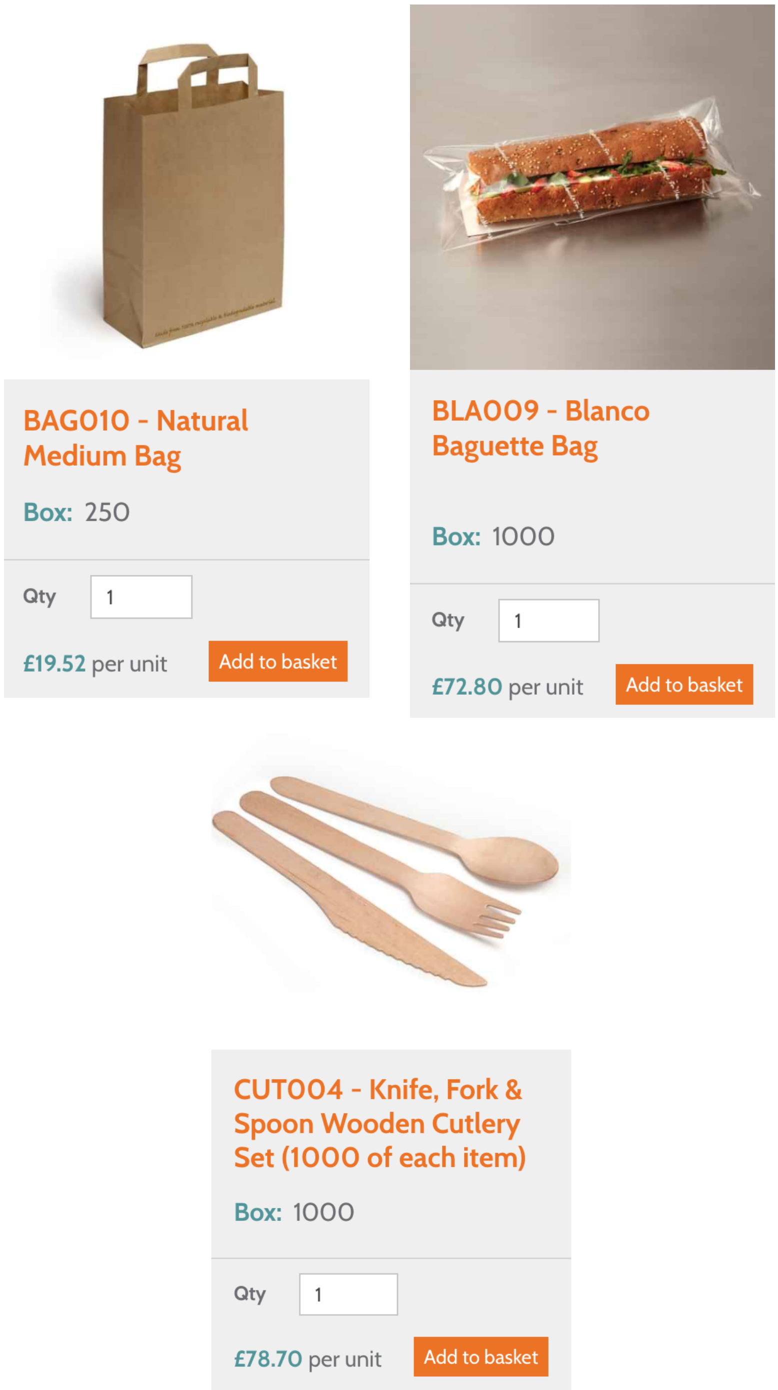

Figure 8.3: Example product.

Freezer-burned Foods

Fruits & Vegetables: peels/pits/seeds Grains: Pasta/bread/rice Seeds/Nuts/Nut shells

Processed Food

Powdered Milk

Pizza

Rotten/Moldy Food

- ORGANIC MATERIALS

Compost ONLY IF it fits in your bin

BPI-Certified Compostable Ware

Hair Clippings- Human or Animal

Nail Clippings

Pencil Shavings

Toothpicks

Wool/Dryer Lint

Fireplace Ashes

Garden/Yard Trimmings

Houseplant Trimmings

Sawdust

Feathers

We do not accept:

- FOOD

Meat/Poultry

Seafood

Shellfish

Gum

- OTHER

Inorganic Materials

Plastic, Acrylic, Polyester, Rubber

Rubber Bands

Twist Ties

Animal or Human Waste Chemicals/Toxics

Cigarette Butts

Coal – Treated

Diapers

Diseased Plants

Herbicides/Pesticides

Kitty Litter

Medicine/Medical Waste

Treated Woods

Used Tissues (due to COVID)

E-waste

2. Kitchen Harvest, Inc.

   Drexel Hill, PA 19026

   Contct: Chris@MyKitchenHarvest.com, https://www.mykitchenharvest.com/

   Category: Residential, community, and commercial composter. https://www.mykitchenharvest.com/

   Feedstocks Accepted: Fruits and vegetables, Nuts, shells, Coffee grounds, paper filters, Tea bags (no staples), Grains like bread, crackers, cereal, cookies, pasta, flour, rice, Egg shells, Houseplant trimmings, cut flowers, Paper products like napkins, towels, plates Yard Waste, Leaves, Grass clippings, Flowers, plants and weeds, Straw and hay, Yard trimmings

3. Circle Compost

   https://www.circlecompost.com/.

   Category: Local community composter. Reported that claims of compostable bottles and tableware is mostly incorrect.

   Feedstocks Accepted: Leaves,Grass,Brush,Tree Trimmings,Clean wood waste,Wood Chips,Garden Waste Yard Trimmings, Source Separated Food Scraps (Vegetative Only), Compostable paper, packaging and serviceware, Certified compostable bioplastic packaging and serviceware Pre-consumer only (including food processing waste) Food Scraps Certified Compostable Bioplastic Bags, Clear Cups, Paper cups with bioplastic lining, Utensils, Plates and carryout containers Compostable Paper Kraft Bags,Soiled paper (e.g., napkins, towels, certified paper plates), Corrugated boxes (including pizza boxes), Wooden-only utensils, Crop/garden residuals.

   Focuses on Center City, Philadelphia. There, $18/month for weekly pickup, $12 for bi-weekly.

4. Philly Compost Inc. Philadelphia, Pennsylvania

   Category: Community Composter, Organics Collection Service No website. Phone: (215) 880-0465.

   Feedstocks Accepted: Leaves, Food Scraps, Bags, Clear cups, Paper cups with bioplastic lining, Utensils, plates and carryout containers.

5. Organic Diversion LLC

   http://www.organicdiversion.com/, Address: 46 South Maple Avenue, Marlton, NJ 08053. Phone: (609) 841-1326.

   Commercial composter, focusing on supermarkets, restaurants, colleges.

   Strictly food waste and a few other items.

   Pricing depends on: location/distance, how it's collected, how much material is collected.

6. County Conservation Co. LLC

https://www.countyconservation.com/, Address: 212 Blackwood-Bransboro Rd. Sewell, NJ 08080. Phone: T: 856.227.6900, F: 856.228.9600.
Category: Full Scale Composter. Feedstocks Accepted: Leaves, Grass, Brush, Clean wood waste.

7. Laurel Valley Soils
https://laurelvalleysoils.com/, Address: 705 Penn Green Rd Landenberg, PA 19350-9204. Phone: 1-866-LV-SOILS (1-866-587-6457), Local 610-268-5555. Category: Full Scale Composter.
8. Borough Of Phoenixville
https://www.phoenixville.org/212/Composting, Address: 351 Bridge Street Phoenixville, PA 19460. Phone: 610-933-8801. Category: Full Scale Composter.
9. WeCare Denali Burlington County Co-Composting Facility
http://www.wecarecompost.com/ Address: not given. Phone: (888) 325-1522. Category: Full Scale Composter Feedstocks Accepted: Brush, Tree Trimmings, Wood Chips.
10. Fairmount Park Organic Recycling Center Philadelphia, Pennsylvania
Category: Full Scale Composter. Feedstocks Accepted: Horse manure.
11. Bennett Compost
https://www.bennettcompost.com/. Address: 5650 Rising Sun Ave, Philadelphia, PA 19120. Phone: (215) 520-2406.

8.2 Penn Composting Policy Recommendation

8.2.1 Intro

The University of Pennsylvania currently partners with Organic Diversion to collect food waste for composting at all dining hall locations. Sophia Leporte '19 and Tiffany Yung '20 began one of the first composting initiatives in Spring 2018. After 2 years of research, they partnered with Bennett Compost and started a composting pilot program in the Harrison Community Garden, which has been a successful ongoing program for the past 2 school years. The program was paused May 2021 but will hopefully restart in 2021 school year.

In 2019, Eco-Reps Hope Lu and Johanna Inamagua collaborated with PennDesign to launch another composting pilot program at the Meyerson cafe, and they gained valuable insights for future programs. Hope and Johanna's program indicated that there is potential to explore larger scale options. Because student cooperation is key to success for these projects, the University should assess student interest in composting initiatives. If students are receptive, Penn should switch to compostable food packaging in Houston Hall and other dining halls. The University should purchase Panglow Packaging and aim to make compostable packaging available in all dining facilities. First, a pilot program is needed to assess the feasibility of this project.

8.2.2 Who is Panglow?

Panglow designs packaging products made from sustainable natural plant-based materials. Most of Panglow products are made from paper, and the remainder are made from renewable plants, not oil-based plastics! This means their packaging is fully compostable! See Figure 8.4 on the next page.

Including the displayed photos of their products, they also offer cutlery, packaging, sheet labels, roll labels, takeaway packaging, deli papers, food safety stickers, menus and displays, cups/lids, pots/bowls, catering bags.

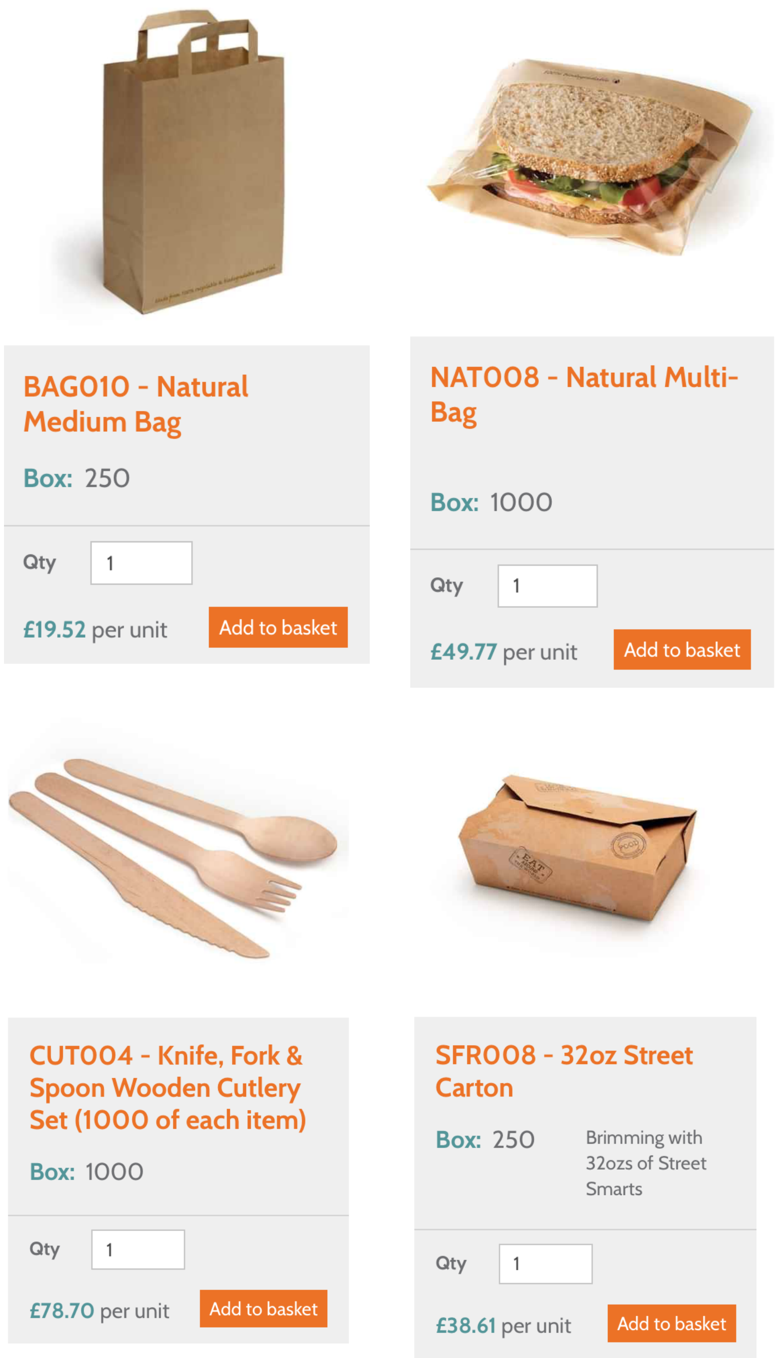

Figure 8.4: Example fully compostable product.

8.2.3 Proposal Plan of Action

In order to make compostable packaging available across Penn, a pilot program must be successful. However, one main issue is that many Philadelphia composters currently only accept food waste and are wary of contamination. Fortunately, JP Mascaro and Sons is open to testing a pilot program with compostable packaging. Our planned steps include. . .

1. Reaching out to Bon Appetit to decide on a pilot location
2. Deciding which compostable products to offer
3. Sending those products to JP to test

A good pilot location would be Joe's Cafe or Mark's Cafe due to the smaller size and traffic. Ideally, all of the cafe's products will be replaced with compostable packaging, which will simplify the waste disposal process. We would love to start the pilot as soon as possible, but we know some of the cafes may have ordered supplies for the fall already. Once we have a good location set, we will further work out these details.

Because of the wide range of products that Panglow offers, we will also have a discussion with Bon Appetit (or the cafe) over which products we want to pilot. This discussion will also include the number of utensils and packages we will order, along with our compost transportation plans. The compost must be transported from the cafe to the BioBin at Hill because that is the only location that JP Mascaro and Sons picks up from.

If JP Mascaro and Sons approves the selected pilot products, then we will work out the logistics with the pilot cafe and get into contact with student groups to spread awareness. In the case that JP Mascaro cannot process the products, we will work to hopefully find another composter in Philadelphia that is able to compost the packaging.

8.3 City of Philadelphia Composting Policy Recommendation

Institute a ban on food waste for institutions that generate over one ton per week of organic (compostable) waste.

8.4 Links

1. National locator for composters: www.findacomposter.com Useful site: `http://www.findacomposter.com/`.
2. "Municipal Composting Programs in Massachusetts: What Works, Where, Why and How," a nice report, undergrad thesis: [**?**]
3. U.S. Composting Council
4. "Austin, Texas, pitches customer cost savings as curbside composting reaches over 200K homes" from Wastedive.com, `https://www.wastedive.com/news/austin-residential-curbside-composting-exp`

594499/. (https://www.wastedive.com/news/austin-residential-curbside-composting-expansion/594499/) Interesting story and has several useful links as well.

5. U.S. Composting Council https://www.compostingcouncil.org/?. Trade and promotion organization for the composting industry.
6. Local full scale composting company, MyKitchenHarvest. https://www.mykitchenharvest.com/
7. Local community composter, Dave Bloovman, good guy: Circle Compost https://www.circlecompost.com/
8. Local composter: Bennett Compost https://www.bennettcompost.com/
9. See San Francisco's successful mandatory composting program: https://sfenvironment.org/recycling-composting-faqs.
10. Planet Natural on composting https://www.planetnatural.com/composting-101/making/what-to-use/
11. Wellesley repository https://repository.wellesley.edu/object/ir893

Chapter 9 GEO: Green Extension Office

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Sustainability transitions, to renewable energy and to sustainable living, are underway. The transitions are necessary and will require vast changes in the material bases of our cultures and economies. Those changes in turn will require great institutional changes in how we manage our cultures and economies. They will require as well great conceptual changes in how we as individuals conceive and manage our relationship with the material world.

A flourishing network of green extension offices would play an immensely constructive role in facilitating the institutional and conceptual changes so dearly needed for the energy and sustainability transitions. This would be accomplished by imparting knowledge to clients that empowers them to undertake actions that upon due deliberation they prefer to take. In many cases, these actions would be accompanied by cost savings, health benefits, quality-of-life improvements, and mission-related service advances.

9.1 The idea of a GEO

A green extension office (GEO), as we conceive it, is an organization whose primary mission is to provide support services pertaining to the energy, sustainability, circular economy, and environmental quality transitions. These services include green financing (§19), brokering programs and vendors, information, education, instruction, training, decision support, and discussion fora. Client support may be provided to SMEs (small and medium-sized enterprises) in the commercial, governmental, and non-profit sectors, as well as to individuals.

We incorporate the term extension as a tip-of-the-hat to agricultural extension offices, which have long served as institutions providing up-to-date agricultural information to farmers. The first extension services having appeared about 4,000 years ago in China (see [**?** , chapter 1] which is a generally comprehensive history of extension services). Today in the United States every land-grant university has been tasked since 1887 with responsibility to provide agricultural extension services (`https://en.wikipedia.org/wiki/Agricultural_extension`). Our generalization, and to some extent appropriation, of this enduringly successful idea is hardly the first. It has been widely emulated. See §9.7.

As we envision it, a GEO would be a permanent, staffed organization. Its services and activities would be normally offered for free and its information based on science and objective facts. For example, a GEO would not exhort clients to replace gas heating with electric heat pumps (let alone hector them), but would offer verifiable information about the costs, the benefits, and the drawbacks (if any) of such a change. At the same time, for example, a GEO would not provide information about installing gas furnaces. Similarly, a GEO could connect potential customers with vendors (e.g., a homeowner with an electrical contractor), but would not endorse any individual vendor or product.

9.2 Mission

The overarching goal of green extension is to assist clients (individuals and SMEs) in navigating the sustainability transition. It does this by communicating factual, objective information, from known and transparent sources, eschewing politics and ideology.

Communication may take many forms, including presentations, public discussions, group experiences, and one-on-one conveying of experience and best practices.

Green extension also has a mandate to develop, whether by scholarship or research, new information to be communicated. Its concept presumes active involvement by members of the university community, in the spirit of the passage below.

> Community-engaged Scholarship (CES) is defined as: teaching, research, and scholarly activities that are performed in **equitable, mutually beneficial collaboration** with communities and community members to fulfill campus and community objectives.
>
> (https://morgridge.wisc.edu/faculty-and-staff-get-connected/morgridge-fellows/)

The underlying assumption is that factual, objective information, communicated by agents apolitically and non-ideologically, who have established reputations for such, is in the long run the most legitimate and effective way of influencing belief and behavior. In service of this assumption, green extension seeks to collaborate and coordinate cooperatively with all like-minded parties, in every sector of the economy (government, commercial, non-profit).

Green extension is mindful of its clients' interests and seeks to address them. These include:

1. Saving money (individuals and organizations)
2. Health benefits (individuals and organizations)
3. Enhance resilience and protect against extreme weather (individuals and organizations)
4. Networking and finding community (individuals and organizations)
5. Use of brokering and information services (individuals and organizations)
6. Information on how best to invest to "do the right thing" (individuals and organizations)

In service of this goal, and following the lead of agricultural extension, green extension has as its primary missions or objectives:

1. Communication

   Objectively valid information pertaining to the sustainability (green) transition, of use to clients and potential clients

2. Education and training

   Delivery of educational services (beyond bare information) pertaining to the sustainability (green) transition, of use to clients and potential clients

3. Research

   Pertaining to the sustainability (green) transition, of use to clients and potential clients; locally focused

In addition,

4. Expanded client base

   Serve SMEs from all three sectors as clients (government, commercial ventures, non-profit organizations) as well as individuals

5. Facilitation

   Foster supportive collaboration and cooperation with individuals and SMEs in furtherance of the overall mission

6. Portal services

   GEOs should serve as virtual curated repositories of climate and sustainability related online materials. They would do this by offering a well-known access point (URL), with links to valuable material, whoever develops and hosts it. Fits well with the facilitation mission.

9.3 Fit with university goals and values

These are principally:

A. Education
B. Research
C. Service

9.3.1 Teaching and education

The communication and the education and training facets of the GEO mission fall squarely into this category. Prominent work product of a GEO would include:

1. Classroom teaching and support materials on fundamentals of climate change
2. Classroom teaching and support materials on what clients can do in response (WYCDs or What You Can Dos). Example WYCDs:
   (a). Building electrification

   Use induction hot plates if you can't replace your stove. Heat pump water heaters. Hybrid (heat pump and gas) air heating. Geothermal heat exchange.

   (b). Building weatherization including efficiency improvements
   (c). Refrain from driving so much
   (d). Gardening

(e). Etc.

3. Organize and actually deliver teaching materials of the sorts listed above.
   ABCS classes in high schools, discussion sessions at libraries and with community organizations, . . . Link with university classes.
4. Community directed communication: distribute door hangers, appear on local podcasts, speak at the invitation of community organizations (example: The Climate Reality Project https://www.climaterealityproject.org/)

9.3.2 Research

A few categorized examples:

1. Programs and policies.
   Any program or policy in Part II can benefit by studies and scientific data collection and modeling.
2. Decision making.
   For selecting transition programs and policies. Much of this is multiple criteria decision making (MCDM) for which decision analysis modeling; see chapter 28. More qualitative studies are also needed and valuable, e.g. facilitated group discussions (see chapter 27) and role-play simulations.
   There is a great deal of research of this sort published in peer reviewed scientific journals; it focuses largely on natural resources management. Only a little work is available on climate change. The main research questions are: What methods work and for whom? and What do participants decide?
3. Community design.
   Modeling and analysis, often GIS-based for revised transportation systems, recreational facilities, resilience investments, . . . The fields of the Design School, the fields of engineering systems and design, and the fields of operations research and management science all have interests here and manifold contributions to make.
   There is an obvious link with agriculture and horticulture, although perhaps this should be led by existing ag extension outfits, ideally as partners.
   Obvious link with decision making.
4. Related general social science, locally focused.
   Think: Bill Labov and the Philadelphia Neighborhood Corpus. Decades of painstaking and invaluable work, yet remains far from completion. This is only about speech practices! The need for data collection, modeling, and theorizing on localized social phenomena pertaining to the sustainability transition is unlimited. The occasion of the sustainability transition is a unique leverage point. Things are in motion and need study.

Note: Plus bolster citizen science, high school science projects, etc. as well as professional-grade research.

reference earlier discussion

9.3.3 Service

Here the case is transparent. We can add: Useful for university based learning on how to teach (opportunities for students to learn especially); useful for attracting perhaps new sources of giving and funding.

9.4 Examples of what GEOs might do

Among the services and activities that might be offered (assumed to be free unless otherwise stated) would be:

1. Speakers Bureau.
   Organize and undertake public presentations on green topics to schools, citizens groups, the general public. Topics include climate change, building electrification and weatherization, composting, nature monitoring, health effects of burning fossil fuels in residences, resiliency preparation, and much more.
   Note two important themes that should be emphasized here and throughout: (i) health and wellness (healthy living); and (ii) adaptation and resilience preparation (e.g., protection from heat waves, heavy precipitation, and extreme weather events generally).
   Complementing these themes is that of design of the built environment to afford healthy living, https://theconversation.com/heart-health-design-cities-differently-and-it-can-help-us-live-longer-16203.
   Note also that many NGOs specialize in serving as speaker's bureaus. The Climate Reality Project (`https://www.climaterealityproject.org/`) is one such prominent organization. A GEO could collaborate with and broker presentations from independent groups. Coordination with other groups is a main role in all of a GEO's activities and will be presumed in what follows.
2. Informational brochures.
   And on the Web of course. Could be distributed periodically as part of awareness campaigns.
3. Short courses and training on how to take green actions.
   Again for civic groups, schools, the general public, and even individuals.
4. Community bulletin boards.
   Helping to match clients, volunteers, vendors, etc.
5. Teaching materials.
   Appropriate for schools as well as less formal situations, such as clubs, associations, and summer camps.
   Help might be provided for student science projects.
   Deliberation support tools and concepts, which are inherently interactive and participatory, may often be useful in this context as well.

6. Meet up events.

   In which vendors, contractors, NGOs and the general public meet and greet.

7. Manage and supervise green climate and environment corps work.

   The idea of a climate and environment corps is inspired by the New Deal CCC. See §22. A GEO could broker projects and manage the work, given funding for the workers.

8. Broker external funding.

   There are a large number of ongoing state and federal funding programs that may be drawn upon for broadly green purposes. The state programs are catalogued by the DSIRE site (Database of State Incentives for Renewables & Efficiency® https://www.dsireusa.org/). In addition funding is available on an ad hoc basis from many private foundations.

   GEOs could render valuable service by being knowledgeable of these sources and skilled in making applications to them, both for their own benefit and for that of clients, including individuals seeking incentives for green investments.

9. Green financing or green bank.

   By reducing financing costs for green investments, green banks and related green financing arrangements maximize economically sound green investments and with them transition to climate- and environmentally-friendly built environments.

   A GEO might serve as a green back in the brokering sense in which it partners with an actual bank by attracting potential customers and vetting them (see below). In doing do the green bank reduces the lender's costs and thereby the financing costs of the loans, which are for broadly green purposes, such as building weatherization and electrification, solar PV and so on.

   See the Montgomery County, MD, Green Bank for an excellent example of a locally-scaled institution on the brokering model (https://mcgreenbank.org/).

   A green bank is an institution that is created to provide opportunities and funding for green initiatives. It is important to note that, contrary to the name, a green bank is not actually a bank; the institution is often a nonprofit that acts more as an investment vehicle. Rather than competing with existing financial institutions, a green bank provides financing with the goal of creating environmental impact, not maximizing profit. The green bank reduces the cost of capital for green projects, thus incentivizing the change towards a more sustainable future. Some green banks take on many smaller, conventionally unprofitable loans and securitize them for larger banks; this allows the green bank to pursue smaller projects and enables larger banks to partake in financing green projects. In addition to simple financing, green banks may implement creative or non-traditional methods of allocating capital to customers unable to dedicate sufficient money to green projects. For example, a green bank may choose to co-invest in a project that does not have sufficient funds or resort to On-Bill financing(allowing customers to include repayment as a part of their utility bill).

However, the function of a green bank does not stop with financing; green banks provide ancillary services to customers, ranging from standardized contracts to project-specific consultation. (See §19.)

10. Citizen science and data collection.

    Agricultural extension offices often have a mandate to conduct experiments and collect data. This is another area for promising service by GEOs.

    By promoting and managing citizen science efforts (see https://citizenscience.org/ and https://en.wikipedia.org/wiki/Citizen_science), GEOs would engage members of the community of all ages in collecting and creating new data to support policy making and local governance.

    Examples of data to be collected include air pollution data, noise pollution data, weather-related data, traffic counts of various kinds (vehicular, foot, bicycle, use of playgrounds and other facilities, etc.), household and business surveys (e.g., regarding openness to composting), and much else. In addition, GEOs could curate data from other sources and make it conveniently accessible (e.g., Census Bureau data, certain weather data, police reports, tax and real estate data, travel data from regional planning authorities, etc.).

    These data may be analyzed in support of decision making an policy making. A GEO could teach and support such endeavors, e.g., for citizens groups, for student science projects, and in conjunction with local governmental authorities who might need the information.

    Further, studies based on experiments (technically, quasi-experiments) might be conducted and the results promulgated.

    Descriptive summaries of the data could be published and maintained online for purposes of monitoring the functioning of the local community.

11. Deliberation support for green choices.

    Helping communities and organizations prioritize and tune their climate and sustainability action planning. This includes facilitated discussions, ranging from very informal community discussion groups to town halls to very structured processes aimed at larger organizations.

12. Geographically-based census studies.

    For example, "Mapping the Best and Worst Bus Stops in San Francisco" For transit users, amenities like seating, shelter and good signage can be hard to come by, according to a census of Bay Area bus stops.

    By Laura Bliss, August 3, 2021,

    Link

    The underlying study, "Are Shelters in Place?: Mapping the Distribution of Transit Amenities via a Bus-Stop Census of San Francisco" [**?**]

    Census or accounting models more generally:

    "The Big Moment for Carbon Accounting" August 13, 2021, The Interchange podcast, [**?**

].

9.5 GEO organization and startup

It should be plain from the previous section that there is no shortage of jobs for GEOs to do. Given this, two questions immediately present themselves: How should GEOs be organized? and How should they be launched?

In the United States, agricultural extension offices are entities of land-grant universities, managed and funded by them, with some federal funding and whatever grant support is raised. In the present political climate, it is unlikely that a similarly broad mandate can be obtained for GEOs, therefore an NGO, non-profit organization is likely most feasible and promising organizational structure.

A minimal staff configuration would have a senior professional as director of 2–3 junior professionals. The director should be skilled at fundraising, interacting with stakeholders, presenting information to clients, and managing a small organization. The junior professionals should be able to create content and deliver it to clients, as well as work with partners who would also create or deliver content. In addition a GEO should have a coterie of partners and volunteer contributors.

Startup requires funding and a definite organizational basis. Because creating a 501c(3) non-profit entity is costly and time consuming, it should not be undertaken speculatively. The GEO would better first be formed under the auspices of another entity, such as a governmental organization, an academic institution, or a pre-existing 501c(c). In a pinch, the GEO could be created on an informal basis after arranging for services with a fiscal sponsor (a 502c(3) that would handle all financial dealings and reporting, and to whom a funding agent can cut a check). Funding at startup should guarantee at least 2–3 years of operation in order to demonstrate value.

Funding should be sought (at least in part) by composing funding proposals and submitting them to funding agencies, whether public or private. Once key players are identified and brought on board, development of funding proposals is the key step towards success, as it forces a careful thinking through of what in detail the GEO's mission, focus, and initial operation should be.

9.6 Startup proposal (notes only)

1. The GEO idea, if it works at all, merits rolling out nationally, on the scale at least of the existing agricultural extension system.
2. The GEO idea has prima facie credibility because (i) the need for individuals and SMEs to have information and advice for the sustainability transition is apparent and will be long lasting, and (ii) the GEO idea emulates a model that works and works well, agricultural extension.

3. Even so, it is only prudent to conduct pilot studies of the GEO idea in order to assess its value and its practicability for full scale roll out.
4. We can expect important positive network effects if many GEOs are in operation and collaboration with each other.
5. Even so, it is possible to design a 2–3 year pilot study to assess feasibility and uptake.
6. We propose here the lineaments of such a program.

9.6.1 Immediate goals upon starting up

1. Acquire (create or obtain by collaboration) teaching materials on the sustainability transition.

   Basics of climate science findings and global warming. WYCDs. Group discussion and decision analysis protocols.
2. Deliver, communicate these teaching materials.

   ABCS classes, community discussions and presentations, leafleting.
3. Identify and if feasible commence research projects.
4. Establish and develop a green extension portal, expansively linking information from multiple sources.
5. Networking, team building, development of strategic partners
6. Undertake foundational work for ongoing operations.

   Advisory board; systematic vetting of educational and informational materials; policy and code of ethics; policy and plans for defense from adversarial activities; funding, near- and long-term; program evaluation.
7. Develop knowledge and a repository of funding programs for which sustainability actions are eligible. This knowledge is to be used in service of the clients. A good starting point: Database of State Incentives for Renewables & Efficiency® (DSIRE) `https://www.dsireusa.org/`.

Other considerations include:

- Ultimate organizational home and relationship with existing extension offices.

9.6.2 Client values

Discuss motivation/attractors for clients. These include:

1. Saving money (individuals and organizations)
2. Health benefits (individuals and organizations)
3. Enhance resilience and protect against extreme weather (individuals and organizations)
4. Networking and finding community (individuals and organizations)
5. Use of brokering and information services (individuals and organizations)
6. Information on how best to invest to "do the right thing" (individuals and organizations)

Client values to be addressed include:

1. reduce GHG emissions. Perhaps out of altruism or good citizenship.
2. reduce health risks.
   Here, electrifying buildings, especially residences, has much to offer.
3. protection against severe weather events. Includes heat waves, flooding, windstorms, cold snaps.
4. improve quality of life. Lifestyle items such as walking and enjoyment of nature. Citizen science activities with a community (bird watching, e.g.). Meaning through assistance to others (Habitat for Humanity, e.g.).

9.7 Links

1. Recommended: background on agricultural extension. *Improving Agricultural Extension: A Reference Manual* [**?**]. Available online at http://www.fao.org/3/w5830e/w5830e00.htm#Contents
2. Background on agricultural extension offices. https://en.wikipedia.org/wiki/Agricultural_extension
3. Directory of county agricultural extension offices. https://pickyourown.org/countyextensionagentoffices.htm
4. U.S. federal extension programs. https://en.wikipedia.org/wiki/Cooperative_State_Research,_Education,_and_Extension_Service
5. The Netter Center at Penn http://www.nettercenter.upenn.edu/
6. "Heart health: design cities differently and it can help us live longer" https://theconversation.com/heart-health-design-cities-differently-and-it-can-hel
7. Citizen Science Association https://citizenscience.org/
8. Citizen science Wikipedia entry https://en.wikipedia.org/wiki/Citizen_science

9. "Paris's 15-minute city could be coming to an urban area near you" https://www.bloomberg.com/news/features/2020-11-12/paris-s-15-minute-city-could-be-co
10. Georgetown Climate Center https://www.georgetownclimate.org/, accessed 2021-08-15.

    Interesting and useful information. Recent content dated July 2020.
11. Urban Climate Change Research Network (North America) https://uccrnna.org/, accessed 2021-08-15. Most recent blog posts dated November 2017. Most recent publications dated 2018 https://uccrn.ei.columbia.edu/publications, accessed 2021-81-18.
12. PennState Extension https://extension.psu.edu/. Example ag extension service.
13. University of Wisconsin-Madison extension https://extension.wisc.edu/. Perhaps not surprisingly, it appears to have a broader mission than ag extension, befitting the Wisconsin Idea and using Deweyian language:

    > Extension's mission is to connect people with the University of Wisconsin. Thanks to joining forces with UW-Madison, we'll strengthen each other through exchanging experience and research statewide. No matter what you're trying to accomplish in Wisconsin, you'll find the support you need as we continue to bring our home state together, community by community.
    >
    > [https://extension.wisc.edu/, accessed 2021-08-15]

    Notice the variety of programs featured on the home page.
14. Illinois Extension https://extension.illinois.edu/. Like Wisconsin, expansively characterized:

    > Build your best life. Trust Extension to help.
    >
    > Illinois Extension experts are here to help families, businesses, and communities solve problems and learn new skills with research-based webinars, virtual meetings, videos, and more.
15. University of Minnesota Extension https://extension.umn.edu/
16. The Oregon Extension https://www.oregonextension.org/
17. Federal Sea Grant Program https://seagrant.noaa.gov/

    > For over 50 years, the National Sea Grant College Program has supported coastal and Great Lakes communities through research, extension and education.
    >
    > Sea Grant's mission is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment.

    They fund research and other programs.

18. National Institute of Food and Agriculture Extension https://nifa.usda.gov/extension

    Extension

    Extension provides non-formal education and learning activities to people throughout the country — to farmers and other residents of rural communities as well as to people living in urban areas. It emphasizes taking knowledge gained through research and education and bringing it directly to the people to create positive changes.

    All universities engage in research and teaching, but the nation's more than 100 land-grant colleges and universities have a third, critical mission — extension. Through extension, land-grant colleges and universities bring vital, practical information to agricultural producers, small business owners, consumers, families, and young people.

    NIFA supports both universities and local offices of the Cooperative Extension System (CES) to provide research-based information to its range of audiences. As the CES federal partner, NIFA plays a key role in the mission by distributing annual congressionally appropriated formula grants to supplement state and county funds.

    They fund research and other programs.
19. Michael Wood's story of England. BBC production, available on YouTube. Documentary based on citizen science about a small town, Kibworth, going back to Roman times.
20. Public Benefit Funds. Potential funding sources for GEOs. https://www.c2es.org/document/public-benefit-funds/

    Public Benefit Funds (PBF), also frequently referred to as system benefits charge, are state-level programs developed through the electric industry restructuring process. PBFs allocate most of their money to energy efficiency, renewable energy, and low-income assistance programs. PBF-supported programs include research and development and demand-side management. Furthermore, several utilities may apply PBFs to help meet their Renewable Portfolio Standards (RPS) and/or their state's Energy Efficiency Resource Standard (EERS).

    The funds are most commonly supported through a small charge on the customer utility bills (e.g., cents per kWh of electricity sales or per therm of natural gas sales) or through specified contributions from utilities (e.g., percentage of contributions from a utility's gross operating revenue). In some cases, a fee on the customer's bill is assessed for using the electricity distribution system and can not be bypassed. However, some states allow a customer to opt-out, or bypass the fee, if electricity is either self generated, purchased from exempted markets, or the customer's assets are restructured to avoid fee eligibility.

* * *

GEOs could coordinate with elected officials in their community services efforts so long as the content is non-partisan. See Figure 9.1.

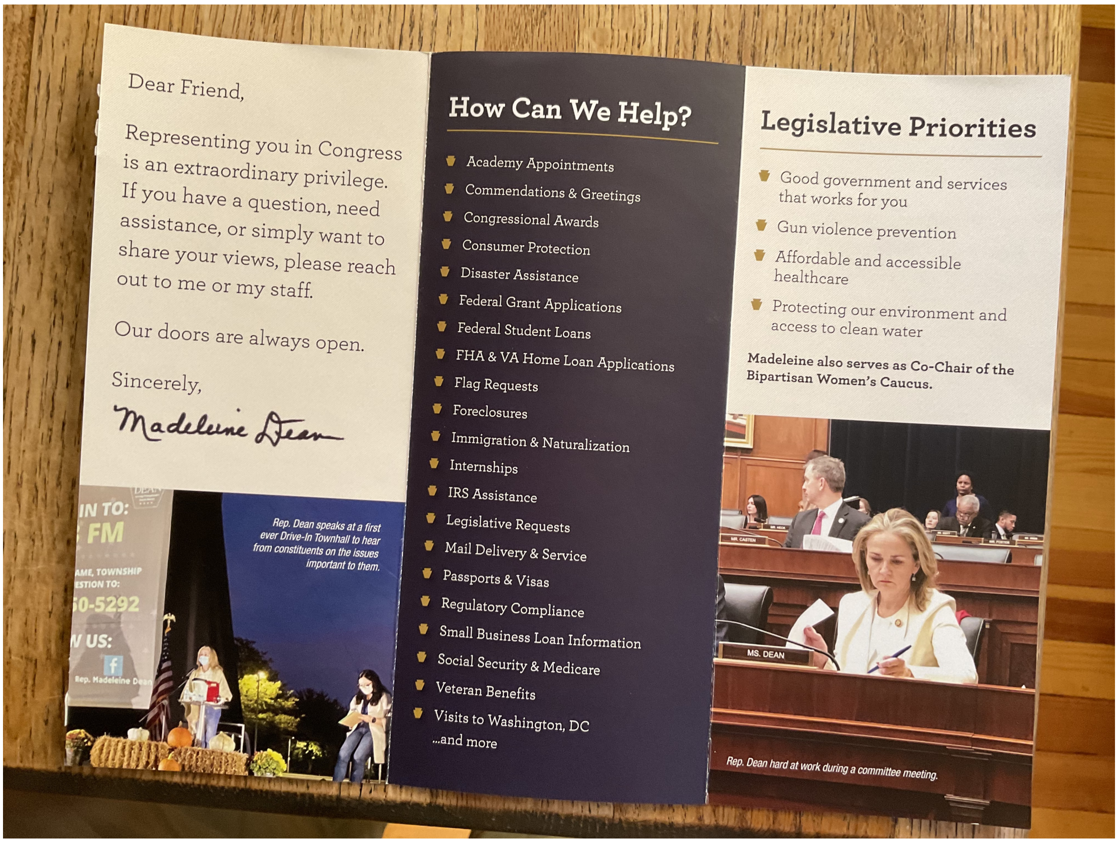

Figure 9.1: Congresswoman Dean's constituent services brochure.

Chapter 10 EBuild: Building Electrification

By: Anvit Rao and others

Revised: 2022-01-31

10.1 FAQs

1. What is the name of the policy program?
   Building Electrification
2. What is building electrification?
   Building electrification is the process of using electricity to power buildings and appliances as opposed to fossil fuels. This will comprise of both upgrading buildings themselves as well as using renewable sources such as solar, wind, and others to power them. This is an important task because buildings proportionally consume a significant amount of energy in the US and other countries as well.
3. What are some examples in practice?
   The most popular form of building electrification in practice is the replacements of gas furnaces and air conditions with heat pumps. Heat pumps rely on transferring air from outside a home to inside to heat and cool. Electricity is used to send heat where it is needed and remove it from where it is not. Other forms of electric heating in buildings is geothermal heating, which functions similarly to a heat pump except it uses heat from the earth. Additionally, there are also systems that rely on water to heat and cool buildings, sending it back and forth from a central location. The most significant for the future, however, will be heat pumps opposed to electric space heaters. There are many electric heating programs that have been implemented across the country. The most notable ones are:
   - Many states such as Maine and California mandated that all new construction must incorporate heat pumps. Maine specifically has a goal set for 100,000 new heat pumps by 2025. States like Vermont and New York are also implementing heat pump rebate programs.
   - In a case study done by the Sacramento Municipal Utility District, heat pumps were very economically advantageous for new residential buildings and for existing units that housed multiple families. Heat pumps were slightly more expensive for existing single family homes, as well as more expensive for small to medium sized office buildings.
   - There was a case study in Austin Texas that showed that adjusting building codes in addition to making electrification updates resulted in a 37% greater savings that

having a system that only makes electrification updates.

- Stanford University fully converted its campus heating and cooling systems to a water-based system, and has cut emissions by 65 %

In addition to the area of heating, there is also potential to navigate away from the use of gas ovens and stove tops through the use of electric induction stoves. Currently, this write up focuses on heating and cooling, but there is more research to be done on electric appliances like inductions stove-tops

4. Important policy areas and considerations:
   - Incentivize use of electric heating and cooling
   - Manage increased demand on the grid

     There is potential for the involvement of smart grid technology, and there are multiple ways through which local governments can do this:
     - The incorporate of customer feedback on energy use. This is effective in both allowing customers to understand the impact they are having, as well as making a behavioral chance. BCG reports that utilities boosted their gross margin by more than 20% after incorporating more customer feedback methods.
     - Implementing a demand-response grid system. This would adjust utility service prices based on peaks in energy usage as well as allow for customers to sell electricity back to the grid for credit. Measures like these will incentivize off-peak electricity usage and have the positive impact of decreasing grid stress to accommodate for greater use of electricity in buildings
   - Improve technology to benefit building efficiency
5. What do heat pumps cost and who pays?

   On the residential side, heat pumps for a whole house can cost between $2,500 and $7,500 depending on the size of the home. These fees will generally come out of the pocket of the homeowner unless there is a government rebate. For larger buildings like universities or commercial buildings, the cost would follow a similar rate but depend on the size of the building

   More research to be done on the cost and varying pricing
6. What are the climate-related benefits of building electrification?

   By relying on electricity instead of natural gas or fossil fuels, building electrification reduces greenhouse gas emissions. Additionally, it caters better to renewable energy because that energy can now be used directly to heat and cool buildings. This is particularly impactful because homes and businesses burning natural gas, oil, or propane account for 560 million tons of CO2 each year, which is 10% of the total US emissions. Looking at universities specifically, on average, 53% of their energy usage comes from heating and cooling buildings. Making a dent in these highly energy-consuming processes has the potential for big climate impacts through reducing emissions as a result of less reliance on fossil fuels.

7. What are some additional benefits, co-benefits?

   One of the first benefits is in terms of cost. For new buildings being made, it is clearly more cost-efficient for them to rely on electric methods such as heat pumps. This is because, in the long run, electric heating methods can some roughly 30 to 40% on utility bills. On the other hand, the decision to renovate old buildings is a little bit more difficult, but once again, in the long run, switching to electric heating will lead to emissions savings. Additionally, electric systems such as heat pumps offer benefits in terms of health and safety. Studies have linked the presence of gas furnaces in homes to developing conditions such as asthma. Additionally, electric systems remove the risk of gas explosions and carbon monoxide leaks.

   More data on safety and health related risk still needs to be found

8. What are the dis-benefits?

   There are negative effects for natural gas and oil companies that rely on building heating and cooling systems to sell a lot of their product, as well as utilities that send these products to customers.

   This section still needs to be flushed out

9. How difficult is it to implement and maintain building electrification

   The biggest struggle with implementing large-scale heat pumps is the installation process, but states are already starting to develop groups that are trained for this installation. One note on the maintenance of this switch to electricity is the stress that it could potentially put on the electricity grid.

10. Additional notes on building electrification

    Something very interesting about building electrification is the possibility for it to work in tandem with other sustainability policies. First, because building electrification marks the transition away from natural gas, decoupling could be a potential solution to managing the effect on utilities. Second, because there will be more stress on the grid, smart grid and storage advancements could become even more important in managing the nation's electricity usage. Finally, green financing could play a significant role in funding building construction and retrofitting.

    There is more research still to be done on these policies and how they could work together with building electrification

10.2 Links

- Roberts, D. (Jan 28, 2022). Volts podcast: Panama Bartholomy on decarbonizing America's buildings. Retrieved January 31, 2022, from https://www.volts.wtf/p/volts-podcast-panama-bartholomy-on

Terrific podcast with key reference: The Building Decarbonization Coalition's Member Portal. (2022). The Building Decarbonization Coalition's Member Portal. Retrieved January 31, 2022, from https://www.buildingdecarb.org/

Good on health issues. Discussion of important issue: operational versus embodied emissions.

- "A Furious Industry Backlash Greets Moves by California Cities to Ban Natural Gas in New Construction"
  https://insideclimatenews.org/news/05032021/gas-industry-fights-bans-in-homes-businesses/
  https://insideclimatenews.org/news/05032021/gas-industry-fights-bans-in-h
- https://www.huffpost.com/entry/climate-green-building-codes_n_60381e23c5b60d98bec8dc7d
- "How Dangerous is Natural Gas?" (August 8, 2017) https://safer-america.com/dangerous-natural-gas/
- "The devious plan to keep us hooked on gas," A Matter of Degrees podcast, by Leah Stokes and Katherine Wilkinson, August 9, 2021 https://a-matter-of-degrees.simplecast.com/episodes/hooked-on-gas-ggTcUPGL Alternatively Link .
  Good references in the notes on health aspects of fossil gas in buildings. See next three items below.
- Noor, D. (2020, October 28). Gas Stoves Are the Scariest Thing in the Kitchen. Gizmodo. Link
  https://gizmodo.com/gas-stoves-are-the-scariest-thing-in-the-kitchen-1845467748
- Seals, B. (2020, May 5). Indoor Air Pollution: The Link between Climate and Health. RMI. Link
  https://rmi.org/indoor-air-pollution-the-link-between-climate-and-health/
- Griffith, S. (2021, July 21). One Billion Machines. Medium.
  https://blog.usejournal.com/one-billion-machines-48a7c3cf0694

Chapter 11 ELawn: Electrification of Lawn Care Equipment

Gabriela Garity

2021-07-01; 2021-08-10

11.1 Background and Motivation

Gasoline-powered lawn equipment significantly deteriorates air quality and endangers the health of workers and citizens alike. Nearly 54 million Americans mow their lawns every weekend, and the vast majority of their mowers are powered by fossil fuels.[1] According to EPA statistics, mowing our lawns requires about 800 million gallons of gasoline annually, plus 17 million gallons spilled in the process.[2] Although gas-powered lawn and garden equipment are only responsible for about 0.5 percent of all US greenhouse gas emissions, other particles are more worrisome.[3] These gas-powered machines also release hazardous air pollutants including volatile organic compounds (VOCs), carbon monoxide, nitrogen oxide, and particulate matter.[4] Most of this equipment is powered by two-stroke engines that mix fuel and oil, which results in about 30% of the fuel remaining incompletely combusted, releasing toxic gases into the air. Four-stroke engines are slightly more environmentally friendly, but a four-stroke lawnmower operating for one hour still emits as much pollution as a vehicle traveling 500 miles. EPA data estimates that gas-powered lawn mowers alone make up 5 percent of total air pollution in the US, with higher percentages in urban areas. The California Resources board released a report in 2017 warning that "by 2020, gas-powered leaf blowers, lawn mowers, and similar equipment in the state could produce more ozone pollution than all the millions of cars in California combined." These toxic and carcinogenic pollutants adversely affect the health of the American public. Extensive evidence suggests that exhaust emissions and fine particulates cause cardiovascular disease, stroke, respiratory disease, cancer, neurological conditions, premature death, and effects on prenatal development.

The zero-emissions alternative is electric lawn care equipment, which has been on the rise in recent years and now constitutes about 44 percent of the market. According to the manufacturer Stanley Black and Decker, the volume of electric lawn equipment shipped by North American manufacturers jumped from about 9 million units in 2015 to over 16 million units in 2020 - a more than 75 percent increase in only five years. The Freedonia Group estimates that the battery-

[1] https://fresh-energy.org/say-goodbye-to-gas-this-summer-electrify-your-yard-care

[2] https://psci.princeton.edu/tips/2020/5/11/law-maintenance-and-climate-change

[3] https://www.basco.com/content/dam/basco/na/en_us/files/6018%20Position%20Paper_v9.pdf

[4] https://www.epa.gov/sites/default/files/2015-09/documents/banks.pdf

powered lawn equipment sector is growing three times faster than gas.[5] Models have improved in recent years, with more affordable, longer-lasting options becoming available. Although gas-powered mowers are still better suited for extra large lawns, the environmental benefits of electrifying the majority of lawn care equipment would be immense.

11.2 FAQs

11.2.1 What are some examples in practice?

At least 170 US communities have restricted the use of gas-powered leaf blowers.[6] The District of Columbia banned them outright in 2018 after a group of local activists brought to light the intense hearing-loss and pollution they cause, harming workers and the public alike. Battery-powered leaf blowers are still permitted, but they reduce both air and noise pollution. According to a study by acoustic engineers, a gas-powered leaf blower at 75 decibels of noise can affect 15 times as many households as its battery-powered counterpart with the same noise rating.[7] Many California cities have also banned gas-powered leaf blowers, and the state of California is considering a statewide ban. The bill proposes rebates for commercial users, such as landscapers, to purchase electric equipment.[8] South Pasadena became the first "Green Zone" City certified by the American Green Zone alliance in 2016, having converted all outdoor maintenance equipment for city-owned land to electric equipment.[9] Santa Barbara's Landscape Equipment Electrification Fund (LEEF) offers a rebate of up to 60% of the purchase price for electric equipment for commercial companies.[10]

There are now loads of options for battery-powered lawn care alternatives on the market. From small yards to large yards, different price levels and features exist for different homeowners' needs. A popular choice is the EGO 21" Power+ Self Propelled Lawn Mower. This model runs for up to an hour per charge and recharges in about an hour. Customers say it is sturdy, lightweight, and adept at handling difficult jobs.[11] At $459, this mower is on par with or a little pricier than its gas-powered counterparts. Although the up-front costs may be higher, owners of electric mowers save significantly on operating and maintenance costs. Gasoline prices are rising, and

[5] https://www.washingtonpost.com/climate-solutions/2021/06/30/electric-lawn-care/

[6] https://www.sciforschenonline.org/journals/environmental-toxicological-studies/article-data/JETS-2-118/JETS-2-118.pdf

[7] https://www.theatlantic.com/magazine/archive/2019/04/james-fallows-leaf-blower-ban/583210/

[8] https://www.sacbee.com/news/politics-government/capitol-alert/article251037629.html

[9] https://www.washingtonpost.com/climate-solutions/2021/06/30/electric-lawn-care/

[10] https://www.lawnsandpalmsfl.com/an-electric-future-for-landscape-and-lawn-care-companies/

[11] https://www.thespruce.com/best-electric-lawn-mowers-4175254

gas mowers have tons of parts that often need replacement. The Electric Mower Report found that battery-powered mowers save about 35% over their lifetime.[12]

Corded electric mowers are an even more affordable option. They require the least amount of maintenance, have infinite run time, and are very lightweight and maneuverable.[13] However, they are not suitable for large lawns and tough terrain, and the cord can take some getting used to. For leaf blowers, the electric versions are cheaper, quieter, cleaner, lighter, and easier to maneuver. Cordless and battery-powered options are both available. However, gas-powered blowers are still more powerful, which gets the job done faster, especially for large yards.[14] However, for the average homeowner with a small yard, the pros of an electric option could outweigh the cons.

