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Supplementary Information for

A Framework for Localizing Global Climate Solutions and their Carbon Reduction Potential

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S1. Introduction

This paper illustrates the use of systems framing in the assessment of sub-national climate solutions with a case study of the Drawdown Georgia project. The project was undertaken in part to illustrate how robust place-specific plans for climate action could be derived from the foundational global work of Project Drawdown (1) and by embedding that research into the context of socio-technical-ecological-systems.

Most detailed analyses of pathways for achieving economywide emission reductions are at the global or national scale. While these studies provide a powerful point-of-departure, their perspective must be tailored to meet the unique needs, resources, and preferences of specific sub-national localities, such as regions, states, or municipalities. We develop a replicable process and methodology for identifying high-potential solutions that advances the traditional wedge approach for portraying carbon abatement potential by incorporating solution interdependencies and by spanning both carbon sources and sinks. We also produce a carbon abatement cost curve that aligns private as well as social costs and benefits with each million-metric ton of carbon dioxide equivalent (CO_2-e) that could be avoided. These financial impacts are aligned with an array of co-costs and co-benefits to foster consideration of societal concerns extending beyond climate impacts, including public health, environmental quality, employment, and equity.

In this Supporting Information Appendix, we describe the materials and methods as well as the results that underpin the key findings presented in the main text of the paper.

S2. Materials and Methods

Multiple materials and methods were used to 1) describe the wide variation in state-level climate policies to date; 2) engage with stakeholders across Georgia; 3) complete the down-selection of solutions from about 100 to 20; 4) provide an overview of Georgia's current emissions; 5) provide a baseline forecast of Georgia's greenhouse gas (GHG) emissions and sinks, and 6) estimate the emission reduction potential of 20 climate solutions for the state of Georgia over the next decade.

Summary of Current State-Level Climate Plans. Climate policy varies widely state by state. Georgia currently has no economy-wide emission reduction target or state-level climate action plan. We reviewed the current policy landscape. This includes a survey of state-level economywide GHG reduction goals and targets as well as a survey of state-level climate action plans. For states with climate action plans, we report whether the plans address both carbon mitigation and sequestration, and if they consider equity issues. Equity is a key pillar of the co-benefit analysis for this work, which is highlighted in Figure 3 of the main document. We have mapped co-benefits consideration for equity, public health, economic development and the larger environment for mitigation and sequestration solutions.

Engagement with Stakeholders Across Georgia. In order to engage with the general public, we hosted informational webinars, accepted comments through the Drawdown Georgia website, and sought input about climate solution preferences via an online public survey. A total of 280 respondents provided input via the public survey. Respondents could weigh in on all sectors analyzed or a subset that matched their expertise or interests. For example, 82 of the respondents answered questions about land sink solutions while 98 respondents answered questions about electricity sector solutions. Respondents included people both inside and outside of Georgia, with a bias toward affluence and education. A majority of respondents were white (2). We also reviewed existing public opinion research on Georgia. Our county-level analysis of a 2019 Yale and George Mason University survey (3) helped to better understand opinions in the state about climate change. The national survey found 72% of Americans think that global warming is happening and 59% believe that it is mostly human caused. Georgia residents believe that global warming is happening, but the degree of certainty is lower in rural counties. Compared to the average American, Georgia residents are less certain that climate change is caused by human activity: in particular, a majority of residents in rural counties in Georgia do not agree that climate change is mostly caused by humans.