What are some climate-related benefits of lawn care equipment electrification?

The EPA estimates that a gas-powered lawn mower emits 11 times as much pollution as a new car. Given that the average homeowner mows their lawn 22 times a year, the emissions produced by these machines can accumulate rapidly.[15] Estimates vary from 16 to 41 billion pounds of CO2 equivalent released by lawn mowers every year.[16] Nonetheless, when compared to total CO2 emissions in the US, lawn and garden equipment makes up less than 5 percent of it. Gas-powered lawn mowers also release nitrogen oxides, which create acid rain and react with hydrocarbons in the atmosphere to form ground-level ozone.[17]

What are some additional benefits?

Electric equipment costs less over its lifetime, lasts longer, requires less maintenance, uses less energy, weighs less, stores easier, is more comfortable to use, and always starts, unlike gas engines. It is also quieter, which improves quality of life in local communities and prevents permanent hearing loss for workers and the public. Workers also do not have to wear ear protection or worry about smelling like gas or getting it on their skin, which increases their workplace quality of life.

Perhaps the most significant benefit is improved public health. Exhaust emissions and fine particulates from gas-powered motors are linked to a slew of health issues, including cardiovascular disease, stroke, respiratory disease, cancer, neurological conditions, premature death, and effects on prenatal development. Benzene, butadiene, and formaldehyde are cancer causing compounds that the public is routinely exposed to thanks to these machines. There is evidence that autism is one of the neurological disorders that these pollutants can cause. Asthma and chronic obstructive pulmonary disease (COPD) are also linked. Preventing early death ought to be a priority for municipal governments. Landscaping companies can also gain a

[12] https://www.electricmowerreport.com/are-electric-mowers-cheaper/

[13] https://gardenbeast.com/electric-vs-gas-lawn-mowers/

[14] https://www.diffen.com/difference/Electric_Leaf_Blower_vs_Gas_Leaf_Blower

[15] https://sciencing.com/calculate-carbon-footprint-lawn-mower-24046.html

[16] https://www.onlynaturalenergy.com/grass-lawns-are-an-ecological-catastrophe/

[17] https://www.leafscore.com/eco-friendly-garden-products/the-environmental-impact-of-lawn-mowers

marketing advantage from promoting themselves as green. Being able to deliver all services with rechargeable equipment that is both cleaner and quieter can help them appeal to customers and charge a premium while adhering to increasingly stringent emissions and noise standards. There are also productivity advantages, like being able to work early in the morning or late into the evening with less noise disruption. Not having to fix broken throttle cables and plugged air filters or refuel saves time, both on the job and for mechanical training beforehand.[18] In an interview with Dan Mabe, the founder of the American Green Zone Alliance, he says that 90 percent of routine maintenance can be done with battery-powered equipment, even for commercial companies.[19]

What are the dis-benefits?

The up-front costs of electric equipment can sometimes be higher than gas-powered options. Runtime is also a significant hurdle, especially for larger areas, as some battery-powered equipment requires recharging after every hour or so of use. Interchangeable batteries could solve that problem, but they can get expensive. Electric leaf blowers have less torque and can make jobs slower, which could offset the financial savings of cheaper equipment. Lastly, dead batteries can end up in landfill. Education can help encourage recycling of batteries and make consumers aware of best practices for prolonging battery life, like keeping them in the right temperature and charging them before storage.[20]

Policy Proposals

Bans and restrictions

Gas-powered lawn mowers and leaf blowers could be outright banned or limited to certain uses, as Washington D.C. and many California cities have done. The language of the proposed California statewide ban[21] or the City of Ojai's municipal code can be modeled.[22]

Rebates

No federal rebates for electric lawn equipment currently exist, so it is up to state and local governments to incentivize their adoption. Since the upfront costs of electric equipment can be higher, these sorts of incentive programs can be important to facilitate the green transition. The South Coast Air Quality Management District in California's Incentive and Exchange Programs are a worthy model. The district currently offers a rebate of up to $250 for any citizen who purchases a cordless, battery-electric lawn mower and scraps their gas-powered one. Commercial landscapers, nonprofits, local governments, colleges and school districts can get up to 75% off commercial equipment through pre-authorized dealerships when they get rid of equivalent gas

[18] https://www.greenindustrypros.com/mowing-maintenance/article/21068282/electrification-of-an-industry-batteries-spark-product-innovation

[19] https://cleantechnica.com/2021/06/19/the-fully-electric-future-of-landscape-maintenance/

[20] https://www.leafscore.com/eco-friendly-garden-products/the-environmental-impact-of-lawn-mower

[21] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220AB1346

[22] https://ojaicity.org/wp-content/uploads/2015/07/Noise-Ordinance-Title-5-Chapter-11.pdf

or diesel machines.[23]

Santa Barbara County's Air Pollution Control District held a pilot program offering vouchers to organizations that covered 60% of the purchase price of electric landscape equipment. Voucher funds were capped at $7,000 per organization. The agency also conducted a participant survey to determine satisfaction with the different types of equipment subsidized by the pilot program.[24]

Green landscaping: re education campaigns and incentives

Municipalities can launch or support education campaigns that promote lawn care equipment electrification. For example, the Mow Electric! campaign in Vermont is a grassroots initiative that demos commercial electric equipment and educates the public about related financial incentives. Its website has an interactive calculator to help consumers compare gas-powered and electric equipment in terms of long-term savings as well as CO2 emissions. They have also compiled user reviews, comparisons of different models, and a directory of local businesses that use electric equipment.[25] Municipalities can support these types of organizations with funding or even just a physical space like a park to conduct their demonstrations.

Battery recycling initiatives should be promoted along with lawn care electrification to encourage eco-friendly battery disposal. Many counties already have battery disposal guidelines available, and neighborhood nonprofits host battery recycling programs. These resources can be attached to the lawn care electrification project.

Lastly, governments should offer incentives and take part in education campaigns to reduce lawns overall. Lawns are not climate friendly - besides guzzling millions of gallons of gas for mowing, they also use nearly 3 trillion gallons of water and 70 million pounds of pesticides across the country every year. Lawns harm animals in a variety of ways. They not only reduce habitats for pollinators and other animals, but also poison birds that eat berries and seeds contaminated with lawn pesticides. Runoff from lawns carries toxins into local bodies of water, poisoning fish and aquatic life and harming humans who swim, surf and eat contaminated seafood.[26] Southern California's Turf Replacement Program intends to encourage homeowners to replace existing lawns with drought-tolerant, organic landscapes made up of native plants. The Metropolitan Water District offers up to $2.00 per square foot in rebates for up to 5,000 square feet of converted yard per year. Additional rebates are available for weather-based irrigation controllers, soil moisture sensors, rotating nozzles, rain barrels and cisterns.[27] Municipalities can offer these sorts of incentives and produce guides on turf replacement to help popularize climate-friendly yards.

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[23] `http://www.aqmd.gov/home/programs/community/community-detail?title=lawn-equipment`

[24] `https://www.ourair.org/leefprogram/`

[25] **Link** https://www.sevendaysvt.com/vermont/mow-electric-helps-vermonters-ditch-gas-powered-lawn-equipment/Content?oid=32955644

[26] `https://www.nrdc.org/stories/more-sustainable-and-beautiful-alternatives-grass-lawn`

[27] `https://socalwatersmart.com/en/residential/rebates/available-rebates/turf-replacement-program/`

11.2.2 How much would lawn care electrification programs cost and who would pay?

Bans and restrictions alone would pass the costs of lawn care electrification to consumers. Without a local market for gas-powered equipment, costs would equal the price of a new electric lawn mower or leaf blower, which can range from less than a hundred to a few thousand dollars. In order to share the burden of the electric lawn care transition with its citizens, governments can initiate incentive programs. The total cost of these incentives to municipalities can be limited by capping total cost, setting a hard deadline for incentive applications, and/or awarding grants through a lottery-based system. For example, programs like the South Coast Air Quality Management District's rebates (up to $250 per individual) or Santa Barbara County's vouchers (up to $7,000 per organization) could be implemented with limits to ensure financial sustainability for the municipality.

11.3 Policy alternatives

11.3.1 Pilot Program Proposal

An initial policy to introduce electric landscaping equipment to a community could involve municipal rebates similar to those of California's South Coast Air Quality Management District or Santa Barbara County, as detailed above. The municipality could conduct a study on the effectiveness of the pilot program, similar to Santa Barbara County's participant survey. Based on the results of the study, the municipality can choose to expand the pilot program into a permanent rebate policy or implement a full electrification policy via bans and restrictions. The municipality can also implement a combination of these two options, for example by banning electric leaf blowers and providing rebates for electric lawn mowers, depending on study results.

Chapter 12 EBus: Electrification of Transit Buses and Utility Vehicles

By: Jae Kwak
2021-08-12

12.1 FAQ for transit bus electrification

1. What is the name of the policy or program type?
   Transit Bus Electrification
2. What is transit bus electrification?
   Local policies that will replace diesel transit buses with electric battery-powered transit buses.
3. What are some examples in practice?
   Seneca, SC: In 2014, Seneca, SC became the first city in the world to launch an all-electric bus fleet. The policy is considered successful so far, as the new fleet has outperformed diesel equivalents in terms of fuel and maintenance costs and have beat expectations regarding range and charging times.
   Chicago, IL: The Chicago Transit Authority(CTA) launched 2 electric buses in 2014 as a test pilot, and found that they saved more than $24,000 each in fuel costs and $30,000 each in maintenance costs. Most importantly, the vehicles performed well without much difficulty in extreme cold weather. CTA is planning to fully electrify the bus fleet by 2040.
   King County, WA: Since 2016, the King County Metro Transit has been testing electric buses, and found them to perform well in a variety of weather conditions. However, there were some issues regarding battery life, range, and higher (than diesel) per-mile fuel costs due to high electricity demand charges. However, the King County Metro Transit considers the ROI to be reasonable if emissions reductions and other co-benefits are considered and is planning to expand the rollout.
   Albuquerque, NM: Albuquerque tested electric buses in 2018, but eventually cancelled the contract due to issues such as subpar battery life, inadequate range, and sensitivity to extreme heat. However, in August 2019, the city announced it would purchase five new 40-foot electric buses.
4. What does transit bus electrification cost and who pays?
   There are two main components of costs in providing public transportation service: operating costs and capital expenditures. On average, 25.4% of the total costs are funded by fares, 37.4% from Local governments, 20.5% from State governments, and 16.8% by the Federal Government. Operating costs are funded mostly with fares and local government

funds, and capital expenditures are mostly funded by the local governments and the federal government.

As of 2019, according to PIRG, on average diesel transit buses cost $500,000 while electric buses cost $750,000. Most of the difference in upfront costs will likely have to be borne by local governments through municipal bonds and local option transportation taxes. State grant programs and subsidies like in the case of California, if possible, will help cover the difference in upfront costs. The Federal Transit Administration's (FTA) Low or No Emissions Program, which funds state and local government agencies for low-emissions transit buses and related infrastructures, can also lower the cost burden for local government.

As long as electricity prices are stable, electric buses can produce substantial savings in terms of lower fuel and maintenance costs relative to diesel buses despite higher upfront costs. Proterra, one of the leading electric bus manufacturers, says its electric buses can save up to $50,000 a year relative to fossil fuel powered buses, indicating a 5 year payback period. However, as seen in the case from King County, WA, the cost savings of electric buses depend on electricity rate structures.

There is potential for even more cost savings if Vehicle-to-Grid (V2G) operations are implemented. Under V2G operations, the electric bus batteries are charged at times when electricity prices are cheap, while discharging power back to the grid at peak demand times. Partnerships with utilities are crucial for V2G to be viable.

5. What are the climate-related benefits of transit bus electrification?

   Electric buses emit substantially less carbon than diesel counterparts, even when the electric grid is carbon intensive. If an electric bus is charged with the national electricity mix, it produces less than half of carbon emissions per mile produced by diesel-hybrid or natural gas buses, which are considered to be "cleaner" than diesel buses. The reduction in carbon emissions will increase even more as the percentage of electricity generated by renewables and other clean energy sources increases.

   According to a 2019 PIRG report, replacing all of US diesel transit buses could eliminate more than 2 million tons of greenhouse gas emissions per year. On the local level, the Chicago Transit Authority can save approximately 55,000 tons of greenhouse gas per year if they electrify its entire fleet. Similarly, the Southeastern Pennsylvania Transportation Authority can reduce 2,000 tons of greenhouse gas emissions per year if they electrify all of its transit buses. These figures will further improve as US grids move towards more clean, renewable energy.

6. What are some additional benefits?

   Improved air quality:

   By replacing diesel buses, this program can reduce harmful emissions from diesel exhaust that pollute the air, thereby reducing health care costs. Pollutants that are expected to be reduced are ozone, lead, diesel particulate matter, carbon monoxide, sulfur oxides, and nitrogen oxides, which are all harmful for the human health and the environment. Exhaust from diesel buses are designated by the IARC to be carcinogenic and are linked to premature death, aggravated asthma, and decreased lung function. The exhausts are also linked to ozone pollution and acid rain. Air pollution tends to be more severe in low-income and minority communities, so municipalities like King County, WA are considering to first electrify buses in such communities to address social equity concerns.

Grid Balancing:

If V2G operations are possible, the electric bus batteries can be used as energy storage for the grid by charging them when prices are cheap and discharging power back to the grid at peak times. Electric transit buses have potential for V2G because of large capacity sizes and predictable operation schedules. Battery life reduction is a potential concern for V2G operations, but the Becker et al.(2019) case study shows that as long as proper thermal management is conducted, battery degradation can be minimized.

Noise Reduction:

Traditional diesel buses contribute to noise pollution, which can be harmful in some instances. A Toronto study found that 12% of transit bus noise exposure exceeded the EPA threshold for hearing damage risk. Electric buses can reduce the risk substantially because they are mostly quiet.

Lower Maintenance and Fuel Costs:

As mentioned earlier, electric buses can save more in lifetime costs due to lower maintenance and fuel costs.

7. What are the dis-benefits?

Range:

Range has often been cited as an issue for electric vehicles in general, especially during the early stages of development. Local municipalities need to test thoroughly before mass deployment to ensure that the original routes would not be disrupted, especially during extreme weather conditions. In King County Metro's electric bus pilot programs, there were some instances when the batteries were depleted faster than usual, especially in cold temperatures. The case was more severe for Albuquerque, as the average 177 mile range failed to meet the contractually-stipulated 275 mile per charge range, especially in hot temperatures. However, this doesn't mean that electric buses always fail to provide enough range. In the case of Seneca, the new electric buses were expected to provide a range of 30 miles, but the buses exceeded ranges of 40 miles. Similarly, the Chicago Transit Authority found its new electric buses to maintain its range through extreme cold temperatures. Overall, we recommend that local governments test the vehicles thoroughly in different conditions before committing to a contract.

Infrastructure:

Building out the charging infrastructure will likely be a costly expenditure. The costs will be higher if on-route charging infrastructure is needed. However, as fleet sizes become larger, there is greater potential of economies of scale, which would bring down the infrastructure cost per vehicle. Furthermore, partnering with a local utility may bring opportunities to bring down the cost of installing charging infrastructure.

Operational Complexity:

In the transition period where traditional buses and electric buses coexist, the complexity of managing the vehicles and organizing routes may sharply increase. Additional staff training will also be necessary. However, as we see more successful cases of adoption, it may be possible for more guidelines to be established that will help local transit authorities adjust to the changes.

Potential stress on the Electric Grid:

If the transition to electric buses happens in a short period, it may potentially cause strain on the local electric grid. If electricity prices increase sharply due to strain, lifetime costs of electric buses may increase. One potential solution to mitigate this is to partner with utilities to coordinate charging and V2G operations.

8. How difficult is it to implement and maintain transit bus electrification?

   As mentioned above, the biggest obstacles for implementing would be the difference in upfront costs and the installment of charging infrastructure. For these financial obstacles, local governments should actively seek out federal and state grants or even pursue partnerships with local utilities.

   In terms of maintenance, the largest challenges would come from changes in operational complexity. However, we believe that these operational challenges would become easier to overcome as more and more transit authorities experiment with potential solutions.

9. What are the leading vendors pertaining to transit bus electrification?

   Electric Bus Manufacturers

   Yutong

   BYD Motors

   Proterra

   AB Volvo

10. References and Links

   "Cargo bikes deliver faster and cleaner than vans, study finds" The Guardian, August 5, 2021, Link. Article about a recent study finding in favor of using electric bikes for delivery services in London. The study is entitled "The Promise of Low-Carbon Freight" and is posted at Link.

   EPA on air pollution: Link.

   2019 PIRG Report: `https://uspirg.org/sites/pirg/files/reports/ElectricBusesInA`
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https://www.greentechmedia.com/articles/read/on-heels-of-253m-raise-highl
s

12.2 FAQ for Municipal Service Vehicle Electrification

1. What is the name of the policy or program type?

   Municipal Service Vehicle Electrification. For this FAQ, the focus will primarily be on police patrol car electrification.

2. What is municipal service vehicle electrification?

   These are efforts in the local municipal level to replace fossil-fueled vehicles operated by municipal service departments with electric-powered vehicles. There are various types of vehicles operated by municipal governments, ranging from fire trucks and garbage trucks to police cars. The focus of this FAQ will be on electrifying police patrol cars, which has had more pilot experiments conducted on.

   Although there are less examples of implementation, replacing diesel municipal garbage trucks with electric garbage trucks also appears to be promising.

3. What are some examples in practice?

   Police patrol cars

   In 2019, Bargersville, Indiana became the first police department in the nation to deploy a Tesla Model 3. At a price tag of $39,500, the Model 3 cost about $14,500 more than its non-EV counterpart, the Dodge Charger, but over 6 years it is expected to save about $21,000 in fuel and maintenance costs. The department is planning on incrementally expanding its EV fleet.

In 2019, the Fremont, CA police department deployed a 2014 Tesla S 85 as a patrol car. After a highly publicized incident in which this vehicle ran out of battery in the middle of a high-speed pursuit, the department has made some improvements in how it operates the vehicle. Despite the incident, overall, the department evaluated the pilot to be successful in terms of emissions, costs, range, and service life. It acquired an additional 2020 Tesla Model Y at $57,000 and a 2021 Ford Utility Hybrid PPV for $48,000, with plans for further expansion.

In 2019, the Westport, CT Police Department paid $52,900 to purchase a Tesla Model 3, compared to the $37,000 Ford Explorer which makes the majority of the fleet. The police chief believes that the fuel and maintenance savings over the life of the vehicle will compensate for the higher purchase price.

In 2015, the LAPD announced that it is leasing 288 electric vehicles, including 160 fully-electric vehicles, which were mostly BMW i3s. However, it was later found that the all-electric vehicles were barely being used, with those with the most mileage having only a few thousand miles and most cars having only a few hundred miles on the odometer. It is speculated that they were rarely used because of range anxiety stemming from the fact that the vehicles can only go 80-100 miles on a charge. Eventually, the i-3 vehicles were sold by dealerships at cheap prices after the lease ended.

Garbage trucks and other vehicles
As part of Mayor Deblasio's executive order mandating a fully electric municipal fleet by 2040, the New York City Sanitation department retrofitted 12 refuse collection trucks with a form of hybrid-electric technology employing ultracapacitors.

Ultracapacitors can store relatively quick bursts of energy with minimal impact on battery life, making them suitable for heavy-duty and high-power applications. However, they have relatively low energy storage capacity. The trucks are expected to yield a 30 percent reduction in fuel consumption, and the Sanitation Department ordered 14 more trucks using the same technology.

The LA fire department plans to introduce the first electric-powered fire truck in North America. By 2035, the LA Sanitation and Environment department plans to transition its garbage truck fleet to EVs.

4. What does municipal service vehicle cost and who pays?
Police patrol cars
In the case of mid-size patrol cars, the Chevrolet Bolt EV costs around $31,995, while

the non-EV counterpart Dodge Charger costs around $25,000 For police patrol SUVs, the Chevrolet Bolt EUV costs $33,995 while the non-EV counterpart Ford Explorer costs $33,000.

In terms of lifetime fuels and maintenance costs, EV's are expected to save about $21,000 to $30,000.

Garbage trucks

Although exact figures aren't available for both the vehicle prices and operation costs for EV garbage trucks, garbage trucks are optimal for reducing operating costs through electrification due to their "closed-loop" routes: low daily distance covered and speed, repetitive accelerating and braking, and predictable schedules. EV garbage truck manufacturer Wrightspeed claims that its model can reduce up to 60% in fuel consumption, and Lion touts that its Lion8 trash truck can save 80% on total energy costs, while offering a 400 km range.

Financing

Vehicle purchases are financed by the municipal budget. State and federal grants and subsidies, if applicable, can help overcome the differences in upfront costs.

5. What are the climate-related benefits of municipal service vehicle electrification?

   Relative to petrol cars, average lifetime emissions from electric cars are up to 70% lower in places where most of the electricity is generated from clean sources, and is at worst 30% lower for areas where the grid is carbon intensive

6. What are some additional benefits?

   Decreased Air Pollution: Because of its zero direct emissions, all-electric vehicles can improve air quality in urban areas. The improved air quality will also lead to decreased health-related costs.

   Lower fuel and Maintenance Costs: As mentioned earlier, electric vehicles can reduce maintenance and fuel costs over its lifetime relative to non-EV counterparts.

   Virtually quiet: For police officers, the fact that a Tesla can go to zero to 60 mph in 3.2 seconds without making a sound may be beneficial to their operations. For EV garbage trucks, whose extremely loud noise negatively impacts both people outside and inside the truck, the reduction in noise is a significant benefit.

7. What are the dis-benefits?

   Range: Range is the biggest concern for using EV as police patrol cars, as officers usually travel 70-90 miles in a 11-hour shift. Most EV models that police departments are considering using have ranges over 200 miles, so technically it wouldn't be an issue if the cars are always charged before shifts. However, as in the Fremont case where a Tesla had to drop out of a high-speed pursuit due to battery issues, the batteries aren't always fully charged before shifts. This is more of a compliance/logistics issue as police officers aren't used to charging the vehicles after shifts. There needs to be clear guidelines and routines in place to ensure that the batteries are sufficiently charged before shifts.

Charging Infrastructure: To ensure that the service EVs have sufficient powers for their operations, adequate charging infrastructure needs to be in place. Level 2 commercial chargers cost from $2500 to $7210, and 50-kw DC fast chargers can cost from $20,000 up to $35,800. The upfront capital expenditures of charging infrastructure will likely be an obstacle in early stages, but will become less of an issue as the scale of the EV fleets increase.

Compliance and Training: As seen from the Fremont example, there is a need to establish guidelines and protocols regarding the operation of electric service vehicles that would be different from what the personnel are used to. Rules like charging immediately after duty and only using vehicles that have at least a certain amount of battery would be necessary.

8. How difficult is it to implement and maintain municipal service vehicle electrification?

   The biggest obstacles to the widespread adoption of EV for municipal service vehicles is the higher upfront costs, lack of charging infrastructure, and potential range issues. The reductions in emission and cost savings from fuel and maintenance should be clearly quantified to justify the higher initial expenditures regarding electric vehicles. In order to ensure that range is sufficient, clear guidelines regarding charging and usage should be established.

9. What are the leading vendors pertaining to municipal service vehicle electrification?

   Midsize and SUV:

   - Tesla
   - Chevrolet
   - Hyundai
   - BMW
   - Kia

   Fire Truck:

   - Rosenbauer

   Garbage Truck:

   - Mack Truck
   - Wrightspeed
   - Effenco

   Electric Truck and Vans:

   - BYD
   - Daimler
   - Ford
   - Volvo
   - Tesla
   - Arrival

- Rivian
- Workhorse

10. Reference and useful links

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12.3 Policy alternatives for municipal vehicle electrification

12.3.1 Policy 1 (EBus1): Trial run of transit bus electrification with 4 buses

Overview

As a trial run to test for feasibility, local transit agencies can decide to replace 4 of their diesel buses with electric battery-powered buses. They can decide to expand the electrification program after monitoring the operation of the 4 EV buses. They should also make sure to request for the FTA's Low or No Emission Vehicle Program - 5339(C).

Costs

Over 12 years, expect a positive NPV of $785,000 with federal grants or a negative NPV of $715,000 without grants, according to an extensive 2020 NREL financial analysis on replacing 4 diesel transit buses with electric buses. The grant amount is $375,000 per bus based on the median 2018 FTA Low or No Emissions Bus Grants. The first year negative cash flow with the grants is $322,000.

12.3.2 Policy 2 (EBus2): Full electrification of transit buses

Overview

The local transit agency can decide to replace all of its diesel transit buses with EV battery buses over the next 3 years. The local transit agency should make sure to request for the FTA's Low or No Emission Vehicle Program - 5339(C).

Costs

According to a 2018 US Department of Transportation report, there were 64,398 public transit buses across 2350 local transit agencies in 2017. On average, each local transit agency operated 27 transit buses. Using the values from the 2020 NREL study, full electrification of the transit buses operated by the average local transit agency would result in a positive NPV of $5.3 million over 12 years with the FTA grant. The first year negative cash flow with the grant would be $2.2 million.

12.3.3 Policy 3 (EBus3): Trial run of electrifying 6 local police patrol cars.

Overview

The local police department can initiate a pilot program where 6 fossil-fuel police patrol cars are replaced with electric battery-powered vehicles to test for feasibility. It can decide to expand the electrification program after monitoring the operation of the 6 EV patrol cars.

Costs

Local police departments in the US commonly use Dodge Chargers and Ford Explorers as patrol vehicles. US-manufactured EV equivalents would be the Chevrolet Bolt and the Chevrolet Bolt EUV, respectively. The price premium for these electric vehicles are around $1000 to $1800. With Level 1 Chargers offered for free for each vehicle, if we assume that we install a Level 2 Charger for every 2 vehicles, we would incur a cost of about $4300 including installation costs for every 2 EV patrol cars. Including Level 2 charger costs, the net costs for electrifying a single police patrol car would be around $3150 to $3950. At 6 police patrol cars, the total net costs would amount to around $18,900 to $23,700. This estimate, however, does not account for the lifetime cost savings in maintenance and fuel.

12.3.4 Policy 4 (EBus 4): Full electrification of local police patrol cars

Overview

The local police department can replace all fossil-fuel police patrol cars with electric battery-powered vehicles.

Costs

Using the statistics provided by a BJS 2003 report, it can be estimated that on average there are 19 patrol cars per local police department. Using the unit net costs from above, full electrification would incur a cost on average of $59,850 to $75,050. This estimate, however, does not account for the lifetime cost savings in maintenance and fuel.

Chapter 13 FoodR: Food Rescue

Gabriela Garity

2021-08-11

13.1 Background and Motivation

The U.S. wastes a whole lot of food. According to the Food and Agriculture Organization of the United Nations, the world wastes 1.3 billion tons, or approximately one-third, of food produced for human consumption. That proportion is similar within the US—approximately 31% food at the retail and consumer level goes uneaten each year. In industrialized nations, most of this waste is food discarded while it is still edible. Food waste not only deprives people in need - it also increases GHG emissions, municipal waste, which is expensive, and expends enormous amounts of energy and water.[1] The problem is to find a way to make the situation better.

Food rescue programs seek to collect food that would otherwise go to waste and deliver it to those in need. Most of these programs are run by charitable organizations, which transport excess food from farms, manufacturers and retailers. Food rescue programs for restaurants are less common due to efficiency barriers, and those that do exist rely on volunteers who accept individual requests by restaurants to transport food to donation centers. Motivations for donor participants include not only sustainability goals of reducing food waste, but also financial benefits of tax write-offs for charitable donations and reduced waste management fees. Restaurant and grocery store participation could be improved by increasing awareness of the Bill Emerson Good Samaritan Act, which protects donors from liability even if the food causes harm to the recipient. The following document outlines examples of current food rescue programs, benefits and dis-benefits of these programs, and a proposed government policy.

13.2 What are some examples in practice?

• Food Rescue US

Food Rescue US leverages their innovative crowd-shipping platform to connect volunteers and recipients of food donations like Uber Eats and Doordash connect drivers to customers. Their "direct transfer" model eliminates the need for warehouses and large nonprofit infrastructure, providing quicker access to fresh, perishable food by utilizing existing resources of the community. Volunteers log into the online portal and select a rescue that fits their schedule. During the rescue, they pick up food from a participating restaurant, grocer, or other food establishment, and drive it to a local social service agency site. Food Rescue US's technology-based model

[1] AN AGENT-BASED MODEL OF SURPLUS FOOD RESCUE USING CROWD-SHIPPING

is designed to be sustainable and scalable to support its expansion throughout the nation. It currently operates in 36 sites and 20 states plus the District of Columbia, and has rescued over 95 million pounds of food to create over 73 million meals throughout its decade-long lifetime.[2]

• City Harvest

City Harvest is a nonprofit organization in New York City that uses their fleet of 26 refrigerated trucks to deliver food from nearly 2,000 restaurants, grocers, manufacturers, and farms to nearly 400 soup kitchens, food pantries, and community food programs, rescuing nearly 300,000 pounds of food each day. Volunteers can sign up for a shift online through their virtual calendar. Besides transporting food, City Harvest also hosts Mobile Markets as fresh food distribution sites for communities in need. They also created a smartphone app called Plentiful that helps people locate food pantries and reserve a time to pick up food in advance, helping reduce wait times and allowing recipients to access important information in their own language.[3]

• CalRecycle

The state of California's Senate Bill 1383 will implement new requirements for jurisdictions, food donors and food recovery organizations to improve food rescue networks in order to meet the statewide requirement of recovering at least 20% of edible food for human consumption that would otherwise be discarded. Each jurisdiction in California must implement a food recovery program, identify and educate commercial food generators, assess and expand food recovery infrastructure, and monitor food donor compliance beginning in 2022. Food businesses must establish contracts with food recovery organizations in order to donate the maximum amount of food possible, as well as keep records of donations. Food recovery organizations and services that choose to participate in this program must similarly form contracts with donors and keep records of donations. The state's CalRecycle program has also provided $20 million in grants to fund food rescue projects that have created 86 million meals and prevented 103 million pounds of food from entering landfills since 2018.[4]

• Canadian Government Programs

The federal government of Canada as well as the provincial government of Ontario have recently funded existing food rescue programs, allocating $50 million and $5 million, respectively. The federal program is helping eight organizations recover the cost of their efforts to redistribute surplus food to food insecure families during the COVID-19 pandemic. It also supports Nutri-Group, a high-quality sustainable egg producer that enhances quality of life for rural farmers and donation recipients alike.[5] Ontario's investments are reserved for food rescue infrastructure, including refrigerated trucks, freezers, storage space and kitchen equipment. These facilities and materials will serve nearly 30 community-based organizations, Indigenous organizations, and

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[2] https://foodrescue.us/about/faqs/

[3] https://www.cityharvest.org/programs/food-rescue/

[4] https://www.calrecycle.ca.gov/Organics/SLCP/FoodRecovery

[5] Link

First Nation Communities.[6]

13.3 What are some climate-related benefits of food rescue programs?

Food waste accounts for about 8 percent of global greenhouse gas emissions.[7] The World Resources Institute reports that if food waste were a country, it would be the third-largest emitter of greenhouse gases, behind China and the US.[8] Within the US, food waste is the single largest category of waste in municipal landfills, which are the third-largest source of human-related methane emissions.[9] The decaying of uneaten food accounts for approximately 16% of human-related methane production.[10] Since the warming power of methane is 80 times that of carbon dioxide over a period of 20 years, reducing methane production is the fastest way to reduce the rate of global warming, according to the Environmental Defense Fund.[11] By preventing uneaten food from reaching landfills, food rescue programs help prevent methane from being released into the atmosphere.

13.4 What are some additional benefits?

• Addressing food insecurity and malnutrition

Nearly 50 million (approximately 1 in 6) Americans are currently experiencing food insecurity according to Feeding America. Rescuing nutritious food from restaurants and grocery stores could help solve this problem.[12]

• Reducing healthcare costs associated with poor nutrition and obesity

Fruit, vegetable, dairy and meat discards provide high-quality nutrition for food insecure individuals, helping improve health outcomes.

• Preventing economic costs of landfilling food waste For governments, less landfilled food means lower transportation costs and extends the life of existing landfills, which are costly. For businesses, less wasted food reduces disposal costs and generates tax deductions for donations.

• Minimizing government expenditures associated with feeding hungry citizens

Partnering with private donors and nonprofit, volunteer-based organizations could reduce government costs and replace existing food programs.[13]

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[6] Link

[7] https://www.drawdown.org/solutions/reduced-food-waste

[8] https://www.wri.org/insights/whats-food-loss-and-waste-got-do-climate-change-lot-actually

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• Spreading awareness

Expanding food rescue programs could help reach a broader audience to educate them about food waste, food insecurity, and climate-related impacts through community and volunteer mobilization.

• Creating meaningful jobs Jobs related to organizing food rescue programs, maintaining infrastructure, and transporting donations could be created, providing fulfilling work opportunities for unemployed people.

• Reducing landfill growth By diverting organic materials that would otherwise end up in landfills, food rescue programs prevent pollution of soil, surface water and groundwater, wasted land space, and deterioration of the aesthetic qualities of cities.

13.5 What are the dis-benefits?

• Climate effects Greenhouse gases may be created while transporting and storing food.

• Safety dangers Donation recipients' health could be endangered if food is not inspected, handled and stored properly. Workers recovering food could also get hurt while carrying and transporting donations.

• Volunteer-based models can be unreliable Nonprofit organizations that rely on volunteers to carry out food rescue missions face the problem of lacking any significant form of ensuring accountability, which sometimes means that promises are broken. Restaurants and grocery stores that go through the work of preparing food for donation expect follow-through from their partnering nonprofit organization. When deliveries repeatedly go unfulfilled, donors may be discouraged from participating in food rescue programs at all.[14]

13.6 Policy proposals

See as well Link to NRDC.

• Assess and address gaps in food rescue coordination

Many cities already have effective food bank systems in place to rescue food from predictable centers like manufacturers and grocery stores. However, food rescue from restaurants, hospitals, airports, colleges, cultural and sports venues, schools and other sources is usually less developed. Governments should invest in data collection to improve current networks, especially to determine where there are gaps in food rescue infrastructure, coordination, and staffing. Next, government departments can spearhead efforts to create partnerships between organizations and businesses to coordinate donations. For example, the Orange County Environmental Health Department and the Orange County Food Bank led a campaign called Waste Not Orange County that partnered with Yellow Cab to pick up and deliver surplus food when other transportation options were

[14] AN AGENT-BASED MODEL OF SURPLUS FOOD RESCUE USING CROWD-SHIPPING

unavailable, such as late at night. Drivers dropped donations off at 7-11 stores, where they were stored temporarily until regular food rescue systems could deliver them to distribution centers.

• Initiate grant programs for food donation

Local governments could initiate grant programs that reward food rescue projects. For example, Alameda County in California awarded up to $20,000 per applicant for innovative projects that prevented surplus food from being wasted and provided it to people in need through food donation.[15] Cities could also provide grants for equipment like vehicles and coolers, storage and processing facilities, software platforms, and key staffing costs. A successful example is Seattle's Food Recovery Program, which has invested nearly $400,000 to help hunger relief organizations purchase storage, transportation and food processing equipment since 2006. This program is expected to divert about 23,000 tons of food waste over 10 years at a cost of $29 per ton. Disposal costs approximately $53 per ton, so the program will save the city about $1.2 million over 10 years.

• Enhance tax incentives for food donations

Cost is one of the main barriers to food donation. States, cities and municipalities can create or expand tax incentives for businesses that donate to food rescue programs. At the federal government level, tax incentives have been highly successful in encouraging greater donations. For example, when tax incentives were expanded to cover more businesses after Hurricane Katrina in 2005, food donations across the US rose 136% in 2006. Governments could increase limits for tax deductions for charitable food donations.

• Reduce legal barriers to food donation

Cities and municipalities should work to streamline, consolidate and clarify regulations related to food donation to reduce logistical challenges and confusion among donors. City health regulations should be compiled and easy to access on the health department website. This guide should also clarify liability protections, as fear of liability often discourages businesses from donating food. They could also enhance existing liability protections for donors and nonprofit organizations involved in food rescue and explicitly allow past-date food to be sold or donated after the date.[16] An example in practice is the Los Angeles County Public Health Department's Food Redistribution Initiative, which provided resources on safe food donation, including a straightforward, easily understood document with instructions on topics like food donation sources and temperature control.

• Alter waste management policies

Municipal garbage collection policies that charge a flat-rate fee regardless of the amount of waste generated disincentivize waste reduction and food rescue efforts. Instead, municipalities can implement Pay-As-You-Throw or Save-As-You-Throw incentive-based pricing systems that use container size, collection frequency, or pre-paid bags as units for tracking waste generation.

[15] https://www.stopwaste.org/at-work/stopwaste-grants/food-waste-reduction-grants

[16] https://www.chlpi.org/wp-content/uploads/2013/12/Food-Recovery_D.C._Final.pdf

Besides potentially increasing incentives for businesses to donate food rather than discard it, these policies can also reduce residential solid waste, increase recycling, and save governments money. For example, in Gainesville, Florida, implementing a Pay-As-You-Throw policy (PAYT) reduced solid waste by 18%, increased recyclables recovery by 25%, and saved the residential sector $186,200 in the first year. Increasing recycling could also earn more revenue for a town.[17] A study promoted by the Connecticut Department of Energy and Environmental Protection found that PAYT programs reduced household trash generation by 40-55%. In Stonington, Connecticut, PAYT has saved the city approximately $7 million since the program's inception in 1997 and has increased recycling from 27% to 40%. PAYT programs are best suited for metropolitan areas where the population generates a large volume of waste, and where landfills are nearing capacity or municipal waste is expensive to dump.[18]

13.7 Pilot Program Proposal: PAYT and Food Rescue Grants

One low-cost or zero-cost option for municipalities to simultaneously reduce waste and help feed hungry citizens involves coupling two policies: altering waste management policies and providing grants for food rescue program development. Since implementing a Pay-As-You-Throw waste pricing system has been proven to reduce costs for municipalities by incentivizing the reduction of solid waste,[19] municipalities could commit to contributing the same amount saved via these policies to food rescue grants. These grants could be awarded on a competitive basis to organizations with promising plans for using the money, whether for storage and transportation equipment, staffing, data collection, or other projects.

The Pay-As-You-Throw program would require some initial heavy lifting. First, a system for tracking waste disposal would have to be chosen. One option is mandating town-approved trash bags. These bags would be sold at local retail stores and municipal outlets in multiple sizes, strengths and colors. Second, a pricing system would have to be chosen. This system could be developed by examining programs in neighboring communities with similar demographics, reviewing current data on annual waste volume and program costs, and even hiring economists and accountants for more advanced analysis.[20] Third, an effective campaign to educate residents on the new waste collection pricing system would have to be carried out. Public hearings and presentations, press releases to local media outlets, mail brochures and flyers, and educational events for students and organized community groups would have to be implemented to ensure residents are aware of new norms as well as program benefits. This would require some initial financial investment. Next, a special fund could be created to accrue revenues from per-unit waste

[17] http://www.rcapsolutions.org/wp-content/uploads/2013/06/Pay_As_You_Throw_Handout.pdf

[18] Link

[19] Link

[20] https://archive.epa.gov/wastes/conserve/tools/payt/web/html/top15.html

collection and recycling. According to the nonprofit organization RCAP Solutions, PAYT should lower the municipal solid waste management budget overall, between 25-45% on average.[21] Lastly, the municipality could promote their grant program for food rescue organizations using the funds saved through PAYT. Even if savings are modest at first, any government contribution to improve food rescue could be impactful.

A pilot program could be implemented to test the viability of a full-blown PAYT policy. Municipalities could offer tax rebates for a variety of individuals and organizations that agree to participate in the program and provide data. The municipality could study the program's effectiveness and estimate cost savings achieved by a broader policy.

13.8 Resources

- Mugica, Y., Rose, T., & Hoover, D. (2019). Tackling Food Waste in Cities: A Policy and Program Toolkit (p. 53). Natural Resources Defense Council. https://www.nrdc.org/sites/default/files/food-waste-cities-policy-toolkit-report.pdf Link to NRDC Report.

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[21] http://www.rcapsolutions.org/wp-content/uploads/2013/06/Pay_As_You_Throw_Handout.pdf

Chapter 14 EVChrg: EV charging

Jae Kwak
2021-08-11

14.1 FAQs

1. What is the name of the policy or program type?

Electric vehicle charging infrastructure policies, also referred to as EV Supply Equipment (EVSE) infrastructure policies.

2. How do you define EV charging infrastructure policies?

Here, we are loosely referring to policies that facilitate the expansion of EV charging facilities. The following are some potential policies that can be done at the state and local government level:

- Through EV infrastructure building codes, local governments can require new buildings that meet certain thresholds to ensure easy access to electric vehicle charging stations
- Streamlining the process for constructing new EV charging stations to spur private investment into these facilities
- Forge collaborations with electric utilities, giving them an incentive to manage charging costs while preventing strain to electric grids
- Encourage and incentivize local retailers to install and host charging infrastructure so they can increase foot traffic and earn revenue from charging stations. A tangentially related policy to this would be incentivizing local gas stations to install and operate EV charging stations.

3. What are some examples in practice?

- *EV infrastructure building codes*: A number of US local governments have adopted EV charging building codes for new constructions. A list of the US cities and states implementing these is available here: https://docs.google.com/spreadsheets/d/1lgppSv7HvU4ExH8TJarE23o8-Y-q9oLV0TaBPBMKaiE/edit#gid=27292754

  For example, the city of Dever, CO mandates the following EV charging spot requirements for new buildings, depending on the type of building:

  - Single-family residential units: 1 EV-ready space per dwelling unit
  - Multi-family residential units: 5% of parking spots should have EV charging stations, 15% should be EV-ready, and 80% should be EV-capable.
  - Commercial buildings: 5% of parking spots should have EV charging stations, 10

  Definitions of terms related to EV infrastructure building codes:

  - EV-Capable Parking Space: panel capacity and conduit that can accommodate future

  constructions of EV charging with 208/240 V, 40-amp circuits are installed This covers the most difficult parts in retrofitting buildings for EVSE installation, while minimizing other up-front costs
  - EV-Ready Parking Space: full circuit installation, including 208/240V, 40-amp panel capacity, raceway, wiring, receptacle, and over protection devices Fully ready for installation of EVSE
  - EV-Installed: charging stations are installed during new construction
- *EV charging station streamlining*: In 2015, the State of California passed AB 1236, which requires all cities and counties to develop an expedited, streamlined permitting process for all levels of charging stations. The progress of each California county in their streamlining process can be monitored in the following map: https://www.arcgis.com/apps/webappviewer/index.html?id=5b3 Green indicates the city or county has fully streamlined its charging infrastructure permitting process Yellow indicates partial completion of streamlining Red indicates the city or county has not streamlined its EVCS permitting process
- *Partnerships with utility companies*: Although it is technically not a partnership with local and state governments, 6 major utility companies created the Electric Highway coalition to provide charging stations within their service territories. This initiative came after the current administration pledged to build 550,000 new EV charging stations. Local and state governments can play a more active role in facilitating these partnerships.
- *Incentives for EV charging station*: The following link provides a list of EVSE tax incentives and rebates for installing EV charging stations, provided by federal and local governments and utilities.

  Federal and State Electric Car Tax Credits, Incentives & Rebates
  https://evcharging.enelx.com/resources/federal-and-state-electric-vehicle-incentives
  (ENEL: `https://evcharging.enelx.com/`)
  For example, in the State of New York, NYSERDA offers rebates of $4000 toward the purchase and installation of each Level 2 EV charging station.
- *Installing EV charging stations at gas stations*: On June 4th, Germany mandated all gas stations to offer electric car charging stations.

4. The costs of EV infrastructure policies and who pays?

Hardware and installation costs for EVSE

Level 1 EV charger:

- Voltage: 110/120 V
- Estimated Charging time to provide 80 miles of range: 16 hours
- Unit cost: close to zero because most EV vehicles provide level 1 chargers
- Installation: close to zero because people can just use a 110V wall socket, but it may be a good idea to install a dedicated circuit for EV charging.

Level 2 EV charger:

- Voltage: 240V (residential) / 208 V (commercial)
- Estimated Charging time to provide 80 miles of range: 3.5 hours
- Unit cost: $380 - $5000
- Installation: Level 2 EV chargers often require new circuit installations, which could be costly. Installation costs can vary widely, but expect around $400-$1200 excluding unit costs.

Direct current fast charger (DCFC)

- Voltage: 480V
- Estimated Charging time to provide 80 miles of range: 30 minutes
- Unit cost: $28,401 for 50 kW, $75,000 for 150 kW, and $140,000 for 350 kW.
- Installation cost per unit: Can range from $17,700 to $65,984, depending on kW capacity and the number of chargers per site

Additional features like network contracts can range from $200 to $250 per year per contract, while credit card readers can cost from $325 to $1000.

If the total charging capacity goes over that of a 50 kW DCFC, or an equivalent load of several Level 2 chargers, there is a high chance the site will require a transformer upgrade, whose cost will likely be borne by the local utility. Transformer costs can range from $35,000 to $173,000 depending on the electric current specifications.

EV infrastructure building codes

Costs are borne by developers

EV charging station permit streamlining

Costs are borne by property owners and managers

Partnerships with utility companies

Most of the costs are shifted to utility companies. Likely, we will see costs shared by utility companies and other private sector partners. Joint ventures with local governments are also possible if they have the budget and are legally allowed to enter such ventures.

Incentives for EV charging station

Non-federal tax rebates and incentives come from state and local government budgets. The rest of the costs are borne by property owners and managers. State and local governments may be able to take advantage of new federal green infrastructure funds

Installing EV charging stations at gas stations

Costs are borne by gas station operators and owners

5. What are the climate-related benefits of EV infrastructure policies?

Although the exact figure depends on the electricity mix of the area, EVs have substantially lower lifetime carbon emissions relative to ICE vehicles. For instance, a Nissan Leaf EV in the UK has lifetime emissions that are about three times lower than an average conventional car.

With range anxiety and lack of easy access to charging stations being the two of the biggest obstacles for widespread EV adoption, policies that facilitate the expansion of EV charging infrastructure will help increase EV adoption. With transportation accounting for about 30% of carbon emissions, these policies would contribute to substantial carbon emission reductions.

6. What are some additional benefits?

Benefits from EVSE building codes for new constructions:

It is much easier and cheaper to install EV capable infrastructure in new constructions relative to retrofits. In the long run, this will save money and time for property owners, as projections in EV adoption indicate that most buildings will eventually need EV charging infrastructure in the future.

Benefits from permit streamlining:

Reduce burden of city/county staff Decrease soft costs associated with installing charging stations

Utilities benefit from EV infrastructure partnerships:

Opportunity for utilities to extend service territory to customers beyond traditional footprint Increase goodwill associated with the brand of the utility company May help adoption of vehicle-to-grid (V2G) operations

Benefits for local retail businesses:

Commercial buildings with EV charging stations may be able to attract more foot traffic for retailers. Gas station operators can hedge against decreases in gasoline and diesel demand by installing direct current fast chargers. Because direct current fast chargers are often too expensive for most residential and commercial buildings to install, gas station operators can charge a premium for rapid charges. 7-Eleven, whose business model often relies on gas stations driving foot-traffic to their stores, announced it will install 500 direct-current fast charging ports at 250 locations across North America by the end of 2022

7. What are the dis-benefits?

EV infrastructure building codes:

Increases the costs for new constructions, may stall new developments May be politically unpopular due to the increased burden on new constructions

EV charging station permit streamlining:

Need to make sure conflicts with zoning and other local codes are resolved

Partnerships with utility companies:

A more general disbenefit with increasing EV charging stations is the possibility of overwhelming electric grids. However, if this is the case, it may make more sense for utility companies to take more control in the deployment of EVSE infrastructure to actively manage the increased load on their system.

8. How difficult is it to implement and maintain EV infrastructure policies?

EV infrastructure building codes:

Will likely receive backlash from business associations A phased approach of gradually increasing the requirements may be more feasible. For example, in the short term, the codes can be applied to only residential and commercial buildings exceeding a certain capacity threshold, and that threshold can be lowered as time progresses.

EV charging station permit streamlining:
Common problems that occurred in the permit streamlining process for the State of California were zoning issues, concerns over aesthetics, different interpretations of the code, and the lack of awareness of the streamlining mandate. As a result, there is substantial geographical variation in the progress of the streamlining process in California.

Partnerships with utility companies:
The key factor in successful implementation would be the willingness of utilities to cooperate. Policies that will help mitigate the risks for utilities may facilitate their cooperation.

Incentives for EV charging station:
Ease of implementation and maintenance will depend on budgetary constraints and the availability of federal funds

Installing EV charging stations at gas stations:
Mandates may face backlash from gas station operators. However, as in the 7-Eleven example, it would be important for them to realize it would be beneficial in the long-run. Also, the recent trend of energy companies like BP and Shell acquiring EV charging platform providers and manufacturers indicate that gas station operators may become increasingly receptive to installing EV charging stations.

9. What are the leading vendors pertaining to EV infrastructure policies?

EV charging station manufacturers and providers:

- EVgo
- EVBox
- Tesla
- ChargePoint
- BP (ChargeMaster)
- Shell (GreenLots and NewMotion)
- ABB
- Siemens AG
- Schneider Electric
- Webasto
- Hyundai
- RWE Effizienz

14.2 Municipal government policy proposal for EV charging infrastructure

14.2.1 Background

With the transportation sector amounting to about 30% of greenhouse gas emissions, the widespread adoption of electric vehicles is a necessary condition for keeping the global temperature increase less than 1.5 degrees celsius. According to the Rocky Mountain Institute, in order to achieve this goal, the US needs to electrify at least 70 million vehicles by 2030, which amounts to about a 25% adoption rate. Considering that the current US EV adoption rate is 0.5%, achieving a 25% adoption rate in 10 years is a significant challenge.

Two of the biggest obstacles to the widespread adoption of electric vehicles are range anxiety and the lack of easy access to charging infrastructure. Municipal policies that address these issues and facilitate the expansion of EV charging infrastructure, or electric vehicle supply equipment (EVSE), will have a substantial impact on increasing EV adoption.

Refer to the FAQ document regarding EV charging infrastructure policies for a more detailed overview, available through the following link: Link

14.2.2 Programs

14.2.2.1 EV Infrastructure building codes

Level 2 chargers and direct-current fast chargers often require circuitry and panel installations that can be costly and difficult to retrofit in existing buildings. It would be less costly to install EV charging stations or enable the circuitry while construction than to retrofit it later.

Municipal governments can enact building codes for new commercial and residential constructions to meet a certain threshold in the percentage or number of parking spots that have EV-charging or have the circuitry ready for easy installation. Different thresholds can be set for buildings of different types and scale. For example, the city of Denver enacted EV infrastructure building codes like the following:

Single-family residential units: 1 EV-ready space per dwelling unit Multi-family residential units: 5% of parking spots should have EV charging stations, 15% should be EV-ready, and 80% should be EV-capable.

Commercial buildings: 5% of parking spots should have EV charging stations, 10% should be EV-ready, and 10% should be EV-capable. Definitions of terms related to EV infrastructure building codes: EV-Capable Parking Space: panel capacity and conduit that can accommodate future constructions of EV charging with 208/240 V, 40-amp circuits are installed. This covers the most difficult parts in retrofitting buildings for EVSE installation, while minimizing other up-front costs

EV-Ready Parking Space: full circuit installation, including 208/240V, 40-amp panel capacity, raceway, wiring, receptacle, and over protection devices. These spaces are fully ready for the installation of EVSE EV-Installed: charging stations are installed during new construction

The City of Denver's building code for EVSE is a reasonable benchmark for other municipal governments, but they can be tweaked according to climate goals and stakeholder concerns.

14.2.2.2 Streamlining permits for EV charging stations

With installation being responsible for a large portion of EV infrastructure costs, reducing the soft costs associated with municipal permits for EVSE installation can be a source of immediate cost reductions at very little cost to local governments.

A typical EV charging station permit application approval process involves a review of important components like safety, electric load, accuracy, and compliance with building codes and zoning laws. However, this process can become very time-consuming and costly if municipal governments handle it in an outdated, inefficient manner. In addition to a municipal ordinance creating an expedited, streamlined permitting process, local governments should look into implementing the following practices to assist applicants for EV charging station permits.

Checklist for requirements for an expedited permit process, as well as other relevant information and guidance documents, posted on a website

- Accept electronic submission of permits as well as electronic signatures
- Offer pre-application meetings for applicants with knowledgeable staff
- Allow concurrent reviews for building and electrical components of the permit
- EV charging stations should be classified as an accessory use to a site, not as a traditional fueling station for zoning purposes.

The State of California issued AB-1236 mandating municipal governments in CA to create a streamlined, expedited process for EV charging station permits. Refer to this guidebook made by the State of California for more information on how to make permit applications more frictionless. Link

14.2.2.3 Installing EV charging stations on municipal property

Municipal government buildings like town and city halls are often located in central areas with high traffic. Municipal governments can lead by example if they install Level 2 or direct current fast chargers at local government buildings that are in heavily-frequented areas. Municipal governments should take advantage of rebates and incentives offered by federal and state governments and utilities to lower the cost of purchasing and installing EV charging stations. For instance, municipal governments in the State of New York can qualify for a $4000 per station rebate for Level 2 charging stations under the EVSE infrastructure rebate and a maximum $250,000 per facility rebate under the New York State Department of Environmental Conservation's (DEC) Municipal ZEV Rebate Program.

An option for cities is to implement curbside charging, where Level 1, or even possibly Level 2 chargers are connected to street lamps so that EV owners can charge even when their cars are parked in the street. The City of LA installed charging stations attached to more than 130 street light poles and plans to install hundreds of more. It costs $1 to $2 to charge per hour, while parking itself is free.

Refer to the following website to check what rebates and incentives are available by state. https://clippercreek.com/evse-rebates-and-tax-credits-by-state/

14.2.2.4 Municipal incentives for EV charging stations

Most EV infrastructure incentives and rebates are carried out by the federal government, state governments, and utility companies. A potential option for municipal governments to encourage EVSE investments is to offer a small tax rebate on municipal property taxes for property owners that invest in new charging stations.

14.2.3 Costs

Hardware and installation costs for EVSE

Level 1 EV charger:

- Voltage: 110/120 V
- Estimated Charging time to provide 80 miles of range: 16 hours
- Unit cost: close to zero because most EV vehicles provide level 1 chargers
- Installation: close to zero because people can just use a 110V wall socket, but it may be a good idea to install a dedicated circuit for EV charging.

Level 2 EV charger:

- Voltage: 240V (residential) / 208 V (commercial)
- Estimated Charging time to provide 80 miles of range: 3.5 hours
- Unit cost: $380 - $5000
- Installation: Level 2 EV chargers often require new circuit installations, which could be costly. Installation costs can vary widely, but expect around $400-$1200 excluding unit costs.

Direct current fast charger (DCFC)

- Voltage: 480V
- Estimated Charging time to provide 80 miles of range: 30 minutes
- Unit cost: $28,401 for 50 kW, $75,000 for 150 kW, and $140,000 for 350 kW.
- Installation cost per unit: Can range from $17,700 to $65,984, depending on kW capacity and the number of chargers per site

Additional features like network contracts can range from $200 to 250$ per year per contract, while credit card readers can cost from $325 to 1000$.

If the total charging capacity goes over that of a 50 kW DCFC, or an equivalent load of several Level 2 chargers, there is a high chance the site will require a transformer upgrade, whose cost will likely be borne by the local utility. Transformer costs can range from $35,000 to $173,000 depending on the electric current specifications.

EV Infrastructure building codes

While costs will be close to none for municipal governments, developers and property owners will have to bear the costs of EVSE. Discussion with local stakeholders will be necessary to implement a reasonable building code.

Streamlining permits for EV charging stations

Costs will be minimal for municipal governments. Soft costs are reduced for individuals and businesses installing new EVSE.

Installing EV charging stations on municipal property

Municipal governments will have to bear the cost of purchasing and installing EVSE. As mentioned earlier, they should actively utilize available incentives and rebates.

Municipal incentives for EV charging stations

Property tax rebates will be a net cost to municipal governments. They can set a rebate amount per charger that is financially and politically acceptable.

14.2.4 References

EV Charging Infrastructure FAQ Link

EPA, Sources of Greenhouse Gas Emissions Link

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File: EV-charging.tex

Chapter 15 NMThru: Non-Motorized (Pedestrian and Bicycle) Thoroughfares

By: Gabriela Garity

2021-08-04

15.1 Background and Motivation

Expanding and improving bicycle and pedestrian infrastructure has numerous benefits related to safety, economy, environment, equity, and health. From bike lanes to curb extensions to sidewalks to signage, upgrading non-motorized transportation can help make communities cleaner and more livable. As one of the most obvious and commonly cited solutions to climate change, walking and biking rather than driving can significantly reduce greenhouse gas emissions. Meeting emissions targets will require a significant transition away from motorized transport.[1] EPA data indicates that transportation is the primary source of greenhouse gas emissions in the US, constituting 29 percent of total pollution.[2] In the most congested cities in the nation, 48 percent of all car trips are less than three miles in length, which is no more than a 15-20 minute bike ride.[3] A University of Oxford study found that if just 10 percent of the population replaced car transport with "active travel" for one day a week, total life cycle emissions from car travel would be cut by 4%.[4] Studies show that people do use the bike lanes that cities construct for them, so investing in non-motorized infrastructure could help change behavior and reduce personal emissions.[5]

In addition, according to the 2021 edition of "Dangerous by Design", an annual report published by the nonprofit Smart Growth America, the number of people struck and killed by drivers in the United States while walking increased by 45 percent over the last decade.[6] The National Safety council found that the number of preventable deaths from bicycle transportation incidents has increased 37 percent over the last decade.[7] An additional 65,000 pedestrians and 48,000 bicyclists are injured in roadway crashes every year.[8] Creating more safe and convenient infrastructure would protect pedestrians and cyclists while helping to encourage smart sharing of streets and increased active travel choices.

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[1] https://www.sciencedaily.com/releases/2021/02/210208104624.htm

[2] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[3] Link

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[5] https://activelivingresearch.org/bike-lanes-increase-cycling

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[7] https://injuryfacts.nsc.org/home-and-community/safety-topics/bicycle-deaths/

[8] https://safety.fhwa.dot.gov/ped_bike/

15.2 What are some examples in practice?

15.2.1 The Circuit Trails - Southeastern Pennsylvania and Southern New Jersey

The Circuit Trails are a network of off-road trails in Southeastern Pennsylvania and Southern New Jersey that are currently 300 miles long, with a total of 750 miles planned to be completed. They include the Schuylkill River Trail, the Philadelphia portion of which hosts 1 million pedestrians and cyclists annually. The trail provides convenient access to public transportation, employment centers, open space, and various town centers. Over a quarter of the Philadelphia region lives within 1 mile of a completed Circuit trail. The former mayor of Philadelphia, Michael Nutter, said that "Of the top ten big cities of America, Philadelphia has the highest percentage of bicycle commuters per capita". Besides promoting a sustainable and healthy lifestyle for local residents, the Circuit also generates tens of millions of dollars in economic impact for its surrounding communities every year. Property values are higher near the trails, and commercial development thrives along their routes. Municipalities also save hundreds of millions of dollars annually in direct and indirect medical costs as a result of residents' use of Greater Philadelphia trails and parks. The Circuit Trails have been funded by federal, state, and local transportation funds, nonprofit groups, and donations from area residents and private companies, including real estate development firms with properties near the Circuit.[9]

15.2.2 Cycle Superhighways in Denmark

As an exemplar nation for eco-friendly living, it is no surprise that Denmark invests in high-quality regional bike paths for its citizens. The national government plus a coalition of 23 municipalities are working together to fund and maintain the network of over 311 miles of superhighways, which are being formed by patching together and improving existing routes. Their design features make them inviting to long-distance and short-distance cyclists alike, with smooth asphalt surfaces, shelters, sensor-activated LED lights, shelters, foot rests at intersections, and bike pumps at every mile ensuring cyclist comfort and safety. In addition, "green wave" technology times traffic lights to the average biking speed of 12 miles per hour, providing continuous green lights for cyclists travelling at this speed. The city of Copenhagen found that every kilometer travelled by bike earns the country $0.18, while every kilometer travelled by car costs the country $0.10, in addition to an annual cost of $1.45 billion from automobile traffic congestion in the Capital Region. By reducing healthcare costs, reducing air pollution, and preventing road fatalities, the superhighways are expected to generate significant economic returns.[10]

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[9] Link

[10] Link

15.2.3 New York City Pedestrian Safety Study & Action Plan

The New York City Department of Transportation undertook an unprecedented project that evaluated more than 7,000 records of crashes that resulted in serious injury or death of pedestrians and developed policy solutions to address the causes of these accidents. Accomplishments included: installing countdown pedestrian signals at 1,500 intersections; retrofitting 60 miles of streets to improve pedestrian safety; reengineering 20 intersections for pedestrian safety on major two-way streets; launching a pilot program to test the safety performance of neighborhood 20 m.p.h zone; and implementing a pilot program to improve visibility at left turns along avenues in Manhattan.[11] The Department has also installed over 30 miles of protected bicycle lanes throughout the city since 2007. These lanes have contributed to 75% lower risk of serious injury for cyclists between 2001 and 2013, increased retail sales, and improved travel times. Contrary to popular belief, bike lanes do not decrease traffic flow; in fact, data from New York City shows that the creation of these protected lanes has created space for left-turn pockets, which means that turning cars no longer block through lanes and traffic flow increases.[12]

15.3 What are some climate-related benefits of expanding non-motorized thoroughfares?

Riding a bike saves 150 grams of carbon dioxide per kilometer (0.6 miles) traveled compared to driving.[13] The Institute for Transportation and Development Policy estimates that increasing bicycle use could help reduce carbon emissions from urban transportation by 11 percent. This estimate is based on a goal of increasing urban mileage by bike from 6 percent to 11 percent by 2030 and 14 percent by 2050. In order to achieve this level of cycling, cities around the world will need to invest in rapidly developing large-scale networks of bike and walking infrastructure, among other policies.[14] A study from New Zealand found that investing in bike and pedestrian infrastructure reduces driving-related emissions. Two New Zealand cities that underwent significant improvements to walking and biking networks experienced a 30 percent increase in active travel, which reduced distance travelled per vehicle by 1 percent and CO2 emissions by 1.6 percent.[15] As a zero-emissions form of transportation, any increase in bicycle ridership reduces emissions. Given that cities where bike infrastructure was added saw 48 higher increases in cycling than cities that did not add bike lanes according to the National Academy of

[11] https://www1.nyc.gov/html/dot/html/pedestrians/pedsafetyreport.shtml

[12] https://www.livablestreets.info/traffic_congestion_why_its_increasing_and_how_to_reduce_it

[13] Link

[14] Link

[15] Link

Sciences, improving cycling infrastructure is a proven way to curb climate change.[16]

15.4 What are some additional benefits?

15.4.1 Safety

Increasing bike lanes improves traffic safety for everyone, including drivers, cyclists and pedestrians. An extensive 13-year study of multiple cities in the US found that streets with protected bike lanes, which have a physical barrier between cyclists and vehicle traffic, had dramatically less road fatalities. Protected bike lanes have a traffic calming effect on all road users, lowering traffic speeds and thus fatality rates.[17] The US is the most dangerous among wealthy nations for cyclists, and adding bike lanes can reduce all types of injury by 25%.[18]

15.4.2 Health

Research shows that creating bike lanes, whether with paint or barriers, increases ridership.[19] By allowing for increased physical activity and decreased air pollution, bike lanes are one of the most cost-effective public health investments a government can make. Every $1,300 New York City invested in constructing bike lanes in 2015 equated to one additional year of life at full health over the lifetime of city residents. Economically speaking, bike lanes are a much better investment than direct medical treatments, which are much more costly per quality-adjusted life year.[20] Bike lanes normalize exercise behaviors and may help address the obesity epidemic in the US.

15.4.3 Economy

Evidence indicates that bike lanes bolster local economies. A comprehensive study in New York City found that businesses on streets with bike lanes grew faster on average than streets without them.[21] Other studies show that replacing street parking with bike lanes has little to no impact on business, and in some cases may even increase business. Although cyclists tend to spend less money per trip than drivers, they also tend to make more trips, which puts more money into the local economy over time.[22] Bike lanes also increase property values. The Indianapolis

[16] https://www.nytimes.com/2021/04/01/climate/bikes-climate-change.html

[17] https://www.pasadenacsc.org/blog/protected-bike-lanes-increase-traffic-safety-for-everyone

[18] Link

[19] https://www.nytimes.com/2021/04/01/climate/bikes-climate-change.html

[20] https://www.reuters.com/article/us-health-costbenefit-bike-lanes-idUSKCN11Z23A

[21] https://www.theguardian.com/environment/bike-blog/2019/jul/03/ten-common-myths-about-bike-lanes-and-why-theyre-wrong

[22] Link

Cultural Trail helped create $1 billion in additional assessed property value for properties within a block.[23]

15.4.4 Equity

In the US, the sector of the population most likely to walk or bike to work are the very poor - those who make less than $10,000 a year.[24] Yet, research shows that residents of underserved communities are less likely to live near safe, high-quality and accessible pedestrian and bicycle facilities. This increases the rate of crashes and fatalities and disproportionately affects minorities and low-income children. Investing in non-vehicle infrastructure in light of equity considerations can help alleviate this problem.[25]

15.5 What are the dis-benefits?

Unprotected bike lanes can create a false sense of security for cyclists that increase the risk of accidents. Bike lanes constructed in low-speed or congested areas could worsen traffic. Local business owners could be offended if they sense bike lanes are taking away convenient parking spaces. Poorly-designed lanes can increase confusion and conflict at intersections, creating dangerous situations.

15.6 Policy Proposal

Research finds that protected bike lanes are seven times more effective than painted ones. Survey respondents indicate that they make cycling safer and easier, increasing cycling rates. Studies of metropolitan areas including New York City, Washington, D.C., San Francisco, Chicago, Philadelphia, as well as cities abroad find that building protected bike lanes significantly boosts bike commuting. For example, after buffered bike lanes were installed on Philadelphia's Spruce and Pine streets, bike traffic increased 95 percent. Therefore, expanding protected bike lanes is potentially a highly effective policy for encouraging cycling.[26]

The Pedestrian Bicycle and Information Center finds that the cost of traditional protected bike lanes made from heavy construction materials like concrete ranges from $5,360 to $536,680 per mile, with a median cost of $89,470 per mile.[27]

An "ultra-affordable" and more eco-friendly alternative repurposes used tires into planters outfitted with reflective tape. Car tires are often found discarded in underserved neighborhoods, providing a free base for the delineators. With a few inexpensive hardware store materials and a

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[23] https://www.peopleforbikes.org/statistics/economic-benefits

[24] Link

[25] https://www.pedbikeinfo.org/cms/downloads/PBIC_WhitePaper_Equity.pdf

[26] https://www.peopleforbikes.org/statistics/economic-benefits

[27] Link

simple installation process, cities can rapidly improve their citizens' commuting experience. The lemon-shaped lane delineators, called WeCLAIM "Eye" planter barriers, won first place in the Build a Better Barrier competition hosted by the micromobility company Spin. The planters are one of the cheapest protected bike lanes available, and still provide highly-visible, durable and effective protection for bikers. Interested cities can reach out to Spin for more information.[28]

Figure 15.1: Happy cyclist.

File: bike-pedestrian-paths.tex

[28]Link

Chapter 16 CSNG: Clean-Sourced Natural Gas

Jae Kwak
2021-07-28

16.1 FAQs

1. What is the name of the policy or program type?

Purchasing certified, responsibly-sourced natural gas for municipal governments

2. What is this policy about?

Natural gas has often been referred to as a relatively "clean" fossil fuel. When combusted as a fuel, natural gas emits almost 50% less CO2 relative to coal for the same amount of energy. However, natural gas primarily consists of methane, which is 25 times more potent than CO2 at trapping heat in the atmosphere, and it is often released into the atmosphere during production and distribution. A study by the Environmental Defense Fund estimates that in 2015, methane emissions from the US oil and natural gas chain was about 13 teragrams, equivalent to 2.3% of the gross US gas production.

Recently, there have been efforts to create a certification system to provide responsibly sourced natural gas at a premium. Project Canary, which merged with the International Energy Standards Corporation, through its Trustwell Certification program evaluates the impact and risk for gas production, especially on water, air, land, and the community. Providing 10 times the amount of data points typically recorded for wells on 600 items including methane emissions, use of fracking fluids, and wastewater disposal, Project Canary performs comprehensive measurements on the natural gas supply chain. Natural gas certifications are also provided by organizations like Equitable Origin (EO), MiQ, and the Rocky Mountain Institute. With the April 2021 reversal of the Trump administration's rollback of the Obama administration's methane emissions regulations, it can be expected that the market for certified natural gas will continue to grow.

Municipal governments can set aside an annual fund to commit a percentage of their natural gas usage to certified, responsibly-sourced natural gas. The caveat, however, is that certified natural gas is part of a recent trend, and not many utilities offer it yet, so the current bottleneck for this policy would be the availability of certified natural gas. Meanwhile, a temporary, more accessible option while the market for certified natural gas becomes established is to pair purchases of natural gas with carbon offsets. The City of Palo Alto Utilities provides a product called PaloAltoGreen Gas, which pairs natural gas usage with corresponding Green-e Climate certified carbon offsets.

3. What are some examples in practice?

Precedents for municipal governments purchasing certified, responsibly-sourced natural gas have not yet been established, but more natural gas producers and utilities are showing interest in certified natural gas.

EQT, the largest natural gas producer in the US, launched a pilot program in April 2021 to certify more than 200 well pads by separate standards from Equitable Origin (EO) and MiQ. After this pilot program, the amount of certified gas EQT produces will amount to 4.5

In April 2021, Chesapeake Energy Corp launched a pilot program with Project Canary to constantly monitor methane emissions and receive certification for natural gas produced from the Marcellus and Haynesville Shale wells.

In May 2021, utility company Xcel Energy announced a pilot program to purchase low-methane emission natural gas at a premium from Colorado supplier Crestone Peak Resources, which is certified by Project Canary. The methane leakage in production and transport will also be tracked by a third-party, the Payne institute at the Colorado School of Mines.

4. What does this policy cost and who pays?

Certified, responsibly sourced natural gas is estimated to demand a premium up to 5% of market price, or up to about 15-cents per thousand cubic feet (mcf).

Although data on average municipal government natural gas consumption is not readily available, in 2019 the US federal government consumed around 132 million mmBtu of energy from natural gas, which is equivalent to about 127 million mcf. If the US federal government were to pay the 15-cent per mcf premium for all of its natural gas consumption, it would incur an additional cost of $19 million.

If the additional cost to purchase all of their natural gas consumption from certified sources is prohibitive, municipal governments can set a realistic target and procure a percentage of their natural gas consumption from certified sources. This target can be readjusted every year as budgetary conditions and climate-related goals change.

5. What are the climate-related benefits of this policy?

The Environmental Defense Fund (EDF) estimates that the oil and gas industry annually emits 13 million metric tons of methane, which has a greenhouse effect 25 times more potent than CO2. This amount is equivalent to the volume of natural gas to fuel 10 million homes. According to the International Energy Agency, the oil and gas industry can reduce methane emissions by 75% using current technology; two-thirds of this reduction can be done at no net costs. With natural gas being a largely homogeneous commodity the industry is slow to implement such changes to make this reduction, but the establishment of a market for certified, responsibly sourced natural gas may speed the progress by allowing differentiation. By leading the demand for such certification and communicating a clear preference for low-emission natural gas, municipal governments can help contribute to incentivizing the industry to make substantial reductions in their methane emissions.

While replacing default sources of natural gas consumption with certified sources will have substantial incremental climate benefits, it is still important to note that natural gas still emits about 14.43 kg of carbon per mmbtu when used as a fuel. This policy is sensible because natural gas is currently difficult to replace in many applications, but when possible, replacing natural gas with renewable sources may be preferable.

6. What are the co-benefits of this policy?

Most certification standards do not stop at measuring methane leakage. The environmental impact on air, land, and water as well as corporate governance and ethics are also examined. As more natural gas producers adhere to certification standards, the negative impact of natural gas production on local ecosystems, air quality, and the local community is expected to be mitigated.

7. What are the dis-benefits?

Although ensuring that natural gas is responsibly produced and distributed will have immediate, substantial benefits, some critics worry that certifications may delay a necessary transition away from fossil fuels.

8. How difficult is it to implement and maintain this policy?

The market for certified, responsibly-sourced natural gas has not yet reached sufficient scale to be readily available across the country, as most producers that are interested in certifications are still at the initial stages testing for feasibility. Currently, it may be difficult for municipal governments to purchase certified natural gas, but municipal governments should maintain communication with their local utilities to express demand for such products while asking for a notice when certified natural gas is available. In the meanwhile, they should consider products that pair natural gas purchases with corresponding carbon offsets.

What further complicates the market for certified natural gas is the lack of a unifying standard. Natural gas is a relatively homogeneous commodity, so there is little reason to justify multiple different kinds of standards and certifications. Currently, organizations and companies like Project Canary, the Environmental Defense Fund, the Rocky Mountain Institute, Equitable Origin, MiQ, and Cheniere are all pursuing their own standards. Consolidation and perhaps endorsement from the federal government may clear some of the confusion in the certification market, allowing for a more efficient market for responsibly-sourced natural gas.

16.2 Certified Natural Gas Procurement Policy Proposal for Municipal Governments

16.2.1 Background

While natural gas emits almost 50% less CO2 than coal when it is burned as a fuel, methane leakage during production and transportation is a serious issue, as methane is 25 times more potent than carbon dioxide as a greenhouse gas. Monitoring and reducing methane leakage throughout the natural gas supply chain can therefore yield immediate and substantial benefits in mitigating climate change.

Recently, there have been efforts to create a certification system for natural gas, and organizations are increasingly providing certification for natural gas producers that meet standards in areas like methane emissions and environmental impact. In exchange, natural gas producers can demand a small premium for certified gas. Companies and institutions like Project Canary, Equitable Origin, SYSTEMIQ, and the Rocky Mountain Institute have been working with natural gas companies in pilot programs to certify natural gas with low-methane leakage in its supply chain.

Refer to the FAQ document regarding certified natural gas for a more detailed overview, available through the following link: Link.

16.2.2 Procedure

The current problem with certified natural gas is that it is still in its early stages. Competitive suppliers in deregulated natural gas markets and utilities in regulated markets likely do not offer certified natural gas yet. However, there is a growing interest among natural gas producers to differentiate their product through certifications, so it is expected that the market for certified natural gas will expand quickly over the next couple of years. Municipal governments should therefore maintain communication with their local gas utility or suppliers to express demand for certified natural gas and ask for a notice when these products are available.

When certified natural gas becomes available, municipal governments can set aside an annual fund to commit a percentage of their natural gas usage to certified, responsibly-sourced natural gas. Especially if the additional cost to purchase all of their natural gas consumption from certified sources is prohibitive, municipal governments can set a realistic target percentage that they can afford. This target can be readjusted every year as budgetary conditions and climate-related goals change. Costs

Proponents of certified natural gas expect natural gas certified as low-emissions and responsibly produced to demand a premium up to 5% of market prices, which roughly translates to 15 cents per mcf. In terms of thermal units, this value is equivalent to 14.5 cents per mmBtu.

To put this in perspective, the average US household uses roughly 71.54 mcf of natural gas per year. If a household were to procure all of its natural gas from certified sources, it would only have to pay about $10 extra per year.

As the market for certified natural gas becomes more established, the premiums may drop even further. The reason this is possible is because with the technology available today, the oil and gas industry can reduce methane emissions by about 50% at no net costs. As demand for certified natural gas increases, investments and R&D in monitoring technology will also expand, driving down costs further.

16.2.3 Action recommendation

A committee or individual should be tasked with surveying the market, the vendors, and any relevant NGOs regarding when and how a substantial amount of certified clean production ("certified" for short) natural gas can be made available and at what price. Consider as well the use of certified offsets. It may be the case that certified gas is available but not directly at the place of the governmental entity. Investigate this possibility and assess it as policy.

If certified natural gas is available on the market for residential and commercial uses, conduct a public information campaign to apprise the local citizens of the opportunity. This could be done cooperatively with local activist NGOs.

16.2.4 Leading certification organizations and standards

Project Canary / TrustWell Certification

Rocky Mountain Institute and SYSTEMIQ / MiQ

Equitable Origins / EO100

16.3 Certified Natural Gas Procurement Policy Proposal for Academic Institutions

16.3.1 Background

While natural gas emits almost 50% less CO2 than coal when it is burned as a fuel, methane leakage during production and transportation is a serious issue, as methane is 25 times more potent than carbon dioxide as a greenhouse gas. Monitoring and reducing methane leakage throughout the natural gas supply chain can therefore yield immediate and substantial benefits in mitigating climate change.

Recently, there have been efforts to create a certification system for natural gas, and organizations are increasingly providing certification for natural gas producers that meet standards in areas like methane emissions and environmental impact. In exchange, natural gas producers can demand a small premium for certified gas. Companies and institutions like Project Canary, Equitable Origin, SYSTEMIQ, and the Rocky Mountain Institute have been working with natural gas companies in pilot programs to certify natural gas with low-methane leakage in its supply chain.

Certified natural gas can especially reduce carbon footprints for large academic institutions, which often rely on natural gas-powered combined heat and power plants (CHP) to efficiently generate electricity while providing heating and cooling. Institutions utilizing natural gas-powered CHPs are usually large consumers of natural gas, so their adoption of certified natural gas will have a substantial positive impact on both methane emissions and the growth of the market for certified natural gas in general.

Refer to the FAQ document regarding certified natural gas for a more detailed overview, available through the following link: Link.

16.3.2 Procedure

The current problem with certified natural gas is that it is still in its early stages. Competitive suppliers in deregulated natural gas markets and default utilities in regulated markets likely do not offer certified natural gas yet. However, there is a growing interest among natural gas producers to differentiate their product through certifications, so it is expected that the market for certified natural gas will expand quickly over the next couple of years. Academic institutions should therefore maintain communication with their local gas utility or suppliers to express demand for certified natural gas and ask for a notice when these products are available. Academic institutions are usually large customers for utilities and suppliers, with universities and colleges in deregulated states often directly negotiating sizable natural gas contracts with suppliers. Strong interest from such important customers will provide motivation for utilities and gas suppliers to actively seek certified natural gas for distribution.

When certified natural gas becomes available, academic institutions can set aside an annual fund to commit a percentage of their natural gas consumption to certified, responsibly-sourced natural gas. Especially for academic institutions that generate a majority of their power from natural gas CHPs, if the additional cost to purchase all of their natural gas consumption from certified sources is prohibitive, they can set a realistic target percentage that they can afford. This target can be readjusted every year as budgetary conditions and climate-related goals change. Costs

Proponents of certified natural gas expect natural gas certified as low-emissions and responsibly produced to demand a premium up to 5% of market prices, which roughly translates to 15 cents per mcf. In terms of thermal units, this value is equivalent to 14.5 cents per mmBtu.

To put this in perspective, the average US household uses roughly 71.54 mcf of natural gas per year. If a household were to procure all of its natural gas from certified sources, it would only have to pay about $10 extra per year.

As the market for certified natural gas becomes more established, the premiums may drop even further. The reason this is possible is because with the technology available today, the oil and gas industry can reduce methane emissions by about 50% at no net costs. As demand for certified natural gas increases, investments and R&D in monitoring technology will also expand, driving down costs further.

16.3.3 Action recommendation

A committee or individual should be tasked with surveying the market, the vendors, and any relevant NGOs regarding when and how a substantial amount of certified clean production (“certified” for short) natural gas can be made available and at what price. Consider as well the use of certified offsets. It may be the case that certified gas is available but not directly in the place of the institution. Investigate this possibility and assess it as policy.

16.3.4 Leading certification organizations and standards

Project Canary / TrustWell Certification

Rocky Mountain Institute and SYSTEMIQ / MiQ

Equitable Origins / EO100

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File: clean-production-natural-gas.tex

Chapter 17 GreElec: Green Electricity

Jae Kwak

2021-07-28

17.1 FAQs

1. What is the name of the policy or program type?

Municipal Green Electricity Purchasing

2. What is municipal green electricity purchasing?

Municipal Governments can lead the way towards carbon-free energy procurement by committing to purchasing all energy sources. Because municipal governments are large consumers with market power, their electricity consumption choices can influence the demand for new investments in green energy resources.

Green electricity often comes at a premium relative to the default, and this premium will have to be paid from the municipal budget. The municipal government can set a monthly limit on how much it will spend on premiums for green electricity, and adjust that limit depending on budgetary considerations.

Some states have laws that mandate local governments to purchase energy from the lowest responsible bidder, as it was the case in New York State. Legislative change in the State Senate and Assembly may be necessary to allow local governments to purchase green energy at a premium.

3. How is municipal green electricity purchasing done?

Green Pricing Programs

850 utilities nationwide offer products known as a Utility Green Power Product, also known as Green Pricing Programs. Through these programs, municipal governments can purchase green electricity bundled with renewable energy certificates (REC) by paying a per-kilowatt-hour premium on their utility bill, and customers can generally subscribe or unsubscribe at wil. Products are often structured so that customers can choose the amount of green electricity to purchase in increments of 100kWh or a percentage of their electricity bill. These programs are essential for municipal governments under the service of regulated utilities, which generally do not allow customers to choose their own electric supplier.

Competitive Green Power Products

Municipal governments located in the eighteen states or Washington D.C. that have introduced retail choice electricity markets have the option to purchase bundled green electricity and RECs from a competitive electric supplier that is not their default utility supplier. As with Green Pricing Programs, customers pay a per-kilowatt-hour premium based on the supplier's rates, but the delivery of power and billing is still carried out by the default utility.

Municipal governments can choose to purchase from various electric supply companies, which differ in the percentage of renewable energy and resource mix. Contracts are often short-term, ranging from 6 to 24 months. Most states with Competitive Green Power Products offer information to help residents and businesses compare between different green power products. The following EPA page lists links to websites that provide such information: https://www.epa.gov/greenpower/competitive-green-power-products

Green Tariffs, PPAs, and community choice aggregation are alternative methods that are available for procuring green electricity, but utility and competitive green power products are the most frictionless.

4. What are some examples in practice?

City of Aspen

In 2005, the City of Aspen set a goal to acquire 75% of the energy used by the City government, and achieved this goal by December 2006. It then set a new goal of purchasing 100% of the energy used by city-owned buildings from renewable sources by 2020, and met this goal by 2015. The city utility system draws almost all of its energy from wind farms in Nebraska and hydroelectric power, and it sources the remainder from landfill gas.

City of Santa Monica

Through the government affiliated Clean Power Alliance, not only is the municipal government using green electricity, but the default for both residential and commercial utility customers is 100% green electricity.

City of Austin

Austin, TX is the largest city in the US to power all city-owned buildings and facilities with renewable energy resources.

Other

According to the EPA's list of local governments that procure a high percentage of green electricity, local governments that draw more than 80% of their total electricity consumption from green power include the City of Houston, TX, City of Dallas, TX, District of Columbia, City of Austin, TX, County of Santa Clara, CA, City of Portland, OR, City of Alexandria, VA, Rockland County, NY, City of Lawrence, KS, Santa Monica, CA, and the City of Hillsboro, OR.

5. What does municipal green electricity purchasing cost and who pays?

According to a 2016 NREL Report, the average premium for utility green pricing programs was estimated to be $0.017/kWh for non-residential customers. Since green electricity costs have been decreasing since 2016, the current average premium may be lower than this value.

In order to estimate the annual total premium municipal governments have to pay to purchase green electricity, we used the annual municipal government electricity consumption data of the EPA's green power partners. The annual average electricity consumption of this sample is 2.125 million kWh, while the median is 1.242 million kWh. If we use the 2016 NREL average premium from above, the average annual cost for municipal governments to purchase 100% of their power from green power programs is $36,000.

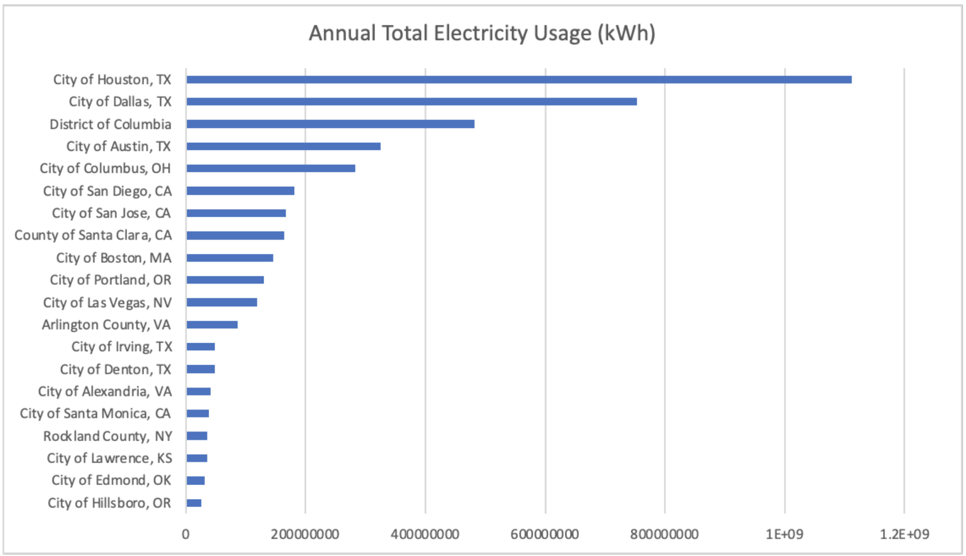

Figure 17.1: Annual Total Electricity Usage for selected cities.

If an extra $36,000 annual cost to taxpayers is deemed excessive, municipal governments can set aside an annual fund to cover the premium for a portion of their annual electricity consumption. They can reassess their availability to pay every year and procure what they can afford, instead of committing to 100% green electricity at once.

6. What are the climate-related benefits of municipal green electricity purchasing?

According to the EIA, in 2019, the CO2 emissions resulting from electricity generated from coal, natural gas, and petroleum were 2.21 lb/kWh, 0.91 lb/kWh, and 2.13 lb/kWh, respectively. On average, the total US electricity generated in 2019 resulted in CO2 emissions of 0.92 lb/kWh.

Using the estimate for the average premium of green electricity, $0.017/kWh, and assuming that the average CO2 emissions per kWh generated by default utility electricity is 0.92 lb/kWh, it can be estimated that municipal governments can reduce CO2 emissions by 54 pounds per dollar spent in premiums.

7. What are some additional benefits?

Reduced air pollution

Electricity generation from fossil fuels is one of the largest industrial sources of air pollution for sulfur dioxide, nitrogen oxides, mercury, and certain types of particulate matter. Such emissions contribute to serious environmental and health problems, but green power generates significantly fewer harmful emissions. According to a study by the Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory, each megawatt-hour of new renewable electricity generation resulted in health and environmental benefits ranging from $16 to $101 per MWh due to emission reductions.

Reduce water environmental impact

Fossil fuel and nuclear electricity generation often require water for fuel extraction, steam production, and power plant cooling. Not only is water consumed, but when cooling water is released, it can increase the temperature of water resources, negatively impacting aquatic ecosystems. Most green power generation methods, however, do not consume or release water into the environment. According to a joint study between the NREL and the Lawrence Berkeley National Laboratory, the increase in renewable energy generation due to the 2013 renewable portfolio standards resulted in savings of 8420 gallons in water withdrawal and 270 gallons in water consumption per MWh of electricity produced.

Encourage residential and commercial green electricity

Leading by example, municipal governments can encourage residents and businesses to start committing to purchasing green electricity.

Job creation and stimulate local economy

By increasing the demand for renewable energy, municipal governments can indirectly contribute to the job growth and economic development that comes with the construction and maintenance of new green energy projects.

8. What are the dis-benefits?

For utility green power products, customers often do not have a choice in the composition of the resource mix or the specific project that the power is sourced from. On the other hand, for competitive green power products, it may be difficult to evaluate and choose the optimal product without sufficient expertise.

Almost all sources of green electricity are variable renewable energy (VRE) resources, whose output generally depends on external factors. As municipal governments increase the proportion of power generated from VREs, they may be subject to more risk stemming from the supply and demand imbalances that may occur in times of high energy demand and/or low supply.

9. How difficult is it to implement and maintain municipal green electricity purchasing?

If the municipal government is located in a competitive retail electricity market, purchasing green electricity is generally a frictionless process. If the region is served by a regulated utility, as long as the utility provides green pricing programs, procuring green electricity is not difficult. However, if the default regulated utility does not offer such programs, the municipal government should pursue alternative methods like virtual PPAs, Green Tariffs, or unbundled Renewable Energy Certificates (REC).

Unlike PPAs and Green Tariffs, which often involve long term contracts spanning at least 10 years, green power products are generally short term, so municipal governments can adjust the amount they purchase depending on their budgetary situation.

As mentioned earlier, if state laws prohibit municipal governments from paying a premium on electricity purchases, legislative changes may be necessary.

10. References and Useful Links

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EIA, Frequently Asked Questions (FAQS): How much carbon dioxide is produced per kilowatt-hour of U.S. electricity generation?
https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

US Department of Energy et al., Guide to Purchasing Green Power
https://www.epa.gov/sites/production/files/2018-08/documents/guide-purchasing
pdf

Wiser et al., A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards
https://www.nrel.gov/docs/fy16osti/65005.pdf

The United States Department of Energy, Buying Clean Electricity
https://www.energy.gov/energysaver/buying-and-making-electricity/buying-clean-electricity

City of Melbourne, Renewable Energy Procurement: A guide to buying off-site renewable electricity
https://www.c40knowledgehub.org/s/article/Renewable-Energy-Procurement-A-guid
language=en_US

Interstate Renewable Energy Council, Municipal Guide to Purchasing Renewable Energy
https://www.mass.gov/doc/esmart-purchasing-renewable-energypdf/download

EPA Green Power Partnership, A Guide to Buying and Benefiting from Green Power https://scdhec.gov/sites/default/files/docs/HomeAndEnvironment/Docs/ModelOrdinances/OtherExamples/EPA-GuideforBuyingandBenefitingFromGreenPower.pdf

17.2 Municipal government policy proposal for purchasing green electricity

17.2.1 Background

Municipal governments consume on average one to three million kilowatt-hours of electricity annually. Using CO2 emission figures from the EIA, this translates to around 0.9 million to 2.7 million pounds of CO2 emissions per year from municipal government electricity usage. Such emissions can be substantially reduced if municipal governments start committing to procuring more of their electricity from green energy sources.

In addition to the climate change-related benefits, purchasing green electricity can reduce harmful air pollution, decrease water consumption, encourage residents and businesses to procure more green electricity, and contribute to job creation and stimulating the local economy.

There are a couple methods to procure green electricity, including power purchase agreements (PPA), green tariffs, and community choice aggregation, but the most frictionless way to purchase green electricity is through green power products.

Refer to the FAQ document regarding Green Electricity for a more detailed overview, available through the following link: Link

17.2.2 Procedure

The options available depend on whether or not the municipal government is serviced by a retail choice electricity market or a regulated utility. In the case of the latter, the municipal government can purchase green electricity directly if its default utility offers a Green Pricing Program. Municipal governments located in retail choice electricity markets can also take advantage of competitive green power products.

Green Pricing Programs

Participating utilities offer customers the opportunity to purchase green electricity bundled with renewable energy certificates (REC) at a premium through Green Pricing Programs, also known as Utility Green Power Products. These products are often structured so that customers can purchase green electricity in block increments of 100kWh or as a percentage of their total electricity bill.

Municipal governments should contact their default utility company to check whether Green Pricing Programs are offered. Municipal governments serviced by regulated utilities that do not offer Green Pricing Programs may have to pursue alternative methods like virtual PPAs, Green Tariffs, or unbundled Renewable Energy Certificates (REC).

Competitive Green Power Products

Municipal governments that are located in retail choice electricity markets can purchase bundled green electricity and RECs from competitive electric suppliers that are not their default utility through Competitive Green Power Products. As with Green Pricing Programs, customers pay a per-kilowatt-hour premium based on the supplier's rates, but the delivery of power and billing is still carried out by the default utility. Contract lengths for these programs range from 6 to 24 months.

Different products from different suppliers need to be compared and evaluated, as pricing, the percentage of renewable energy, and the resource mix may vary. It may be helpful to consult with an expert when making a final decision of which product and supplier to go with. Most states with Competitive Green Power Products offer information to help residents and businesses compare between different green power products. The following EPA page lists links to websites that provide such information: https://www.epa.gov/greenpower/competitive-green-power-products

17.2.3 Costs

According to a NREL study, the average premium for green power products in 2016 was \$0.017 per kilowatt-hour. The current average premium is likely lower due to further decreases in green energy costs. To estimate the total premium that needs to be paid, multiply the target kilowatt-hours of green electricity to be purchased with the \$0.017 per kWh premium. In terms of greenhouse gas emission reductions, using 2019 EIA figures, a dollar spent on premiums for green electricity can reduce 54 pounds of $CO2$ emissions.

After discussion with relevant stakeholders, municipal governments should decide on how much of their budget they can commit to purchasing green electricity, and set a schedule on how that amount will change over the years. Since utility green power products are easy to unsubscribe, and competitive green power product contracts are generally less than 24 months, municipal governments can be flexible in their commitment to green electricity purchasing.

File: green-electricity.tex

Chapter 18 School Bus Electrification

By: Jae Kwak

18.1 Faqs

1. What is the name of the policy or program type?
   School bus electrification
2. What is school bus electrification?
   The program intends to reduce carbon emissions by replacing diesel school buses with electric buses. Optimally, the excess capacity of the electric buses will be used for vehicle-to-grid (V2G) operations to provide electricity to the grid during peak times.
3. What are some examples in practice?
   In March 2020, Highland Electric Transportation made a deal with the city of Beverly, MA to receive an annual fixed fee to provide, fuel, and maintain electric buses for the school district.

   As a pilot program, Dominion Energy, a Virginia utility company, will sell 50 electric buses with bidirectional charging capabilities to a school for the price of typical diesel buses; in exchange, Dominion Energy will own and operate the charging equipment, using the electric bus batteries to help balance the grid.

   In 2018, Lion Electric Company, an electric school bus manufacturer; Nuvve, a V2G tech company; National Express, a British public transport company; and the White Plains School District of New York partnered to deploy five electric buses equipped with V2G technology.

   Since 2016, the Lion Electric Company has delivered 40 all-electric school buses to the Twin Rivers Unified School District in Sacramento, California. The program is part of the California Climate Investments, a state-wide initiative that uses cap-and-trade dollars for projects that improve the environment.

   In 2019, the California Energy Commission allocated $94MM to its School Bus Replacement Program to replace old diesel buses with electric buses. The California Climate Investment Grant has also been funding electric buses at the local level, as in the case of the $7.5MM grant to the Twin Rivers School District. In 2020 August, the state legislature passed a bill that would spend approximately $1BB on green infrastructure for schools, which would also contribute to the efforts of replacing diesel school buses.

4. What does school bus electrification cost and who pays?

   Diesel school buses cost around $100,000, and electric school buses cost around $300,000 to $400,000. In the case of California, there has been a number of local and state-level funding to cover the upfront costs of replacing diesel buses, but without funding they are too large for school districts to cover. In other cases, a utility company like Dominion Energy or a transportation company like Highland Electric Transportation will charge an annual fixed fee or a lump sum cost equivalent to the typical cost of purchasing or operating diesel buses. These companies plan to cover the difference through lower fuel and maintenance costs, and possibly through V2G operations by discharging power to the grid in peak times when electricity prices are high.

   According to a US PIRG Fund Report, an electric school bus costs upfront on average $120,000 more than their diesel equivalent, but can save about $170,000 to $240,000 in lifetime fuel and maintenance costs. Therefore it is highly likely that the upfront costs can be covered within a couple years.

5. What are the climate-related benefits of school bus electrification?

   According to Dominion Energy, replacing one diesel bus can drive down greenhouse gas emissions by 54,000 pounds per year, which translates to 3.75 pounds of CO2 per middle driven.

6. What are some additional benefits, co-benefits?

   Improved air quality inside and outside: By replacing diesel buses, this program can eliminate the diesel exhaust from traditional school buses. The diesel exhaust from diesel school buses are designated by the IARC to be carcinogenic and are linked to premature death, aggravated asthma, and decreased lung function; it can be even more harmful to children. The diesel exhaust affects the air in and around the bus and can potentially enter school buildings. These pollutants also contribute to acid rain and ozone pollution.

   Seat belt installation: Traditional diesel school buses often do not have seat belts equipped, but in the case of Dominion Energy's electric bus contract with the Virginia school districts, seat belts will be installed in the new electric buses. Although buses are generally considered to be very safe, seat belts provide additional protection in the case of serious crashes.

   Lower Maintenance and Fuel Costs: According to Thomas Built Buses, electric school buses can save nearly $2000 per year in lower fuel costs and $4400 per year in maintenance costs.

   Grid Balancing: If V2G operations are possible, the electric school bus batteries can be used as energy storage for the grid by charging them when prices are cheap and discharging power back to the grid at peak times. School buses are especially promising for V2G because of large capacity sizes, predictable operation schedules, and long idle times. Battery life reduction is a potential concern for V2G operations, but the Becker et al.(2019) case study shows that as long as proper thermal management is conducted, battery degradation can be minimized.

7. What are the dis-benefits?

Range: Electric school buses on average have a range of 100-135 miles. While typical bus routes are 30-40 miles in the morning and 30-40 miles in the afternoon, for some rural areas and for long-distance transportation, e.g. field trips, the range may not be enough. Route optimization and the expansion of local charging infrastructure may be able to mitigate this issue.

Charging Infrastructure: Installing, maintaining, and operating charging infrastructure for electric buses are costly tasks and school districts may not be equipped for the task. As a result, companies like Highland Electric Transportation and utilities like Dominion Energy are offering to install and operate the charging infrastructure for the school districts.

Training: Additional training of staff may be required because electric buses are operated and maintained differently from diesel buses.

8. How difficult is it to implement and maintain school bus electrification?

The two major barriers for replacing diesel school buses with electric buses are the higher upfront costs of electric buses and the costs involved in installing and operating charging infrastructure. In order to facilitate implementation, state government grants and funding like in the case of the Twin Rivers school district or contracts with companies like Highland Electric Transportation or Dominion Energy that would cover the difference in upfront costs are necessary. Attention has been slowly building up for this program, marked by increased media coverage. Emphasizing co-benefits like improved air quality for children would be helpful for gaining public support. V2G operations may face more challenges as not all utilities allow them, but it is expected that more and more utilities will be favorable to V2G in the future.

In terms of maintenance, electric buses have fewer parts that require maintenance compared to diesel buses, so they pose less challenges. Operating and maintaining charging infrastructure may be outside the expertise of existing staff employed by school districts, so the service of third parties may be necessary. Complexity will be further increased if V2G operations are employed, but V2G platforms like Nuvve or utility companies may be able to handle them more efficiently.

9. What are the leading vendors pertaining to P?

Bus Manufacturers:

- Proterra
- Yutong
- BYD Motors
- NFI Group

- Lion Electric Company
- Thomas Built Vehicles

V2G Technology:

NUUVE

Utility Company:

Dominion Energy

Transportation Company:

Highland Electric Transportation, National Express

18.2 Useful Links

"Highland Electric Raises $235M, Lands Biggest Electric School Bus Contract in the US" (2021-02-25), Greentechmedia.com. (https://www.greentechmedia.com/articles/read/on-heels-of-253m-raise-highland-electric-lands-biggest-electric-school-bus-contract-in-the-u.s)

https://www.greentechmedia.com/articles/read/on-heels-of-253m-raise-highl
s

"One small idea in Biden's infrastructure plan with big benefits: Electric school buses" (April 6, 2021) https://www.vox.com/future-perfect/2021/4/6/22364385/
one-small-idea-in-bidens-infrastructure-plan-with-big-benefits-electric-s
(https://www.vox.com/future-perfect/2021/4/6/22364385/one-small-idea-in-bidens-infrastructure-plan-with-big-benefits-electric-school-buses)

Chapter 19 Green Financing

By Saahil Kamulkar and Jae Kwak
2021-07-28

19.1 Green Bank Overview

19.1.1 What is a Green Bank?

- Institutions, not programs
- Provide financing not grants
- Prime objectives are modest profit, environmental impact
- The value proposition or mission is to reduce the cost of capital required for these projects, thus increasing the transition to renewables and sustainable living.

19.1.2 What problems do green banks solve?

- Provide customers with necessary information
- On-Bill financing allows customers with limited credit to take action
- Co-investment for areas with limited capital
- Standardized contract to streamline the underwriting process
- Securitization of smaller loans to then incentivize larger banks to participate (scale of larger banks prohibits them from taking such loans)

19.1.3 What are things to be cautious of?

- Crowding out
  The goal is not to compete with private equity, but rather serve projects that would not be able to get off the ground.

19.2 Green Banks: FAQs

We should say a little about costs, how this gets set up and the practicalities of keeping it going. Talk with someone from Montgomery Co. MD?