We also sought input from subject matter experts from universities, government, non-governmental organizations, and business both inside and outside of the state. We created sector specific surveys for Electricity, Transportation, Food and Agriculture, Buildings and Materials, and Land Sinks. We also created a survey that addressed the intersection of climate solutions and equity, public health, environment, and economic development. We also hosted sector-specific focus groups and held an in-person workshop with the expert community to review interim findings and analysis. Finally, the research team engaged more than three dozen representatives from industry and organizations in Georgia through facilitated discussion on solutions. Participants were asked which solutions have the highest activation potential, and they were asked to identify key stakeholders. The team sent a survey to participants following the group discussion to solicit individual responses on which solutions seem most viable, what barriers may exist to deploying solutions, and which solutions are most relevant to the respective company or organization. There were 13 responses to the survey, representing seven companies—four headquartered in Georgia—from different industries and of varying sizes, one municipal government, and two nonprofit organizations. Industry sectors represented by survey respondents include food and beverage, cloud computing services, specialty materials, remanufacturing, energy consulting, and wire/cable manufacturing. Nine respondents selected solar farms and community solar as one of the most viable solutions, and eight respondents selected mass transit as one of the least viable solutions. Respondents rated cogeneration, solar farms/community solar, and rooftop solar as relevant to highly relevant solutions to their respective companies/organizations.

In the “beyond carbon” research, we obtained input from a survey of experts (drawn from non-profit organizations such as American Rivers and Southface Energy Institute, government entities such as U.S. Environmental Protection Agency (EPA) and the Center for Disease Control and Prevention (CDC), and consulting organizations such as Greenlink Analytics, at stakeholder/community meetings (such as the Just Energy Circle and Summit, Greenprints Conference, Drawdown Georgia Workshop, and the Georgia Climate Conference) and from technical working group teams for each solution. In addition, the Partnership for Southern Equity offered input and feedback on the equity dimension.

The color coding in Figure 3 of the main manuscript indicates the existence of material benefits and flags that there are issues necessitating attention or management alongside future benefits (orange). For example, the fact that rooftop solar has more issues than temperate forests that need to be recognized/managed from an equity perspective does not mean it should be a lower priority than temperate forests. Rather, it means there are significant equity issues that need to be considered and managed as part of solution design and implementation. Rooftop solar could, in fact, offer an enormous opportunity for equity benefits depending on how the solution is ultimately shaped and how much intentional focus there is on improving equity-related outcomes.

Down-Selection of Solutions. We developed a systematic and replicable methodology for down-selecting the high-impact solutions for Georgia from Project Drawdown’s original list of about 100 options (1). In particular, the possible solutions were passed through a five-step down-select process (2)

- Is the solution technology & market ready for Georgia?
- Is there sufficient local experience and available data?
- Would the solution deliver a megaton of abatement in 2030?
- Is the solution cost competitive?
- Are there other societal priorities that should be considered?

Georgia’s Baseline Carbon Footprint. To generate projections of emission impacts for each technology, it was crucial to have an accurate accounting of Georgia’s baseline emissions. We focus particular attention on Georgia’s energy economy because the combustion of fossil fuels is the largest source of the state’s carbon dioxide (CO_2) emissions. The four sectors of Georgia’s economy with significant consumers of energy and emitters of CO_2 are transportation, homes, businesses, and industry.

In 2017, Georgia consumed 2,609 TBtu of energy, accounting for 2.8% of U.S. GDP and 2.9% of U.S. energy consumption, indicating that the state’s economy is slightly more energy-intensive than the U.S. economy. The vast majority of this energy budget was spent on fossil fuels, dominated by petroleum (for transportation), natural gas (in electricity and industry), and coal (which was the dominant fuel for electricity generation in 2017, but has recently been eclipsed by natural gas). Transportation is the largest consumer of energy in Georgia, followed by industry, homes, and businesses. This is the same rank order of energy use across sectors in the United States as a whole.

Georgia’s CO_2 emissions from fossil fuel combustion totaled about 141.7 Mt CO_2 (or 141.7 “megatons”) in 2017, representing 2.9% of U.S. emissions from fossil fuels. As with its energy-intensity, this indicates that in 2017 the state’s economy was slightly more carbon-intensive than the U.S. economy. The dominant sources were transportation (at 69 Mt CO_2) and electricity generation (at 52 Mt CO_2 with 32 from coal and 20 from natural gas), suggesting that these sectors could be particularly potential targets for emission reductions.