19.2.1 What is a Green Bank?

A green bank is an institution that is created to provide opportunities and funding for green initiatives. It is important to note that, contrary to the name, a green bank is not actually a bank;

the institution is often a nonprofit that acts more as an investment vehicle. Rather than competing with existing financial institutions, a green bank provides financing with the goal of creating environmental impact, not maximizing profit. The green bank reduces the cost of capital for green projects, thus incentivizing the change towards a more sustainable future. Some green banks take on many smaller, conventionally unprofitable loans and securitize them for larger banks; this allows the green bank to pursue smaller projects and enables larger banks to partake in financing green projects. In addition to simple financing, green banks may implement creative or non-traditional methods of allocating capital to customers unable to dedicate sufficient money to green projects. For example, a green bank may choose to co-invest in a project that does not have sufficient funds or resort to On-Bill financing(allowing customers to include repayment as a part of their utility bill). However, the function of a green bank does not stop with financing; green banks provide ancillary services to customers, ranging from standardized contracts to project-specific consultation.

19.2.2 Where do Green Banks Invest?

Traditionally, a green bank primarily focuses on low-income areas. These areas are often too risky for traditional banks and are unable to secure enough funding to make the transition to more environmentally friendly projects. Many green banks declare their primary focus to be serving low- and moderate-income consumers, LMI. For the aforementioned reasons, these communities are often underserved; however, in order to create meaningful change, everyone must strive towards sustainability. Many community green banks have focused their attention on allocating capital to community solar projects, enabling low-income areas to switch to renewable power generation and saving money in the future. In terms of the actual projects that green banks commonly fund, there are seven primary categories:

1. Renewable power generation: solar, wind, geothermal, hydropower, ocean and hydrokinetic, and fuel cells
2. building efficiency, fuel-switching and electrification
3. clean transportation: electric vehicles, hydrogen vehicles, and associated charging or fueling infrastructure
4. industrial decarbonization
5. grid infrastructure including transmission, distribution, and storage;
6. sustainable agriculture: reforestation, afforestation, and regenerative agriculture climate-resilient infrastructure

19.2.3 How do Green Banks Invest?

As mentioned before, Green Banks play a key role in enabling small, underserved communities to transition towards sustainability. In order to do this, the Green Bank must provide low-cost capital to places where traditional banks and traditional investments do not service; it is important to note that these investors do not necessarily pass on these investments because of the risk involved, but rather because of the projects' size. The smaller transactions still have the same fixed and due diligence costs, making them less attractive compared to larger projects.

This is where Green Banks have a critical role. Green Banks work to take on and aggregate many small and medium-sized loans until the aggregate size is something that is sufficient for larger institutions. Then, the Green Banks works to securitize the loans or projects so that other, larger investors may invest. Green Banks utilize standardized contracts to create economies of scale that dilute the fixed cost relative to the total benefit. In essence, the Green Bank works to bundle the smaller projects into a singular larger project. Since institutional investors, like Penn, have a lower cost of capital and risk tolerance, a Green Bank would facilitate more investment into sustainability.

19.2.4 The Effects of the Green Bank Movement

Since 2011, green banks have caused over $5 billion in investments. This considerable funding was made possible by the partnership between publicly allocated money and investment from private organizations. Although the green banks themselves only invested $1.8 billion, they were able to actively attract further private investment of $3.8 billion. Over the past few years, cumulative investment caused by green banks has grown considerably. Moreover, many people consider green banks to be unsustainable long-term because green banks do not prioritize profits. However, this is not accurate. Over the last few years, many green banks have been able to grow operating income significantly. "Green banks in the United States collected $55.9 million in earned revenue to support their operations in 2019, a 22% increase over 2018's $46.0 million in earned revenue and a 141% increase from 2017's $23.2 million in earned revenue."

Do we have a source for this figure or its information?

19.2.5 Connecticut Green Bank Case Study

The Connecticut Green Bank had the goal of bringing solar energy and energy efficiency to LMI homeowners (these homeowners stand to benefit the most from this kind of project, because energy is a large cost relative to their annual income). The Connecticut Green Bank accomplished this using the following steps:

- Initiated a Request-for-Proposal Process: a general outline of the project that outlined the following features
- The project offered solar to single-family households.
- Incentivized LMI households through elevated performance based incentives (paying a certain amount ($/kWh) based on the energy production of the solar energy production)
- Offers Photovoltaic Systems that are leased to owners, so homeowners don't have to pay up-front. The lease has a 20-year term with fixed lease payments, allows the homeowner

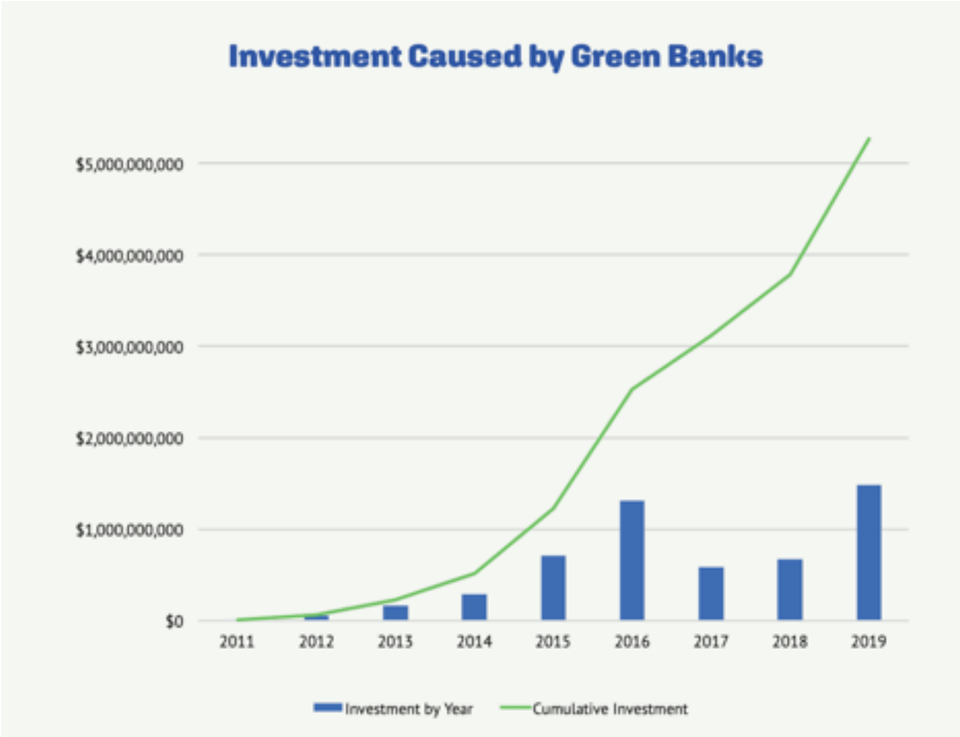

Figure 19.1: Green bank investment.

to purchase at the end of the term, and has a production guarantee (reimbursement if the system fails to provide enough energy).

- Bundled with a basic energy efficiency package from the local utility's Home Energy Solutions, with an EE installment option (ESA).
- Established Financing Logistics

  The project requires many people to participate: PosiGen(PV installer), tax equity investors, private-sector lenders, and CT Greenbank.
- Created a Special Purpose Entity which is owned by tax equity investors.

  This entity would own the project and thus benefit from the tax credit, benefits, and depreciation (these benefits replace the need for substantial cash flow from the project). PosiGen also invests in these SPEs utilizing senior third-party debt and subordinated CT Green Bank debt ("back leverage").
- Assisting with Deployment

  The Green Bank then helps by co-branded marketing This may include canvassing and troubleshooting market barriers In doing so, the Green Bank lowers the customer acquisition costs to PosiGen while raising awareness.
- Incentivizing Continued Operation

  The Green Bank continues to provide PBI's to the SPE, which incentivizes the LLC to continue to operate the solar panels efficiently (as they are paid per kWh)[PBIs end at a certain date, or kWh amount, if earlier]

  Homeowners benefit from lower cash payments, as tax equity investors are harvesting the benefit of the Tax Credits that would otherwise be largely unused by individual homeowners; LMI homeowners also benefit from the increased availability of credit, since the creditworthiness is not necessarily based on FICO(it may be based on other things like utility bill payment).

19.3 Implementing a Green Bank at Penn

The most effective way to implement a Green Bank at Penn would probably be to use a combination of the Bank and broker method. Rather than simply being an intermediary for green projects, Penn can start a green Bank that has some financial autonomy and power of its own. As opposed to simply raising awareness, these funds would be able to catalyze development by putting some teeth into the action (without independent funds of its own, this process might be more tedious, as it would require more stakeholders). In terms of marketing and legal operations, a hybrid method would certainly necessitate more personnel. However, along with this personnel, Penn would be better able to utilize the carbon credits cost-effectively and allocate the ancillary benefits(like tax credits) in the way it sees best. Nevertheless, the critical benefits to Penn will not be financial. Since the bank would be a non-profit, the green bank's primary aim would be to benefit the community– much like the purpose of most other green banks; this goal aligns well with Penn's philosophy and many of the outreach projects that Penn undertakes. The advantage of having a Green Bank is that it could be closely intertwined with some existing initiatives that Penn already funds; one such program is the Penn CURF Projects of Progress Prizes. A similar layout could help with funding projects that specifically address environmentally-conscious community improvements.

Expanding a little more on the ancillary benefits, including the Carbon benefits and the tax benefits. Both of these will be highly related to the project at hand; some projects may be more tax-advantaged than others, based on state tax laws. Similarly, the carbon offsets that Penn could use from the project will also depend on the logistics of the individual projects; certain projects will obviously be more impactful in terms of the environment. Going over the logistics of the Carbon Offsets, Penn has a few options. The first option is to undertake calculations of the offset independently. Under this method, Penn as an institution might be able to calculate and establish the carbon offsets of every project that it undertakes. One concern with this method might be the veracity of claims made by Penn, as there is a small conflict of interest: Penn stands to benefit from inflating the carbon offset number. An alternative method is to use a third-party verification service. Some of the services I found included American Carbon Registry, Verra, and Climate Action Reserve. These organizations are often the ones recognized by states like California, and thus are likely to be generally acceptable. Although using these reputable companies may be slightly more expensive, it is something that the Penn faculty would have to consider.

The following is incomplete. Good notes for further development.

Penn green bank lend to faculty and staff + landlords in Philadelphia

Maybe we can use payroll deductions

Externally funded greenbank

Projects for progress

19.4 Municipal Green Bank policy recommendation

19.4.1 Background

Clean energy and energy efficiency projects for local commercial and residential properties are essential for the transition towards a carbon-free society. However, the pace at which these projects are being implemented are currently sub-optimal, mainly for two reasons:

- Property owners lack information or motivation to carry out clean energy and energy efficiency projects.
- Even when property owners are willing and aware of clean energy and energy efficiency projects, most do not want to be burdened with the up-front costs of these projects. However, traditional financing institutions are often reluctant to provide capital because they have trouble evaluating the risks and individual loans are often too small and fragmented for traditional banks to underwrite.

Green Banks have been created across the US to address these issues by stimulating demand for clean energy and energy efficiency projects while bridging the financing gap. Notable Green Banks on the local level include the Montgomery County, MD Green Bank, the Washington DC Green Bank, and the New York City Energy Efficiency Corporation.

Refer to the FAQ document regarding Green Banks for a more detailed overview, available through the following link. Link.

19.4.2 Mission

The mission of a municipal Green Bank should be to partner with both the public and private sector to accelerate affordable energy efficiency and clean energy investments while promoting equity and economic development.

19.4.3 Structure

Although there has been some success with some public state-level Green Banks, in general independent non-profit corporation Green Banks have been found to be much more flexible and less costly for local governments. Municipal Green Banks can be set up as an independent non-profit corporation, but at the same time designated as the municipal government's partner through municipal legislation. The legislation should include provisions that authorize the municipal government to designate a Green Bank, specify the process of designating a non-profit corporation as the municipal Green Bank, define the nature and powers of the Green Bank, create a group to oversee the implementation of this Green Bank, and establish guidelines regarding the Green Bank's board of directors and bylaws. The county legislation that established the Montgomery County, MD Green Bank is a good example: Link

It is also integral for the Green Bank to apply for federal 501(c)(3) status to take advantage of charitable contributions.

19.4.4 Function

There are three main functions that a municipal Green Bank can carry out: direct financing, facilitating financing, and demand stimulation for clean energy and energy efficiency projects.

19.4.4.1 Direct financing

Municipal Green Banks can directly provide financing or investments for clean energy and energy efficiency projects with their own funds and capital from other private partners. Successful projects that received direct financing from Green Banks can serve as first-in-kind investments, proving the viability of such projects for private investors in the future.

Although this is the most straightforward method to bridge gaps in green financing, for municipal Green Banks that have limited sources of capitalization, direct financing may not be the most efficient use of their resources.

19.4.4.2 Supporting private financing and investments

Municipal Green Banks can decrease the perceived risk of local clean energy and energy efficiency projects for private investors by carrying out credit enhancement with loan loss reserves. Through loan loss reserves, Green Banks set aside a certain percentage of the loan provided by private investors to cover a portion of the loss in case of default. Such credit enhancement can attract more private investors and lower costs of capital, allowing municipal Green Banks to maximize the impact of their limited funds.

Municipal Green Banks can also carry out warehousing and securitization of loans for smaller green projects. They can underwrite loans for these smaller projects, warehouse them until sufficient scale is attained, and then package the loans into a security that they can sell to private investors. Municipal Green Banks can maximize the impact of their limited capital because this method allows them to recycle their funds more frequently than direct loans.

19.4.4.3 Demand Stimulation

Although financing is often the bottleneck for clean energy and energy efficiency projects, lack of awareness and inertia on the demand side are also problematic. Municipal Green Banks, even if they are short on capital for direct lending, can play an important role in facilitating partnerships between private lenders and local contractors to expedite the project implementation process for property owners and renters. Green Banks can negotiate with contractors and lenders to reduce project costs and costs of capital, while providing neatly packaged clean energy and energy efficiency programs with lists of pre-approved contractors and lenders on behalf of property owners and renters. Green Banks should focus on making this process as friction-free as possible for customers, offering a clean, informative user interface in their websites that allow property owners and renters to access information on project costs and financing options as well as on how to proceed with the projects.

Common programs that reduce the friction for local property owners and renters seeking clean energy and energy efficiency projects are the Commercial Loan for Energy Efficiency and Renewables (CLEER), the Property-Assessed Clean Energy Program (PACE), On-Bill Financing, Energy Service Agreements (ESA), and Power Purchase Agreements (PPA). For all of these programs Green Banks can create partnerships between the relevant parties, namely lenders, contractors, local governments, and utility companies, to facilitate clean energy and energy efficiency projects. Refer to the FAQ document for more details on these programs.

Marketing and education for awareness of clean energy and energy efficiency programs are also important functions that can be carried out by Green Banks. Examples include education workshops for local property owners, workshops with the local chamber of commerce, and outreach at local green festivals and energy summits. Local governments can also assist by canvassing target communities.

19.4.5 Costs

Municipal governments often do not have the means to provide substantial, recurring funding for Green Banks, so it is integral for them to be operationally self-sufficient. Self-sufficiency can be achieved by careful risk management and by maximizing the use of outside capital through the facilitator model. The Montgomery Green Bank, which does not have a recurring source of funding from its local government, has been operationally self-sufficient since its first year of operations. For the fiscal year ending June 2020, it had a net income margin of 47%. For the fiscal years 2019, 2018, and 2017, it had gross profit margins of 97%, 82%, and 94%, respectively, according to its annual reports. Taxpayer money is not necessary for the maintenance of its operations, and non-investment revenue mostly comes from charitable organizations.

Initial capitalization, however, is an area that may be burdensome to municipal government budgets. Even the self-sufficient Montgomery County Green Bank was initially capitalized with a $14MM settlement fee from a merger between two utility companies, Pepco and Exelon. Unless other municipal governments also happen to receive a similar amount of cash that can be earmarked for sustainability programs, initial capitalization of local Green Banks may be a struggle. Potential sources of initial capitalization include surcharges on utility bills, federal or state grants, and charitable contributions.

19.5 Academic institution policy recommendation

Do we need this? I think so. Can be very short. Establish a working committee and go for a brokering model. Do a feasibility study and report back.

19.6 Useful Links

For more information:

1. https://www.forest-trends.org/wp-content/uploads/2018/07/Factsheet_Producing-a-Voluntary-Carbon-Offset.pdf
2. https://coalitionforgreencapital.com/what-is-a-green-bank/
3. https://mcgreenbank.org/
4. https://michigansaves.org/about-us/
5. https://static1.squarespace.com/static/59bc05f0c534a543a9f96b0d/t/5edf9fbd8285f063f6c13bbe/15917137329
   Saahil says read this. See page 7.
6. https://greenbanknetwork.org/reports-white-papers/
7. Mechanics of a transaction: https://greenbanknetwork.org/wp-content/uploads/2018/07/GB-TT-Connecticut-18-07-A_05-1.pdf
8. Agg. and sec.: https://greenbanknetwork.org/wp-content/uploads/2019/04/Green-Bank-Aggregation-and-Securitization-Coalition-for-Green-Cap pdf
9. https://cgs.umd.edu/sites/default/files/2020-12/CGS_Public-Private%20Partnership%20%26%20Clean%20Energy%20FInance_Green%20Bank_Final%20Report_ENG.pdf

https://coalitionforgreencapital.com/what-is-a-green-bank/ (https://coalitionforgreencapital.com/what-is-a-green-bank/)

https://mcgreenbank.org/

https://michigansaves.org/about-us/

https://static1.squarespace.com/static/59bc05f0c534a543a9f96b0d/t/5edf9fbd8285f063f6c13bbe/1591713732941/2020+Annual+Industry+Report+Final.pdf

https://greenbanknetwork.org/reports-white-papers/

Mechanics of a transaction:

https://greenbanknetwork.org/wp-content/uploads/2018/07/GB-TT-Connecticut- 05-1.pdf

Agg. and sec.:

https://greenbanknetwork.org/wp-content/uploads/2019/04/Green-Bank-Aggrega pdf

* * *

Montgomery County Maryland https://mcgreenbank.org/ Has a video

Green Bank Network https://greenbanknetwork.org/

Coalition for Green Capital https://coalitionforgreencapital.com/what-is-a-green-ban

New York Green Bank https://greenbank.ny.gov/

American Green Bank Consortium https://greenbankconsortium.org/

Chapter 20 Internal Carbon Pricing

By Steven O. Kimbrough

State of the draft: This is a work in progress. The first section, on FAQs, is reasonably mature and can be circulated for comment.

Are there any studies of these programs?

20.1 FAQs

1. What is internal carbon pricing?

   Internal carbon pricing occurs when an organization—whether public, private or third sector—imposes on itself a price for greenhouse gas (GHG) emissions. The price is normally expressed in dollars per metric tonne of CO_2e (carbon dioxide equivalent) emissions. See `https://www.c2es.org/content/internal-carbon-pricing` for a standard description, aimed at the private sector but applicable generally.

2. Are there different ways of doing internal carbon pricing? If so, what are they?

   Yes, and they are not mutually exclusive and may be used in combination. See Figure 20.1 for a summary.

   For present purposes, we focus on pricing by *carbon fee* because it is likely the most important option for local governments and academic institutions. The *shadow price* method is mainly apt as a planning tool, to ascertain robustness of investments in a future in which external carbon pricing might be imposed.

3. How does a carbon fee work?

   (a). The institution identifies activities to be subject to the fees and quantifies CO_2e emissions for them.

   For example, an institution might designate a standard CO_2e emissions rate in tonnes per passenger mile traveled by airplane.

   (b). The institution sets the internal carbon price in dollars per tonne of CO_2e emitted.

   (c). When institutional funds are expended for a covered activity a carbon pricing fee is assessed for the activity. Typically, this would be internal carbon price times the standard rate for the activity times the amount of activity, e.g., carbon price $\times$ emissions per mile $\times$ miles traveled.

4. How much is the carbon fee?

   The level of carbon fee varies and is typically adjusted dynamically during an internal carbon pricing program. Figure 20.1 reports a range of \$5–\$20 per metric tonne of CO_2e. The Yale experiment set the price at \$40. Microsoft's current price is \$15.

5. What happens to the money collected by imposing the fee?

   The money is put into a special fund. Let us call it the Sustainability Fund. The institution then decides what to do with the money in the Fund. Common uses of the monies include:

   (a). Purchase carbon offsets.

   (b). Invest in greening the institution, that is in further reducing GHG emissions.

6. What are some examples in practice?

   There are many. In the private sector Microsoft and Disney, among others, have long had carbon fees.

   Among academic institutions, Yale University has experimented with a carbon fee. See `https://carbon.yale.edu/project-overview`, `https://carbon.yale.edu/` and:

   (https://shopcases.som.yale.edu/products/putting-a-price-on-emissions-yale-universitys-internal-carbon-charge-experiment).

7. How is it working out?

   In the private sector it appears that a number of firms have carbon fees that have been in place for several years, perhaps most notably Microsoft:

   > In July 2020, we will start phasing in our current internal carbon tax to cover our scope 3 emissions. Currently this fee is $15/metric ton and covers all scope 1 and 2 emissions, plus scope 3 travel emissions. Unlike some other companies, our internal carbon tax isn't a "shadow fee" that is calculated but not charged. Our fee is paid by each division in our business based on its carbon emissions, and the funds are used to pay for sustainability improvements.
   >
   > https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030/, 2020-01-16, accessed 2021-03-05.

   Examples of municipal and academic carbon pricing, especially carbon fees, are thin. Yale did an experiment that was considered successful. The following is from [**?**].

   > Yale University's carbon-charge pilot was launched as part of the university's broader sustainability initiative and ran from December 2015 to May 2016. The charges covered direct and indirect emissions from consuming energy sources such as electricity, gas, steam and chilled water. The price was set at $40 per tonne of CO2, which was close to the US government's estimated social cost.
   >
   > . . . By the end of the trial, buildings that had faced carbon charges had used less energy than those that had not (see 'Energy savings'). Reasons for this included increased awareness of energy use, competition between buildings and the higher price of energy.
   >
   > . . . At the end of the pilot, the university selected the revenue-neutral pricing structure to implement campus-wide, because of its financial stability. The

structure is not subject to potentially large outflows of funds if buildings exceed a target, saving energy because of an unusually mild winter, for example, or if energy needs rise unexpectedly owing to a cold snap or other reasons.

Yale implemented a carbon charging program in 2017, which continues today https://carbon.yale.edu/implementation.

Regarding municipal carbon pricing, the following is an interesting and well-researched proposal: "An Internal Carbon Price for the City of Ann Arbor" by Adam Freed, Lauren Jones, Yu-Ting (Eileen) Lo, Rosanna Ren.

https://deepblue.lib.umich.edu/bitstream/handle/2027.42/155014/354%20internal%20carbon%20price%20for%20city%20of%20ann%20arbor.pdf?sequence=1&isAllowed=y

8. Pros?
   (a). Promotes environmental awareness in stakeholders.
   (b). Encourages reduction in GHG emisssions, and efficiently so.
   (c). Prepares the institution for external carbon pricing.
9. Actual or Potential Barriers and Impediments?
   (a). Charging a fee for an expenditure that is funded by outside grants or donations. Is it permitted?
   (b). Administrative mechanics.
   (c). Setting the fee basis and maintaining it.
10. Bottom line?

    It's a contender. Careful follow up needed to ascertain feasibility and workability. Potentially an efficient way for an organization to reduce GHG emissions, by encouraging individual behavior.

20.2 Assessment of the Yale program and experience

20.3 Assessment of the Ann Arbor proposal

20.4 Model program for academic institutions

20.5 Model program for municipalities

20.6 Resources on Municipal Carbon Pricing

White paper on municipal carbon pricing: "IMPLEMENTING CARBON PRICING AT THE MUNICIPAL LEVEL".

https://climate-xchange.org/wp-content/uploads/2018/08/Implementing-a-Carbon-Price-at-

	CARBON FEE	SHADOW PRICE	IMPLICIT CARBON PRICE
Definition	A monetary value attached to each metric ton of emissions charged to business units for their emissions.	A theoretical internal cost of carbon applied in project planning processes to test the feasibility of capital expenditure and R&D investment decisions.	The value of past measures and initiatives implemented to reduce a company's greenhouse gas emissions and/or comply with climate policies and regulations.
Key Objectives	To create a dedicated revenue or investment stream that can fund projects to help meet a company's greenhouse gas reduction targets, and establish a common business "language" internally to address climate change.	To screen potential business risks of future carbon regulations, build a business case to shift investments to low-carbon options.	Identify marginal abatement costs of mitigating greenhouse gas emissions and complying with climate policies and regulations.
Calculation	Commonly calculated as the amount of funding or level of investment needed to meet the company's greenhouse gas reduction targets.	Commonly calculated as the current or expected future price of carbon regulations along with other market, technology, and policy factors (including indirect carbon pricing policies).	Can be calculated as the marginal abatement cost of reducing a company's greenhouse gas emissions and/or the cost of complying with regulations. Some companies calculate an implicit price as the costs associated with buying and generating renewable energy divided by the number of tons of emissions saved.
Observed Price Range[123]	\$5–\$20 per metric ton of CO_2e.	\$2–\$893 per metric ton of CO_2e.	No revealed prices or price ranges.[124]
Investment and Revenue Allocation	Revenues used to fund sustainability projects, realized as an actual monetary transaction between business unit(s) and the department collecting the fee.	A theoretical price that is not collected, but which guides future investments and research and development activities toward low-carbon alternatives.	There is no reinvestment or revenue allocation since the price is derived retroactively.
Key Benefits	Sends a direct price signal to business units to justify investments in low-carbon options and raise awareness among employees that carbon reductions are valuable. May help reduce greenhouse gas emissions and drive cultural change and accountability.	Can help prioritize investments in low-carbon options and prepare a company for future carbon pricing regulations. Easier to gain buy-in from C-suite executives. Often viewed a part of a risk management strategy, rather than a cost imposed across business units.	Helps understanding of a company's carbon footprint and the costs of abatement or compliance. It can serve as a benchmark before launching an explicit internal carbon pricing program.
Key Challenges	May pose upfront challenges for implementing, administering, and gaining internal buy-in because it is an actual financial cost imposed throughout the organization. Requires an administrative structure to collect revenues, evaluate revenue/investment allocation, and distribute funds to projects across business units.	As the theoretical price is not reflected in a company's or a business unit's budget, it may not shift investments to low-carbon options, may not provide a strong near-term signal or incentive to reduce emissions. It will also likely not motivate changes to employee behavior. Because it is part of a risk strategy, employees may not be engaged or aware of the price.	Retroactively calculated after measures have been implemented, therefore may not have same incentivizing effect as a carbon fee (and in some cases a shadow price) to mitigate greenhouse gas emissions and shift investments to low-carbon options.

Figure 20.1: From "The Business of Pricing Carbon: How Companies are Pricing Carbon to Mitigate Risks and Prepare for a Low-Carbon Future," Center for Climate and Energy Solutions, (http://www.c2es.org/document/the-business-of-pricing-carbon-how-companies-are-pricing-carbon-to-mitigate-risks-and-prepare-for-a-low-carbon-future/)

the-Municipal-Level-Climate-XChange-compressed.pdf

https://climate-xchange.org/wp-content/uploads/2018/08/Implementing-a-Carb pdf

"Designing an European municipal Carbon pricing model: A collaborative project between Klimaatverbond Nederlandand Climate Alliance"

https://www.climatealliance.org/fileadmin/Inhalte/4_Activities/Projects/Carbon_pricing_working_group.pdf

20.7 Resources on Academic Carbon Pricing

The University of Illinois discussed it only, it seems: https://icap.sustainability.illinois.edu/project/internal-price-carbon

Swarthmore https://www.swarthmore.edu/sustainability/carbon-pricing-policy-br and Vassar appear to have instituted shadow pricing of carbon. (This is principally a planning tool. See Figure 20.1).

20.8 Useful Links

1. The Work Bank maintains a useful collection of links on carbon pricing: https://carbonpricingdashboard.worldbank.org/resources https://carbonpricingdashboard.worldbank.org/resources
2. "The Business of Pricing Carbon: How Companies are Pricing Carbon to Mitigate Risks and Prepare for a Low-Carbon Future," Center for Climate and Energy Solutions, (http://www.c2es.org/document/the-business-of-pricing-carbon-how-companies-are-pricing-carbon-to-mitigate-risks-and-prepare-for-a-low-carbon-future/)
3. "The State of Internal Carbon Pricing" McKinsey & Company, February 10, 2021 https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-state-of-internal-carbon-pricing https://www.mckinsey.com/business-functions/strategy-and-corporate-financ our-insights/the-state-of-internal-carbon-pricing

Chapter 21 Behavioral Interventions

1. Past programs and policies have thrived on using competition to motivate behavior. Take, for example, the company OPower. It showed a household's energy usage compared to others with the same house size and background. By creating a competitive environment, OPower successfully influenced peoples' actions.
2. Following the same line, something that OPower and other companies do that is very effective is making sure that
3. Toyota Prius Dashboard
   (a). Real-time and continuous feedback is important; people respond more to what they can directly see
   (b). Shows drivers real time how much energy their car is using and how much they are saving
4. Price base approaches have seen limited success and can be financially challenging
5. A more involved smartphone ap could be successful in making change
   (a). Visualizing behavior goals
   (b). Create a displace that is continually present on the lock screen, giving the effect of continuous feedback
6. Certain behaviors are easy to chnage by educating people when there are few disincentives to act
   (a). Recycling, turning off the lights
   (b). But it is not as successful when there are major disincentives to act like using public transportation of changing ones diet
7. It is important to make people feel that they have the ability to have a significant impact; if their self-efficacy is low, they are less likely to change their behavior in a positive way
   (a). Show people that they are having a significant positive impact
   (b). This relates to giving them reasonable outcome expectations
   (c). Help them estimate the impact of their actions
   (d). Compare actions in order to help consumers visualize the effect of their actions
8. There are a variety of views on being able to affect actions
   (a). People should be made aware of the negative impact of their actions
   (b). People should recognize their responsibility to act in a positive way
   (c). Behaviors should be related to one's personal values; if they believe their values are under threat and that they have the ability to protect their personal values
9. It is is important that set goals are both realistic and measurable
10. It is important to consider contextual factors; everyone will respond differently

   (a). Take note of what population you are trying to affect
   (b). People have difference mindsets when it comes to sustainable behavior: alarmed, concerned, cautious, disengaged, doubtful. Each of these groups represent different approaches and should be treated differently when it comes to trying to create change
11. Just information isn't enough to make change; emphasis needs to be placed on how and when information is delivered
   (a). People need to be aware of opportunities
   (b). People need to be provided with guidance and technical assistance
12. Everyone has the intent to act in a pro-environmental way, but they are not always able to do so
13. Changing the way people make decisions: choice architecture, is a way to adjust how they make decisions while still preserving their freedom to decide
14. Making the default the "green" setting
   (a). People are less likely to change from the default setting, so this will increase the likelihood that they will participate in green behavior
   (b). Make it an opt-out rather than an opt-in
15. Quotas can be very effective because they create an "either this or that" mindset
16. It is important to make people feel personally connected
   (a). Make people feel close and related to the issues they are trying to prevent Don't focus on the "future" or "over there", focus on "right here, and "right now"
17. It is important to reward people for their behavior, this keeps them engaged and motivated
18. Sustainable actions should be made the norm, so people do them without thinking and it becomes a habit
19. Small changes add up
20. Individual changes lead to large group changes
21. Frame your information in a way that makes it more likely for people to respond
22. Provide many opportunities for people to act sustainably
   (a). Give them more than one way to help make change
23. Create support networks; create a sense of community. This helps keep people more engaged in sustainable behavior
24. Foster mindfulness, get people thinking about sustainable behavior
   (a). This keeps them more engaged
25. Changing a physical environment can make it easier for people to act sustainabily

21.1

Chapter 22 Climate and Environmental Corps

Nice article at
https://e360.yale.edu/features/how-a-climate-corps-could-put-youth-to-work-ir
(https://e360.yale.edu/features/how-a-climate-corps-could-put-youth-to-work-in-greening-america), "How a Climate Corps Could Put Youth to Work in Greening America." I don't agree with everything, but this is a fine start. A related point is made in The Energy Gang podcast, on December 11,
https://www.greentechmedia.com/articles/read/revisiting-pandemic-predictions-
(https://www.greentechmedia.com/articles/read/revisiting-pandemic-predictions-for-energy). See (hear) the discussion on the "Youth Climate Corps" beginning just after 21 minutes from the end, about 45 minutes from the start. Jigar Shah makes a really interesting point that this sort of thing should not be just for youth. There are, he observes, lots of people who would like to "give back", participate in a non-commercial enterprise, "who don't believe in the capitalist system," etc. We should leverage this impulse and all the NGOs out there who have been working in this space. The comments by all three participants in the podcast are terrific. This idea is redolent with promise.

22.1 Links and other information

1. Markey, E. (2021, April 20). Senator Markey and Rep. Ocasio-Cortez Introduce Civilian Climate Corps for Jobs and Justice to Rebuild America | U.S. Senator Ed Markey of Massachusetts.
   Link
   https://www.markey.senate.gov/news/press-releases/senator-markey-and-rep-ocasio-cortez-introduce-civilian-climate-corps-for-jobs-and-justice-to-rebuild-america

File: climate-corps.tex

Chapter 23 Renewable Energy Certificates (RECs)

Steven O. Kimbrough

2022-04-11

In what follows I present a simplified account of RECs. I leave out details that are common knowledge or that do not bear materially on the substantive points I wish to make.

Renewable energy certificates or RECs (aka renewable energy credits) arise in a clever financial institution created for the purpose of providing subsidies to commercial sector organizations that own renewable energy generators. The main reason or goal for the design objective–subsidies for commercial firms–is to incentivize private production of renewable energy by making it (more) profitable, thus leading to more construction of renewable capacity, and thereby reducing GHG emissions and mitigating climate change.

The institution operates as a market in which donors purchase RECs from firms producing renewable energy. The system was designed with two types of donors/buyers in mind: compliance and voluntary. Typical compliance buyers are electric utilities with obligations (under law or regulation) to have a certain percent of their electricity generation come from renewable sources. Renewable portfolio standards are often the source of the obligations in states that have them, such as Pennsylvania. Voluntary buyers/donors may be individuals or any public, commercial, or third sector (nonprofit) organization. All are permitted to purchase RECs and many do. Leaving aside speculators and brokers in the industry, the primary motivations for voluntary purchasing of RECs are to mitigate climate change and to gain legitimacy and good will from targeted publics, as posited in general by legitimacy theory, which is well supported empirically.

There are two broad criticisms that have been widely made of the institution of RECs, at least as it applies to voluntary participation. The first is encapsulated in the longstanding folk saying in the industry: "If you want to claim you are using 100 percent renewable energy, buy RECs. If you want to reduce GHG emissions, invest in a solar farm." (The wag's comment probably antedates the existence of RECs, originating in the planning period. The oldest instance that I have found of something like the saying appeared in the Harvard Business Review in 2006.)

The incisive point of the wag's comment is that when you make an investment you should always consider the alternatives. In the case of voluntary purchase of RECs for the purpose of mitigating climate change, the buyers/donors should consider alternative actions or investments they could make that would have an equivalent cost and be more effective at climate mitigation than the RECs on offer. Here it is important to appreciate two kinds of RECs: current and future. Current RECs are purchased for the output of an existing renewable generator. Because the plant has already been constructed and put into operation, the incentive value of the RECs is attenuated. It appears that documenting a strong incentive effect is challenging. Future RECs are sold contingent on future deployment of a renewable generator. They are more likely to have an incentive effect on developers, but this has to be documented. The gold standard measure would be the cost of eliminating 1 tonne of CO2e emissions. I know of no study that gets anywhere near approximating this with RECs (but there may be some; if so it would be illuminating to read them).

As for alternatives, there would appear to be very many ways for using funds that would go for RECs to reduce GHG emissions, e.g., conduct a lottery to give away and install residential heat pump water heaters to replace natural gas fired water heaters. This has to be looked into carefully, of course.

A significant disadvantage of pulling REC funding in favor of a more efficient investment in climate mitigation is the potential loss of bragging rights and virtue signaling. An organization that covers the total amount of its **annual** electricity consumption is authorized (by the RECs institution) to proclaim that it has "Elected to purchase 100 percent renewable energy". The problem here is that this phrasing suggests that the organization has reached the ideal endpoint of its transition to renewable energy and there is nothing left to transition to clean energy. This is quite false, as we shall see shortly, but being authorized to say this certainly looks good (with its implicit suggestion) and scores high on signaling virtue to stakeholders. Municipal officials therefore might be reluctant to forego the bragging rights in favor of more cost effective action.

The second major criticism that has been leveled at RECs is related to the last point discussed. "100 percent renewable energy" sounds like the ideal we all agree we should aspire to. It isn't. In fact, another standard is in place and widely recognized as superior. It goes by different names, but "24/7 carbon emission free energy" serves well enough to identify the idea.

Consider an organization that purchased a solar farm that over the course of a year generates and puts into the grid a number of kilowatt hours equal to the total energy use of the organization for the year. That organization can claim to be using 100 percent renewable energy, but it cannot claim to be using 24/7 carbon emission free energy if any generator, in the mix of energy sources it draws upon when its demand is at the time greater than the production of its solar farm, is not carbon emission free. The difference is not a trifling matter and the 24/7 standard is properly being seen as the correct one, the correct ideal. The reader can get a sense of this from a podcast (The Interchange) at Link. The program notes begin as follows:

> In 2017, Google became the first major company to reach 100% renewable energy through corporate renewables procurement.
>
> But it was also the first major company to acknowledge that 100% renewable is not really 100% carbon-free.
>
> So Google set out to go further, and match procurement on an hourly basis, to reach the promised land of 24/7 zero carbon energy.

The podcast is clear and well worth the listen.

Finally, I am **not** saying that 100 percent renewable energy is a false ideal. It is a demi-ideal and a legitimate focus for policy. The name, however, is misleading (remember: the name comes from the REC industry; they have an incentive to spin and they do). If an organization in its wisdom decides to buy RECs in sufficient amounts to cover its annual electricity consumption, that's fine. In the interests of honesty, of avoiding charges of greenwashing, and of maintaining public confidence, I would urge the organization to say plainly and accurately what it has done and to eschew the "100 percent renewable energy" moniker.

Also:

Here is fundamentally why I balk at ESG and divestment, etc.: opportunity cost. IMHO, we should see things this way. ESG investing is a philanthropic act. That's fine and laudable, but empirically the donated funds can usually be employed more cost effectively in other ways. If an investor has a non-ESG fund and wishes to do something for the climate, the investor might consider taking an annual hit of $X as the size of the philanthropic act. One way to achieve this would be to convert some of the investor's investment portfolio into an ESG fund to the effect that the investor's net return for the year is $X less than it would have been (all in expectation, of course). The observation I am making is (i) that the investor should consider alternate uses of the $X donation for their climate effects and (ii) I believe that nearly always there will be alternatives available that are superior to the ESG investment.

So, maximize the return on your investment portfolio, then get an objective estimate of the excess return you achieved from fossil fuel, etc. investments and commit that return to direct destruction of demand for fossil fuels (e.g., buy a poor person a heat pump water heater, etc.). This has the advantage of being effective and of denying unscrupulous investors access to cheap fossil fuel investments.

What would be useful is to publicize menus of options for such investments, e.g., home electrification.

23.1 Links and References

1. "Renewable Energy Credits (RECs): What You Need To Know"
   https://www.energysage.com/other-clean-options/renewable-energy-credits-recs/
2. "2019 REC Prices: How Are They Set?"
   https://www.energysage.com/other-clean-options/renewable-energy-credits-recs/renewable-energy-credit-prices/
3. "The Interchange: The Magnitude of 24/7 Zero-Carbon Energy"

   > In 2017, Google became the first major company to reach 100% renewable energy through corporate renewables procurement. But it was also the first major company to acknowledge that 100% renewable is not really 100% carbon-free. So Google set out to go further, and match procurement on an hourly basis,

> to reach the promised land of 24/7 zero carbon energy. It's going to be hard. But Michael Terrell, Google's Director of Energy, thinks it's doable. In this episode, Michael talks with Shayle about how it could even become a new norm for corporate and state commitments. But first: What will it take to get there? Shayle and Michael cover the datasets, the accounting mechanisms, and the massive scale of transactions needed to make it possible. They break down about Google's efforts to shift computing load across its fleet of data centers. They talk about the power of corporate buyers to push policymakers to clean up grids. Where current clean technologies fall short, Google is looking at new technologies to fill in the gaps. They talk about that lineup of potential solutions, such as long-duration storage, carbon capture and storage, geothermal, advanced nuclear, and lithium-ion batteries. And finally they tackle cost and scalability: Will organizations without the capital and expertise that Google enjoys be able to follow its lead?

Listen on Apple Podcasts:
https://podcasts.apple.com/us/podcast/the-interchange/id1221460035?i=1000516300171

4. "24/7 Renewables: The Emerging Art of Matching Renewables With Demand"
On this week's Interchange podcast: We can't talk about 100% renewables without talking about time of use.
Stephen Lacey
https://www.greentechmedia.com/articles/read/24-7-renewables-the-emerging-art-of-matching-renewables-with-demand

> A lot of companies and governments are committing to 100% renewable energy. But a target of that scope without considering the timing of energy use isn't technically or economically optimal.
>
> So how do we get 24/7 renewables for offices, data centers, municipal buildings, cities and eventually countries?
>
> Calculating renewables consumption on an annual basis isn't sufficient. If we really want to make them an effective decarbonization tool, we need to match them to real-time demand. And there are a lot of ways to do it.
>
> In the last few months, we've seen examples of large corporations taking the challenge head-on. We've also seen the negative consequences for a city when it failed to account for time of use.
>
> Melissa Lott, a senior research scholar at Columbia University's Center on Global Energy Policy, joins co-host Shayle Kann for a deep dive into 24/7 renewables.

See useful links in the program notes.

5. Schendler, Auden. “Energy-credit buyers beware.” Harvard Business Review (2006): 23-25. [**?**]

> If your goal is to *claim* that your company offsets the carbon produced by 100% of its electricity usage, buy RECs and leave it at that. But if your goal is to directly reduce carbon emissions, there are better ways to do that, such as investing in a new wind farm.

File: renewable-energy-certificates.tex

Part III

Deliberation Support

Chapter 24 Overview of Deliberation Support Methods

Deliberation proper can begin once a pool of policies and programs, serving as a consideration set of alternative, is to hand and available for discussion. The previous section presented a small example of such a pool. How, then, should deliberation proceed once a pool is available?

A healthy process will be inclusive and iterative, seeking information and comment by the broadest possible range of stakeholders and iteratively revising and refining the consideration set and the policies in it. An exemplary deliberation may surely occur under the usual norms and procedures of committees, civic organizations, and legislative bodies. Deliberation is familiar, something done in the usual course of events. The important question is, then, what else, if anything, might assist deliberation about policies and programs for sustainability. Far from wishing to prescribe deliberation processes to those already immersed in them professionally, our aim in this handbook is additive. We offer concepts, tools, and methods that may prove to be useful, and that we are prepared to support.

We envision several kinds of optional supports for policy deliberation on sustainability. In brief:

1. Information about policies and programs.
2. Group discussion processes.
3. Decision processes for group decision making.
4. Decision analysis modeling.
5. Role-play simulations for policy design.

24.1 Information about Policies and Programs

In discussing example sustainability policies, §1.2 gave brief descriptions of the example policies. Deeper background on them is presented in the chapters of part II. Our aspiration is for this *Handbook* to evolve to encompass a comprehensive repository of information about sustainability programs and policies, amenable to implementation at the state and local levels of government and administration.

We note that there are collections of information about these policies, for example the Inventory of Climate and Clean Energy Policies from the U.S. Climate Alliance, `http://www.usclimatealliance.org/state-climate-energy-policies`. The policies in the lists we are acquainted with require more elaboration and description than is normally present. We see these lists as starting points for the repository we envision.

See also town hall meetings in §24.2.

24.2 Group Discussion Processes

There are any number of informal methodologies used successfully in practice that aim to facilitate civic engagement, discussion, and deliberation with members of the general public. There follows below a sample list of more prominent and promising methods.

1. Town hall meeting

   These are generally open-ended as to subject matter and not intended to constitute deliberation. Instead, they are seen as useful preliminaries to further discussion. Potentially valuable for surfacing issues and worries, and for addressing immediate concerns.

   Town hall meetings are perhaps best seen as a way to communicate information about policies and programs, §24.1.

2. Public debate

   Perhaps followed by moderated open discussion and voting. A traditional form, perhaps not well suited for these times and their hyper-contested issues. Instead of focusing on a win-lose contest, perhaps better to frame discussion around finding good, widely attractive solutions, unless of course it precedes an election or referendum.

3. Focus group

   A mainstay of product marketing and politics. Used to discover reactions to ideas and to see what is on people's minds. Useful for framing a marketing pitch.

4. Nominal group technique

   Nominal groups are more structured than a focus group. They are oriented towards choice and group decision making, normally without much in the way of more formal decision analysis methods. See [4] for how to conduct them. The technique has gained good empirical support and has shown real staying power.[1]

5. World Café method

   `http://www.theworldcafe.com/key-concepts-resources/world-cafe-method/`

6. "Business plan" competition

   Groups form, develop ideas, present plans to a panel which judges them and awards funding.

7. Design charrette

   Established practice in the architecture and landscape design fields. Has shown success in community engagement and in reaching consensus.

8. Participatory budgeting

   > Participatory Budgeting (PB) is a democratic process in which community members directly decide how to spend part of a public budget. The process began in Porto Alegre, Brazil in 1989. Today, there are more than 3,000

[1] A favorite technique of SOK's. Appropriate for gaining a group decision or judgement when formal methods and modeling are not appropriate or not available.

participatory budgeting processes around the world, most at the municipal level. (https://council.nyc.gov/pb/)

And it has been done with success on a small scale in Philadelphia.

- Excellent source: https://www.participatorybudgeting.org/
- New York City's program https://council.nyc.gov/pb/.
- Inevitably, but not bad: https://en.wikipedia.org/wiki/Participatory_budgeting

24.2.1 A Straw Man Process: Participatory Design & Budgeting

Here is a straw man process, meant for feedback and discussion. It and this document are intended as evolving entities. Most assuredly, the number of valuable variations is indefinitely large, and many details remain to be worked out.

The Participatory Design & Budgeting process I have in mind draws upon and recombines many if not all of the processes listed above. It perhaps most closely resembles participatory budgeting, augmented by design charrette. In a nutshell, the workflow for participatory budgeting is:

(i) Generate ideas.
(ii) Work with experts to refine ideas and transit them to specific proposals.
(iii) Discuss and vote on the resulting proposals. Fund and implement as decided, as resources permit.

Points arising:

(a) Step ((i)) might be preceded by information sessions and/or materials that guided participants about possibilities and resources. Also, basic background on the energy transition (see below). This might be done with a teach-in process.
(b) Step ((i)) might be facilitated (in part, but we would always want an open submission process, as in the 2019 Your Big Idea contest) by nominal group sessions held with various community organizations, for example.
(c) Step ((ii)) might be facilitated by Penn's Academically Based Community Service (ABCS) courses or other similar initiatives, including Senior Design Projects in SEAS, and much else. There is ample scope for participation from those beyond the immediately Penn community.
(d) Step ((iii)) might be articulated into multiple steps, including presentation by teams, facilitated discussion as in a civic engagement forum, and much else.
(e) In parallel, there needs to be a process that identifies and characterizes evaluation attributes, such as cost, feasibility, amount of GHG saved, disruption, preservation of communities, promotion of broader values, and so on.

24.3 Decision processes for group decision making

There is a substantial literature and body of experience on *group decision making* (GDM) and on *multiple criteria decision making* (MCDM).[2] Both of which are highly pertinent. We can be assisted, at least conceptually, by this extensive body of knowledge.

These methods are used widely in practice, especially for natural resources planning and policy making, and are designed to administered by facilitators working with groups of stakeholders, who do not need to have technical knowledge of, or exposure to, the methods, some of which rely on mathematical underpinnings that are not broadly accessible. Figure 24.1 on page 166 shows the workflow of a GDM methodology developed and used for securing energy supplies for Fairbanks, Alaska.

In a typical case, after planning and preparation by a team of facilitators, a group of stakeholders will meet for a day-long session to undertake the decision process with the facilitators, and arrive at a consensus decision, e.g., selection of one or more policies. The results—whether in the form of recommendations or a report on lessons learned—may then be implemented or forwarded as advice to decision makers. Participants often aver that insights gleaned from the exercise constitute ample justification for the effort.

24.4 Decision analysis modeling

Decision analysis is a body of theory and practice, widely used, that constructs mathematical models of decision makers' preferences in order to gain insights for choosing among alternatives. Construction of the models needs to be facilitated by experts, who know how to assure the models are valid. As in the case of group decision making, §24.3, which is a form of decision analysis, it is part of the job of the expert facilitators to shield the participants from exposure to the underlying mathematics (unless they want to see it!). Models of this kind are sometimes used to determine choices, for example, in scoring multiple work proposals solicited from vendors. More often, the models are probed for their behavior under varying assumptions and their answers are taken into account in a governing but a less formal deliberation process.

Table 24.1 contains a schema that illustrates a common form of MCDM decision analysis model, one that may be well suited for selection of a policy from a consideration set of policies (and programs). In the table, the alternatives, $a_1, \ldots, a_m$, correspond to the programs and policies in the pool of policies (consideration set), an example of which was developed in §1.2.

The columns headed by the weights, $w_1, \ldots, w_n$ represent multiple evaluation criteria for the alternatives in the policy pool. Examples of evaluation criteria include: budget cost, social cost,

[2] See `https://en.wikipedia.org/wiki/Group_decision-making` for a very high level account. See [8, 12, 20] among others for textbook treatments of standard decision-making methods in environmental policy, which is a close cousin of policy for the great transition. See [24] for a relatively rare GDM and MCDM study of energy policy.

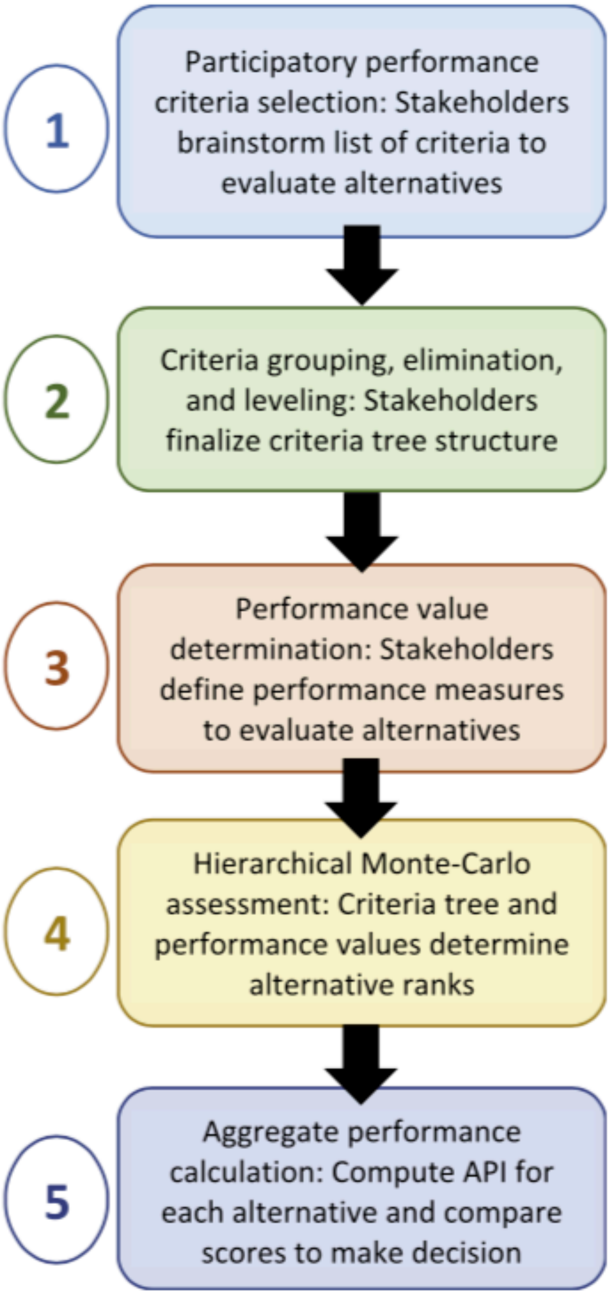

Figure 24.1: Workflow of GDM methodology from [24].