Off-setting these emissions, Georgia has carbon sinks (or "negative emissions"), resulting from the uptake of CO_2 in forests and agricultural soils. The World Resources Institute (4) estimates an annual sequestration of roughly 46 Mt CO_2 in Georgia in 2011. This is equivalent to about 32% of Georgia's CO_2 emissions from fossil fuels in 2017. Assuming that this value holds true in 2017, Georgia's net carbon footprint would have been 108.8 Mt CO_2 in 2017.

In addition to CO_2, there are several other sources of GHGs whose global warming potentials can be considered using standardized equivalency metrics called CO_2-e. EPA's 2017 national GHG emissions inventory (5) estimated that Georgia emitted 174.1 Mt CO2-e, of which 6% was from NOx, 2.7% was from methane, and 2.3% was from fluorinated gas. Altogether, the three non-CO_2 sources of GHG emissions contributed an estimated 19.3 Mt CO2-e or 11% of Georgia's total GHG emissions. The remaining 89% of Georgia's total emissions are from CO_2.

In sum, Georgia's net GHG emissions in 2017 are estimated to have been 128 Mt CO_2-e: 142 Mt emissions from energy consumption plus 13 Mt from non-energy CO_2 emissions plus 19 Mt from three non-CO_2 GHG emissions minus 46 Mt from carbon sinks. The World Resources Institute (4) estimates that Georgia's net GHG emissions in 2005 were 156.5 Mt CO_2-e.

Baseline Forecast of Georgia's GHG Emissions and Sinks. To provide a baseline forecast of Georgia's GHG emissions in 2030, we used Georgia Tech's National Energy Modeling System (GT-NEMS), a computable general equilibrium model of the U.S. energy economy. Applying a region-to-state proportioning method, the GT-NEMS Reference Case forecasts that Georgia's energy-based CO_2 emissions will be 122 megatons in 2030. In that year, CO_2 emissions from energy consumption in Georgia are forecast to come 41% from electricity and 39% from transportation. Residential and commercial buildings are forecasted to be responsible for 22% and 21% of energy-related CO_2 emissions in 2030, much of which comes from their consumption. To round out the picture, industry, which includes the manufacturing of materials such as aluminum, chemicals, and paper, is expected to be responsible for 17% of energy-related CO_2 emissions in 2030.

We consulted numerous sources to establish this baseline information. The survey of state-level policies came from the Center for Climate and Energy Solutions' U.S. State Greenhouse Gas Emissions Target Map and information compiled by the National Conference of State Legislators. The description of Georgia's baseline emissions is based on data from the Georgia Tech National Energy Modeling System (GT-NEMS), the U.S. Energy Information Administration's State Energy Data System, and the Environmental Protection Division of the Georgia Department of Natural Resource's 2012 Greenhouse Gas Emissions Inventory for the State of Georgia. We estimated kg of carbon per million Btu based on data from the U.S. Environmental Protection Agency's Fast Facts of their National Level Greenhouse Gas Inventory for 1990-2017. We used national growth percentages from EPA's 2017 national GHG emissions inventory (5) to scale state-level emissions from 2008 provided by the Georgia Department of Natural Resources' Environmental Protection Division. This was the most recent state-level data available.

Estimating Carbon Reduction Potential of High Impact Climate Solutions in Georgia by 2030. Beginning with the 100 solutions listed in Hawken (1) Drawdown book, our research team divided these solutions into five working groups: Electricity; Transportation; Buildings and Materials; Food and Agriculture Systems; and Land Sinks. Each working group conducted surveys and assembled focus groups to help determine whether there were additional solutions that should be considered and to solicit input from industry, nonprofit organizations, and government experts on potential modeling approaches. Due to limited resources and a recognition that not all of the Drawdown solutions would be appropriate for Georgia, several criteria were used to guide the down-select process. First, given the short analytic time horizon of the project, 2030, emphasis was placed on solutions that were deemed market ready. Second, due to modeling requirements, we looked for solutions that have publicly available data that could allow for rigorous modeling. Third, using some initial modeling efforts, we sought solutions that could achieve additional carbon reduction potential from the baseline of 1 million metric tons per year by 2030. This figure represents approximately one percent of Georgia's net CO2e emissions. This down-select process is described in more detail in Brown et al (2).