	Criteria [Weights]				
Alternatives	$c_1[w_1]$	$c_2[w_2]$	$\ldots$	$c_n[w_n]$	Alternatives Utilities
a_1	$u_1(s_{1,1})$		$\ldots$	$u_n(s_{1,n})$	$U(a_1) = \sum_{j=1}^{n} w_i u_i(s_{1,j})$
$\vdots$	$\vdots$			$\vdots$	$\vdots$
a_m	$u_1(s_{m,1})$		$\ldots$	$u_n(s_{m,n})$	$U(a_m) = \sum_{j=1}^{n} w_i u_i(s_{m,j})$

Table 24.1: ACS table: Alternatives (a_is), criteria (c_js) [and their weights for an additive model], and scores (s_{ij}s) [given as utilities ($u_j(s_{ij})$s)] for a single stakeholder or decision maker.

time and attention, political capital, mitigation, adaptation, transition, environmental, health, job creation, local business stimulation, aesthetics, and land use disruption. Ascertaining what the evaluation criteria should be is a key and crucial step in any decision analysis exercise. It is facilitated by an expert, whose job is to ferret out the values from the stakeholder participants. The $w_1, \ldots, w_n$ values themselves are weights on the corresponding criteria. If a criterion, such as social cost, is judged to be comparatively more important, it will have a correspondingly higher weight.

The $u_i(s_{i,j})$ values within the table represent normalized scores: $u_i(s_{i,j})$ is the score of alternative i on evaluation criterion j. Finally, the $U(a_1), \ldots, U(a_m)$ values in the Alternatives Utilities column represent overall assessment values (higher is better) for the alternatives, taking into account how they score on the multiple evaluation criteria.

The upshot of such a model, prepared under the leadership of an expert facilitator, is to give each alternative an overall evaluation score, thereby providing a preference ranking of the alternatives, and serving to serve to provide additional insights based on, for example, how close various alternatives are to each other. Again, it is to be emphasized that the expert and technical work is lead by a specialist, but the method is designed to work with non-specialist stakeholders.

The core of Table 24.1 is called the *alternatives-criteria-scores* (ACS) table. It is foundational for the other decision analysis exercises.

24.5 Role-play simulations

Role-play simulations originate in military war games and have much in common with certain, but not all, types of them. The term *war gaming* is often used in non-military as well as military contexts, as no alternative terminology has emerged as a generally accepted standard. "Role-play simulation," however, is standard terminology in teaching negotiation and we retain it here because our concept is that of a kind of negotiation and not at all that of a kind of military exercise.

A prototypical role-play simulation begins by characterizing a negotiation context, associated rules of play, and representative roles for players. The players in their assigned roles then negotiate and otherwise act in accordance with the rules. The ensuing outcomes and behaviors are recorded and examined for insight and understanding.

Role-play simulations may to a degree resemble and take on the functions of group decision making (GDM) exercises. Role-plays, however, tend to be more free form, open, and exploratory than GDM exercises, which unlike role-plays aim at the outset to settle on an alternative. Role-plays are more expansive and may be used to discover alternatives to the given consideration set.

Our concept revolves around developing *realistic* role-play simulations to model policy deliberations pertaining to climate change, based in part on a well-developed pool of policies and programs and the problem of deciding which, if any, to implement. Further, we would hope to engage representative stakeholders as players in the exercises. We believe that both participants and observers stand to benefit by coming to better understandings of which policies can be implemented and accepted, and why.

Two recent examples of role-play simulations with high-end production values are:

- Event 201 (`https://www.centerforhealthsecurity.org/event201/`) which was about responding to a viral pandemic.
- The Transition Integrity Project (TIP, `http://transitionintegrityproject.net`) which was about dealing with anticipated attempts to undermine the 2020 election.

Each is in retrospect remarkably prescient and insightful.

The Harborco role-play `https://www.pon.harvard.edu/freemium/harborco-role-play-si` (https://www.pon.harvard.edu/freemium/harborco-role-play-simulation-2/) is a popular case for teaching negotiation. Although it is fictional, it nicely illustrates a valuable exercise developed with a minimal budget and level of effort.

An interesting and valuable climate-related role-play simulation has been developed at MIT by John Sterman and the Systems Dynamics group:

- `https://mitsloan.mit.edu/teaching-resources-library/world-energy-a-climat` (https://mitsloan.mit.edu/teaching-resources-library/world-energy-a-climate-and-energy-policy-negotiation-game)
- `https://www.climateinteractive.org/tools/world-climate-simulation/` (https://www.climateinteractive.org/tools/world-climate-simulation/)

It has a global rather than local outlook and is not focused on policies and programs per se, nor is it focused on negotiation.

If a role-play along the lines indicated is rich enough and realistic enough it will have a recurring value. The exercise could be played multiple times, presumably with revisions, and reported.

24.6 From the slides

- Necessary and underway; fraught and contentious
    - Difficult tradeoffs
- Requires decision making over *large numbers of policies and programs*

- Interacting with each other; Interacting with stakeholders and special interests

Mission The mission of the Deliberation Modeling project of the Climate Decisions Lab is to investigate the policy and program alternatives in this space, for the sake of facilitating good decision making for the energy and sustainability transition.

Premises (1) There is much to be gained in considering the alternatives in bundles. (2) The analysis will be permanently incomplete, with imprecise data present. The trick is to make the most of what we have. (3) Above all, there is much value in undertaking group deliberations.

24.6.1 Purpose of this presentation: Focus on (3)

Introduce, motivate, advocate, and sketch an idea:

Group deliberation on portfolios of climate and sustainability policies.

Elements of the Context

A. Alternatives

B. Criteria

C. Participants

   Stakeholders, decision makers, students, experimental subjects

D. Deliberation processes

   Purposes ranging from education to decision making.

   Forms ranging from discussion to decision, from informal to form.

24.6.2 To illustrate. . . A. Alternatives.

Focusing on state and local programs and policies (“programs”). Some programs:

LECC Low embodied carbon concrete

CSCom Curb side composting

GreF Green financing

EBus Electric buses and utility vehicles

InCP Internal carbon pricing

SusL Sustainable living information

GasB Ban natural gas in new construction

Bhav Behavioral interventions

We could go on at length. See for more:

https://github.com/stevenokimbrough/sokpapers/blob/master/ClimateDecisions
Climate_Decisions_Lab_Workbook_Local.pdf

https://github.com/stevenokimbrough/sokpapers/blob/master/ClimateDecisions
Climate_Decisions_Lab_Handbook_Academic.pdf

24.6.3 To illustrate... B. Evaluation Criteria.

BCO Budget expense (cost) to the local government or other organization net of outside grants and program funding such as federal programs. A 1 indicates that the organization actually profits in a meaningful way. A 0 indicates a small profit (rare) or expense, say on the order of funding one employee for a year. A -1 indicates substantial expense to the organization, paid out of its own funds net of outside grants and other funding programs; roughly, these are general revenue dollars raised from the tax payers.

SCO Social expense (cost) to the pertinent body of stakeholders. A -1 indicates a substantial expense. This may occur, for example, due to mandated behavior, such as building improvement, that is not compensated. A 0 indicates a small expense or payment. A 1 indicates a meaningful payment to members of the stakeholders.

GHG Greenhouse gas emission reduction, also called climate mitigation. 1: indicates a definite and discernible positive value. 0: intermediate value, which may be slightly positive or slightly negative. -1: definite and discernible negative value.

HnS Health and safety effects.

CoB Co-benefits, positive consequences other than cost and GHG emissions. Example: a program that creates or improves a recreational area as a side-effect.

DiB Disbenefits, positive consequences other than cost and GHG emissions. Example: a program that destroys or degrades a recreational area as a side-effect.

TRA Transition effects. Are we moving in the right direction? Does it favor something that has to be done eventually? Does it help with adaptation or resilience?

24.6.4 First-cut ACS (alternatives, criteria, scores) table

Program	BCO	SCO	GHG	HnS	CoB	DiB	TRA
LECC	0	0	1	0	0	0	1
CSCom	0	0	1	0	1	0	1
GreF	0	0	1	1	1	0	1
EBus	-1	0	1	1	1	0	1
InCP	-1	0	1	1	1	0	1
SusL	0	0	1	1	1	0	1
GasB	0	-1	1	1	1	-1	1
Bhav	0	0	1	1	1	0	1

Table 24.2: Example First-Cut ACS (alternatives, criteria, scores) table.

This is a very rough cut indeed, but it is apt as an early step in deliberation. We can learn much from it.

24.6.5 To illustrate... C. Participants

- High school students

- College students
- Decision makers and influencers

  Township commissioners, administrators; business executives and other representatives, policy makers at all levels (local, state, national, international); stakeholders and general public (NGOs, faith organizations, civic organizations, etc.)

24.6.6 frame

To illustrate. . . D. Group processes

1. Focus groups
2. Nominal groups

   More structured than a focus group. Oriented towards choice and group decision making.
3. World Café method

   http://www.theworldcafe.com/key-concepts-resources/world-cafe-method/
4. "Business plan" competition

   Groups form, develop ideas, present plans to a panel.
5. Design charrette

   Established practice in the architecture and landscape design fields. Has shown success in community engagement and in reaching consensus.
6. Participatory budgeting

   https://www.participatorybudgeting.org/
7. Role-play simulations
8. Various MCDM methods
9. Enterprise crowdfunding

24.6.7 Now what?

- Identify participants (α customer)
- Settle on an initial group process

  Design and evaluation plan. (Funding in place for starting on role-play simulations.)
- Develop supporting materials
  - Expand the consideration set of programs
  - Develop and curate background information on each of the program areas
  - Consider further evaluation criteria
  - Undertake a much deeper scoring effort
  - Develop support tools (computational)
  - . . .

  (Some of these may become part of the deliberation process itself.)
- Hold group process session(s)
- Assess results

- Revise and extend
- Rinse and repeat

Discuss voting systems. Range voting, ranked choice voting. Etc.

24.7 Related Literature

Multicriteria Analysis for Environmental Decision-Making [2]

Multiple Criteria Decision Making: State of the Art Surveys [10]

"Stakeholder-driven multi-attribute analysis for energy project selection under uncertainty" [24]

Portfolio Decision Analysis: Improved Methods for Resources Allocation [25]

Decision Making Under Deep Uncertainty [21]

Chapter 25 Overview notes on PROMETHEE

25.1 Preparatory

A. We are using the PROMETHEE methodology as a conceptual tool for the purpose of *supporting* deliberation pertaining to climate change and sustainability. PROMETHEE is a family of multi-criteria decision modeling methods. There are other families of methods as well. Members of other families are certainly worth considering. We simply choose to focus for the present.

B. There is a great amount of theory, mathematics, psychology, and practical experience associated with PROMETHEE and multi-criteria methods generally. PROMETHEE is designed in light of all this knowledge. It is also designed to not require much background knowledge on the part of the participant(s) in a decision context.

C. What *is* required is a trained facilitator to conduct interactive sessions.

D. Everything is driven by an *evaluation* or *ACS* table (ACS = alternatives, criteria, scores), including importance weights for the criteria and the sense of the scores for each criterion (Is higher better or worse?).

Provide an example ACS table here. Here's a temporary one:

	A	B	C	D	E	F	G	H
1								
2	**Program**	**BCO**	**SCO**	**GHG**	**HnS**	**CoB**	**DiB**	**TRA**
3	LECC	3	4	6	3	4	5	5
4	CSCom	3	3	5	4	4	4	4
5	GreF	4	4	7	4	5	4	4
6	EBus	3	4	6	5	4	3	5
7	InCP	1	4	6	3	3	3	4
8	GasB	4	1	7	4	4	2	5
9	EVCharge	2	2	6	4	3	5	5
10	ELawn*	4	2	5	5	2	4	5
11	FoodR	3	3	5	5	3	4	4
12	BnP	2	4	6	5	3	2	3
13	WorkR*	4	2	5	4	4	1	2
14	GreElec	1	4	7	4	2	4	5
15								
16	Direction of	1	1	1	1	1	1	1
17								
18	Raw Factor Weights:							
19		7	5	6	6	5	4	2

Figure 25.1: example ACS table

E. Building an evaluation table is its own story. With the help of facilitators, non-experts can construct ACS tables.

For the present we assume that this has been done and ACS tables are available to us.

25.2 Context I: Single alternative choice by an individual

PROMETHEE software processes the given ACS table and returns scores for each of the alternatives, indicating their quality according to the model.

Aided by the facilitator, the individual decision maker engages in *post-solution analysis*, with the aid of the software. A notable feature of PROMETHEE is that it supports assessments of clear differences among alternatives, as well as insignificant differences. Post-solution analysis is about exploring the model's behavior under varying assumptions. This is directed by the decision maker with assistance from the facilitator. In the end, the decision maker, weighing all the information disclosed, may prefer to choose an alternative that is not the highest scored originally.

25.3 Context II: Single alternative choice by a group

Now, instead of one ACS table, each individual has their own. Differences may be minor, such as differences only in criteria weights.

Each individual conducts their own Context I analysis, reaching their own scoring for the alternatives, normalized to the range 1–100 with the best score = 100.

The group then discusses the alternatives and exchanges the views of the members. When the discussion is over individuals may revisit their scores for the alternatives.

The group then engages in range voting for the alternatives. Each individual gives a score in the 1–100 range for each of the alternatives. The winning alternative is that with the largest total of scores.

Optionally, group discussion and negotiation ensues, followed by another round of voting.

During the deliberations, each individual has access privately to PROMETHEE software, which may be used for post-solution analysis (what-ifing etc.) on their own or someone else's preferences.

25.4 Context III: Portfolio choice by an individual

The individual begins with a Context I analysis. To this is added, with the aid of the facilitator, constraints on possible portfolios. Normally, one of the constraints is on the total cost of the portfolio, obtained by summing the costs of the alternatives in any portfolio. Many other kinds of constraints are possible, for example a requirement that no more than one of a given group of projects can be taken in the portfolio, or a requirement that either alternative A or B must be taken.

With the aid of the facilitator, this information is translated into a constrained optimization problem and solved for the optimal portfolio of alternatives.

Post-solution analysis is then undertaken at the end of which the individual has identified and scored a small set of more preferred portfolios (required to be feasible, to satisfy the constraints).

25.5 Context IV: Portfolio choice by a group

Each member of the group undertakes a Context III analysis, resulting in a set of scored, feasible portfolios.

The group meets and each individual reveals their set of preferred portfolios. A group discussion ensues.

The group then engages in range voting for the alternatives. Each individual gives a score in the 1–100 range for each of the alternatives. The winning alternative is that with the largest total of scores.

Optionally, group discussion and negotiation ensues, followed by another round of voting.

During the deliberations, each individual has access privately to PROMETHEE software, which may be used for post-solution analysis (what-ifing etc.) on their own or someone else's portfolio.

* * *

See the video `PROMETHEE_video2.mp4` at https://www.dropbox.com/sh/05x02cn5lrvpkyf/AAAaJROZhjmhressHC2uoM_pa?dl=0 for detailed information on how PROMETHEE works.

See [10], chapter 6, "PROMETHEE Methods" by Jean-Pierre Brans and Yves De Smet, pages 187–220, for an authoritative description of PROMETHEE. Our description in this chapter extends the standard PROMETHEE methods.

File: promethee-overview-notes.tex

Chapter 26 PROMETHEE

Ishaan to take the lead on this. Organized into phases:

I. Pre-processing

II. Core processing

III. Group decision making

IV. Portfolio decision making

For starters, work on II, core processing. That is, assume you have an ACS table in good order numerically. Some scores are ordinal, some cardinal (either ratio or interval scales). Do not assume the numbers are all on the same scale, so the first step is to deal with this if necessary.

Then step through what has to be done, explaining the calculations etc., including asking for human judgments. Be explicit with examples.

And in going along, show how your code gets used to actually make the calculations.

The purpose here is to document everything very clearly. Also we will draw upon this for instructional purposes.

Put the code in the Google Docs folder I will set up.

You might want to set up a Jupyter Notebook for demonstration purposes. (Hint: recommended!)

Actually, as we think of it, do first a nice Jupyter Notebook implementation, possibly importing the basic code and stepping through the steps in the notebook, with comments and documentation. Once this is working, we can use it as the primary documentation vehicle and draw from it for instructional material, which can be put here.

26.1 Introduction

The "Preference Ranking Organization Method for Enrichment of Evaluations" (PROMETHEE) is multi-criteria decision analysis (MCDM) method in the class of outranking methods. It relies on comparing pairs of alternatives.

An authoritative reference on all facets of PROMETHEE is [10, chapter 6]. See the file `Greco et al. - 2016 - Multiple Criteria Decision Making State of the Ar.pdf` in the Climate Decisions Lab public Dropbox folder: `https://www.dropbox.com/sh/05x02cn5lrvpkyf/AAAaJROZhjmhressHC2uoM_pa?dl=0`.

A very good YouTube presentation on how to make the PROMETHEE II calculations can be found at [1]. Also good is [?], which presents PROMETHETHEE I calculations as well.

Neither presentation says much about assumptions, proper uses, etc. Both assume cardinal input data and neither have much to say about where criteria weights come from. For use of ordinal data see [11]. This is important material but I propose to eschew ordinal scores in favor of linguistic ratings (see below). We can return to this if need be.

Now, following [1] as much as possible for the sake of tracking we will lay out the basic PROMETHEE II procedure and calculations. In doing so, we introduce two phases of the calculation procedure.

26.1.1 Phase 1: Preparing the ACS or Evaluation Table

ACS = alternatives, criteria, scores table, known as the evaluation table and the decision matrix in PROMETHEE.

26.1.1.1 Swag Table

A swag table is meant to be a precursor to a proper ACS or evaluation table with which we start the PROMETHEE calculations. The swag table, again, is meant as an open-ended scratch table, from which extractions are made to create a single ACS table for PROMETHEE calculations (and indeed for calculations for other MCDM methods). Constructions pointers:

- Rows: distinct programs/policies (these are alternatives). In the swag table, freely add or remove or reorder alternatives, even if they are duplicative. Keep a record of links to information (such as chapters in this workbook) about the individual policies and programs, the alternatives. **These records and records subsequently described for the swag table should be place in a Swag Table Records document and kept organized.**
- Columns: evaluation criteria (these are criteria). As in the case of alternatives, freely add or remove or reorder evaluation criteria. Keep a record of links to information (such as chapters in this workbook) about the individual evaluation criteria.
- Table entries: evaluation information for the associated program (row) and criterion (column) (these are or become scores). Feel free to use either cardinal numbers or linguistic descriptors that can be put on a scale (e.g., high, medium, low). Do not record rankings. The sense of the scores can be either direction: higher is better (GHG reductions) or lower is better (costs). Keep a record of the sense of the scores for each evaluation criterion. The several criteria should at this point be seen as having its own unique scaling. So, on one criterion the scores may range from -6 to 17, while on another they may range from 0 to 100.
- Evaluation information (scores) may be specified specified loosely (as falling in a range), and locally in the sense that the meaning is conditioned by the intended context. For example, what is high cost will vary by funding source. Keep a record of this score metadata. For the present the record can be informal, textual. If possible, provide confidence levels for the scores. The UN IPCC practice is a good model.

Complete this prepatory step by creating an initial ACS table. Do this by extracting rows and column (and their associated scores) from the swag table. For any column of scores with phrase (linguistic) scoring, develop and record a numerical score for the several phases, e.g., high = 5, medium = 3, low = 1. Develop and substitute into the ACS table a *phrase-anchored scale*. Likert scales are good models for this, e.g., `https://www.extension.iastate.edu/Documents/ANR/LikertScaleExamplesforSurveys.pdf`.

Having thus extracted an ACS table (with m rows and n columns) we will have completed

Step 1: Determine the criteria $(j = 1, \ldots, n)$

of the PROMETHEE II procecess as described by Martin in her YouTube video [1], but as you can see much more is involved than she describes.

To be emphasized: In extracting the ACS table from the swag table we are provisionally deciding which alternatives to consider and which criteria we are to use to evaluate them. This decision can of course be revisited in the sequel.

26.1.1.2 Calculations with the ACS Table

The first thing to be done is to address the weighting of the criteria. In terms of Martin's video, [1], this is

Step 2: Determine weight w_j of each criterion, such that

$$\sum_{j=1}^{n} w_j = 1$$

and

$$w_j \geq 0, \quad \forall j$$

(Here we are modifying Martin's formulation in the direction of full specification.)

How is this to be done? The simplest place to start is to set the weights to be equal to each other

$$w_j = \frac{1}{n}$$

With this assignment, all criteria a judged to be equally important. This is fine for testing purposes, and may even be a good starting point for analysis, once the ACS table has been normalized (see below) and the scores places on a common scale. There are methods, from expected utility theory, for validating weight assignments, but for now we'll proceed without them.

Perhaps the second simplest way of assigning weights to criteria is to first rank the criteria by importance (be sure this is done after normalization!) and then use the formula for assigning weights that is given in [16, chapter 16].

Will fill this in later.

A third way is perhaps the one to recommend. Begin by subjectively assigning nominal weights to the criteria. For example, find the least important criterion, assign it a value of 10, then assign the others relative to the 10 value. Once this is done, normalize the assigned weights by dividing the individual nominal values by the sum of the nominal values. This is easily done with a spreadsheet program and affords explorations with weightings.

Finally, the underlying assumption here that is begin made by PROMETHEE is that weights are appropriate because they are the parameters we need for a weighted average. But there is no necessity that our aggregated preference function should have the form of a (linear) weighted average. This is, as we just said above, something that can be tested.

The assumption of a linear preference function is *prima facie* reasonable. See [3] on "improper" linear models and how they tend to perform well. So, we should proceed, but keep this all in mind and be prepared to revisit assumptions. There is one way especially that the linear model can be mistaken and we should be on guard for this. The linear model is said to be a *compensatory* decision model (or preference model) because no matter how badly an alternative does on one criterion it is possible to make up for the deficit on another criterion, which compensates for the shortcoming. Decision makers, however, often reveal non-compensatory preferences. Great guy, but he killed your brother, so don't marry him. Hot and powerful woman, would make you king, but after all she's your mother, so don't make her your wife, too. (See `https://www.hospitalitynet.org/opinion/4056066.html`, the best short description I could find on the Web on short notice.)

Once we create the criteria weights, normalized to 1, we normalize the ACS table ("decision matrix" in [1]). This is step 3.

Step 3: Normalize the ACS table.

Martin [1] gets the formulas wrong, but they are almost right. Corrected, the key formulas are:

$$S_{ij}^{B} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, \quad \forall j = 1, \ldots n \tag{26.1}$$

$$S_{ij}^{C} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, \quad \forall j = 1, \ldots n \tag{26.2}$$

(Here we are modifying Martin's formulation in the direction of full specification.) S_{ij}^{B} signifies the x_{ij} score in the ACS table in the case that the jth criterion is a "benefit" criterion in which, crucially, higher values for x_{ij} are better. Similarly, S_{ij}^{C} signifies the x_{ij} score in the ACS table in the case that the jth criterion is a "cost" criterion in which, crucially, lower values for x_{ij} are better. The key thing is that the formulas are applied on individual columns—you fix the j value first—and S_{ij}^{B} or S_{ij}^{C} are calculated and written into the ACS table according to whether the column in question is a benefit or a cost column. Thus, for example, $\max(x_{ij}$ fixes j and the maximum is taken over all values of i, i.e., $i = 1, \ldots, m$. The effect is to scale everything from 0 to 1 such that 1 is best and 0 is worst. This step in PROMETHEE does not accommodate the case in which the best or the worst value in a column lies between the extreme values. If this occurs a different transformation is required, one which we'll skip over for the present.

Let's put an example before us. We'll begin with the normalized evaluation/ACS table example from Manoj [**?**]. You can see the interpretation in the original video. Here we'll abstract the table to a matrix, E, representing a normalized evaluation.

$$E = \begin{pmatrix} 0.5 & 0 & 0.5 & 1 \\ 1 & 0 & 0 & 0.3333 \\ 0 & 1 & 1 & 0.6667 \\ 0.25 & 1 & 0 & 0 \end{pmatrix} \tag{26.3}$$

Martin's next step [1] is

Step 4: Determination of deviation by pairwise comparison
$d_j(a, b) = g_j(a) - g_j(b)$

This is not as clear as it could be, although the video makes it clear later when the spreadsheet calculations are demonstrated. Mathematical notation is helpful here, perhaps.

Let e_{ij} be the element at row i and column j of E. Then $e_{i\bullet}$ is the ith row of E, a vector. Continuing, $e_{i\bullet} - e_{h\bullet} = d(i, h)$ is the vector obtained by subtracting row h of E from row i of E. For this step of PROMETHEE, we obtain *all* $d(i, h)$ values for which $i \neq h$. For the example before us, we calculate $d(1, 2), d(1, 3), d(1, 4), d(2, 1), d(2, 3), d(2, 4), \ldots, d(4, 3)$, for a total of $m(m - 1)$ in all and here $4(4 - 1) = 12$. To illustrate,

$$d(1,2) = \begin{pmatrix} 0.5 & 0 & 0.5 & 1 \end{pmatrix} - \begin{pmatrix} 1 & 0 & 0 & 0.3333 \end{pmatrix} \tag{26.4}$$

$$= \begin{pmatrix} -0.5 & 0 & 0.5 & 0.6667 \end{pmatrix} \tag{26.5}$$

Martin's next step [1] is even more unclear.

Step 5: Define the preference function
$P_j(a, b) = F_j(d_j(a, b))$
$P_j(a, b)$ represents the function of the difference between the evaluations of alternative a regarding alternative b on each criterion into a degree ranging from 0 to 1.

But the underlying PROMETHEE idea is straightforward. For every $m(m - 1)$ of the $d(i, h)$ (our notation) values we replace negative values by zeros. Thus for example

$$P(a, b) = F(d(a, b)) = \begin{cases} d(a, b) & \text{if } d(a, b) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{26.6}$$

So really the notation $F(d(a, b))$ does no work. Calling $P(a, b)$ profit is a bit odd, but there you have it. Maybe positive surplus. From our previous example,

$$P(1, 2) = \begin{pmatrix} 0 & 0 & 0.5 & 0.6667 \end{pmatrix} \tag{26.7}$$

Step 6: Determine the multi-criteria preference index

$\pi(a,b) = \sum_{j=1}^{n} P(a,b)w_j$

This is again incorrect. Instead, let

$$P = \begin{pmatrix} P(1,2) \\ P(1,3) \\ \vdots \\ P(m,m-1) \end{pmatrix} \tag{26.8}$$

So, P is a matrix (or array) with dimensions $m(m-1) \times n$ where n is the number of criteria. Let

$$W = \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} \tag{26.9}$$

be the vector (or array) of criteria weights, w_j. It has dimensions $n \times 1$. Then

$$\pi(P) = P \times W \tag{26.10}$$

and $\pi(P)$ has dimensions $m(m-1) \times 1$. Let $\pi(P(a,b))$ be that element of $\pi(P)$ corresponding to $d(a,b)$.

Note that

$$\pi(P(a,b)) = \pi(p_i) \text{ where } i = (m-1)(a-1) + \begin{cases} b & \text{if } b < a \\ b-1 & \text{if } b > a \end{cases} \tag{26.11}$$

and p_i is the ith element of P (assuming P was constructed along the same lines).

26.2 In detail

In the following document, we outline the first and second version of the PROMETHEE outranking method by utilizing PROMETHEE calculations on a dataframe consisting of multiple alternatives and criteria.

As per usual, begin by importing the important python packages. Python offers a "pymcdm" library which can do PROMETHEE calculations. We can either use this pymcdm library, or do our own calculations by hand.

```
# python library used for reading and modifying dataframes
import pandas as pd
#python library used for mathematical calculations with matrices/dataframes
import numpy as np
# python library for data visualization
import seaborn as sns
import math
```

```
# python library for data visualization
import networkx as nx

# pre-made python library for multicriteria decision making
from pymcdm import methods as mcdm\textunderscore methods
from pymcdm import weights as mcdm\textunderscore weights
from pymcdm import normalizations as norm
from pymcdm import correlations as corr
from pymcdm.helpers import rankdata, rrankdata
import inspect

# python library for data visualization
import matplotlib.pyplot as plt
#from pymcdm.methods import PROMETHEE
#from pymcdm.helpers import rrankdata
```

PROMETHEE requires two pieces of data. First is an $n \times m$ matrix of alternatives and criteria with each entry of the matrix being the corresponding 'score' for the alternative on the criterion. Secondly, if applicable, PROMETHEE needs an $1 \times m$ matrix of weights corresponding to each criterion where the sum of the weights equals 1.

The first step of PROMETHEE is to pre-process the data into dataframes that are useable for calculations. Data can be read using the pd.read function. For example, if data is located in an Excel sheet called 'data.xlsx', then we would the read the data by using pd.read_excel('data.xlsx'). The data for weights, if present, can be read in a similar fashion. Below is an example of reading the data from an excel sheet and storing it in dataframes:

```
acsdf = pd.read_excel('TestACS1.xlsx', header=1, index_col=0, nrows=20)
acsdf = acsdf.drop(axis=1, columns=['Unnamed: 11'])
acsdf2 = acsdf.copy(deep = True)
acsdf.head()

weights=pd.read_excel('TestACS1.xlsx',header=1,index_col=0,nrows=1,skiprows=2
# Drop the extra column
weights=weights.drop(axis=1,columns=['Unnamed: 11'])
# Set the column names
weights.columns = acsdf.columns
weights2 = weights.copy(deep = True)
weights
```

Now, for a brief interlude on notation. We denote a_i to be the ith alternative such that

$1 \leq i \leq n$ and n is the amount of alternatives. Additionally, we denote $g_j(.)$ to be the jth criteria such that $1 \leq j \leq k$ and k is the amount of criteria. Lastly, $g_j(a_i)$ is the evaluation for the jth criteria for the ith alternative. This value of $g_j(a_i)$ corresponds to the value in the ith row and jth column of the dataframe.

As stated before, PROMETHEE is an outranking method that relies on pairwise comparisons. Consider the following example with two alternatives and two criteria (equally weighted):

X	Crit 1	Crit 2
Alt 1	5	5
Alt 2	3	1

Suppose we wish to maximize the values for all criteria. In this example, it is evident that Alternative 1 is the better choice because it outperforms Alternative 2 for both Criteria.

Now, consider this next example:

x	Crit 1	Crit 2	Crit 3
Alt 1	3	7	4
Alt 2	6	5	2

For this example, it may not be immediately obvious which alternative is the better choice. We could claim that Alternative 1 is better because the sum of its scores is greater than the sum of scores for Alternative 2. But on the other hand, Alternative 2 might be better because its performance on criteria 1 & 2 are decent with only criterion 3 being bad, but Alternative 1 has two bad scores.

With a larger dataframe with more alternatives and more criteria, it is very challenging to determine the best choices for alternatives. Additionally, when considering the weights for each criterion, the problem becomes more challenging

The way PROMETHEE handles the difficulty of choosing between two alternatives is by considering the deviations between each criteria for two specific alternatives. Utilizing our notation, the deviation between a_i and a_j is a list $[d_1, d_2, ..., d_k]$ of size k (the number of criteria) such that $d(a_i, a_j)_m = g_m(a_i) - g_m(a_j)$.

Utilizing the second example from above, the deviation between alternatives 1 and 2 is the list $[-3, 2, 2]$.

The following cell of code establishes a method called 'get _deviation' which takes in two integer parameters – 'alt1' and 'alt2'. The method returns a list of the deviations between the two alternatives specified.

For example, get _deviation(2, 4) would return the list of deviations between the 2nd and 4th alternatives of the dataframe.

```
def get_deviation(alt1, alt2):
# obtain the two rows of the dataframe corresponding to parameters
```

```
    alternative1 = acsdf.iloc[alt1]
    alternative2 = acsdf.iloc[alt2]
    deviations = []
    #loop through every entry of each row and append their deviation to a list
    for i in range(len(alternative1)):
        deviations.append(alternative1[i] - alternative2[i])
    return deviations
```

Obtaining deviations for each criterion between two alternatives is the first step of PROMETHEE, but the next step is to develop a 'preference function'. A preference function, denoted as $P_j(a, b)$ returns a value between 0 and 1 inclusive which indicates how preferable alternative a is to alternative b for the jth criterion.

In fact, the preference function is a function of the deviation between two alternatives: $P_j(a, b) = F_j[d_j(a, b)], \quad \forall a, b \in A$ where A is the set of alternatives

$P_j(a, b) = 1$ indicates that alternative a is strongly preferred to alternative b for the jth criterion.

$P_j(a, b) = 0$ indicates that alternative b is strongly preferred to alternative a for the jth criterion.

The Preference Function can be mathematically computed using predetermined functions, or it may be possible to use user input to generate a new preference function. For the remainder of the code, we will use predetermined preference functions.

Some of these function require parameters. These parameters are described as follows: q - The threshold of indifference. This parameter indicates the largest deviation for which the decision maker deems negligible. p - the threshold of strict preference. This parameter indicates the smallest deviation for which the decision maker has a strict preference. s - an intermediate value in between q and p.

It is of utmost importance to recognize the type of data included in the dataframe. Thus far, we have assumed the data to be of cardinal values where a higher number indicates that an alternative exceeds at a particular criteria, and a lower number indicates failure.

Under the condition that the dataframe contains purely ordinal values, different parameter values should be used. For example, an alternative that has an ordinal ranking of 1 may be strongly preferred to an alternative with an ordinal ranking of 5.

In the case of mixed data, meaning that there is both cardinal and ordinal values, it may be necessary to include two sets of parameters and use the appropriate set of parameters for cardinal data and the other set for ordinal data. An example of defining parameters is seen below:

```
param_q = 2
param_p = 5
param_s = 3
```

```
# Parameters for ordinal criteria
# NOTE: FOR ORDINAL CRITERIA, WE ASSUME THE HIGHEST VALUE IS THE BEST AND THE
# For example, an alternative with a ranking of 2 for a ordinal criteria woul
# an alternative with a ranking of 15 out of 20 total alternatives would be c

param_q_ord = 1
param_p_ord = 3
param_s_ord = 2

# A list indicating which columns in the dataframe contain ordinal values
ord_cols = [0, 2, 4]
```

To understand the meanings of the parameters more thoroughly, let's investigate an example brought up previously.

x	Crit 1	Crit 2	Crit 3
Alt 1	3	7	4
Alt 2	6	5	2

And suppose we introduce parameters q = 2, p = 3, s = 2.5. From this, we can gather that for criteria 1, Alternative 2 is fully preferred to Alternative 1 because $(6-3) \geq p$. For criteria 2 and 3, the absolute value of the deviation is 2, which is exactly equal to the parameter of q which means that this deviation is considered as negligible.

Therefore, with these parameters, Alternative 2 would be the best choice.

One common preference function that can be used with PROMETHEE is the Gaussian function. The Gaussian function, which we will denote as $P(d)$ uses two parameters, d and s, where d is a single deviation, and s the parameter s specified above.

If $d \leq 0$, then $P(d) = 0$.

If $d > 0$, then $P(d) = 1 - e^{-\frac{-d^2}{2s^2}}$

Graphically, the Gaussian function remains increasing and has no discontinuities or corners (which makes it differentiable). The parameter s determines the inflection point of the distribution.

In the following cell of code, we create a method called get_gaussian_value, which takes in two parameters, and returns the appropriate Gaussian value.

```
def get_gaussian_value(deviation, s_param):
# By definition, if deviation <=0, then the preference value will be 0
# because the second alternative is clearly better
if (deviation <= 0):
```

```
        return 0
    else:
        # computes the gaussian value using the exponential equation from abov
        exponent = - ((math.pow(deviation, 2))/(2*math.pow(s_param, 2)))
        return (1 - math.exp(exponent))
```

Note for Ishaan: Perhaps revisit the next few paragraphs if you decide to switch from adjaceny list to dictionary

Next, we define the tuple $\{g_j(.), P_j(a, b)\}$ to be the "generalized criterion" associated to criterion $g_j(.)$

Suppose we have a alternatives and c criteria. Then this would mean that each of the c criteria would have $\binom{a}{2}$ preference values associated with it for the "generalized criterion". This is because $P_j(a, b)$ is the preference value between ANY two alternatives a, b.

In the following cell of code, we create these generalized criteria in the form of an adjaceny list. Calling the following method get_adj_list will return a list of lists.

The specific generalized criterion of $\{g_j(.), P_j(a, b)\}$ is located in the adjacency list at:

```
adj_list[j][num_alternatives*a + b]
```

```
    # considers cardinal values and ordinal values
def get_adj_list_v2():
    adj_list = []
    for i in range (num_criteria):
        preferences = []
        # for each criterion, loop through every pair of alternatives
        if i in ord_cols:
            for j in range(num_alternatives):
                for k in range(num_alternatives):
                    preferences.append(round(get_gaussian_value(get_deviation
        else:
            for j in range(num_alternatives):
                for k in range(num_alternatives):
                    # appen the preference value to a sub-list by getting the
                    # the preference value is rounded to 3 decimal places
                    preferences.append(round(get_gaussian_value(get_deviation
            #append the sublist to the larger adjaceny list
        adj_list.append(preferences)
    return adj_list
```

While the adjacency list is quite helpful to obtain the preference value for specific alternatives for a specific criterion, it is equally important to create an aggregate preference index.

We define $\pi(a, b)$ to be an "Aggregate Preference Index" which specifies with which degrees alternative a is preferred to alternative b.

Mathematically, the Aggregate Preference Index is defined as:

$\pi(a, b) = \sum_{j=1}^{k} P_j(a, b) \cdot w_j$ where k is the number of criteria.

Since $0 \leq P_j(a, b) \leq 1$ and $0 \leq w_j \leq 1$, this implies that $0 \leq \pi(a, b) \leq 1$

A value of $\pi(a, b)$ close to 0 indicates that there is a weak global preference of alternative a over b.

A value of $\pi(a, b)$ close to 1 indicates that there is a strong global preference of alternative a over b.

The code below runs through all pairs of alternatives and compares the Aggregate Preference Index between them. The method returns a list of size *num _alternatives*^{2}. To obtain the value of $\pi(a, b)$, we dereference the list in the following way:

```
list[num_alternatives*a + b]
```

The method takes two parameters. First is the adjacency list from the code above, and second is the list of weights. Originally when we read the weights from the csv file in the pre-processing stage, the data was stored in a pandas dataframe. For this method to work, the weights dataframe should be converted into an array. This can be done using the function .to_numpy()

```
def get_pi(adj_list, weights):
    pi_sum_list = []
    # loop through every pair of alternatives
    for a in range(num_alternatives):
        for b in range(num_alternatives):
            pi_sum = 0
            # next, obtain the aggregate preference index
            for j in range(num_criteria):
                # Pj(a,b) * wj
                temp_sum = adj_list[j][20*a + b] * weights[j]
                pi_sum += temp_sum
            # append this aggregate index to a list (rounded to 3 decimal plac
            pi_sum_list.append(round(pi_sum, 3))
    return pi_sum_list
```

Finally, we reach the outranking section of PROMETHEE. To do this, we compute "Outranking Flows". First, let's introduce some terms and their definitions.

The Positive Outranking Flow, denoted $\phi^+(a)$, for alternative a expresses the outranking power of alternative a. A better alternative will have a higher value for ϕ^+.

The Negative Outranking Flow, denoted $\phi^{-}(a)$, for alternative a expresses how that alternative is outranked by all other alternatives. While ϕ^{+} shows an alternative's power, ϕ^{-} indicates the alternative's weakness. A better alternative will have a lower value for ϕ^{-}.

We will next define these terms mathematically. Suppose A is the set of all alternatives and n is the amount of alternatives (this means that $|A| = n$). Then the Positive Outranking Flow and Negative Outranking Flow are defined as follows:

$\phi^{+}(a) = \frac{1}{n-1}\sum_{x\in A}\pi(a,x)$

$\phi^{-}(a) = \frac{1}{n-1}\sum_{x\in A}\pi(x,a)$

Below, we define four methods: get_pos_flow, get_neg_flow, get_all_pos_flow, and get_all_neg_flow. The first two methods are helper methods for the last two methods.

get_pos_flow and get_neg_flow both take in two parameters. The first parameter is the aggregate list of all values of $\pi(a,b)$ that was previously computed. The second parameter is an integer value indicating which alternative to analyze. get_pos_flow returns a float value which is equivalent to $\phi^{+}(a)$, and similarly, get_neg_flow returns a float equivalent to $\phi^{-}(a)$.

The methods get_all_pos_flow and get_all_neg_flow compute the outranking flow for all alternatives and compile them into one list. These methods return said list. For example, for get_all_pos_flow, list[i] would return $\phi^{+}(i)$ and for get_all_neg_flow, list[i] would return $\phi^{-}(i)$

```
def get_pos_flow(list_pi, a):
    flow_sum = 0
    for x in range(num_alternatives):
        # flow_sum(a) = sum(pi(a, x))
        flow_sum += list_pi[num_alternatives*a + x]
    # phi_pos(a) = 1/(n-1) * flow_sum(a)
    return (1/(num_alternatives - 1))*(flow_sum)



def get_neg_flow(list_pi, a):
    neg_flow_sum = 0
    for x in range(num_alternatives):
        # neg_flow_sum(a) = sum(pi(x, ))
        neg_flow_sum += list_pi[num_alternatives*x + a]
    # phi_neg(a) = 1/(n-1) * neg_flow_sum(a)
    return (1/(num_alternatives -1))*(neg_flow_sum)


def get_all_pos_flows(pl):
    all_pos_flows = []
    for a in range(num_alternatives):
        # loops through all alternatives and appends their pos_flow to a list
```

```
        all_pos_flows.append(get_pos_flow(pl, a))
    return all_pos_flows

def get_all_neg_flows(pl):
    all_neg_flows = []
    for a in range(num_alternatives):
        # loops through all alternatives and appends their neg_flow to a list
        all_neg_flows.append(get_neg_flow(pl, a))
    return all_neg_flows
```

While PROMETHEE I relies solely on the positive and negative outranking flows for all alternatives, PROMETHEE II requires a last calculation which computes the net outranking flow (ϕ_{net}) for all alternatives.

$\phi_{net}(a) = \phi^{+}(a) - \phi^{-}(a)$

The method get_net_flow defined below computes the net outranking flows for all alternatives and compiles them into a list where list[i] returns $\phi_{net}(i)$

```
# PROMETHEE II Complete Ranking
def get_net_flow(pl):
    pos_flows = get_all_pos_flows(pl)
    neg_flows = get_all_neg_flows(pl)
    net_flows = []
    for a in range(num_alternatives):
        #net flow(a) = pos_flow(a) - neg_flow(a)
        # append net flow for each alternative to a list
        net_flows.append(pos_flows[a] - neg_flows[a])
    return net_flows
```

Up to this point, we have computed all PROMETHEE calculations from scratch. Now, we will spend some time exploring the pymcdm library. This library does very similar calculations to what we have done thus far. However, the PROMETHEE method in pymcdm only has five different preference functions, these being 'usual', 'vshape', 'ushape', 'level', and 'vshape_2'. So while using pymcdm saves a lot of code, it limits creativity due to the very few preference functions. With the code written thus far, we can define other preference functions (not just gaussian), and make minimal adjustments such that the PROMETHEE calculations will still work for customized preference functions.

```
preference_functions = ['usual', 'vshape', 'ushape', 'level', 'vshape_2']
promethee_methods = {
    f'{pref}' : mcdm_methods.PROMETHEE_II(preference_function = pref)
```

```
    for pref in preference_functions
}
```

PROMETHEE from pymcdm also requires a new parameter that we have not yet explored. The new parameter is a "types" array. The size of this array is equivalent to the amount of criteria. Within this array, the value "1" indicates that a higher score for the criteria is better, whereas a value of "-1" indicates that a lower score is better for the criteria.

```
types = np.array([1, 1, 1, 1, 1, 1, 1, 1, 1, 1])
acsdf_np = acsdf2.to_numpy()
acsdf_np_f = acsdf_np.astype(float)
weights_np = weights.to_numpy()[0]
p = np.random.rand(acsdf.shape[1]) / 2
q = np.random.rand(acsdf.shape[1]) / 2 + 0.5

results = {}
for name, function in promethee_methods.items():
    results[name] = function(acsdf_np_f, weights_np, types, p=p, q=q)
```

Lastly, we do some data visualization. Below are some methods to visualize PROMETHEE I and II data.

```
# graphs the data from PROMETHEE 1. A coordinate closer to the top right is co
def specialized_visual(pos_outflows, neg_outflows, x_low_lim, x_lim, y_low_lin
    plt.figure(1)
    fig, ax = plt.subplots()
    ax.set_xlim(x_low_lim, x_lim)
    ax.set_ylim(y_low_lim, y_lim)
    for i in np.arange(x_low_lim, x_lim+0.01, 0.1):
        ax.plot([0, 0.01], [i,i], 'k')
    for i in np.arange(y_low_lim, y_lim+0.01, 0.1):
        ax.plot([i,i], [0, 0.01], 'k')
    x_coor = [0,x_lim]
    y_coor = [0,y_lim]
    plt.plot(x_coor, y_coor, linewidth = 3)

    ax.text(-0.08, y_low_lim + 0.2, 'Phi-', fontsize='large')
    ax.text(0.2,y_low_lim-0.08, 'Phi+', fontsize='large')
    ax.axis('on')
```

```
for i in range(len(pos_outflows)):
    phi_pos = pos_outflows[i]
    phi_neg = neg_outflows[i]
    plt.scatter(phi_pos, 1-phi_neg, label = f'A{i}')
    ax.text(phi_pos, 1-phi_neg+0.01, f'A{i}')
    start_coors = [phi_pos, phi_pos]
    end_coors = [0, phi_neg]
    #plt.plot(start_coors, end_coors, linewidth = 1, linestyle = '--', co
    start_coors = [0, phi_pos]
    end_coors = [phi_neg, phi_neg]
    #plt.plot(start_coors, end_coors, linewidth = 1, linestyle = '--', co
plt.legend()
```

For visualization, we have to define two arrays for parameters p and q. The meaning of these parameters is the same as before, but now we are defining the parameter values for each criterion.

```
q_vals = [3, 3, 3, 3, 3, 3, 3, 3, 3, 3]
p_vals = [5, 5, 5, 5, 5, 5, 5, 5, 5, 5]
```

An example of using the visual is seen here:

```
prom_usual = mcdm_methods.PROMETHEE_II('usual')
Fp_usual, Fm_usual = prom_usual(acsdf_np_f, weights_np, types, p = p_vals, q =
specialized_visual(Fp_usual, Fm_usual, 0.1, 0.8, 0.1, 0.8)
plt.title('usual')
```

Similarly, we can graph the net flows into a nice visual by utilizing the barplot feature of the python library "seaborn". Below is an example implementation:

```
plt.figure(1)
plt.title('usual')
prom_usual = mcdm_methods.PROMETHEE_II('usual')
Fp_usual, Fm_usual = prom_usual(acsdf_np_f, weights_np, types, p = p_vals,
Fi_usual = prom_usual(acsdf_np_f, weights_np, types, p=p_vals, q=q_vals)
#barplot_x is essentially an array = [0, 1, 2, ..., (num_alternatives - 1
sns.barplot(x = barplot_x, y = Fi_usual)
```

26.3 Links

1. PYMCDM [27]

Chapter 27 Group Facilitation Exercises

By: Jennifer Beer

2021-08-15

These are instructions for organizing and conduction group discussions on policy choices, with a facilitator present and guiding.

- Priority Discussions: Facilitation guidelines
- Group size: 1-25 people (1 facilitator) or up to about 50 (2+ facilitators)
- Group type: people who know each other somewhat and/or share belonging to one community, one organization:
- Purpose: To collectively consider (a pre-meeting determined) range of GHG reduction strategies and begin sorting out priorities – whether for activism, for programmatic decisions, for advising.
- Method: Combining the power of data analysis to rank alternatives and compare them combining both "hard" data about costs and outcomes, as well as the "soft" judgments of participants.
- Rationale: The number of possible actions, the large amount of data to consider, and the uncertainty of much of that information make AI-assisted decision making invaluable. However, human judgments and motivations and assumptions must be part of any real-world action.

27.1 Structure / Time-frame

27.1.1 Step one—Choosing the group, the facilitators, building buy in

Address: Who decides who will participate? Who decides the parameters of the time and focus?

Articulate the method and goal of having a facilitated process. Help the group choose the focus of conversation/decision-making. Determine what will help the participants actively WANT to participate. Participants need both clarity of purpose and motivation to sustain their attention, as they will be dealing with complex options and subjects and potentially stressful decisions.

Choose facilitators – find out whether the group is okay with external facilitators. You may get more buy-in by either having 2-3 people advising you, and/or by inviting one or two of the group to help you facilitate. Groups may expect facilitators to be subject experts as well, which is not optimal but may be necessary to get senior participants to attend or to trust the outcomes.

27.1.2 Step two—Education about the alternatives on the table

(Depends on the group, education may be part of buy-in as well). Optimally this happens well before priorities discussions are held. If it is all happening on one day, separate the preliminary education segment from the discussion segment, preferably with a mind-clearing hour+ break between them.

Presently, 2021-08-15, we have 11 policy/program alternative categories written up in a usable fashion. They reside in chapters 7–17 and may be shared. The current plan is to supplement each of them with a 1 (at most 2) page summary. Very likely it is these summaries that should first be shared with participants.

Remember that people's brains have very very limited capacity to absorb a lot of new information and to keep it all in mind when comparing and discussing. Highlight the KEY baseline info they need for useful participation, and put detailed explanations and data in a separate location. Use visuals.

Avoid using presentation format – either online or in person, if (as we are presuming) there are more than 3 alternatives/programs under consideration.

One potential format for in-person education could be setting up a "gallery walk" with examples/explanations, and possibly a knowledgeable person to answer questions set up in different corners of a large room or hallway. People either walk around freely, or are asked to spend X minutes in one location of their choice, and move to another one when the facilitator calls time, which saves the knowledgeable persons from having to endlessly repeat the same information. Another option is to have a place where people can put comments and questions that other visitors can read and add to. The gallery walk can of course be duplicated online through web pages or breakout rooms, the latter being more interactive and allowing people to ask questions.

If you will be using any ACS tables or interactive software for alternative comparisons, give participants time to play with the app so that they are comfortable with it.

27.1.3 Step three: Finalize the participant input you want

Such as surveys, rankings for your ACS tables, any interactive data gathering, etc. before, during, and after the facilitation. Conduct a test run.

27.1.4 Step four: Preparing for facilitation

Facilitators during previous steps take note of the expertise, opinions, feelings, assumptions, interest-level, awareness level, agency etc. of the participants. Identify what topics are likely to generate the most conversation, enthusiasm, disagreement. Pare alternatives down to the most realistic and/or popular ideas. (Leaving room for some to get added back in later, if the group wants to.)

27.1.5 Step five: Facilitated discussion

1. Introductions:

   Plan a way for people to know who is present that takes no more than 20 minutes. This will differ depending on how well the group knows each other and how many people are present. Giving people a participant list that has a brief note about why each person is a participant can save time. Time saver: have people stand or raise hands in clusters (Who here is knowledgeable about water management? Who lives on the north side of the highway? Who is a member of . . . etc).

   In person: Have people turn to their neighbor and mention what brings them to this work (reducing GHG or whatever the group's purpose is) or to the session today. [facilitator goal here is to remind people of their personal, emotional commitment to being here.]

   Online: Invite people to put one sentence into the chat or on a common posted document answering the above question.

2. Framing:

   Purpose: Explain the purpose of the facilitation and check carefully that people understand it and buy into it and don't have way-out expectations. Don't forget the big picture – Why does reducing GHG matter? What role can they play?

   Agenda: Outline your agenda and timeframe, the input that has gone into structuring the session.

   Participation: Explain that this session focuses on deeply listening to the varying perspectives in the group. We are dealing with a complex topic and there are many POV and pieces to the puzzle. Explain how you will help people participate fully. What are you asking of the participants in terms of making this session worth their time? How will you ensure all voices are heard? In what ways will extra weight be given to the "expert" people present? Who makes the decisions? Mention that you expect people to experiment with considering different alternatives, and expect people to leave thinking a little differently than when they came in. Which means that we allow each other to be contradictory, to change our minds, to explore.

   Product: Be clear about what will happen with their conclusions at the end of the facilitation process – is this just a stimulating discussion to get the group thinking and motivated? What decisions will the group be making? Are external decision-makers expecting the group's conclusions to be advisory? etc. If participants are going to work seriously on the task at hand, you don't want them to feel that their work and conclusions are disregarded.

3. Ranking, round one. Review the alternatives and criteria. Ask for their **informational** questions (not their opinions) and put those up on a whiteboard rapidly (or have them enter those questions simultaneously on a shared that is also on the screen). Single out the ones that really need an answer before people can do a first round of ranking.

   Give them specific steps for ranking the alternatives and criteria and entering that data.

Do not show the results until everyone has entered their data.

4. Small groups. Divide into random groups of 3-4 to discuss what they notice in the combined results. Have them post 3 observations or questions arising from what they observed.
5. BREAK while facilitators group and select the replies. Sort out those that are needs for plain data, and those that seem to be most salient for discussion. Optional – invite participants to checkmark the posted observations they think are most important or they most want to discuss.
6. Facilitators invite knowledgeable participants to answer data questions that can be briefly explained.
7. Facilitators propose 3-5 topics raised. Does the group agree that they want to talk about these in more depth? Adjust as needed.
8. Delving into topics – two sessions of 10-15 minutes each. Assign each topic to a breakout room or an area of the room. Invite people to go to a discussion that interests them (either because they want to share their knowledge and opinions or because they want to learn more). If a topic draws more than 12 people, break them into two groups, or ask some to go to their second choice. The discussion group can note their key comments on a whiteboard or flipchart. The next group that arrives will then look at what's been covered and go from there.

   Facilitator sends a signal for people to change to another discussion. That new group adds to the whiteboard/flipchart page.
9. LONG BREAK (longer than usual) Invite people to look through the posted comments from the other discussion groups during the break. Encourage people during the break to chat with other participants. You can also invite people to add to the "useful to have further information" board you started earlier.
10. Ranking, round two. Post break, facilitators ask everyone to fill out the ranking survey again.
11. Break out groups – either random, or in affiliated clusters. What has changed, what has not? What potential priorities are emerging?
12. Whole group – review answers to the priorities question and the implications. With a large group, note down what people say but discourage interactive discussions about particular points.
13. Round Three: Then invite people to adjust their scoring one more time. Post the aggregate response but don't discuss it this time.
14. Then ask what the group would like to do with these conclusions – more discussion? investigate details of certain possibilities? Advocate? Invite experts to inform the group? If you have a larger group, to get everyone's opinion have them post it simultaneously. Are structures in place to oversee these next steps?

15. Conclude with appreciations and maybe an upbeat story of how a similar priority choice in another community led to positive action. In a group of 12 or fewer, you can go around the circle and ask for "one thing about today's discussion that energizes you."

27.1.6 Extras

Depending on length of time and type of group: After Round Two small group reviews, give people a chance in pairs (with someone they know?) to talk about their personal and/or emotional response to the alternatives and to the information that has come out during the session. Final conversation possibilities: Where would you like the group to move towards commitment? Where are you personally led to spend your time/effort?

Chapter 28 Deliberation Exercises: Decision Analysis

These exercises explore deliberation and decision making for choosing among a collection of sustainability transition programs that could be implemented at the sub-national level, for example by municipalities, counties, or even sizable academic institutions. Our perspective here is broadly that of decision analysis, which offers a variety of quantitative techniques in support of deliberation and decision making. We explore more qualitative techniques in other exercises.

The deliberation process we explore begins with an ACS table, as in Figure 28.1. ACS = program alternatives, evaluation criteria and scores (of the program alternatives on the individual criteria). In the Reference ACS table of Figure 28.1, the program alternatives are presented in rows 3 through 24, with their labels (abbreviated names) given in column A. Figure 28.2 briefly describes the programs and shows their labels. Further detail about the programs may be found by following the links in the figure and below in §28.7. We call the program or policy alternatives in Figure 28.2 our baseline policy alternatives.

	A	B	C	D	E	F	G
1							
2	**Program**	**BCO**	**SCO**	**GHG**	**CoB**	**DiB**	**TRA**
3	LECC1	6	3	5	3	1	6
4	LECC2	1	6	6	5	4	6
5	CSCom1	7	3	3	5	3	6
6	GEO1	7	3	4	5	1	5
7	EBuild1	1	7	7	3	5	7
8	ELawn1	3	3	4	5	2	6
9	ELawn2	1	5	5	6	2	6
10	EBus1	2	3	2	3	2	4
11	EBus2	2	3	6	7	4	6
12	EBus3	2	3	2	3	2	4
13	EBus4	3	3	6	7	4	6
14	FoodR1	5	3	2	6	2	5
15	EVChrg1	1	6	6	6	4	7
16	EVChrg2	3	3	4	4	1	6
17	EVChrg3	3	1	5	5	2	6
18	NMThru1	7	2	2	6	5	4
19	CSNG1	1	3	3	2	2	3
20	CSNG2	2	3	4	3	2	3
21	CSNG3	3	3	5	4	2	3
22	GreElec1	3	3	5	4	2	5
23	GreElec2	4	3	6	5	2	6
24	GreElec3	5	3	7	6	2	7
25							
26	Direction of	-1	-1	1	1	-1	1
27	Attribute (1 indicates that higher number is positive, -1 indicates that higher number implies negativ						
28	Raw Factor	25	15	15	15	15	15
29	Weights:						

Figure 28.1: Reference ACS table. Original file, ExtendedACSTable.xlsx, at https://www.dropbox.com/sh/05x02cn5lrvpkyf/AAAaJROZhjmhressHC2uoM_pa?dl=0

1. LECC. Low embodied carbon concrete. (See chapter 7.)
2. CSCom. Curb-side composting. (See chapter 8.
3. GEO. Green extension office. (See chapter 9.)
4. EBuild. Building electrification. (See chapter 10.)
5. ELawn. Electrification of lawn care equipment. (See chapter 11.)
6. EBus. Electrification of transit buses and utility vehicles. (See chapter 12.)
7. FoodR. Food rescue. (See chapter 13.)
8. EVChrg. EV charging stations. (See chapter 14.)
9. NMThru. Non-motorized (pedestrian and bicycle) thoroughfares. (See chapter 15.)
10. CSNG. Clean-sourced natural gas. (See chapter 16.)
11. GreElec. Green electricity. (See chapter 17.)

Figure 28.2: Baseline policy alternatives and their labels. Following numbers signify distinct versions of alternatives, thus LECC1 and LECC2 are two distinct versions of LECC. See §28.7 for further details.

In the Reference ACS table of Figure 28.1, the evaluation criteria labels are presented in row 2, columns B:G. These are our baseline evaluation criteria. They are summarized in Figure 28.3, which also presents their labels. Each is scored on a 1-to-7 scale for the purpose of this exercise. The *preferential* direction or sense of a scale can either be increasing, signified with a 1, or decreasing, signified with a -1. Thus, for example, a cost such as BCO and SCO will range from 1 (lowest) to 7 (highest) but its sense is -1 because lower costs are preferred to higher costs.

Finally, the scores of the ACS table, see Figure 28.1, are for (program, criterion) pairs. For example, in the table of Figure 28.1 the LECC1 program is scored a 6 on BCO (the budget cost criterion) and a 5 on GHG (greenhouse gas emissions reduction). In comparison, the FoodR (food rescue) program is scored a 6 on CoB and a 2 on GHG. In the ACS table every (program, criterion) combination is given a score. There are $11 \times 6 = 66$ scores in all in our Reference ACS table, shown in Figure 28.1. For the purposes of our exercise, we assume that the scores have been compiled by relevant experts. Although the scores should be understood as merely approximate and are always revisable in practice, you should assume they have been competently derived.

28.1 Task 1: Criteria weights

We will be using software that implements a version of a decision analysis method, called PROMETHEE. It is useful for making decision recommendations and helping the user to explore possible choices, recommended or not. In particular, once we have sufficient information we will use the PROMETHEE method to give scores for each of the programs/policies under consideration (shown in the ACS table, Figure 28.1).

Most of the information we need is contained in the ACS table. Two additional items are needed from you. We cover these in this and the next section.

The first information we need is importance weights for the several criteria. In our case there are six criteria, described in Figure 28.3. The task at hand is for you to arrive at weights that reflect your preferences and judgments. Here is how it works. There are 6 criteria. We need, for using PROMETHEE, to associate a weight for each criterion that ranges between 0 and 1, such that they sum to 1. To make this task easier for you we ask you to proceed in any of the following ways, whatever is comfortable for you.

- Method 1: Directly allocate 100 points.

  Assume that you have 100 points to allocate among the (six) criteria. If you think each is equally important, then you would give the same weight to each criterion, 100/6 = 16.67 (don't worry, we'll handle the rounding errors).

  In Figure 28.1, line 28 holds someone's weights, which we call the *Raw Factor Weights*. The weights given allocate 25 of 100 points to BCO (budget cost) and 15 to each of the remaining five criteria.

- Method 2: Allocate points and await normalization.

  In this method, you give points to each criterion without regard to the total number of points. Focus on your judgement of the ensemble, so that you are comfortable with the comparative point values taking all six criteria together.

  Our PROMETHEE code will accept your values and perform the necessary normalization for use in the program.

- Method 3: Rank order and then assign values relatively.

  1. Rank order the criteria in order of importance as you judge it to be. If, for example, you think budget cost is the most important criterion for comparing the several programs, then put it first. Once you have identified what you think is the most important criterion, examine the remain criteria and identify the most important of them. Put it as next in importance. Continue in this way until you are satisfied with the ranking.
  2. Assign a value 10 to your *least* important criterion. Having done that, consider the next least important criterion and give it a value, which should be greater than 10 of course. This value should capture how much more important the criterion is than

BCO Budget expense (cost) to the local government or other organization net of outside grants and program funding such as federal programs.
Note that alternatives might save money so that a 1 may indicate a negative cost.
1 (lowest) to 7 (highest) cost. Sense: -1.

SCO Social expense (cost) to the pertinent body of stakeholders.
This criterion is used to represent the amount of "heavy lifting" politically that would be necessary to implement the associated program alternative. Think of the scale as phrase anchored, with 1 = uncontroversial or even generally welcomed and 7 = extremely controversial and likely to engender active resistance.
1 (lowest) to 7 (highest) cost. Sense: -1.

GHG Greenhouse gas emission reduction, also called climate mitigation. Think of the scale as phrase anchored, with 1 = negligible GHG emissions reduction and 7 = very high and cost effective GHG emissions reduction.
1 (lowest) to 7 (highest) cost. Sense: 1.

CoB Co-benefits, positive consequences other than cost savings and GHG emissions. Example: a program that creates or improves a recreational area as a side-effect.
Included here are health and safety effects.
Note: This criterion is especially difficult. Not only are data generally lacking at the local level, even when health effects are known, for example, their magnitudes are fairly small. Nothing under consideration is likely to have a positive effect on anything like that of ceasing to smoke. So, **consider that the scale here is a relative one, comparing the alternatives under consideration. The weakest alternative gets a 1, the strongest a 7.** Also, what counts as a co-benefit can be expansive, for example, reduction in noise pollution.
1 (lowest) to 7 (highest) cost. Sense: 1.

DiB Disbenefits, negative consequences other than cost and GHG emissions. Example: a program that destroys or degrades a recreational area as a side-effect.
Again, **consider that the scale here is a relative one, comparing the alternatives under consideration. The worst alternative on the scale gets a 7, the bst a 1.**
1 (lowest) to 7 (highest) cost. Sense: -1.

TRA Transition effects. Are we moving in the right direction? Does it favor something that has to be done eventually? Does it help with adaptation or resilience?
consider that the scale here is a relative one, comparing the alternatives under consideration. The weakest alternative gets a 1, the strongest a 7.
1 (lowest) to 7 (highest) cost. Sense: 1.

Figure 28.3: Baseline evaluation criteria and their labels.

its comparison criterion. Continue in this way until each criterion has been given a value and you are satisfied with the assignments.

3. Record your final criteria values in the "Raw Factor Weights" section of the spreadsheet containing the ACS table (see Figure 28.1). The software will normalize your given values to a proper 0–1 range.

Having thus identified *your* (unnormalized) importance weights, consider what you think the importance weights will be if others give them. Identify one or more reference groups of stakeholders and record what you think their values would be.

28.2 Task 2: Minimum significant differences

We have in our reference ACS six decision criteria for evaluating the several alternatives under consideration. These criteria are described in Figure 28.3 and are each scaled to a 1–7 range. In the PROMETHEE calculations each criterion score is weighted by its criterion weights, which we discussed in Task 1. Thus, for example a 5 score on a criterion with weight of 0.12 would receive a weighted score of $5 \times 0.12 = 0.6$.

1. Identify what is for you the size of a minimum significant difference in these weighted criteria scores. For example, if in comparing two alternatives on a single criterion, one has a weighted criterion score of 0.625 and another has a score of 0.629 you <u>might</u> judge that for practical purposes there is no real difference in these scores. If so, then your minimum significant difference value is no larger than $0.629 - 0.625 = 0.004$ and it may be smaller. Think about it, record what you decide, and record why you got to that conclusion.
2. As in the previous task, identify one or more reference groups of stakeholders and record what you think their values would be. Discuss why you got to the conclusion you did.

28.3 Post-solution analysis

Forthcoming. Here we use the PROMETHEE software to explore how definitely or not the overall scores distinguish the various alternatives, and whether all things considered you would like to change your decision.

28.4 Group Decision and Voting

Forthcoming. Now we consider decision context II. Individuals in a group each do their context I exercise (above), then openly discuss and vote on alternatives. The exercises explore difference voting methods, including plurality, range voting (sok's favorite), ranked choice voting, and approval voting.

28.5 Context III: Individual portfolio choice

Forthcoming. We consider all 220 3 element portfolios of the 11 alternative programs.

28.6 Context IV: Group portfolio choice

Forthcoming. We consider all 220 3 element portfolios of the 11 alternative programs. We add group voting and discussion, and bargaining.

28.7 Appendix A: Program guide for ACS table

28.7.1 Low Embodied Carbon Concrete (LECC)

- Policy 1 (LECC1): Purchasing low-embodied-carbon concrete for government contracts
  - Overview: For contracts related to municipal government contracts, require that all concrete used is low-embodied-carbon concrete.
  - Cost: Low-embodied-carbon concrete only adds about 1% to total project costs. The local government can set a maximum budget that it can spend on premiums for projects involving low-embodied carbon concrete. A reasonable maximum would be $50,000 annually, which would cover project costs of $5 million annually.
- Policy 2 (LECC2): Mandate low-embodied-carbon concrete
  - Overview: For all projects in the municipality, require that concrete used is low-embodied-carbon concrete.
  - Cost: Low BCO, but non-trivial social cost for developers and property owners. Expect 1% premium to total project costs.

28.7.2 Curb-side Composting (CSCom)

- Policy 1 (CSCom1): Pilot program offering municipal curb-side composting for 1000 residents
  - Overview: A pilot program where the municipal government hires a contractor to carry-out curb-side composting for about 1000 residents.
  - Cost: At about $5 per resident each month, we can expect a total cost of $5,000 per month and $60,000 annually. This cost doesn't account for the cost savings incurred in other waste management services.

28.7.3 Green Extension Office (GEO)

- Policy 1 (CSNG1): Small Green Extension Office staffed with two people

  - Cost: \$60,000 salary per year per person with employee benefits of around \$7000. If a rent-free office is available in a government building or an academic institution, estimate office and travel expenses to be around \$20,000. Total cost estimate is \$147,000 per year.

28.7.4 Building electrification and subventions (EBuild)

- Policy 1 (EBuild1): Mandating fully electrified buildings for new constructions
  - Overview: Mandate the installation of heat pumps, heat pump water heaters, and induction cooktop ranges for new constructions.
  - Cost: Low BCO, but significant social costs incurred by developers and property owners. The total cost of installing a heat pump, heat pump water heater, and induction cooktop range is about \$6200 for warm climates, \$8000 for moderate climates, and about \$12,000 for cold climates. There are small energy cost savings in moderate and warm climates relative to gas, but for cold climates the energy costs for electrified buildings are expected to be higher.

28.7.5 Electrifying lawn care equipment (ELawn)

- Policy 1 (ELawn1): Electrifying lawn care equipment for municipal operations
  - Overview: Replace all lawn care equipment operated by the municipal government to electric-battery powered equipment and mandate contractors with the municipal government to operate electric-battery powered lawn care equipment.
  - Cost: Electric versions of lawn care equipment cost about \$200 more than gas-powered counterparts. However, fuel costs and maintenance costs are cheaper for electric equipment, leading this report to estimate a 35% saving in lifetime costs for electric lawn care equipment. There is no data available on the average number of lawn care equipment local governments operate. If we assume that each municipal government operates on average 30 devices, the upfront cost that needs to be covered to replace these would be around \$60,000.
- Policy 2 (ELawn2): Restriction on new purchases of gas-powered leaf blowers and lawn mowers
  - Overview: After a 1-year grace period, mandate all new purchases on lawn-care equipment to be electric-battery powered.
  - Cost: Low BCO, but a non-trivial upfront social cost. As estimated above, expect about a \$200 per unit premium for electric battery powered devices. However, the upfront costs can be recovered through life-time savings in fuel and maintenance costs.

28.7.6 Electrification of transit bus and utility vehicles (EBus)

Transit bus electrification

- Policy 1 (EBus1): Trial run of transit bus electrification with 4 buses
  - Overview: As a trial run to test for feasibility, local transit agencies can decide to replace 4 of their diesel buses with electric battery-powered buses. They can decide to expand the electrification program after monitoring the operation of the 4 EV buses. They should also make sure to request for the FTA's Low or No Emission Vehicle Program - 5339(C).
  - Costs: Over 12 years, expect a positive NPV of $785,000 with federal grants or a negative NPV of $715,000 without grants, according to an extensive 2020 NREL financial analysis on replacing 4 diesel transit buses with electric buses. The grant amount is $375,000 per bus based on the median 2018 FTA Low or No Emissions Bus Grants. The first year negative cash flow with the grants is $322,000.
- Policy 2 (EBus2): Full electrification of transit buses
  - Overview: The local transit agency can decide to replace all of its diesel transit buses with EV battery buses over the next 3 years. The local transit agency should make sure to request for the FTA's Low or No Emission Vehicle Program - 5339(C).
  - Costs: According to a 2018 US Department of Transportation report, there were 64,398 public transit buses across 2350 local transit agencies in 2017. On average, each local transit agency operated 27 transit buses. Using the values from the 2020 NREL study, full electrification of the transit buses operated by the average local transit agency would result in a positive NPV of $5.3 million over 12 years with the FTA grant. The first year negative cash flow with the grant would be $2.2 million.

Local police patrol car electrification

- Policy 3 (EBus3): Trial run of electrifying 6 local police patrol cars.
  - Overview: The local police department can initiate a pilot program where 6 fossil-fuel police patrol cars are replaced with electric battery-powered vehicles to test for feasibility. It can decide to expand the electrification program after monitoring the operation of the 6 EV patrol cars.
  - Costs: Local police departments in the US commonly use Dodge Chargers and Ford Explorers as patrol vehicles. US-manufactured EV equivalents would be the Chevrolet Bolt and the Chevrolet Bolt EUV, respectively. The price premium for these electric vehicles are around $1000 to $1800. With Level 1 Chargers offered for free for each vehicle, if we assume that we install a Level 2 Charger for every 2 vehicles, we would incur a cost of about $4300 including installation costs for every 2 EV patrol cars. Including Level 2 charger costs, the net costs for electrifying a single police patrol car would be around $3150 to $3950. At 6 police patrol cars, the total net costs would amount to around $18,900 to $23,700. This estimate, however,

does not account for the lifetime cost savings in maintenance and fuel.

- Policy 4 (EBus 4): Full electrification of local police patrol cars.
  - Overview: The local police department can replace all fossil-fuel police patrol cars with electric battery-powered vehicles.
  - Costs: Using the statistics provided by a BJS 2003 report, it can be estimated that on average there are 19 patrol cars per local police department. Using the unit net costs from above, full electrification would incur a cost on average of $59,850 to $75,050. This estimate, however, does not account for the lifetime cost savings in maintenance and fuel.

28.7.7 Food Rescue Program (FoodR)

- Policy 1 (FoodR1): Implement a food rescue pilot program
  - Implement a pilot program for a food rescue program.
  - Cost: About $12,000 per year if operated mostly by volunteers, and about $40,000 a year if mostly paid part-time workers are involved.

28.7.8 EV Charging Infrastructure Policies (EVChrg)

- Policy 1 (EVChrg1): EVSE building code for new construction.
  - Overview:
    - Single-family residential units: 1 EV-ready parking spot per unit
    - Multi-family residential units: 20% EV-charging installed or EV-ready, 80% EV-capable
    - Commercial buildings: 15% are EV-charging installed or EV-ready, 10% EV-capable
  - Costs: Negligible budget costs for municipalities, but non-trivial social costs incurred from new constructions due to wiring and panel installations in addition to the Level 2 charger unit costs. Level 2 charger unit and installation costs total around $1100 for residential chargers and $4300 for commercial chargers.
- Policy 2 (EVChrg2): Pilot program of installing EV chargers on municipal government property
  - Overview: Install 20 Level 2 chargers on local government property with high-traffic.
  - Cost: At $4300 per unit including installation costs, this pilot program costs around $86,000. Costs can be reduced further if federal and state EVSE incentives are taken advantage of.
- Policy 3 (EVChrg3): Pilot program to provide municipal incentives for Level 2 charger installations
  - Overview: Provide incentives equalling 10% of the unit costs for 200 Level 2 chargers in high traffic areas.

- Cost: With the assumption that the unit price for Level 2 commercial chargers is $3500, the incentives would be $350 per unit. The total cost to provide incentives for 200 chargers would be $70,000.

28.7.9 Expand bike and pedestrian paths (NMThru)

- Policy 1 (NMThru1): Install a 20 mile bike path
  - Cost: DOT estimates that bike paths can cost about $5000 to $50,000 per mile to install depending on different conditions. If we assume a cost of $20,000 per mile, the cost for a 20 mile bike path would be around $400,000.

28.7.10 Certified Natural Gas (CSNG)

- Policy 1 (CSNG1): Spend $1000 on premiums for certified natural gas per year, which corresponds to about 6,700 mcf of natural gas per year.
  - Overview: Set aside a budget of $1000 to use on premiums for certified natural gas
  - Cost: $1,000, based on a 15 cent per mcf premium for natural gas
- Policy 2 (CSNG2): Spend $2000 on premiums for certified natural gas per year, which corresponds to about 13,000 mcf of natural gas per year.
  - Overview: Set aside a budget of $2000 to use on premiums for certified natural gas
  - Cost: $2,000, based on a 15 cent per mcf premium for natural gas
- Policy 3 (CSNG3): Spend $3000 on premiums for certified natural gas per year, which corresponds to about 20,000 mcf of natural gas per year.
  - Overview: Set aside a budget of $3000 to use on premiums for certified natural gas
  - Cost: $3,000, based on a 15 cent per mcf premium for natural gas

28.7.11 Procuring green electricity (GreElec)

- Policy 1 (GreElec1): Procure 25% of municipal government electricity consumption from green electricity
  - Overview: Set aside a budget to spend on premiums for green electricity for 25% of the municipal government's electricity consumption.
  - Cost: We can assume that the average municipal government electricity consumption is 2.125 million kWh as estimated from the EPA sample and apply the 2016 NREL average green electricity premium of $0.017kWh. The average incremental cost for procuring 25% of annual municipal electricity usage from green power products would be about $9,000 per year.
- Policy 2 (GreElec2): Procure 50% of municipal government electricity consumption from green electricity

  - Overview: Set aside a budget to spend on premiums for green electricity for 50% of the municipal government's electricity consumption.
  - Cost: Using the values above, the expected average cost is $18,000 per year.
- Policy 3 (GreElec3): Procure 75% of municipal government electricity consumption from green electricity
  - Overview: Set aside a budget to spend on premiums for green electricity for 75% of the municipal government's electricity consumption.
  - Cost: Using the values above, the expected average cost is $27,000 per year.

Chapter 29 Nominal Group Role Play Exercises

The material in the section has been hastily assembled for the purpose of filling out a concept. My intention is that after getting comment and feedback I will produce a complete and usable instruction set for the NGT exercise. And then we'll play it and get some usable data!! –sk 26/9/21 PS I estimate the exercise can be completed with a little hustling along in 2 hours, but plan for 3.

29.1 Background

The following passage is from "Gaining Consensus Among Stakeholders Through the Nominal Group Technique" [7]:

> Nominal (meaning in name only) group technique (NGT) is a structured variation of a small-group discussion to reach consensus. NGT gathers information by asking individuals to respond to questions posed by a moderator, and then asking participants to prioritize the ideas or suggestions of all group members. The process prevents the domination of the discussion by a single person, encourages all group members to participate, and results in a set of prioritized solutions or recommendations that represent the group's preferences.

NGT dates from the early 1970's and even earlier.[1] Over the years it has been used with considerable success and has received favorable evaluations when its efficacy has been studied. Today it is an established, widely-accepted method for facilitating decision making and judgment by small groups.

This chapter presents and discusses a protocol incorporating some incremental innovations in NGT. Use and evaluation of this protocol is experimental.

In its standard version, NGT is used to assess the true views and values of the participants, who are identified as knowledgeable on the matters to hand and, ideally, are also stakeholders for whom the results matter. NGT is then used to facilitate discussion among the participants to the end of arriving at consensus judgements.

In the innovation proposed here, participants are asked to imaginatively and sympathetically step into the roles of *other* stakeholders and to condition their participation with their assigned roles. For example, in considering (as we shall) an ensemble of policies for possible implementation.

[1] https://en.wikipedia.org/wiki/Nominal_group_technique

The main *reasons* for the innovation, for the proposed use of role-playing participants, are twofold. First, we hope this method may be developed and validated to the point that it can confidently be used to get an early and rapid assessment of how and why stakeholders of various kinds might comparatively value policy options. Of course, where possible and practicable, real stakeholders rather than role-playing stand-ins, should be consulted. The method proposed here is best seen as preparatory for that when it is possible, and a surrogate when it is not.

The protocol described here assumes players who need not be deeply acquainted with the roles they are asked to inhabit. Using players that have studied and are deeply acquainted with the roles they are asked to play is a natural, and in our view, much to be desired extension, which itself may be extended to other, perhaps more realistic, decision contexts. (I'm looking at you, UNFCCC!)

29.2 Consideration Set of Policies/Programs

Short descriptions.

1. Low Embodied Carbon Concrete: EPD Price Bids

   This policy intends to increase local governments' purchase of low embodied concrete for government contracts by creating a tax rebate that funds Environmental Product Declarations (EPDs) for concrete producers, which report the' global warming potential (GWP) of their products. Concrete producers bidding on public projects will be ranked based on the GWP of their concrete, and an artificial 5% discount will be applied to the bid prices of producers with the lowest GWPs, potentially making their bids more competitive. An additional 3% discount will be applied to producers that use any carbon capture, utilization, or storage technology to manufacture their concrete.
2. Food Rescue: PAYT and Food Rescue Grants

   This policy intends to simultaneously reduce waste and feed hungry citizens by coupling two programs: altering waste management policies and providing grants for food rescue program development. Implementing a Pay-As-You-Throw waste pricing system has been proven to reduce costs for municipalities by incentivizing the reduction of solid waste, so municipalities could commit to contributing the same amount saved via these policies to food rescue grants. These grants could be awarded on a competitive basis to organizations with promising plans for using the money, whether for storage and transportation equipment, staffing, data collection, or other projects.
3. Non-motorized thoroughfares: Eco-Friendly Protected Bike Lanes

   This policy funds the installation of "ultra-affordable", eco-friendly protected bike lanes made from used tires repurposed into planters outfitted with reflective tape. For example, the WeCLAIM "Eye" planter barriers created by Spin are one of the cheapest protected bike lanes available and still provide highly-visible, durable and effective protection for bikers.

4. Lawn Care Electrification: Vouchers for Electric Landscape Equipment
This policy offers vouchers to organizations that cover 60% of the purchase price of electric landscape equipment, with a cap of $7,000 per organization. The policy also mandates a study of participant satisfaction with electric equipment to inform future policies such as full bans of certain gas-powered lawn care tools.

29.3 Session protocol: Introduction

Note that the Wikipedia article has a standard procedure on display. It is broadly very useful. See https://en.wikipedia.org/wiki/Nominal_group_technique. See Figure 28.3 on page 200 for the original of Figure 29.1.

The following actions are taken by the facilitator. This portion of the exercise should take about 30–45 minutes, no longer. The presentation should be reformulated as a slide deck, once it is stable and complete in this document.

1. Greet and welcome the participants.
2. Explain what the session is about. This is a decision making role play exercise. We will ask you to imaginatively step into particular roles as you participate in the group exercise.
3. The assumed context is this. A local government is considering a number of policies and programs to undertake in response to climate change and environmental sustainability challenges. In doing so, it will be important to evaluate the several policies and programs according to a number of evaluation criteria, which are to be made public.
4. This exercise is about our asking you (participants assuming a role) about the evaluation criteria for the various programs.
5. There are two parts to this. First, we need to come to a group agreement on what the criteria should be. Second, we need to come to a group agreement on the importance weights of the criteria. Some criteria will be more important than others. We will be asking the group to tell us what it thinks is more and less important among the evaluation criteria.
6. A sample list of programs and policies, along with short explanations, is given in the handout entitled “Example Programs under Consideration.” This is to give you a rough idea of what the exercise is ultimately about. But we emphasize: The point of this exercise is not to choose among the programs under consideration. Instead it is about making decisions on how the programs are to be evaluated. We will show you some results in this regard towards the end of the exercise.
7. Figure 29.1 describes 6 criteria that many people thing are important for evaluating climate change programs. Let’s go through them and discuss them. Do ask questions if you have any.

8. You may or may not feel that the criteria in Figure 29.1 are complete. Perhaps there are other criteria that are important and should be used in program evaluations. We will look into this during the debriefing discussion held after our NGT session. For now, a little more patience before we begin.
9. Finally, the roles. Each of you will be assigned a role to play in the two NGT runs. The roles are described in the accompanying handout, "NGT Exercise Role(s)." [Discuss it now. There may be just one role, in which case everyone assumes it. If there are multiple roles, they will be randomly and publicly assigned to the participants, who are free trade them if they think dong so will lead to better results. Example roles: (i) trades person living in the community with a business doing electrical, plumbing, carpentry, heating and cooling systems, etc. work. (ii) middle class adult in the community, living with a partner and younger dependents in school; both partners working at least part time. (iii) empty nester couple both with good jobs. (iv) single adult head of household, 2 younger dependents in school, employed but with at best a median income.]

   [Once the roles have been assigned, discuss them and take questions from the participants.]
10. Finally, this is how we will proceed in the NGT session proper. We will proceed in steps as follows.
    (a). Silent generation of ideas: The Facilitator provides each participant with a sheet of paper with the question to be addressed and ask them to write down all ideas that come to mind when considering the question. During this period, the facilitator asks participants not to consult or discuss their ideas with others. This stage lasts approximately 10 minutes.
    (b). Sharing ideas: The Facilitator invites participants to share the ideas they have generated. She records each idea on a flip chart using the words spoken by the participant. The round robin process continues until all ideas have been presented. There is no debate about items at this stage and participants are encouraged to write down any new ideas that may arise from what others share. This process ensures all participants get an opportunity to make an equal contribution and provides a written record of all ideas generated by the group. This stage may take 15–30 minutes.
    (c). Group discussion: Participants are invited to seek verbal explanation or further details about any of the ideas that colleagues have produced that may not be clear to them. The facilitator's task is to ensure that each person is allowed to contribute and that discussion of all ideas is thorough without spending too long on a single idea. It is important to ensure that the process is as neutral as possible, avoiding judgment and criticism. The group may suggest new items for discussion and combine items into categories, but no ideas should be eliminated. This stage lasts 30–45 minutes.
    (d). Voting and ranking: This involves prioritizing the recorded ideas in relation to the original question. Following the voting and ranking process, immediate results in

response to the question is available to participants so the meeting concludes having reached a specific outcome.

Note: In the interests of speed I have copied the above from the Wikipedia article. Their list is accurate, but I'll want to do some editing on it.

BCO Budget expense (cost) to the local government or other organization net of outside grants and program funding such as federal programs.
Note that alternatives might save money so that a 1 may indicate a negative cost.
1 (lowest) to 7 (highest) cost. Sense: -1.

SCO Social expense (cost) to the pertinent body of stakeholders.
This criterion is used to represent the amount of "heavy lifting" politically that would be necessary to implement the associated program alternative. Think of the scale as phrase anchored, with 1 = uncontroversial or even generally welcomed and 7 = extremely controversial and likely to engender active resistance.
1 (lowest) to 7 (highest) cost. Sense: -1.

GHG Greenhouse gas emission reduction, also called climate mitigation. Think of the scale as phrase anchored, with 1 = negligible GHG emissions reduction and 7 = very high and cost effective GHG emissions reduction.
1 (lowest) to 7 (highest) cost. Sense: 1.

CoB Co-benefits, positive consequences other than cost savings and GHG emissions. Example: a program that creates or improves a recreational area as a side-effect.
Included here are health and safety effects.
Note: This criterion is especially difficult. Not only are data generally lacking at the local level, even when health effects are known, for example, their magnitudes are fairly small. Nothing under consideration is likely to have a positive effect on anything like that of ceasing to smoke. So, **consider that the scale here is a relative one, comparing the alternatives under consideration. The weakest alternative gets a 1, the strongest a 7.** Also, what counts as a co-benefit can be expansive, for example, reduction in noise pollution.
1 (lowest) to 7 (highest) cost. Sense: 1.

DiB Disbenefits, negative consequences other than cost and GHG emissions. Example: a program that destroys or degrades a recreational area as a side-effect.
Again, **consider that the scale here is a relative one, comparing the alternatives under consideration. The worst alternative on the scale gets a 7, the bst a 1.**
1 (lowest) to 7 (highest) cost. Sense: -1.

TRA Transition effects. Are we moving in the right direction? Does it favor something that has to be done eventually? Does it help with adaptation or resilience?
consider that the scale here is a relative one, comparing the alternatives under consideration. The weakest alternative gets a 1, the strongest a 7.
1 (lowest) to 7 (highest) cost. Sense: 1.

Figure 29.1: Baseline evaluation criteria and their labels.

29.4 The NGT session

The facilitator guides the participants through the four steps, along the following lines.

1. Silent generation of ideas.

   Working individually (but feel free to ask questions), you are to step into your assigned role and allocate as best you can 120 points among the 6 criteria.

   If you think each is equally important, then you would give the same weight to each criterion, 120/6 = 20. This would be unusual. More likely, you think some criteria are more important than others.

   Consider placing the six criteria in rank order of importance from your perspective. Once you have the ranking, you can assign numbers so that more important criteria get comparatively larger numbers. In the end, however, you only have 120 points to allocate and you should allocate all of them.

   We'll take 15–20 minutes for this task.

2. Sharing ideas.

   We'll begin by publicly recording everyone's scores for the attributes.

3. Group discussion. There will be an open discussion that will try to explain any differences and try to resolve them. Also, we will try to get at why people gave the judgments they did.

4. Final judgments and consolidation.

   Following the group discussion, everyone will be asked to give their final distribution of points, having participated in the discussion.

   These will again be written down publicly by the facilitator, who will then consolidate them to a group net weighting of the scores (by averaging and normalizing, using a spreadsheet program).

29.5 Debriefing the NGT session

Begin with putting the group's criteria weights into the PROMETHEE program for a selected ACS table matching the example program list shown earlier. Discuss the resulting program ranking and ask the participants what they think of it, given their roles and given the group's criteria weights.

End with a general, open-ended discussion of the exercise. What did the participants think of it? Do they think they adequately represented the roles they were asked to play? Etc.

Chapter 30 MCDM Introduction: Choosing Policies

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Investing is the art of using imperfect information to make probabilistic assessments about an inherently unknowable future.

—Folk saying, quoted at https://ritholtz.com/2022/03/judgment/

There are two main goals for this chapter. The first is to begin a gentle introduction, for the uninitiated, to multiple criteria decision making (MCDM), also known as multiple criteria decision analysis (MCDA),[1] using the context of decision making on climate and sustainability policies. We proceed by example, demonstration and comment, in contradistinction to building from foundations and axioms. For the most part we relegate theoretical and foundation matters to another venue.[2]

The second main goal is to describe—with examples and demonstrations—processes by which *sufficient decision models* may be constructed in our chosen context. We mean by sufficient decision model a model that is good enough for present purposes because it affords the decision makers (DMs) with the means, acceptable to them, of solving the problem to hand.[3] Developing a workable concept of sufficient modeling is key to the success of decision making in our chosen context, and in the policy making domain generally. This is because there is rarely if ever fully adequate—independently verified, precise and accurate—data available for decision making. Instead, we are normally confronted with information that is ambiguous, vague, and uncertain in one way or another, often to a very high degree. At the same time, decisions have to be made and it will simply not do to await full clarity. Instead we must find ways to make the best of what we have at a given time. This is especially the case with social programs, where experience is often quite limited, and with value judgments—a key input to decision models. Such judgments are imprecise and will differ by individual and even within an individual over time.

[1] And MADM, multi-attribute decision making. Terminology in the field is not standardized. We freely use variant terms as suits the need, while endeavoring to minimize the number of synonymous terms in play. In fact the terminology in the vast associated literature is neither standardized nor consistent. We aim to use terms that are broadly recognized and accepted, and to use them as coherently as possible. With this in mind and a little flexibility, the reader should be able to navigate the literature, even without precise and global definitions.

[2] Including supplementary information, SI, sections, which are so labeled and may be skipped on first readings.

[3] Phillips [23] in an early, important and insightful article introduces the term *requisite decision model*. Our meaning with *sufficient decision model* is essentially that of Phillips, who even defines requisite decision models as sufficient for solving the problem at hand. We use "sufficient" simply because we find it a more apt term and because "requisite" has not caught on, although the associated concept certainly has. We note as well how the notion of sufficient for present purposes in scientific and other epistemic enterprises is foundational for and pervasive in philosophical pragmatism, beginning with Peirce [22] on the fixation of belief.

In the end, however, we should not simply throw up our hands and make decisions based on whim, chance, gut feelings of the moment, or stakeholder power. If we fail to find a sufficient model, then this is what we are left with. It is always there as a backup. MCDM is about essaying to do better.

To begin and to proceed concretely, we wish to develop means of considering scores of policies and programs with complex interactions. Our subject area is the broad one of climate and sustainability. We are especially interested policies and programs that are considered and at times adopted by state and local governments in the United States.

The means for considering such policies—the concepts and tools—can easily become complex, daunting, and demanding, so much so that users reject them. Recognizing this, our goal is to begin simply and to follow a procedure of analysis, critique and refinement to develop a sufficient decision model that can serve as a valued aid to decision making.

Table 30.1 provides an example of an early step in the process of developing a sufficient model. The table is an *ACS table*, presenting an array of alternatives (rows), evaluation criteria (columns), and scores for the alternatives on the criteria (table entries).

ID	Policy_Objective	A	B	C	D	E	F	G	H
0	Green financing	-1	1	1	0	1	2	1	2
1	Composting	1	2	1	0	5	3	0	2
2	Ban single-use plastics	-1	1	0	0	0	4	0	2
3	Electric heat pumps for water heating	-3	3	0	0	3	2	0	2
5	Bicycle and pedestrian thoroughfares	-4	3	1	0	2	3	0	5
6	Buy green electricity	-3	4	0	1	1	4	0	1

Table 30.1: A starter ACS table.

We chose this particular table for the sake of discussion and illustration because it has a tractable but diverse collection of alternatives. These are labeled policy objectives in the table, and there are six of them, green financing, composting, and so on. In practice, which we will engage in the sequel, there are scores of distinct policy objectives. We conceive of policy objectives as high-level objectives in service to a set of goals (highest level values). Operationally, these are the criteria we will discuss shortly. Also, policy objectives are general and subsume their instances, which we tend to call programs. Thus, for example, there are many possible programs (rules, regulations, etc.) that count as banning single-use plastics. Some would prohibit using plastic bags for taking way purchases at retail establishments. Other programs would charge a fee for them. Other programs would include plastic straws, etc. Any single policy objective may cover an indefinitely large number of different programs. At present, we are attempting to build decision models that work at the more abstract level of policy objectives, as a means of winnowing the decision space before we get to the much larger space of particular programs. Finally for now on policies, we acknowledge that concise labels fail to do them justice and that in practice it would be necessary to inform stakeholders in some detail what the several policies amount to and what they are about. Patience, dear reader, it's coming.

The second element in the ACS table, after alternatives, is evaluation criteria, C. These appear as column headings, labeled A–H in Table 30.1. The meanings of the labels are given in Table 30.2. Criterion A is cost. This can itself have different meanings (Whose cost? How is it paid? etc.). For now, let us assume this is an annual budget cost charged to a municipality's (or county's) general funds for the duration of the planning period, e.g., one year or five years. Criteria B–G originate in the European Union's green taxonomy (Link). They constitute a thoughtful and widely consensual body of goals for climate and environmental sustainability policies. Criterion H, co-benefits, seeks to capture forms of value not captured in criteria A–G. For example, health benefits and quality of living benefits. Each of these criteria, but especially H, may itself be complex and need more nuanced modeling. That is something we will get to in due course. Finally, what about other criteria? Table 30.2 is only a starting point. It is natural and expected that during deliberations stakeholders may propose and accept additional evaluation criteria. Especially in a group decision making context with divergent interests and the need to arrive at a group decision, we can expect that side deals will be made to garner votes. Introducing new or modified alternatives with new attributes is how this is represented. It is utterly normal in political deliberations [26]. For example, in consequence of a political deal a composting program may be combined with a new playground in a certain neighborhood.

Criterion ID	Criterion	Criterion Short	Criterion Label
0	Cost	Cost	A
1	Climate change mitigation	Mitigation	B
2	Climate change adaptation	Adaptation	C
3	The sustainable use and protection of water and marine resources	Water	D
4	The transition to a circular economy	Circular	E
5	Pollution prevention and control	Pollution	F
6	The protection and restoration of biodiversity and ecosystems	Biodiversity	G
7	Co-Benefits	CoBenefits	H

Table 30.2: Top level criteria (goals) for policy evaluation, version 1. Criteria B–G from the European Union green taxonomy. Link.

The third element in our ACS framework, S, are the scores of the alternatives on the criteria. These appear as numbers in Table 30.1. They were obtained by subjective assessment by the author, acting as an expert, and are on a scale from -5 (worst) to 5 (best), centered on 0. It would of course be preferable if the scores were sourced objectively, with costs in dollars, mitigation in CO2e reduction, adaptation in . . . what? There are two fundamental problems facing us: (i) On what scales should the alternatives be measured on the criteria? and (ii) Given a measurement scale for a criterion, how is the measurement to be obtained for a given alternative?

We begin for the sake of the exposition with the extreme case of *complete subjectivity*. In this extreme case, a context is specified and both questions are answered by judgments of individuals (aka: subjects). Our context, for the sake of discussion, is decision making by a medium-sized municipality for a two-year planning horizon. Cost is measured in dollars on a -5 to 5 scale, with the most expensive alternative possibly considered a -5, the most profitable a 5. A similar procedure is invoked for each criterion. We develop phrases to anchor the scale points. A 5 might be "As good or better than any alternative likely to be under consideration" while a -5 might be "The worst that can be considered or is likely to be considered." A 0 would be "Midway between 5 and -5" and so on.[4] In this way we resolve our first question of the measurement scales of the alternatives.

To see how we answer the second question, about actually measuring the alternatives on the criteria, let us focus on criterion E in the table, transition to a circular economy. As we see, the scores for the alternatives present range from 0 to 5. These were assessed subjectively, that is, by asking an individual to produce them. The individual is not to answer on a whim. Rather, the individual is treated as a noisy, imperfect meter of something objective. A further instruction is essential. In assigning numbers to alternatives, the difference between x+1 and x+2 is to be the same magnitude as that between y+1 and y+2. Concretely, the alternatives green financing and buy green electricity both get a score of 1, indicating that the subjective judgment was that they are approximately equal. The alternative ban single-use plastics gets a 0 while bicycle thoroughfares gets a 3. This means that the subject judged that it would be an equally good improvement to start at buying green electricity then moving to bicycle thoroughfares or to start at banning single-use plastics and then moving to green financing. And so on. The difference between 5 and 3 equals the difference between 3 and 1, etc. In short, we can stipulate the high and low ends of a scale, then ask for judgments that evenly distribute the alternatives between them, so that equal intervals numerically are equal ranges in terms of value. This is our answer to the second question (and see Section 30.B for additional information on scoring).

We are now in position to address the lurking question, which the reader no doubt is eager to see answered: *How can this procedure possibly be useful for real-world, consequential decision making? The numbers are all extracted by subjective judgment, which can be anything. This cannot possibly be reliable with real money or serious consequences at stake. You are peddling an invitation to fantasy, not to hard-nosed science.* It's a fine question. Here's our response.

a. The extreme subjectivism on scoring is (only) a starting point for analysis.
b. Scores may subsequently be modified in light of experience and new information. In so doing, they may be tied to objectively (i.e., inter-subjectively rather than intra-subjectively)

[4]The aim is to create cardinal (interval scale) measurement scales. We defer discussion of this technicality. See for starters the SI section 30.A and especially section 30.B.

valid observations. When it can be done, it should be done. When this is not possible or is too expensive, we make do with subjective assessment. Subsequent analysis may direct us to make efficient investments in learning, thereby conserving resources. (We illustrate this point in the sequel.)

c. Scores derived from a single subject may be improved by employing many subjects. In fact what we would normally begin with a "team scoring" exercise in which each score is assessed by several different people who then compare their judgments, discuss matters, and arrive at team consensus. This is a standard kind of practice in the social sciences, e.g., in content analysis where meanings of texts are scored [19].

d. The subjects are not entirely free to report arbitrary scores. Subjects are treated as sincere but imperfect instruments for reading the real world. In this they are thus not philosophically different than actual laboratory meters, just noisier than usual. We use subjects because we believe they do have some knowledge of the situation, are willing to convey it and because we do not have better instruments. If we think otherwise of a subject, then they should not be used. If we cannot find a subject who plausibly has knowledge of the matters to hand and who is cooperative, then we are stuck. In consequence, the extreme subjectivism that we begin with is able to deliver otherwise unavailable scores, at the price of sometimes failing to do so.

e. Even in the presence of objective and easily measurable scales for an attribute we still need subjective judgments to transform the attribute's scores to reflect preference. For example, if monetary cost is the raw measure of an attribute we need to translate this measure to a value (or utility) score. It is generally not the case that an improvement of x dollars is equally valued in comparison to different starting points. Gaining \$100 dollars if you are homeless is worth to you a lot more than gaining \$100 dollars if you are wealthy (in non-pathological cases). We need subjective judgments to create value scales from publicly observable scales and scores.

f. In constructing interval scales we can check the subject's assessments for (a degree of) consistency. Put otherwise, the scaling theory we use indicates additional questions we can ask a subject in order to test the consistency and coherence of its answers. How this is done is a matter for the sequel. It has been done for the scores in Table 30.1.

g. Finally, our goal is not to develop the one true model. Instead, our aim is to find a sufficient model, a model that our DMs are content to use to make their decision and are reasonable in doing so. If the scores contain information—and we argue that they do because the subjects who produced them are informed to a degree—then they may well be able to discriminate alternatives sufficiently well to come to a decision. Signs can be read by people with blurred vision, providing the vision is not too blurred.

We turn in the following chapters to redeeming the promise implicit in these remarks, viz., that sufficient models can be had even in the presence of very noisy scores and other data, at least oftentimes. We discuss two general cases: best alternative MCDM for choosing one alternative, and multi-criteria (or multiple criteria) portfolio analysis (aka: PDA, portfolio decision analysis) for choosing collections of alternatives. We begin in the next chapter with the former.

Appendix

30.A SI: Measurement scales

Four scales of measurement are Nominal, Ordinal, Interval, and Ratio

1. Nominal

Nominal levels of measurement are used to distinguish between features only on the basis of qualitative information.

Nominal data does not imply quantitative differences. We can only say that A is different to B.

It is meaningless to add,subtract multiply or divide nominal data. If points on a map were coded to represent towns, buildings, population clusters or mountains they would represent nominal data.

Nominal Data Set

A = Russia B = Spain C = France D = Poland

2. Ordinal

Ordinal scales involve differentation by class, but they also differnentiate within a class of features on the basis of rank according to some qualitative measure.

Only rank is involved in ordinal scales. We are able to say that object A has a higher rank than object B, but we cannot say by how much.

Examples might be differentiating between major roads and minor roads or small, medium and large cities.

Ordinal scales inform the map reader that some features are larger or smaller, more important or less important or younger or older.

Ordinal Data Set A = Melbourne B = Sydney C = Brisbane D = Perth

3. Interval

Also known as the cardinal level of measurement, interval scales add information about the distance between ranks.

To employ an interval scale we must use some kind of standard unit. For example, we differentiate between temperatures by using the standard unit of degrees celcius.

We distinguish among elevations by using the arbitrary datum of mean sea level. We cannot multiply or divide interval scale data. For example, it would be incorrect to say 40 °C = 2 * 20 °C.

Interval scales have no true or absolute zero. A temperature of 0 °C does not imply an absence of heat, it is just the point at which water freezes.

4. Ratio

Ratio data is the highest measurement scale. All forms of arithmetic operations can be meningfully applied to ratio scale data.

Distance, tonnes of wheat, number of people are examples of ratio scale measurements.

Zero has real meaning in ratio level measures. It is not possible to have less than zero people or to travel less than 0km.

Ratio Data Operation

30 metres x 30 metres = 900 metres

30.B SI: Ordinal and cardinal subjective scoring

Section 30.A notes that there are four measurement scales in principle available generally, and specifically to us in scoring the entries in an ACS table. The scores are present for the purpose of indicating preference or desirability numerically. Preferences are inherently subjective in the sense of subject-based or founded. When "objective" scales are present, for example monetary costs, these are in the end based on a collective judgement that indeed the relevant subjects agree to the scale and so do not need to be asked or have already been asked. When objective consensual scales are not available, we have recourse to subjective judgements and seek to obtain them in a reliable, honest and accurate manner. At bottom, we need preference information and it ultimately has to come from individual judgments.

The question now is on what scale(s) are the judgments (subjective measurements) to be taken and understood and how is this accomplished.

Nominal scales are not sufficiently information rich to be useful to use, so we dismiss them at the outset. Ratio scales are the richest informationally and the most useful but they are problematic and contested in the case of subjective assessment. This is one reason for preferring objective scales on the criteria: many of them are naturally on a ratio scale. Examples include cost and level of GHG emissions. This leaves us with ordinal and cardinal (interval) scales. We should truck with both.

To score an ACS table on an ordinal scale all that needs to be done is, working by columns (by criteria), to give rank scores to the associated alternatives. This is usually a fairly easy and less noisy task for an informed subject. It is convenient for what follows if the scoring is done on the intended range of the attributes, but this is hardly necessary. To illustrate, we are using a scoring range from -5 to 5. For a given criterion, the subject is asked to assign number in this range to each alternative (row), with the stipulation or constraint that for any two alternatives, a and b, the number assigned to a is larger than the number assigned to b if and only if the subject's judgment is that a is better than b or in mathematical shorthand, $a \succ b$. In the event that the subject judges a and b to be equally preferred ($a \sim b$ in mathematical notation), the subject should assign them the same number. The suggested procedure is for the subject to order the alternatives on the criterion in question (including any ties), then assign the best a score of

5 or a little lower, say 4 to give room for further analysis. Similarly, the worst alternative (on the criterion) should be assigned a -4 or something close. The remaining alternatives should be assigned intermediate scores so that the score on alternative a is larger than the score on alternative b—$s(a) > s(b)$—if and only if $a \succ b$ (and similarly in the case of ties).

This suffices to create an ACS table scored on an ordinal scale. The scoring method assumes that the subject is able to compare every two alternatives on each of the criteria and that the subject's preferences are transitive. Empirically, informed subjects are generally able to do this (remember: ties are permitted), but if there is resistance, it is wise to consider why. A restructuring of the problem may be in order, as may be replacement of the subject with another.

To score on an interval (or cardinal) scale we begin with an ordinal scaling. Choosing a criterion, we ask the subject to change the values assigned to the alternatives so as to preserve the order from the ordinal scale but to space them on the -5 to 5 scale so that equal scoring differences between pairs of alternatives correspond to equal preference differences. Expressing this in mathematical notation we want scores with the following property:

$$\forall a, a', b, b' \;\; s(a) - s(b) = s(a') - s(b') \equiv (a \leftarrow b) \sim (a' \leftarrow b') \tag{30.1}$$

The notation $(a \leftarrow b)$ means replacing the a score by the b score. The idea here is that equal scoring intervals are preferentially equivalent; the DM is indifferent ('$\sim$') between equal interval changes regardless of their absolute numerical values. For example, the DM is indifferent between an improvement from -4 to -2 and an improvement from 1 to 3 and would, say, be willing to pay an equal amount for either of the changes.

Temperature on either the Fahrenheit or Celsius scale is perhaps the cardinal scale most familiar to the reader. Note that temperature does not directly measure comfort. A 2° change from 10° to 12° is the same amount of *temperature* changed as the change from 33.5° to 35.5°, in either Fahrenheit or Celsius. Importantly, however, a 2° change in Fahrenheit is not the same as a 2° change in Celsius.

For our present purposes, this suffices to create an ACS table scored on a cardinal (interval) scale. The scoring method assumes that the subject is able to generate first an ordinal scale and then do the numerical adjusts necessary to create a cardinal scale. As in the case of ordinal scaling, informed subjects are generally able to do this (remember: ties are permitted), but if there is resistance, it is wise to consider why. A restructuring of the problem may be in order, as may be replacement of the subject with another.

Chapter 31 MCDM: Choosing a Best Alternative

We now take up the matter of finding a best alternative given a completed ACS table. As before, we proceed by examples and demonstrations, working here with an expanded ACS table that is realistically large, albeit hardly comprehensive, Table 31.1.1. Our purpose in this chapter is to demonstrate a number of analyses that can be used with an ACS table in order to gain insight into the problem of choosing a best alternative from among those given in the table. As usual, our discussion occurs within an assumed realistic context of noisy, highly imperfect information in the model.

31.1 Explorations with ACS Tables

We begin by undertaking a few explorations with ACS tables with the aim of getting some insights into a decision problem. Table 31.1.1 serves as our running example. Recall Table 30.2 on page 217 for the meanings of the criteria (column) labels.

ID	PolicyObjective	A	B	C	D	E	F	G	H
0	Green financing	-1	1	1	0	1	2	1	2
1	Composting	1	2	1	0	5	3	0	2
2	Ban single-use plastics	-1	1	0	0	0	4	0	2
3	Electric heat pumps for water heating	-3	3	0	0	3	2	0	2
4	Electric stoves	-3	2	0	0	3	2	0	3
5	Bicycle and pedestrian thoroughfares	-4	3	1	0	2	3	0	5
6	Buy green electricity	-3	4	0	1	1	4	0	1
7	Complete Streets	-3	2	2	0	2	2	3	3
8	Legal Analysis on Scope	-1	1	1	0	1	0	1	0
9	Sustainability Review	-1	1	1	0	1	0	1	0
10	Sustainability Survey	-1	1	1	0	1	0	1	0
11	Building Efficiency	-2	2	1	1	3	2	2	2
12	Monitor grant & rebate opportunities	-1	1	1	0	1	0	1	0
13	Reduce emissions from conventional vehicles.	-2	3	0	0	0	3	0	2
14	Recycling	-3	3	0	0	4	1	3	1
15	Public Outreach & Education	-1	1	1	0	1	0	1	1

Table 31.1.1: An ACS table.

31.1.1 The Pareto set from the ACS table

The 16 policies in Table 31.1.1 are not entirely incomensurable because 4 of them are strictly dominated by other policies. Alternative a strictly dominates alternative b if and only if a is better than or equal to b on every criterion and is strictly better than b on at least one criterion. See the SI material in Section 31.A for more on Pareto dominance. The remaining non-dominated policies, called the *Pareto set* or the *Pareto frontier* for this set are shown in Table 31.1.2.[1]

ID	A	B	C	D	E	F	G	H
0	-1	1	1	0	1	2	1	2
1	1	2	1	0	5	3	0	2
2	-1	1	0	0	0	4	0	2
3	-3	3	0	0	3	2	0	2
4	-3	2	0	0	3	2	0	3
5	-4	3	1	0	2	3	0	5
6	-3	4	0	1	1	4	0	1
7	-3	2	2	0	2	2	3	3
11	-2	2	1	1	3	2	2	2
13	-2	3	0	0	0	3	0	2
14	-3	3	0	0	4	1	3	1
15	-1	1	1	0	1	0	1	1

Table 31.1.2: Pareto set (non-dominated alternatives) for the ACS table, Table 31.1.1.

The dominated alternatives: (alternative : is dominated by alternative) are:

8: 0, 9: 0, 10: 0, 12: 0

So we see that alternative 0, green financing, dominates alternatives 8, 9, 10, and 12. Alternative 0 is hardly unique in dominating these alternatives.

The Pareto frontier (set of non-dominated alternatives) is reliably informative, even though it rarely suffices to identify a small, let alone singleton, set of attractive alternatives. In this case, 12 of the 16 original alternatives are on the Pareto frontier. Points arising:

a. The Pareto set (frontier) can properly be calculated when the scores are measured on an ordinal scale. Of course, if they are measured on a cardinal or ratio scale, so much the better.

b. It is often rewarding to examine the dominated alternatives as a group. In the present case, each of the four dominated alternatives are comparatively low-cost information gathering activities whose indirect benefits might be compelling. Perhaps they should be seen as broadly necessary activities in going forward, to be undertaken as soon as possible? If so, this would naturally lead to some restructuring of the problem. Perhaps one or more of these alternatives can be done in addition to the more directly impactful activities on the Pareto frontier.

c. Recalling the the ACS table scores were assessed subjectively, even if based on objective observations, after calculating the Pareto frontier it is a good time to revisit the scores. Are there any surprises in the outcome of the Pareto calculations that would seem to indicate some misscoring?

d. The dominance concept creating the Pareto frontier can be modified in a number of

[1]These and other calculations are done via ACSNoodling.py by sok.

ways, making it either more or less restrictive (smaller or larger). The move restrictive move is likely the more useful one when, as in the present case, there is an excess of alternatives in the Pareto set. A simple way to effect such a restriction is (for a pair of non-dominated alternatives) to subtract one from another as vectors, say $a - b$, and then sum the results where they are negative (criteria on which b scores higher than a). If this sum is above a threshold, indicating comparatively small numerical magnitudes, treat b as quasi-dominated, provided there is not a similar result from $b - a$. There are very many operations of this sort that can lead to useful insights into the decision problem to hand. In the sequel, we delve into this further using an MCDM toolkit to provide rapid analysis and reporting.

e. Various kinds of *post-solution analyses* may usefully be applied to ACS tables and Pareto frontier calculator tools. We mention just two here, for others see [17]. First, there is sensitivity analysis, which in this case examines how small perturbations in the scores will affect the constitution of the Pareto frontier. One form of analysis consists in drawing random perturbations of the table scores and recomputing the Pareto frontier. This is done thousands of times and a statistical profile of the resulting frontiers is created. If it is very robust, this constitutes evidence that the scoring is an acceptable basis for discriminating better and worse alternatives. In a second form of analysis, called outcome reach, we ask (in this context) how much an alternative would have to change in order to move into or out of the Pareto frontier. Having found minimal changes that result in movement, we can then focus on whether or not changes to the scores of that magnitude are warranted.
Again, we delve into this further in the sequel, using an MCDM toolkit to provide rapid analysis and reporting.

31.1.2 Beyond Pareto

We can begin our explorations by focusing on just one criterion and sorting the alternatives. This is called a *lexicographic-1 ordering*. See Table 31.1.3 for an example. There, we have sorted the non-dominated alternatives in descending order (from best on down) on column B, mitigation.

Table 31.1.3 is in effect a preference order of the alternatives for someone who only cares about mitigation. That is likely a minority view. The table, however, is useful more broadly because it is relevant to addressing a number of deliberation questions, for example: “What is the least expensive alternative that is close to 6 on the B scale?” (answer: 13); “What alternatives are strong on other dimensions and close to 6 on the B scale?” (answer: 5 and 14). Points arising:

- These questions are quite relevant to seeking out positions that can be supported by a coalition.
- Although we can expect distortion and motivated reasoning in the public presentation of ACS tables, decision makers have ample incentives to work with accurate tables in their

ID	A	B	C	D	E	F	G	H
6	-3	4	0	1	1	4	0	1
3	-3	3	0	0	3	2	0	2
5	-4	3	1	0	2	3	0	5
13	-2	3	0	0	0	3	0	2
14	-3	3	0	0	4	1	3	1
1	1	2	1	0	5	3	0	2
4	-3	2	0	0	3	2	0	3
7	-3	2	2	0	2	2	3	3
11	-2	2	1	1	3	2	2	2
0	-1	1	1	0	1	2	1	2
2	-1	1	0	0	0	4	0	2
15	-1	1	1	0	1	0	1	1

Table 31.1.3: Initial ACS table: sorting the non-dominated alternatives on B, climate mitigation. A lexicographic ordering.

private deliberations. Thus, while a publicly presented table may suffer data distortions and biases, individual actors can benefit from adjusting these tables in the direction of accuracy.

This hardly exhausts the potentials of lexicographic orderings for affording deliberation. Obviously, any and all individual criteria can (and should) be used to sort the ACS table and used for deliberation. Higher orders of lexicographic sorting are often useful. See for example Table 31.1.4.

	A	B	C	D	E	F	G	H
6	-3	4	0	1	1	4	0	1
5	-4	3	1	0	2	3	0	5
3	-3	3	0	0	3	2	0	2
13	-2	3	0	0	0	3	0	2
14	-3	3	0	0	4	1	3	1
4	-3	2	0	0	3	2	0	3
7	-3	2	2	0	2	2	3	3
1	1	2	1	0	5	3	0	2
11	-2	2	1	1	3	2	2	2
0	-1	1	1	0	1	2	1	2
2	-1	1	0	0	0	4	0	2
15	-1	1	1	0	1	0	1	1

Table 31.1.4: B then H lexicographic-2 sort.

To be clear, lexicographic sorts, while useful, are throwing away information. Their saving grace is that they can present points of departure for negotiation and adjustment. They are in principle poor decision rules because they toss out information. Nevertheless, they can be valuable decision aiding and deliberation devices.

A lexicographic-1 sorting is equivalent to taking a weighted average of all of the criteria scores but putting all the weight on a single criterion. Generalizations are obvious and may be useful. For example, Table 31.1.5 shows the sorting of the alternatives with a weight of 0.5 on A, 0.5 on B, and 0.0 on everything else.

	A	B	C	D	E	F	G	H	V-Score
1	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
6	-1.5	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
13	-1.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
0	-0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	-0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	-1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	-1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	-1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	-0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	-1.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5
5	-2.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	-0.5
7	-1.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5

Table 31.1.5: Sort on a 50:50 weighting of criteria A and B. V-Score = value score.

In Table 31.1.5 the V-Score for a row is produced by the ACS table and a criteria weights table, below:

	A	B	C	D	E	F	G	H
0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0

The V-Score value is the sum of the values in the row and the weights, multiplied item-by-item. Thus, for alternative 1 we have $1 \times 0.5 + 2 \times 0.5 = 1.5$, neglecting the 0 terms.

Generalizing further, we can put a non-zero weight on each of the criteria. If we give them equal weights adding to 1, we get the weights table of Table 31.1.6.

A	B	C	D	E	F	G	H
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

Table 31.1.6: Weights table with equal weights.

We can then score the alternatives using this full weighting and sort on V-Score. When we do this we get Table 31.1.7.

Table 31.1.7 may be seen as an example of a (simple) MAVT (multi-attribute value theory)[2] model. It is assumes a weighted average value formulation and the weights are all equal. This limited form is useful for exploratory purposes. In the next section, we begin to discuss relaxing these assumptions and building more general, and we hope more accurate, MAVT models.

[2]Aka: MAUT (multi-attribute utility theory). The technical language of MCDM distinguishes value functions (scores) and utility functions. Our exposition has described making a MAVT model. We leave MAUT to the sequel.

ID	A	B	C	D	E	F	G	H	V-Score
1	0.125	0.250	0.125	0.000	0.625	0.375	0.000	0.250	1.750
7	-0.375	0.250	0.250	0.000	0.250	0.250	0.375	0.375	1.375
11	-0.250	0.250	0.125	0.125	0.375	0.250	0.250	0.250	1.375
5	-0.500	0.375	0.125	0.000	0.250	0.375	0.000	0.625	1.250
14	-0.375	0.375	0.000	0.000	0.500	0.125	0.375	0.125	1.125
6	-0.375	0.500	0.000	0.125	0.125	0.500	0.000	0.125	1.000
0	-0.125	0.125	0.125	0.000	0.125	0.250	0.125	0.250	0.875
3	-0.375	0.375	0.000	0.000	0.375	0.250	0.000	0.250	0.875
4	-0.375	0.250	0.000	0.000	0.375	0.250	0.000	0.375	0.875
2	-0.125	0.125	0.000	0.000	0.000	0.500	0.000	0.250	0.750
13	-0.250	0.375	0.000	0.000	0.000	0.375	0.000	0.250	0.750
15	-0.125	0.125	0.125	0.000	0.125	0.000	0.125	0.125	0.500

Table 31.1.7: Simple MAVT table, scored with weights in Table 31.1.6

Note by-the-bye the robustness of alternative 1, composting. It does fairly well in most of the configurations we have examined and it is a clear winner in the simple MAVT model, Table 31.1.7. Will that hold up as we do more?

31.2 Conclusion

This completes our introductory and very abbreviated account of MCDM. Our aim has been to motivate this kind of modeling and to provide a sense of what it can do and how it can work. We have only scratched the surface.

Detailed discussions of techniques, principles, tools, and applications are to follow. Throughout, we will adhere to a key message conveyed in this and the previous chapter: (i) the need and the necessity of working with models that are far from being complete and highly accurate representations of the facts and values (preferences) involved, and (ii) the practical utility of using model analytics to discover sufficient models and decisions made with their help.

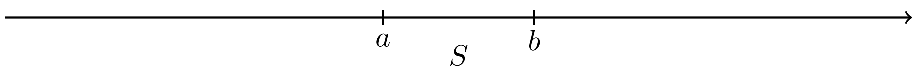
Appendix

31.A SI: Evaluation problems

The purpose of this section of supplementary information is to introduce the complications brought about by multiple criteria instead of a single criterion as a measure of performance (MoP).

31.A.1 Initial approach

- Consider a very general and important problem: How do/can/should we evaluate and compare different things? The basic strategy is to measure and compare them.
  Is a better than b? More valuable? More useful? etc.
  Is a good enough?
  What is the best item in a collection?
- The general approach again is to set up a measurement scale, call it S, measure and compare.



- On scale S, b is greater in magnitude than a.
- All very simple and unproblematic.
- Problems and complexities come from defining the scale (What is it? Is it monotonic? etc.) and from actually obtaining measurements on the items of interest (Is it possible? Practicable? Too noisy or inaccurate? etc.)
- Additional complexities arise in the presence of risk, uncertainty, ambiguity.
- Is there anything missing here?

Yes! Multiple dimensions of value.

31.A.2 Multiple criteria and the Pareto frontier

In the presence of multiple criteria, what can we do to decide among the alternatives? Formally, theoretically, we can at least do the following:

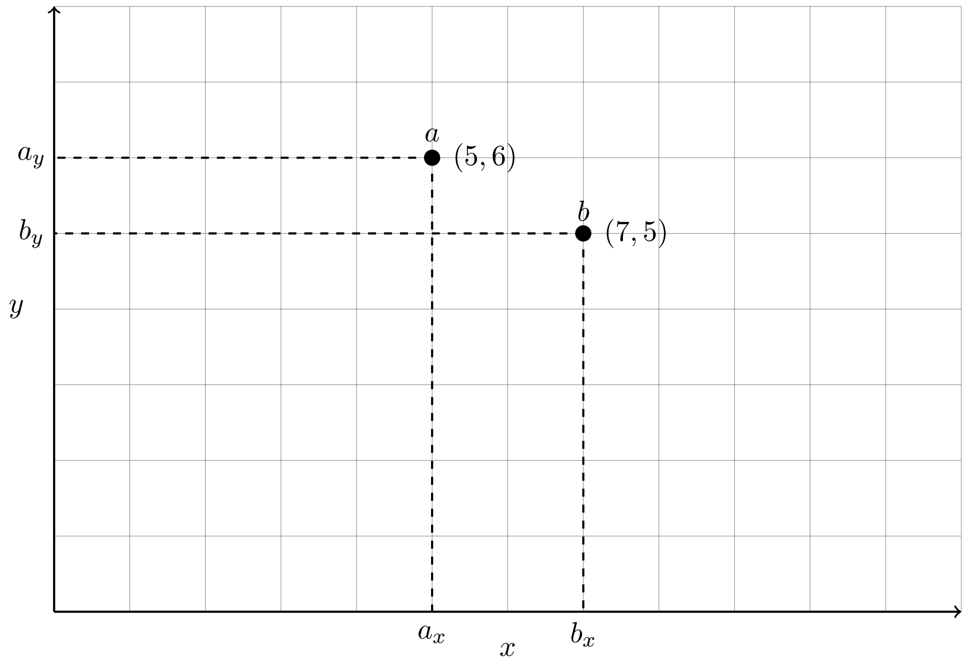
- Identify the criteria we wish to use to evaluate redistricting plans. See Table 30.2 on page 217 of the previous chapter.
- For a given collection of alternatives, we determine the Pareto frontier, based on their scores on the several criteria.

- We leave it to decision makers, with subjective judgments and/or decision analysis, to pick among the plans on the Pareto frontier.

Informally, we proceed with this formal process in mind as something of an ideal. Note that adding dimensions is central for gaining political/group agreements [26].

31.A.3 Dimensions matter

The transition from single to multiple dimensions brings with it immense complications. Dimensions matter.



Which is bigger or better, a or b? Notice $b_x > a_x$ and $a_y > b_y$. **General lesson: it is always possible reverse the size, value, preference order of two objects simply by adding a new dimension. So if we are judging a number of options and we miss out on important dimensions, we are exposed to risk of misjudgment.** Related is work in political science: we make deals by adding dimensions, side payments, 'pork' [26].

What we can, and must, do in the presence of multiple criteria (dimensions) is to

a. Identify the different <u>alternatives</u>
b. Identify the various <u>criteria</u> by which to compare the alternatives
c. <u>Score</u> each alternative on each criterion

Then we can compare the results. Conceptually we can think of ourselves as building an ACS (alternatives, criteria, scores) table.

Here's an example of a very simple ACS table looking at climate change policies or programs as the alternatives.

Now what do we do? How do we compare the alternative programs now that we have scored them on the several criteria?

	Criteria [Weights]				
Alternatives	$c_1[w_1]$	$c_2[w_2]$	$\ldots$	$c_n[w_n]$	Alternatives Utilities
a_1	$u_1(s_{1,1})$		$\ldots$	$u_n(s_{1,n})$	$U(a_1) = \sum_{j=1}^{n} w_i u_i(s_{1,j})$
$\vdots$	$\vdots$			$\vdots$	$\vdots$
a_m	$u_1(s_{m,1})$		$\ldots$	$u_n(s_{m,n})$	$U(a_m) = \sum_{j=1}^{n} w_i u_i(s_{m,j})$

Table 31.A.1: ACS table: Alternatives (a_is), criteria (c_js) [and their weights for an additive model], and scores (s_{ij}s) [given as utilities ($u_j(s_{ij})$s)] for a single stakeholder or decision maker.

Program	BCO	SCO	GHG	HnS	CoB	DiB	TRA
LECC	0	0	1	0	0	0	1
CSCom	0	0	1	0	1	0	1
GreF	0	0	1	1	1	0	1
EBus	-1	0	1	1	1	0	1
InCP	-1	0	1	1	1	0	1
SusL	0	0	1	1	1	0	1
GasB	0	-1	1	1	1	-1	1
Bhav	0	0	1	1	1	0	1

Table 31.A.2: Example First-Cut ACS (alternatives, criteria, scores) table. Alernatives: LECC: Low Embodied Carbon Concrete, CSCom: Curb Side Composting, GreF: Green Financing, EBus: Electrification of Transit Buses and Utility Vehicles, InCP: Internal Carbon Pricing, SusL: Sustainable Living Information and Advice, GasB: Building Electrification, BHav: Behavioral Interventions. Evaluation Criteria: BCO: Budget expense (cost), SCO: Social expense (cost), GHG: Greenhouse gas emission reduction, HnS: Health and safety effects, CoB: Co-benefits, DiB: Disbenefits, TRA: Transition effects.

- We could build a MAUT (multi-attribute utility theory) model, as suggested in Table 31.A.2. But this is problematic on several grounds.
- Instead, we first (and maybe last) want to pare down the consideration set of alternatives to find those that are non-dominated.
- Alternative a is (strictly) dominated by alternative b if on every criterion b is at least as good as a and on at least one criterion b is better than a.
- The collection of non-dominated alternatives (each of them not dominated by any single other alternative) is said to constitute the *Pareto frontier*, after Vilfredo Pareto who originated these concepts.

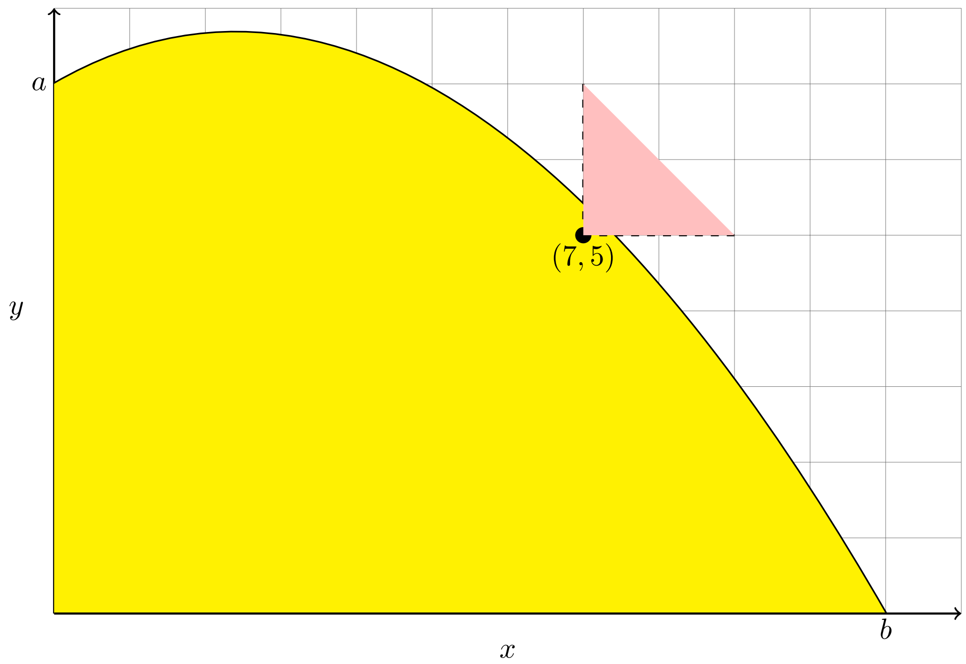
31.A.4 Pareto frontier

These concepts are usefully visualized in two dimensions (criteria) but the core principles apply in any number of dimensions (criteria). We'll begin with continuous space, continuous alternatives.

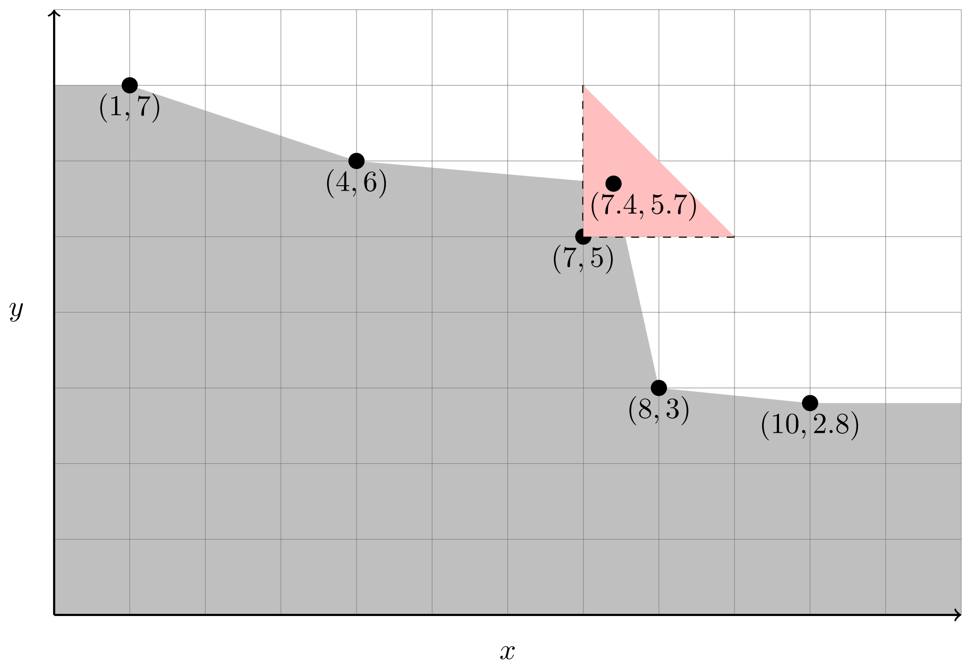
Here we have two criteria, x and y, with values increasing (the more the better). The curve running from a to b constitutes the Pareto frontier. The gray area below it constitutes the available alternatives that are dominated by at least one point on the frontier.

Notice that some points in the interior might be better than some points on the frontier, but for every interior point there is some point on the frontier that is better than it. We get all of this without having to decide on the importance weighting of the criteria or even on the functional form of their combination!

The area in pink is in the *cone of exploration* for the point or alternative (7,5). Any point in the code that we can find will dominate (7,5). So, I'm bringing in the possibility that the Pareto frontier might change as we find new alternatives.



Now the discrete case.

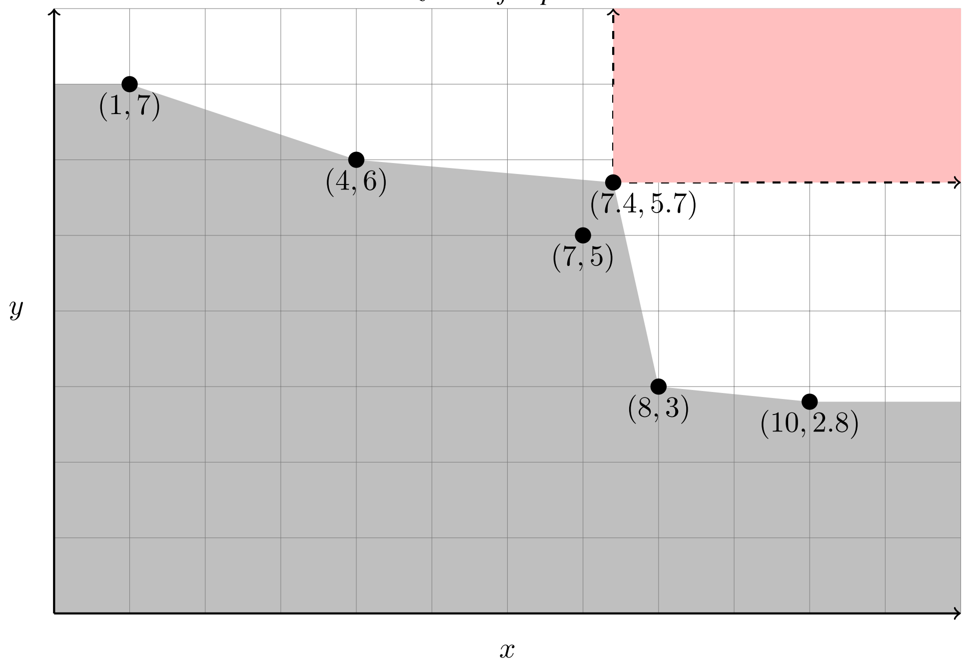


So (7,5) is not on the Pareto frontier but (8,3) is. (7.4,5.7) dominates (7,5). The points (options) on the Pareto frontier are not dominated by any available options.

We are assuming in this diagram that for both x and y more is better.

If we further assume that when we bundle x and y there are no negative interactions between them, so that more of either is always better, then for every item in the interior (off the frontier) we will always prefer some item on the Pareto frontier to it.

In the discrete case we can think of *zones of exploration*.



Each point on the discrete Pareto frontier generates its own zone of exploration. Any point discovered in that zone will replace the original point on the Pareto frontier, because it dominates it (and possibly other points presently on the frontier as well).

Chapter 32 MCDM: Scoring by Ranking

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2022-4-16

32.1 Introduction

The previous two chapters were introductory. They offered a high-level overview of what multi-criteria analysis (MCA, aka MCDA, MCDM, and MADM) is about and can offer. We begin now a series of chapters in which we delve into MCA (and MCDA/MCDM/MADM) in much more detail. Good practical and introductory references include *Multi-criteria Analaysis* [9] and *Multiple Attribute Decision Making* [**?**].

Recall from the previous chapters that in MCA the various alternatives/options are—at least for starters—incommensurate because individual alternatives typically are better on some criteria and worse on other criteria when compared to the other alternatives. Recall as well that analysis begins with data structure called an ACS table (alternatives, criteria, and scores), also known as a *performance matrix*. However named, the data structure has rows corresponding to alternatives (aka options), the columns corresponding to criteria (aka attributes) and the entries corresponding to scores of the corresponding alternatives criteria.

32.2 Informed assessment

Our principal concern in this chapter is with obtaining the scores in an ACS table, particularly in the case of considering local climate policy alternatives. We face two large challenges here and throughout our modeling efforts. The first—dynamic fluctuation—is that any fixed ACS table and any associated information and analysis can only fix a point in time. The deliberation is fluid and forever changing. Alternatives newly appear or are taken off the table. New criteria are identified and brought into consideration; old criteria become less relevant and are dropped. Scores are revised in light of new information. The analysis is always in flux.

The second pervasive major challenge—uncertainty, ambiguity, and vagueness—is that the numbers (measures, scores) we have at any one time will often be very imprecise—how much we might not know—and even biased—in what direction we might not know.

We propose to address these challenges in two ways. The first is a mindset: our understanding and practice must be that a decision model at any moment is highly provisional. It is subject to revision, perhaps radical revision, as new information comes in. Put otherwise, the object of PCA and MCDM is not a model or result that is static because it is founded on overwhelmingly certain assumptions. Instead, the object is a credible and well-founded *process* of successive refinement and revision in light of new information. If compelled to decide, appeal to the model at present is used to inform the decision, keeping in mind the state of the process that led to the model.

The second response to the two major challenges of MCA is to accept, indeed embrace, initial measurements that are far from ideal and to do this by employing, if necessary subjective assessments. We get started with admittedly very uncertain measurements and proceed from there as appropriate. How that is done is something we address in the sequel, but in brief we propose a posit-analyze-revise workflow within the overall MCA process.

Obtaining the initial ACS scores when we must rely on highly subjective measurements is the main topic of this chapter. The issue boils down to the question of how do we even get started with scores in an MCA process. As [9, chapter 5, pages 42–45] notes there are broadly three ways in which the scores in an ACS table may be obtained, depending on circumstances. The first uses objective measurements on a "natural" scale, perhaps dimensioned in dollars or tonnes of CO_2 emissions avoided or amount of landfill diverted to recycling and so on. If this kind of information is available no doubt it should be used, but very often it is not available. The second method for obtaining scores is to use experts to scores by direct rating, say in the 0–100 interval. Done carefully by the right experts, this is a valid and often-used expedient. We are assuming, however, that in our case the many different experts would be needed to cover the rather wide range of policy alternatives and that they simply are not sufficiently available.

This leaves the third common approach to obtaining ACS scores which "is to approach the issue indirectly, by eliciting from the decision maker a series of verbal pairwise assessments expressing a judgement of the performance of each option relative to each of the others." This is central to a number of methods including the popular Analytic Hierarchy Process (AHP) as well as the whimsically named REMBRANDT and MACBETH processes [9, chapter 5, pages 44–45].

We propose a method we call *informed assessment*. It is similar to the third approach above in that we obtain scores by subjective pairwise (or local) comparison of alternatives. Like MCA generally, our approach has both a technical and a social aspect. Technically, we ask for judgments to rank alternatives *by individual criteria*. For each criterion separately, we rank (give ordinal scores for) each alternative. This allows available expertise to be focused where it is most appropriate. For example, the scorer most informed on health could rank the alternatives just on health effects, etc. By ranking the alternatives on individual criteria, the overall complexity of the task is reduced, the work can be distributed, and information resources can be husbanded, compared to holistic ranking of options across all criteria.

The social aspect of our informed assessment ranking method is, in the absence of genuine experts, to rely on informed assessors who are trained in the task asked of them. The assessors for a given criterion are asked to inform themselves on the alternatives to hand with regard to the criterion in question. Thus, for example, an assessor charged with ranking alternatives with regard to health and well-being would read background materials on the alternatives and also use common knowledge/sense to guide them in the ranking task.

Ideally, *team assessment* would be undertaken. Criterion assessment would be undertaken independently by more than one assessor, the results would be compared and discussed, and a final consensus ranking recorded, along with scoring notes for future reference. As noted earlier, this is a standard kind of practice in the social sciences, e.g., in content analysis where meanings of texts are scored by teams of assessors [19]. We emphasize that the resulting rank scores are a point of departure in the MCA process. They are there to get us started on analysis and iterative improvement.

32.3 Ranking by informed assessment

The purpose of this section is to indicate a useful mechanism for doing informed assessment ranking. We assumed the assessor is sufficiently informed to at least begin the task, whose mechanics we describe here.

In Figure 32.3.1 we see in column B that 16 distinct policies have been described briefly and sorted to alphabetical order. Their IDs are listed in column A and were copied to column C, which will be working area that will change during the execution of the task. Column D indicates that the criterion on which ranking is to be done is Health & Well-being. We see that the first three policies in terms of alphabetical order have been moved from column C to column D indicating rank order of 11 (relatively best), 7, and 1 (relatively worst). This is done with the standard spreadsheet operations of cut and then paste.

	A	B	C	D
1	ID	Policy_Objective	To be ranked	Health & Well-being Ranking
2	11	Building Efficiency: Promote and encourage and implement		11
3	7	Complete Streets		7
4	1	Composting		1
5	3	Electric heat pumps for water heating	3	
6	4	Electric stoves	4	
7	12	Grant & rebate opportunities: Monitor	12	
8	6	Green electricity: purchase	6	
9	0	Green finance: Broker and promote loans for efficiency and sustainability	0	
10	8	Legal Analysis on Scope	8	
11	5	Micromobility: Expand and promote bicycle and pedestrian thoroughfares	5	
12	15	Public Outreach & Education	15	
13	14	Recycling	14	
14	13	Reduce emissions from conventional vehicles.	13	
15	2	Single-use plastics: Ban, tax, or otherwise discourage	2	
16	9	Sustainability Review	9	
17	10	Sustainability Survey	10	

Figure 32.3.1: example caption

In Figure 32.3.2 we see that the assessor has judged that the Electric heat pumps for water heating policy (row 5, ID 3) is ranked below ID 11 and above ID 7. In consequence, ID 3 has been inserted into column D, with ID 11 just above and ID 7 just below. This is effected with standard spreadsheet operations. First, a new cell is inserted at D3 with instruction to move the cells down at and below D3 in column D. This leaves an empty cell at D3. The assessor then uses cut and paste to move the 3 in row 5 to D3.

	A	B	C	D
1	ID	Policy_Objective	To be ranked	Health & Well-being Ranking
2	11	Building Efficiency: Promote and encourage and implement		11
3	7	Complete Streets		3
4	1	Composting		7
5	3	Electric heat pumps for water heating		1
6	4	Electric stoves	4	
7	12	Grant & rebate opportunities: Monitor	12	
8	6	Green electricity: purchase	6	
9	0	Green finance: Broker and promote loans for efficiency and sustainability	0	
10	8	Legal Analysis on Scope	8	
11	5	Micromobility: Expand and promote bicycle and pedestrian thoroughfares	5	
12	15	Public Outreach & Education	15	
13	14	Recycling	14	
14	13	Reduce emissions from conventional vehicles.	13	
15	2	Single-use plastics: Ban, tax, or otherwise discourage	2	
16	9	Sustainability Review	9	
17	10	Sustainability Survey	10	

Figure 32.3.2: example caption

Figure 32.3.3 shows IDs 8, 9, and 10 ranked last with notation in column E that they are tied. The assessor has judged these policies to have little or no direct contribution to improving health or well-being.

	A	B	C	D	E
1	ID	Policy_Objective	To be ranked	Health & Well-being Ranking	
2	11	Building Efficiency: Promote and encourage and implement		11	
3	7	Complete Streets		3	
4	1	Composting		7	
5	3	Electric heat pumps for water heating		1	
6	4	Electric stoves	4	8	tied below
7	12	Grant & rebate opportunities: Monitor	12	9	tied below
8	6	Green electricity: purchase	6	10	tied above
9	0	Green finance: Broker and promote loans for efficiency and sustainability	0		
10	8	Legal Analysis on Scope			
11	5	Micromobility: Expand and promote bicycle and pedestrian thoroughfares	5		
12	15	Public Outreach & Education	15		
13	14	Recycling	14		
14	13	Reduce emissions from conventional vehicles.	13		
15	2	Single-use plastics: Ban, tax, or otherwise discourage	2		
16	9	Sustainability Review			
17	10	Sustainability Survey			

Figure 32.3.3: example caption

Figure 32.3.4 shows the completed ranking task. Column D shows the policy IDs in rank order from best to worst, with ties for 12, 8, 9, and 10. Column F shows the raw ranking, translating column D to rank scores. Finally column G resolves the ties in column F. Each alternative in a group of tied alternatives gets a rank score of the average raw rank score of the tied algernatives in the group.

A	B	C	D	E	F	G
ID	Policy_Objective	To be ranked	Health & Well-being Ranking		Raw Ranking	Final Ranking
11	Building Efficiency: Promote and encourage and implement		11		1	1
7	Complete Streets		5		2	2
1	Composting		3		3	3
3	Electric heat pumps for water heating		13		4	4
4	Electric stoves		7		5	5
12	Grant & rebate opportunities: Monitor		4		6	6
6	Green electricity: purchase		1		7	7
0	Green finance: Broker and promote loans for efficiency and sustainability		6		8	8
8	Legal Analysis on Scope		0		9	9
5	Micromobility: Expand and promote bicycle and pedestrian thoroughfares		2		10	10
15	Public Outreach & Education		14		11	11
14	Recycling		15		12	12
13	Reduce emissions from conventional vehicles.		12	tied below	13	14.5
2	Single-use plastics: Ban, tax, or otherwise discourage		8	tied below	14	14.5
9	Sustainability Review		9	tied below	15	14.5
10	Sustainability Survey		10	tied above	16	14.5

Figure 32.3.4: example caption

Is the informed assessment well informed? We certainly and should question whether it is. Would a composting policy (ID 3) really contribute more to health and well-being than electric heat pump water heaters, which would replace natural gas heaters? If ranking decisions are not-obvious more research—getting better informed—can and should be done. Team informed assessment can help as can convening a group for crowd assessment.

At some point, however, we need to move on, always provisionally of course. Next up, we discuss what happens then, once we have provisionally accepted rankings for each of the criteria in play.

Chapter 33 MCDM: Converting Rank Scores to Cardinal Utility Scores

33.1 Utility elicitations

Continuing where we left off in the previous chapter, with the figure there, Figure 32.3.4, reproduced here as Figure 33.1.1.

A	B	C	D	E	F	G
ID	Policy_Objective	To be ranked	Health & Well-being Ranking		Raw Ranking	Final Ranking
11	Building Efficiency: Promote and encourage and implement		11		1	1
7	Complete Streets		5		2	2
1	Composting		3		3	3
3	Electric heat pumps for water heating		13		4	4
4	Electric stoves		7		5	5
12	Grant & rebate opportunities: Monitor		4		6	6
6	Green electricity: purchase		1		7	7
0	Green finance: Broker and promote loans for efficiency and sustainability		6		8	8
8	Legal Analysis on Scope		0		9	9
5	Micromobility: Expand and promote bicycle and pedestrian thoroughfares		2		10	10
15	Public Outreach & Education		14		11	11
14	Recycling		15		12	12
13	Reduce emissions from conventional vehicles.		12	tied below	13	14.5
2	Single-use plastics: Ban, tax, or otherwise discourage		8	tied below	14	14.5
9	Sustainability Review		9	tied below	15	14.5
10	Sustainability Survey		10	tied above	16	14.5

Figure 33.1.1: example caption

We now need to see how to convert the ranking scores in column G, which are on an ordinal scale of preference, to Cardinal utility scores, which are on an interval scale. To do this, we assign a utility of 100 (although this is arbitrary) to the best alternative, ID(11). We assign a utility of 0 (again arbitrary) to the worst alternative. Because there are ties, we pick ID(8) for purposes of reference. Note carefully that we are only evaluating scores for the alternatives on health & well-being. Further, we have all along been making assumptions about *preferential independence*, that is, that how well an alternative ranks on health & well-being is not influenced by the scores of the alternatives on any of the other attributes. This is a reasonable assumption here, we submit, but it has to be checked.

Next, we pick an alternative between ID(11) and ID(8). Because we have an odd number of distinct ranks (13) we pick the one in the middle, rank 7, associated with ID(1), composting. If we had an even number of ranks between ID(11) and ID(8), we would simply pick either of the ranks bordering the midpoint.

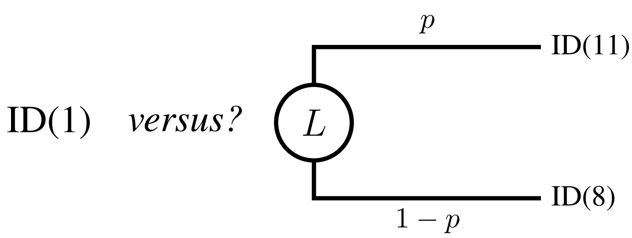

Figure 33.1.2: If $p = 0.5$, does the informed assessor prefer ID(1), on the left, to the lottery on the right?

We are now in position to ask our informed assessor (IA) a crucial question. See Figure 33.1.2. We ask the IA to imagine that it has a choice between ID(1)—implementation of a composting policy—for certain or a lottery in which with probability 0.5 an ID(11)—a building efficiency policy—would be enacted and implemented and with probability 0.5 only an ID(8)—legal analysis on scope—policy would be implemented. After careful reflection, does the IA prefer ID(1) for certain or a lottery on the right of Figure 33.1.2?

We assume that our IA is able to answer the question with one of three responses:

1. IA prefers ID(1) for certain to the lottery. Formally, ID(1) $\succ_{IA} L$.
2. IA prefers the lottery to ID(1). Formally, $L \succ_{IA}$ ID(1).
3. The IA values the lottery and ID(1) equally. Formally, $L \sim_{IA}$ ID(1).

Let's take these cases one at a time.

1. ID(1) $\succ_{IA} L$. Given this we can point out that if p is large enough, and it might equal 1, then the IA would surely prefer the lottery to ID(1). Now the question is: If you could freely set the value of p between 0.5 and 1.0, what would be the smallest value of p at which you would be indifferent between ID(1) and the lottery? In other words, what is the smallest value of $0.5 < p' \leq 1$ such that $L \sim_{IA}$ ID(1)? Once we have our answer we can calculate the utility score of ID(1), $u(ID(1)) = p'u(ID(11) + (1-p')u(ID(8)) = p' \times 100 + (1-p') \times 0 = 100p'$. How do we know this? Because the utility of ID(1) is at p' equal to the utility of the lottery, L, and the utility of the lottery is, by utility theory the expected value of the lottery.
2. $L \succ_{IA}$ ID(1). The IA prefers the lottery to ID(1). Now, much as before, we ask: If you could freely set the value of p between 0.0 and 0.5, what would be the largest value of p at which you would be indifferent between ID(1) and the lottery? As before, this fixes the utility of ID(1) at $100p'$, where p' is the declared indifference probability.
3. Finally, if the IA values the lottery and ID(1) equally, then the utility of ID(1) is the indifference value of p, 0.5, times 100, $100p = 50$.

The straight line has a slope of 1 and the utility values go from 0 to 100. On the straight

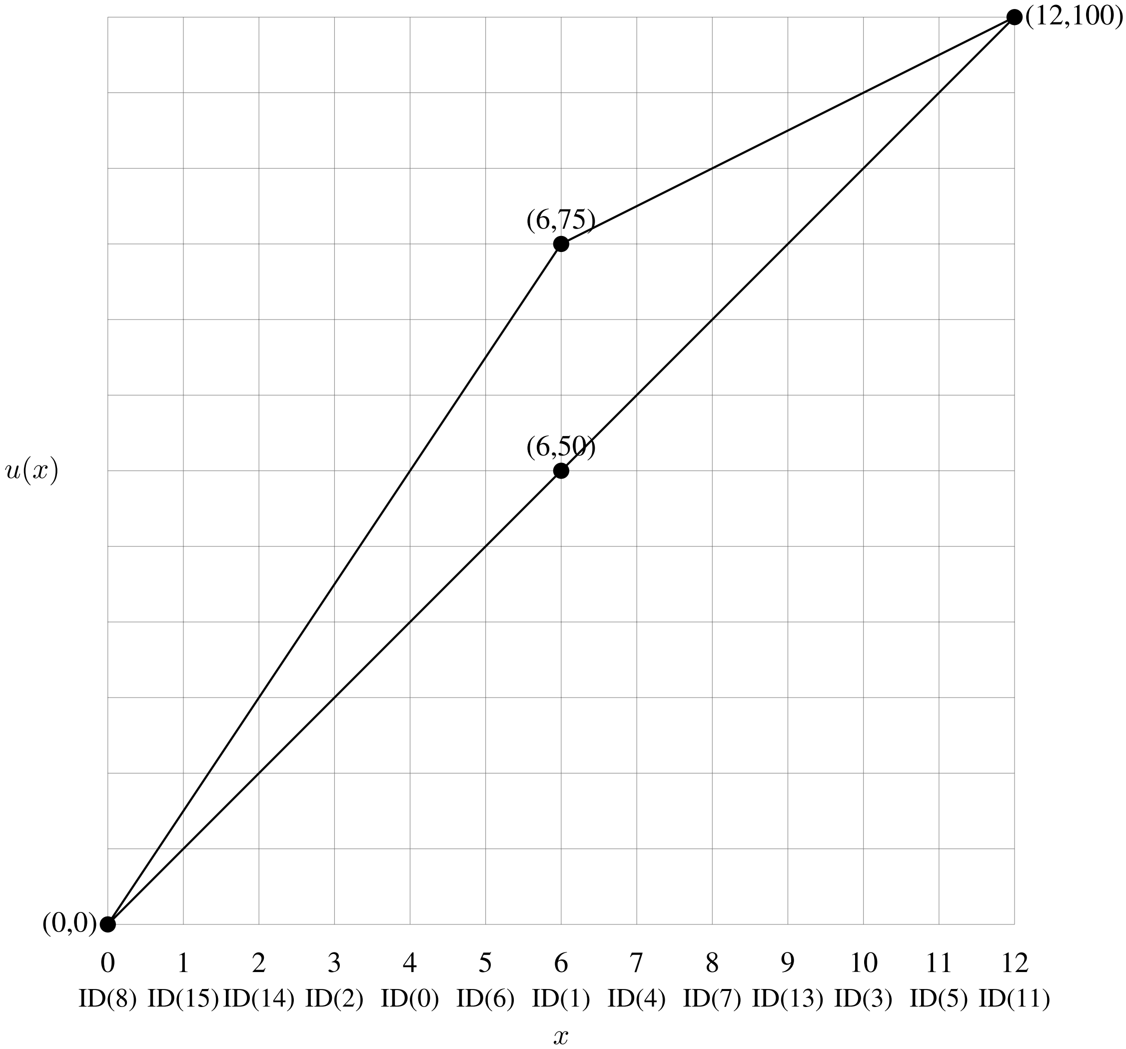

Figure 33.1.3: Utility function on the inverse ranked alternatives, from 0. $0 \leq u(x) \leq 100$.

line, $u(x) = 8\frac{1}{3}$. The squares in the figure are set to $8\frac{1}{3}$ on each side. So, for example, $u(ID(1)) = 6 \times 8\frac{1}{3} = 50.0$. If we accept this, we are assuming that in terms of cardinal utility values, the rank scores are evenly spaced so the the difference in utility between any to adjacent scores is the same. This is not credible in general, although in some cases it may be an acceptable approximation. We can do better with the method introduced above. Let us say for the sake of an example that the indifference probability is 0.75, implying $u(ID(1)) = 75$.

Now we have a new utility function, for $0 \leq x \leq 6, u(x) = 12.5x$ (the slope of the line segment is $(75/6) = 12.5$) and for $6 \leq x \leq 12, u(x) = 75 + 4.166(x - 6)$ (the slope of the line segment is $(25/6) = 4\frac{1}{6}$).

Of course, this assumes equal spacing between 0 and 6 and between 6 and 12. If we want to have a finer grained assessment, we repeat the process, assessing lotteries with outcomes 0 and 6, and with outcomes 6 and 12. We can in this way assess utilities directly for each alternative, either through direct assessment or through approximation.

Points arising:

1. The concave utility curve (of line segments) running from (0,0) to (6,75) to (12, 100) is commonly said to indicate risk averse preferences. That is misleading interpretation in this case. In utility theory, preferences and probabilities are interdefined. They are as Richard Jeffrey calls them *preference-probabilities* [14]. We have exploited that fact in developing our utility function, specifically in finding the utility of ID(1). The correct interpretation is to say that ID(6) is 25 utiles less than ID(11) and 75 utiles greater than ID(8) on the indicated scale.
2. Sensitivity analysis (and more broadly, post-solution analysis or model analysis [16]) needs to be done for every modeling effort. This is most emphatically the case when "heroic approximations" are undertaken. In particular, when utility values for some alternatives are interpolated, as in the (0,0) to (6,75) to (12, 100) curve of Figure 33.1.3. We will lavish much attention to post-solution analysis for decision models in the sequel.

File: MCDM-utility-rank-scoring.tex

Chapter 34 Policy MCA

What can we learn from corpora of climate and environmental policies?

Humanity is engaged in major transitions necessitated by climate and environmental challenges. These include transitions: to net zero greenhouse gas emissions; for adaptation to a much hotter climate; to sustainable use of resources. In the American scene (on which we focus here), as well as many other places, a very large part of the responsibility for undertaking these transitions is distributed to the sub-national level. Even with federal support, state and local authorities will develop and administer programs giving policy response to the transitions.

Several score policy objectives. actively under discussion and implementation by state and local governments, can be used for furthering the major transitions. Examples include policy support for: composting, building electrification, food rescue services, public transit, waste regulation, bicycle and pedestrian thoroughfares, heat gap management, EV charging stations, and much more. We know of no authoritative list that is close to being complete, but we have developed and curated a list that is reasonably comprehensive, and we continue to augment this corpus of sub-national policies.

The complexity of the associated decision processes is daunting. To illustrate with the simplest sort of example, if there is budget during a planning period for 8 policies and there are 50 policies under consideration then there are more than 500 million portfolios of projects to choose from.

Via scholarship, literature surveys, and qualitative research (interviews, participant observations, etc.), we have scored a corpus of more than 50 policies with regard to multiple criteria, social feasibility, and associated uncertainties. We present findings from the resulting scored corpus, based on both exploratory analysis and an expansive form of computational decision analysis methods. These findings offer credible insights into how best to focus resources for the climate and environmental challenges we face. High-level policy assessment yields useful general guidance in devising specific program implementations.

Chapter 35 AHP

2022-5-11: I think this chapter is in pretty good shape. I'll need to develop in-class lecture material, slides. I'm a little worried about having enough material to fill an hour, but perhaps I can fill in with some exercises and/or a case study or two, taken from the next class. For now, however, this is OK.

Main topics:

1. Background and protocol for AHP (analytic hierarchy process) decision modeling
   Slide deck:
2. Example of application of AHP modeling in energy- and sustainability-related studies

Assigned reading(s):

a. This chapter of the *Lecture Notes.*
b. D'Alpaos, C., & Bragolusi, P. (2019). Prioritization of Energy Retrofit Strategies in Public Housing: An AHP Model. [6]

Reference material:

a. Teknomo, K. (n.d.-a). Analytic Hierarchy Process (AHP) Tutorial. https://mathsci2.appstate.edu/~wmcb/Class/5340/ClassNotes141/AHP/AHP%20Tutorial%20Teknomo.pdf

35.1 AHP essentials

The analytic hierarchy process (AHP) was invented by Thomas L. Saaty and has mostly been developed by him as well. This development of AHP has led Saaty to a rather complex generalization, called analytic network process (ANP). We will limit our discussions to AHP because it is so widely used as a multiple criteria decision analysis (MCDA) method. Also, it is more apt than ANP for the applications we have in mind. See the references for pointers to more information on both AHP and ANP.

AHP is a ingenious method for amalgamating preference judgments into an overall scoring (and hence ranking) of objects, whether they be concrete entities of direct interest (shoes, ships, and sealing wax, etc.), weights in a decision model, complex, many-attributed policies, or indeed just about anything. The key to the method is to obtain from the decision makers (DMs) a number of pairwise comparisons of the alternatives to hand, and to do so in a manner that yields a preference judgment score that is on a ratio scale. In consequence, the AHP scores are *not* utilities. Having ratio scores, however, yields a number of advantages and in the end AHP is justified by its performance and acceptance, rather than its foundational credits.

In order to show how this works, I'm going to crib some examples from

Teknomo, K. (2022). Analytic Hierarchy Process (AHP) Tutorial. https://mathsci2.appstate.edu/~wmcb/Class/5340/ClassNotes141/AHP/AHP%20Tutorial%20Teknomo.pdf

and elaborate and comment on them. The main comments I want to make, however, are not present in Teknomo's popular tutorial, useful as it is.

The first and most crucial step in AHP is to identify a collection of n alternatives and then ask the DM(s) to undertake $n(n-1)/2$ pairwise comparisons and report scores in a certain way, which I will now illustrate.

Given n alternatives, we form an $x \times n$ matrix A with typical element a_{ij}:

$$A = (a_{ij})$$

and ask the DM to fill it in with judgments about the attractiveness ratios of the alternatives. The assumption here is that each alternative i has implicitly or explicitly in the DM's mind an attractiveness, $a(i)$ measurable on a ratio scale. Instead of asking the DMs directly for their $a(i)$ attractiveness values, AHP asks them directly for the paired ratios of their attractiveness values:

$$\frac{a(i)}{a(j)}$$

. That is, A matrix element

$$a_{ij} = \frac{a(i)}{a(j)}$$

which is ellicited directly in a certain way from the DM. Again, only the fraction

$$\frac{a(i)}{a(j)}$$

is directly elicited. The AHP protocol then kicks in for everything else.

Let's see how the elicitation works. We'll use an example from Teknomo. The DM is asked to make comparisons pertaining to three items of choice: an apple, a banana and a cherry, with implicit attractivenesses $a(i), a(2) and a(3)$, so our A matrix is 3×3. We need the 9

$$\frac{a(i)}{a(j)}$$

values. We set the diagonal three values to 1, $a_{ii} = 1$ because

$$\frac{a(i)}{a(i)} = 1$$

For the other a_{ij} values, where $i \neq j$, we say this:

> If you like/prefer/desire item i more than item j determine on a 1 to 9 scale how many <u>times</u> i is better than j. For example, if $i = 1$ (apple), $j = 3$ (cherry), and you like the apple 5 times as much as the cherry, enter a 5 for the value of $a_{1,3}$ and enter its reciprocal $\frac{1}{5}$ for $a_{3,1}$.
>
> If you like/prefer/desire item j more than item i determine on a 1 to 9 scale how many <u>times</u> j is better than i. For example, if $i = 1$ (apple), $j = 2$ (banana), and you like the banana 3 times as much as the apple, enter a 3 for the value of $a_{2,1}$ and enter its reciprocal $\frac{1}{3}$ for $a_{1,2}$.

> Continue in this fashion until all of the remaining entries in A are filled in. This part requires $n(n-1)/2$ judgments in all.

Suppose for the sake of the example that our DM has done this and produced the following A matrix of pairwise comparisons.[1]

```
    A
Out[28]:
array([[1.        , 0.33333333, 5.        ],
       [3.        , 1.        , 7.        ],
       [0.2       , 0.14285714, 1.        ]])
```

Here we have entered Python. We now use this code to extract the eigenvalues and the eigenvectors from A:

```
import numpy as np
from numpy.linalg import eig

A = np.array([[1, 1/3, 5],
              [3, 1, 7],
              [1/5,1/7,1]])

print(f'A = {A}')
lambdas,eigens = eig(A)
```

This yields

```
lambdas.round(3)
Out[42]: array([ 3.065+0.j   , -0.032+0.445j, -0.032-0.445j])
```

and

```
eigens.round(3)
Out[41]:
array([[ 0.393+0.j   , -0.196+0.34j , -0.196-0.34j ],
       [ 0.914+0.j   ,  0.914+0.j   ,  0.914-0.j   ],
       [ 0.101+0.j   , -0.051-0.088j, -0.051+0.088j]])
```

Notice that the calculations return imaginary numbers, which we can ignore. That is, we ignore the imaginary parts.

---

[1]See AHP.py for a supporting script.

```
eigens.real.round(3)
Out[47]:
array([[ 0.393, -0.196, -0.196],
       [ 0.914,  0.914,  0.914],
       [ 0.101, -0.051, -0.051]])
```

Anyway, AHP directs us to select the principal (largest) eigenvalue and its associated vector. That would be 3.065 and the corresponding first column of the eigenvector matrix, since the largest eigenvalue is the first one (and hence most influential).

```
eigens.real[:,0].round(3)
Out[48]: array([0.393, 0.914, 0.101])
```

From the selected eigenvector, we can read off the ranking of the three items: banana is preferred to apple is preferred to cherry. Larger numbers indicate higher preference.

This much is easily recovered from the paired comparisons matrix, A. AHP goes further because the eigenvector scores are on a ratio scale. AHP has us normalize the selected eigenvector so that the scores sum to 1. This is called the priority vector.

```
priority = eigens.real[:,0]/eigens.real[:,0].sum()

priority
Out[52]: array([0.27895457, 0.649118  , 0.07192743])
```

This is merely a rescaling of a real-valued (ratio-scaled) vector. We can also rescale it relative to 1, by dividing by the smallest entry:

```
priority/priority[-1]
Out[53]: array([3.87827795, 9.02462393, 1.        ])
```

What's going on here? Well, it's a long and complicated story. Very roughly, think of the principle eigenvector as the "best" estimate of $a(1), a(2), a(3)$, and note that if we were to post-multiply A by such a vector we would get the same vector multiplied by a constant (that's what *eigenvector* means in German!). So, what AHP is doing here is extracting an estimate of the $a(i)$s. It's certainly worth considering how good an estimate this is. We shall focus on the practicalities. Does it seem to give good answers? Certainly it gives answers that have been accepted and used. Again, a key point of the method is that these estimated $a(i)$ values are real numbers measured on a ratio scale, unlike utility values. Note also that everything is linear and additive. This need not be accurate in fact. AHP is an approximation method making strong linearity assumptions.

An attractive feature of AHP is that it easily accommodates group decisions. Instead of relying on a single DM to populate the pairwise comparison matrix, we can use a group of DMs.

Each individual is asked to provide their own pairwise comparison matrix. The group matrix entries are constructed as the geometric mean of the corresponding entries in the individual matrices. The geometric mean is the n^{th} root of the product of n values. In this way, AHP handles interpersonal comparison of preferences, something in theory not permitted in utility theory.

As a form of validation, AHP supports a consistency index (CI) and a consistency ratio (CR). For technical reasons hinted at above, given n alternatives, the largest Eigen value, denoted $\lambda_{\max}$ should equal n. CI is defined as follows:

$$\text{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{35.1}$$

Using simulation, Saaty found random levels of CI for many pairwise comparison tables of various sizes. This led to RI, the random consistency index, shown in Table 35.1.1.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 35.1.1: Random consistency index (RI).

In our running example, CI = 0.0484 and $n = 3$ so CI/RI is 8.3% = 0.0484/0.58. The rule of thumb in AHP is that a CR of less than 10% is acceptable. And if we get a higher score? We go back to the DM(s) and ask them to reconsider and to give us a more consistent pairwise comparison matrix.

35.1.1 Example: AHP with a hierarchy

Next we turn to a question that the reader no doubt has been wondering about: Where is the hierarchy in AHP and how do multiple criteria come in?

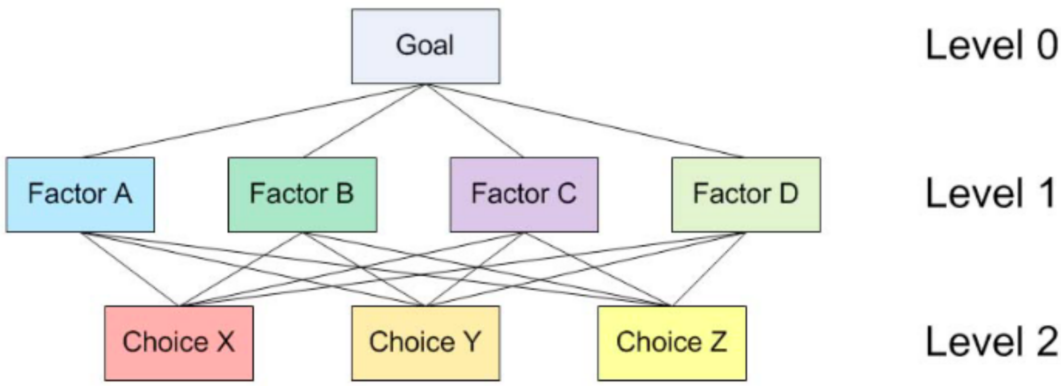

Figure 35.1.1: Example hierarchy for an AHP exercise. From Teknomo.

The answer is straightforward. So far, we have seen how to get the priority vector for a collection of alternatives. Now we will organize a decision problem as a hierarchy with multiple criteria in play. We will straightforwardly apply what we have learned so far about the priority vector, etc. and we will be able to rank and score a number of alternatives that are compared on multiple criteria. I'll continue to crib examples from Teknomo, adding comments and clarification as appropriate.

See Figure 35.1.1. We have a hierarchy with four "factors" (goals, objectives, criteria) at level 1 and three "choices" (alternatives, options) that are to be compared with regard to the four factors. The structure can be elaborated indefinitely. The key thing is to have a single goal (objective, etc.) at the top, level 0. After that, criteria are elaborated in tree fashion down as many levels as desired. For example, factor B might be elaborated in terms of 3 sub-criteria, which may be broken out further, etc. At the bottom of this tree are the "leaves" that is the lowest level criteria. These criteria do not need to be all at the same level. Below the leaves we have, as in Figure 35.1.1 the various alternatives, each alternative connected to each of the leaves of the criteria tree.

We'll stick to the hierarchy in Figure 35.1.1 for the sake of this example, but it should be apparent how it can be extended more or less indefinitely.

The first thing we do at this point is to construct the paired comparison matrix for level 1 and calculate the AHP priority vector, CI and CR. Teknomo asks us to imagine the example in Figure 35.1.2. This is of course an abstract example. We are not told what A, B, C, and D are.

Criteria	A	B	C	D	Priority Vector
A	1.00	3.00	7.00	9.00	57.39%
B	0.33	1.00	5.00	7.00	29.13%
C	0.14	0.20	1.00	3.00	9.03%
D	0.11	0.14	0.33	1.00	4.45%
Sum	1.59	4.34	13.33	20.00	100.00%

λ_{max} =4.2692, CI = 0.0897, CR = 9.97% < 10% (acceptable)

Figure 35.1.2: Example paired comparison matrix for level 1, Figure 35.1.1. From Teknomo.

Finding an acceptable level of inconsistency, we continue to level 2 and develop paired comparison matrices for the individual criteria. Figure 35.1.3 presents the matrix for factor (criterion) A, Figure 35.1.4 for criterion B. Both have acceptable levels of inconsistency.

Choice	X	Y	Z	Priority Vector
X	1.00	1.00	7.00	51.05%
Y	1.00	1.00	3.00	38.93%
Z	0.14	0.33	1.00	10.01%
Sum	2.14	2.33	11.00	100.00%

Figure 35.1.3: Example paired comparison matrix for level 2, criterion (factor) A, Figure 35.1.1. From Teknomo. $\lambda_{\max}$ =3.104, CI = 0.05, CR = 8.97% $<$ 10% (acceptable)

At this point the Teknomo example declines to go further and develop paired comparison

Choice	X	Y	Z	Priority Vector
X	1.00	0.20	0.50	**11.49%**
Y	5.00	1.00	5.00	**70.28%**
Z	2.00	0.20	1.00	**18.22%**
Sum	8.00	1.40	6.50	100.00%

$\lambda_{\max}$ =3.088, CI = 0.04, CR = 7.58% < 10% (acceptable)

Figure 35.1.4: Example paired comparison matrix for level 2, criterion (factor) B, Figure 35.1.1. From Teknomo.

tables for factors C and D. The reason given is that the governing priority vector, for Figure 35.1.2 gives low values for criteria C (9.03%) and D (4.45%) and so Teknomo elects to neglect them as an approximation. In consequence, we adjust the priority vector for Figure 35.1.2. The adjusted weight for factor A is now

$$\frac{57.39\%}{57.39\% + 29.13\%} = 0.663 \tag{35.2}$$

The adjusted weight for factor B is now

$$\frac{29.13\%}{57.39\% + 29.13\%} = 0.337 \tag{35.3}$$

Using these weight factors and Figures 35.1.3 and 35.1.4, we calculate the overall weights (normalized scores) for the three options as follows:

$$X = (0.663)(51.05\%) + (0.337)(11.49\%) = 37.72\% \tag{35.4}$$

$$Y = (0.663)(38.93\%) + (0.337)(70.28\%) = 49.49\% \tag{35.5}$$

$$Z = (0.663)(10.01\%) + (0.337)(18.22\%) = 12.78\% \tag{35.6}$$

These are summarized by Teknomo in Figure 35.1.5.

	Factor A	Factor B	Composite Weight
(Adjusted) Weight	*0.663*	*0.337*	
Choice X	51.05%	11.49%	**37.72%**
Choice Y	38.93%	70.28%	**49.49%**
Choice Z	10.01%	18.22%	**12.78%**

Figure 35.1.5: Overall composite weights of the example. From Teknomo.

35.1.2 Example: Sustainability policies

Now we develop another example, in more specificity. EU taxonomy for sustainable activities `https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en`. The Taxonomy Regulation establishes six environmental objectives

1. Climate change mitigation
2. Climate change adaptation
3. The sustainable use and protection of water and marine resources
4. The transition to a circular economy
5. Pollution prevention and control
6. The protection and restoration of biodiversity and ecosystems

Different means can be required for an activity to make a substantial contribution to each objective.

We consider four criteria from this taxonomy, because they are most pertinent to the policies we shall consider: mitigation (W), adaptation (X), circular (Y), and pollution (Z).

Suppose we are given a pair comparison matrix for these four criteria as follows:

```
EU
Out[11]:
matrix([[1.        , 5.        , 7.        , 3.        ],
        [0.2       , 1.        , 4.        , 2.        ],
        [0.14285714, 0.25      , 1.        , 0.5       ],
        [0.33333333, 0.5       , 2.        , 1.        ]])
```

This matrix has the associated priority vector

```
priority =
 [[0.595]
 [0.205]
 [0.064]
 [0.136]]
```

We now consider four policy alternatives: composting (A), municipal building efficiency (B), tree canopy protection (C), heat pump water heater incentives (D). On each criterion, the alternatives are rated (by expert or informed assessor or objectively if possible) on a scale of 1 to 4 (*,**, ***, ****) with meanings: (1) no or negligible value, (2) some value, (3) substantial value, and (4) high value.

The following ACS table has been produced.

```
ACS
Out[15]:
matrix([[3, 1, 4, 2],
        [3, 2, 1, 2],
        [2, 3, 1, 2],
        [4, 1, 1, 2]])
```

Let's use the ratings this way: we'll just treat them as ratio-scaled scores!

This leads to the following four paired comparison matrices for A, B, C, and D:

```
ACS = np.matrix([[3, 1, 4, 2],
                 [3, 2, 1, 2],
                 [2, 3, 1, 2],
                 [4, 1, 1, 2]])



A = np.matrix([[1,1,3/2,3/4],
               [1,1,3/2,3/4],
               [2/3,2/3,1,1/2],
               [4/3,4/3,2,1]])

B = np.matrix([[1,1/2,1/3,1],
               [2,1,2/3,2],
               [3,3/2,1,3],
               [1,1/2,1/3,1]])

C = np.matrix([[1,4,4,4],
               [1/4,1,1,1],
               [1/4,1,1,1],
               [1/4,1,1,1]])

D = np.matrix([[1,1,1,1],
               [1,1,1,1],
               [1,1,1,1],
               [1,1,1,1]])
```

From these we get the individual priorities:

```
altPriority:
Alternative A:
[[0.25      ]
 [0.25      ]
 [0.16666667]
 [0.33333333]]
altPriority:
Alternative B:
[[0.14285714]
```

```
 [0.28571429]
 [0.42857143]
 [0.14285714]]
altPriority:
Alternative C:
[[0.57142857]
 [0.14285714]
 [0.14285714]
 [0.14285714]]
altPriority:
Alternative D:
[[0.25]
 [0.25]
 [0.25]
 [0.25]]
```

Which nets out as the final priority list:

```
[[0.24877567]
 [0.25040811]
 [0.23009887]
 [0.27071735]]
```

Interestingly, option D is judged the best.

35.1.3 Discussion

The example just presented is a toy instance of an important general class: choosing among a collection of policies on multiple criteria. The example was kept small for the sake of clarity and understanding, but we should like to scale up, and we can and we shall. Points arising:

1. The scores in the ACS table for the alternatives were on a 1-4 scale, which was assumed to be a ratio scale, not an interval or ordinal scale. In short, we did this in order to suit the requirements of the AHP, where we need ratio-scale scoring. Is it convincing and plausible?
2. The results of the analysis are not meant to dictate a decision. Instead, they are meant to serve as useful input for further reflection and discussion. What might we want to know given these results so that we can modify the model and re-run the analysis? Besides the four criteria given, what other criteria are important and how would we score them?
3. How should we analyze the model to get a sense of its resilience and stability under changes in key values?

35.2 A small example

A nice little report, good for illustrating a real use of AHP in energy and sustainability policies.

D'Alpaos, C., & Bragolusi, P. (2019). Prioritization of Energy Retrofit Strategies in Public Housing: An AHP Model. In F. Calabrò, L. Della Spina, & C. Bevilacqua (Eds.), New Metropolitan Perspectives (pp. 534–541). Springer International Publishing. https://doi.org/10.1007/978-3-319-92102-0_56 [6]

Alternative energy-saving measures for a public housing project:

1. Installment of condensing boilers
2. Installment of double-glazed windows
3. Application of insulating layers on the external walls, roofs and ceilings
4. Installment of condensing boilers and double-glazed windows
5. Installment of condensing boilers and application of insulating layers on the external walls, roofs and ceilings
6. Installment of double-glazed windows and application of insulating layers on the external walls, roofs and ceilings
7. Installment of condensing boilers and double-glazed windows and application of insulating layers on the external walls, roofs and ceilings

Process:

- Alternatives determined by "experts"
- Alternatives discussed by focus groups
- Focus groups determined criteria and values hierarchy. See Figure 35.2.1 below.
- Experts produced the pairwise comparison matrices
- AHP then produced results, recorded in Figure 35.2.2 below.

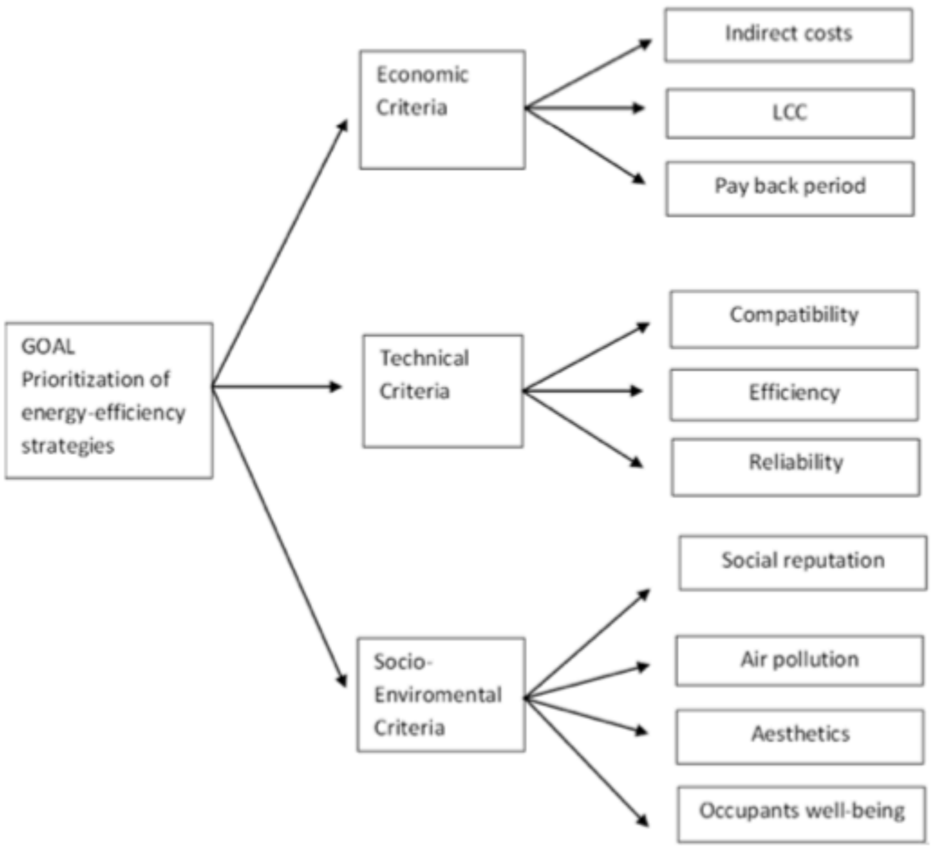

Fig. 1. Hierarchy

Table 1. Descriptions of criteria and sub-criteria.

Criteria	Sub-criteria	Description
Economic	Indirect costs	Costs related to inconveniences to occupants
	LCC	Life cycle cost over a 30-year period
	Pay back period	Time to recover investment costs
Technical	Compatibility	Compatibility of new with older
	Efficiency	Improvement in technical performance
	Reliability	Frequency of failures and system safety
Socio-Environmental	Social reputation	Reputation capital increase
	Air pollution	CO_2 emissions reduction
	Aesthetics	Facade attractiveness improvement
	Occupants' well-being	Comfort improvement

Figure 35.2.1: Fig. 1 and Table 1 from [6]

Table 2. Criteria and sub-criteria priority vectors.

Criteria	Priority vector	Sub-criteria	Priority vector
Economic	0.637	Indirect costs	0.105
		LCC	0.636
		Pay back period	0.259
Technical	0.105	Compatibility	0.143
		Efficiency	0.715
		Reliability	0.142
Socio-Environmental	0.258	Social reputation	0.260
		Air pollution	0.381
		Aesthetics	0.232
		Occupants' well-being	0.127

Table 3. Ranking of alternatives and final priority vectors (ideals and normal).

Alternatives	Normal	Ideals
1	0.100	0.370
2	0.162	0.600
3	0.270	1.000
4	0.057	0.212
5	0.105	0.389
6	0.188	0.694
7	0.118	0.435

Figure 35.2.2: Results: Tables 2 & 3 from [6]

35.2.1 Discussion

What do we think of this? A first point is that the discussion of the model's consistency is technically flawed. That's a minor problem. Here are some questions to chew on.

a. Are the results convincing?
b. What do we think of the hierarchy, the values tree? Is anything important missing? Is it internally coherent?
c. How might they have done better?
d. Is there something else that we'd like to know?
e. Does it seem that the process will satisfy the stakeholders?
f. Parameters given a model may go wrong by being biased (systematically too high or too low) or be being imprecise (having high re-estimation variance). What about the present case? How might we detect bias or imprecision? How might we adapt to it if we think either is present?
g. How much of this problem could be well handled with cost-benefit analysis? What are the pros and cons of it?
h. How might a study such as this be made use of in other circumstances? What can we learn here that would or might be useful elsewhere?
i. The model is atemporal. What could happen in the time domain that would affect outcomes of interest to us? What are the downside risks? What are the upside risks?
j. What if we choose at random among the alternatives considered? How large is the downside? What if we choose at random among the top quartile (more generally, among the top n^{th} quantile)? Are there reasons we might want to consider a randomized choice in some form or another?
k. What is not in the model that might be a cause for worry?

35.3 For more information

Good YouTube overviews:

BPMSG. (2010, April 19). Analytic Hierarchy Process AHP - Business Performance Management. https://www.youtube.com/watch?v=18GWVtVAAzs

BPMSG. (2011, June 27). AHP/ANP Practical Application with Pros and Cons. https://www.youtube.com/watch?v=ydKGNb4bgYY

The analytic hierarchy process in natural resource and environmental decision making /

Title: The analytic hierarchy process in natural resource and environmental decision making Series: Managing forest ecosystems ; v. 3. Publication: Dordrecht ; Boston : Kluwer Academic Publishers, c2001. Format/Description: Book Available Van Pelt Library SD561 .A62 2001

Teknomo, K. (n.d.-a). Analytic Hierarchy Process (AHP) Tutorial. https://mathsci2.appstate.edu/~wmcb/Class/5340/ClassNotes141/AHP/AHP%20Tutorial%20Teknomo.

pdf

Teknomo, K. (n.d.-b). Linear Algebra tutorial: Eigen Value and Eigen Vector. Retrieved May 6, 2022, from https://people.revoledu.com/kardi/tutorial/LinearAlgebra/EigenValueEigenVector.html

Chapter 36 MCDM Tools

2022-5-19: Quickly, as I am as usual behind.

The purpose of this chapter is to record instructions and documentation for a series of decision analysis (DA) tools to be developed by the Lab. We focus above all on multiple criteria decision making (MCDM; alias: analysis, MCDA) tools. These fall broadly into several categories and we want to implement and experiment with them all, including:

1. MAUT, multi-attribute utility theory; discussed above in the *Workbook*, especially wrt SMARTER, which should be our focus.
2. AHP (Analytic Hierarchy Process); discussed in Chapter 35 of the *Workbook*.
3. PROMETHEE
4. ELECTRE
5. TOPSIS

Basically, we need three types of code:

i. Data acquisition and model setup
ii. Model calculation
iii. Model analysis services (post-solution analysis services)

What we are aiming for is a number of end-to-end cases that can be treated by each of the MCDM methods, above. Initially, you should create plausible test cases for purposes of development and use them during development. Realistic cases will be secured as we proceed.

On programming, we'll start with (i). We need a single Python module that performs these tasks. Assume that ACS and other tables are in individual CSV files, perhaps as exported from Excel. Read them individually into Python pandas DataFrames. Assume that each CSV file has a corresponding .txt file that describes it and documents it. Read in the associated .txt file as a string. Then pickle both variables in the order (doc string, DataFrame, DataFrame, . . .), using a suitably descriptive file name. Some (most) models will have more than one DataFrame/table. For example, a MAUT model will typically have an ACS table and a single row table of criteria weights.

On (ii), we need for now one module for each type (one for MAUT/SMARTER, one for AHP, etc.) I suggest we try to get this done for next week. After that we can do the others.

On (iii), this is where the real challenges and creativity come in. But before we can do post-solution analysis, we need to get solutions! So, once (i) and (ii) are under control, we'll commence on (iii).

You can read about the various MCDM methods in:

Greco, S., Ehrgott, M., & Figueira, J. R. (Eds.). (2016). Multiple Criteria Decision Making: State of the Art Surveys (2nd ed.). Springer.

This is posted on the Dropbox folder in Readings/ in the file
Greco et al. - 2016 - Multiple Criteria Decision Making State of the Ar.pdf

This is a good source on MAUT and TOPSIS, and is generally valuable:

Yoon, K. P., & Hwang, C.-L. (1995). Multiple Attribute Decision Making: An introduction. Sage Publications.

It is posted on the Dropbox folder in Readings/.

Then there is

Great Britain & Department for Communities and Local Government. (2009). Multi-criteria analysis: A manual. Communities and Local Government. http://www.communities.gov.uk/documents/corporate/pdf

It is posted on the Dropbox folder in Readings/ as:

Great Britain and Department for Communities and Local Government - 2009 - Multi-criteria analysis a manual.pdf

Part IV

Phase II: Policy Analysis and Configuration

Until this point we have been concerned with Phase I of the Climate Decision Lab's activities, focusing on collecting and documenting a comprehensive set of sub-national policies and on evaluating them comparatively using a MCDM approach (PROMETHEE). In Phase II we focus on analyzing, configuring and assessing individual policies or policy types (again with MCDM methods and taking into account co-benefits).

Chapter 37 Challenge Categories for Energy and Sustainability Modeling

Challenge areas for energy modeling:

1. Cost and consumption models (e.g., EROI calculations); energy and materials accounting models

   Generally, these are "bean counting" models.

   Urban energy use modeling, e.g.,

   > An integrated urban energy model that enables modeling components of urban operational and embodied energy can provide a more holistic image of urban energy use and help understand the interrelation between various components and the trade-offs between the different planning and design strategies to achieve more sustainable cities. [**?**]

   More generally, system energy use models, urban energy use models being a special, albeit important, case.

   Apt approaches include: life cycle assessment modeling https://www.nakedcapitalism.com/2021/07/whats-the-carbon-footprint-of-a-wind-turbine.html
2. Accommodating VRE (variable renewable energy)

   Ümit: district modeling at IIP. Country, district, household.

   Modeling (ultimately individual) behavior and investment in the face of VRE, along with possibilities of storage in various forms.

   Apt approaches include: microsimulation ABMs with simulation optimization, activity based modeling, synthetic data to model behavior.
3. Assessing neighborhoods, amenities, quality of life while going green and having to deal with climate change (e.g., heat waves).

   Access to grocery stores, pharmacies, restaurants, barbershops and beauty salons, cafés and coffee shops, . . . Access by mixed mode of transport, walking, biking, bus, trolley, automobile. Look to develop indexes of neighborhood quality, neighborhood in a broad sense.

   Activity-based modeling: Castiglione, J. (2015). Activity-based travel demand models: A primer. Transportation Research Board. [**?**] and http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_C46.pdf

   Apt approaches: microsimulation ABMs; activity based modeling, synthetic data to model behavior; DEA for comparing neighborhoods (e.g., census tracts) on multiple criteria.
4. Deep decarbonization. And energy systems design.

This can cover many topics, including decarbonizing the electric power grid, but also, e.g., agriculture, cement and steel production. For electric power, apt approaches include capacity planning models, which a constrained optimization models. Note: brownfield versus greenfield models. Also, finding optimal paths (brownfield).

5. Risk assessment and management
   (a). Discovering and estimating risks (climate science, systems analysis for system risks)
   (b). Design in the face of risk.
   Apt approaches include: DMDU, model analysis with synthetic data, and much else.
6. Choice/decision models
   For selecting policies, configuration options, designs, etc. In its core, an MCDM problem. Look to PROMETHEE (and other outranking methods), also MAUT.
7. Opinion management. For lack of a better term. Creating and maintaining mindsets and cultural norms. "Tithing for transition" idea.
   With MM, key idea: public accounting of this. Better called budgeting (investing?) for mitigation of global warming.
   Apt modeling approaches include: microsimulation ABMs with identity models.
8. Synthetic data
   Especially time series data and data for activity based models. Thus relevant to most of the above.
   Time series data: [18] and https://ieeexplore.ieee.org/document/9453485.
   Activity based modeling data: [**?**], and https://www.climatechange.ai/papers/neurips2020/33.html.

Chapter 38 Micro-Modeling and Analysis of the Lived Environment

The primary thrust of this research program concerns modeling and analysis aimed at understanding the performance and operating characteristics of the lived environment, and with finding ways to improve it. As a prototypical example, the focus of a study might be an urban neighborhood and use of electricity under various pricing and control regimes that recognize the varying costs of production. How will people behave in response and what will be the effects on their activities? Alternatively, a study might focus on how much provisioning (food, clothing, personal care products, etc.) can be accomplished within a 15 minute walk by residents in different parts of the neighborhood. Findings in either study may easily lead to policy recommendations.

The primary methodological orientation of this research program is on research questions that are plausibly best addressed with micro-modeling and analysis. There are many cases in which macro-level models and data, relying on high-level, aggregated data and modeling assumptions, will not yield sufficiently accurate representations of their target phenomena. It is these cases that are our main concern.

Micro-modeling and analysis techniques have seen much innovation and advancement of late, for example with the development of activity-based modeling in regional transportation studies [**?**]. These developments are in process of unfolding. They need to be tested in new applications and there is ample room and need for further innovation. It is a main goal of this research program to contribute to those eventualities. In particular, we see a need both for micro-modeling studies on many different detailed topics and for software design and tool creation that makes doing a plurality of studies easier and more robust. Such is a principal aim and motivation for the program.

In brief, we undertake micro-modeling and analysis both for the sake of system modeling and tool development.

* * *

Framing and motivation of a research program are all very well and do serve useful purposes. That said, the real proof of the idea, as with any other idea, is what comes of it, the results it leads to. Given that it is early days of the project, identifying examples of studies and other work product is perhaps the best indicator of its promise.

Examples of policies that can be studied with micro-modeling, and agent-based microsimulation (ABMS) in particular, and would benefit thereby from detailed modeling of agent behavior include the following:

I need to give a sentence or two on each project/model. Detailed specifications and requirements, motivations, research questions, etc. come later.

1. Living on solar.

   Obtain hourly production values for solar PV for at least one year. (e.g., PJM). Scale the alues so that the maximum value corresponds to a reasonable maximum value for a residence,say 2–4 kilowatts. Add battery storage with a 90% round trip efficiency. Add a control system thatturns off sources of load as solar energy becomes unavailable. Model foregoing or postponing the service versus drawing on battery storage, which was created when the sun was shining.Describe life at various levels of solar PV and battery storage.
2. Food rescue program.
3. Curbside composting. Study participation rates and compliance based on costs, emulation of others, etc.
4. Funding of EV charging stations. Study optimal location of stations, effects on commerce, GHG emissions reduction effects, etc.
5. Expansion of non-motorized thoroughfares. Study costs, traffic reduction, GHG emissions reduction, optimal placement, etc.
6. BRT: Bus rapid transit.

   Similar modeling issues and opportunities to expanded non-motorized thoroughfares
7. Alternative provision of electricity

   Time of day pricing. Real time pricing. Time of day absolute limits. Model how households,other establishments might work with these alternative regimes.
8. Revision of municipal work rules such as 4-day work week, working at home, etc.) Study costs, traffic reduction, GHG emissions reduction, etc.
9. Transit Oriented Development (TOD). Study how transit infrastructure can be developed to meet community goals of reducing traffic and GHG emissions, of saving money, or providing improved access to shopping and other amenities.
10. Adoption of building electrification measures. Study how information, behavioral interventions, incentives, social emulation, etc. can speed replacement of fossil fuel heating and cooking devices with electric ones.
11. Demand response.
12. Pickup or delivery?
13. Neighborhood provisioning.

For some of the above modeling projects convention simulation, such as discrete-event simulation, would be appropriate. In all cases, however, very detailed, fine-grained modeling would be interesting and appropriate, as would incorporation into a broad ABMS framework.

Key Travel Questions	Trip-Based Model Components	Activity-Based Model Components
What activities do people want to participate in?	Trip generation	Activity generation and scheduling
Where are these activities?	Trip distribution	Tour and trip destination choice
When are these activities?	None	Tour and trip time of day
What travel mode is used?	Trip mode choice	Tour and trip mode choice
What route is used?	Network assignment	Network assignment

Figure 38.1.1: Key travel questions and answers [? , page 6].

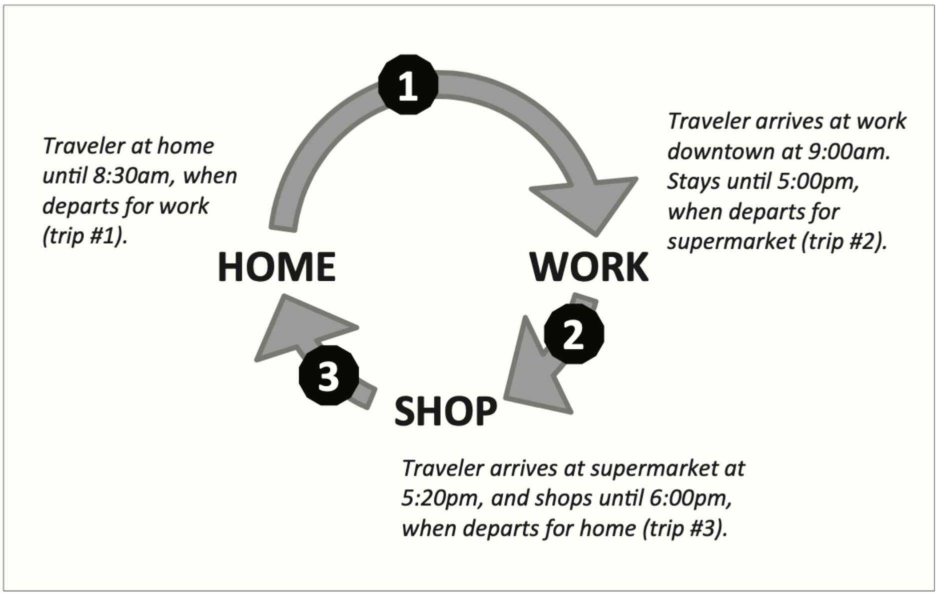

Figure 38.1.2: A tour with three trips [? , page 10].

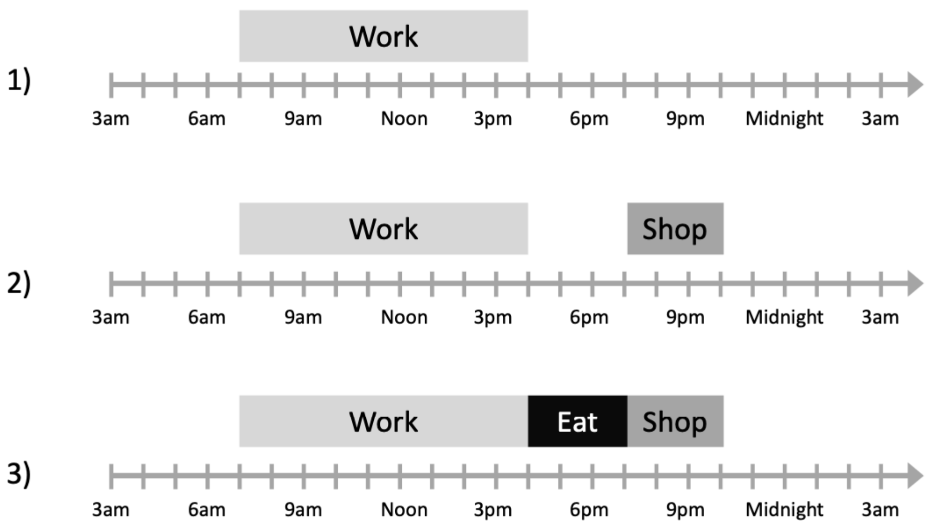

Figure 38.1.3: Example of scheduling priorities [? , page 11].

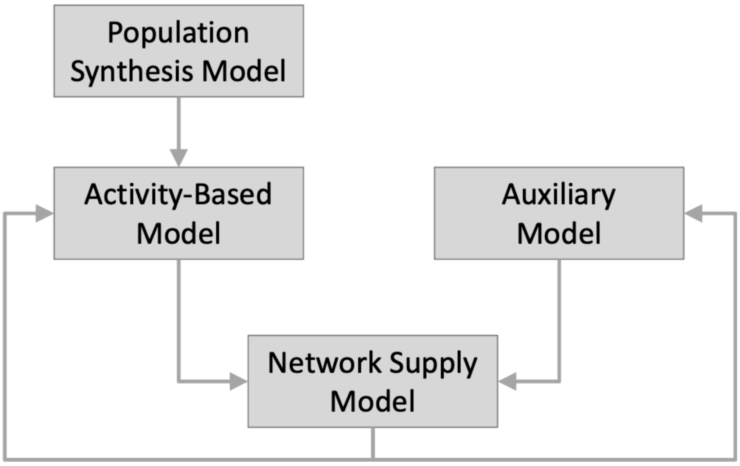

Figure 38.1.4: Basic integrated model components [? , page 12].

38.1 Activity-based modeling concepts

File: microsimulation-brochure.tex

Chapter 39 Modeling Studies: Starters and Building Blocks

The purpose of this chapter is to describe a series of modeling studies that exemplify in the small what we hope to achieve in the large. The models and exercises we describe are suitable for teaching purposes and as conceptual building blocks for larger models.

A key, very common feature of the agents in our microsimulation models is that they somehow acquire plans, representations of what they aim to do. For example, an agent with the goal of traveling to point P and returning will have a representation that can be interpreted by the agent as effective instructions for undertaking the tour, much as human travelers consulting route planners are given a sequence of instructions. In either case, the representations may be given exogenously or with more difficulty constructed by the agent itself. Both of these as well as other possibilities will need to be explored in the research project.

Try implementing in NetLogo. If that proves too awkward, use Python instead (with objects). In any case, document your design and your code. For every model, suggest interesting enhancements to it and sketch how they could be implemented.

39.1 Basic travel script

A map of the environment is presented to the agent. An agent is given a goal location to travel to from its present location, both on the map. The agent is given a script to follow, which is sufficient for transiting from start to finish. The agent when set in motion follows the script, arrives at the destination, and halts.

After implementing the above narrative,

1. Discuss and assess various design alternatives for the agent. How is the script implemented and why? Alternatives?
2. Specify a number of interesting additional features or wrinkles. Implement them and discuss how they were implemented and why that design was chosen? Alternatives?

39.2 Basic travel plan construction

A map of the environment is presented to the agent. An agent is given a goal location to travel to from its present location, both on the map. The agent constructs an efficient plan, which is sufficient for transiting from start to finish. The agent when set in motion follows the plan, arrives at the destination, and halts.

After implementing the above narrative,

1. What are the pros and cons of the two approaches, exogenously given scripts versus self-constructed plans?
2. Discuss and assess various design alternatives for the agent. How is the script implemented and why? Alternatives?
3. Specify a number of interesting additional features or wrinkles. Implement them and discuss how they were implemented and why that design was chosen? Alternatives?

39.3 Local park visits

El Farol++

39.4 Geographic SIR

As in the SIR (susceptible, infectious, recovered) epidemiological model, agents may be in one of these three states. Model the halls of an office building (or the layout of a dormitory). Agents travel through them, entering at various points and walking to various destinations. If an infected agent passes within a certain distance of a susceptible agent, then with a given probability the susceptible agent becomes infected and later infectious. Model the spread of disease under various conditions, especially crowding/level of traffic in the halls.

39.5 Coffee room; office canteen

Model the halls of an office building with a coffee room on the floor. Spread of ideas as well as infections. Crowding.

Riffing on El Farol, add learning by the agents, either to seek or avoid crowding.

39.6 Contagion models with explicit space

As in an office or dorm or department store. Model the pathways and locations and have contagion occur there.

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Chapter 40 ABM Energy Models

Two grand challenge areas for microsimulation ABM energy modeling:

1. Accommodating VRE (variable renewable energy)
   Modeling (ultimately individual) behavior and investment in the face of VRE, along with possibilities of storage in various forms.
2. Assessing neighborhoods, amenities, quality of life while going green and having to deal with climate change (e.g., heat waves).
   Access to grocery stores, pharmacies, restaurants, barbershops and beauty salons, cafés and coffee shops, . . . Access by mixed mode of transport, walking, biking, bus, trolley, automobile.

40.1 Thumbnail project descriptions

40.1.1 Living on solar

Obtain hourly production values for solar PV for at least one year. (e.g., PJM). Scale the values so that the maximum value corresponds to a reasonable maximum value for a residence, say 2–4 kilowatts. Add battery storage with a 90% round trip efficiency. Add a control system that turns off sources of load as solar energy becomes unavailable. Model foregoing or postponing the service versus drawing on battery storage, which was created when the sun was shining. Describe life at various levels of solar PV and battery storage.

40.1.2 Composting

curb-side, routing, etc.

40.1.3 Food rescue program

40.1.4 EV charging stations

Much to be modeled here. Look especially to spillover effects such as placing the stations at commercial or recreational centers.

40.1.5 Expanded non-motorized thoroughfares

Pedestrian and bicycle.

Much to be modeled here. Look especially to spillover effects such as placing the stations at commercial or recreational centers.

40.1.6 BRT: Bus rapid transit

Similar modeling issues and opportunities to expanded non-motorized thoroughfares.

40.1.7 Revision of work rules

4-day week; work at home. Model effects on GHG emissions, on traffic and conjestion, on local businesses, etc. Notice that not everything is transit-centric. Some involves changes of attitudes.

40.1.8 Alternative provision of electricity

Time of day pricing. Real time pricing. Time of day absolute limits. Model how households, other establishments might work with these alternative regimes.

40.1.9 Delivery versus pickup

See 525 notes, fall 2020.

40.1.10 Demand response

Residential, commercial, etc.

40.1.11 Neighborhood modeling

Intriguing topic, but not yet sure how to approach it. Perhaps use microABMs to locate desirable/undesirable residential locations? On the plus side, there are lots of urban data available, e.g. InforGroup on WRDS. Also, consider local services provisioning.

40.1.12 Accommodating VRE

Huge theme. Needs specific modeling ideas.

40.2 **Study designs**

40.2.1 **Pickup or Delivery?**

40.2.2 **Food rescue**

See the WSC study with NetLogo. Expand on it greatly.

40.2.3 **Neighborhood provisioning**

A neighborhood, geographic extent is identified, a synthetic population is generated and placed appropriately in residences. On a daily basis individuals and family groups (broadly defined) consider their provisioning needs for: food, household supplies, medicines and personal care items, clothing, personal services (hair, nails, etc.), recreation (parks, walks, bars, restaurants, etc.), dog walking, etc.

The model simulates the daily activities of the population and collects performance statistics, including but not limited to mode of transport, time consumed in activities, exposure to air and noise pollution, exposure to pleasant surroundings, congestion, etc. Such models would afford comparison of different neighborhoods, development of neighborhood-specific indexes or other indicators of quality or performance, and support for planning interventions.

Points arising:

This might be dubbed food deserts on steroids.

This is a grand project, one that could absorb truly huge amounts of attention and effort (and so might attract funding on a significant scale).

The trick is to be able to produce interesting work product in publishable (or otherwise valuable, as in teaching material) increments.

In any event, this is a challenging software development project and it will require a fair amount of planning and design. For example, how are the various agents to go about traveling? How do we go from an agent with a plan to an agent executing that plan? It will be necessary to design approaches that will be robust with the development of the project.

The vision is that of a very detailed ABMS involving thousands of agents whose life activities are modeled and for purposes of understanding and improved design of the built environment.

As we proceed with the energy and sustainability transitions, I have to believe that tools for envisioning how we can live and flourish (or not) will be tremendously valuable in many ways.

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