The down-select process resulted in 20 solutions to be given more attention and rigorous modeling treatment. In many cases, individual solutions in Drawdown were combined in order to better understand systems of solutions and how they interact together. For example, many of the building solutions (improved insulation, LED lighting, building automation, etc) were jointly assessed in a solution called "retrofitting." And telepresence, biking, and walking were all jointly considered as "alternative transportation". Each of these 20 solutions has unique data sources, unique modeling approaches, and assumptions for the "achievable" and "technical potential" scenarios. These solutions and their accompanying methodologies are listed in Table S2 below. This includes data sources, models, and methodologies used to estimate the abatement potential and cost of abatement. For additional details about the modeling of individual solutions, see the technical reports, PowerPoint presentations, and videos at the following website: https://cepl.gatech.edu/projects/Drawdown-Georgia.

S3. Results

This section provides additional information about the carbon abatement analysis conducted as part of the Drawdown Georgia case study. A summary of the results is presented in Table S3.

Projections of Carbon Abatement Potential. We modeled the carbon abatement potential of the 20 high-impact climate solutions for Georgia out to 2030. The achievable scenario estimates how emissions could fall if each solution was deployed at an ambitious, but achievable level, that considers costs, impacts and stakeholder acceptance. The technical potential scenario estimates the maximum realistic deployment of each solution without regard to cost or other impacts, up to the hard limits on resources such as available land and materials. Table S4 shows the abatement potential by technology by year for each solution analyzed. For more information on the modeling or results for each individual solution, please contact the authors.

Analysis of Solution Interaction. We modeled two bilateral interactions, and the results are now embedded into our analysis of abatement potential and costs. This includes the interaction between electric vehicles (EVs) and large-scale solar as well as the interaction between retrofitting and large-scale solar. We provide a description of those interactions, the conceptual equations, and MATLAB code used to model the relationships below.

Interaction between Large-Scale Solar and Electric Vehicles. A major consideration for the growth of Electric Vehicles (EVs) is the energy-shift from liquid fuels to grid power. Solar Fields have been identified to improve the environmental impact of EVs by reducing the CO2 intensity of grid electricity and maximizing the reduction of carbon emissions when switching from liquid fuels. Three effects of this combination have been modelled, namely the decrease of grid CO2 intensity from solar, the decrease of Light Duty Vehicle (LDV) CO2 emissions in operation, and the increase in LDV electricity demand. This interaction was modeled using the following quantities and formula on MATLAB1. Figure S2 shows the matrix used to conceptualize this relationship, with the results plotted in Figure S3

- **ΔD:** Increase in Electricity Demand from Light Duty Vehicles [GWh] - EV Scenarios
- **ΔE:** Decrease in Emissions from Light Duty Vehicle Operation [MMTCO$_2$] - EV Scenarios
- **C:** CO$_2$ Intensity of the Grid [MMTCO$_2$/GWh] - Solar Fields Scenarios
- **ΔS:** Emission Reduction from the Combined Solar Fields - EV Scenarios [MMTCO$_2$]

$$\Delta S = \Delta D \cdot C + \Delta E$$

As shown in Figure S3, there is no major effect on emissions prior to 2026. Although the introduction of solar fields to the grid generation portfolio has a significant effect on carbon intensity in this time, the predicted increase in LDV electricity demand is not large enough to gain any significant emissions advantage prior to 2026. Until this point, carbon abatement is governed by the reduction of tailpipe emissions. After 2026, the plots diverge to reveal a clear and significant benefit from cleaner grid power. This is consistent with the expectation that EV growth is non-linear and more exponential in nature. Marginal CO2 emissions rates have a large associated error due to the lack of hourly charging/demand data. As the energy required for higher EV penetration would likely be derived from fossil fuels, CO2 reductions from these cases could be lower than currently estimated.

Interaction between Solar Fields and Retrofitting Buildings. Retrofitting reduces carbon emissions through the reduction of building energy consumption. The growth of Solar Fields to replace fossil fuel-based grid power generation decreases the carbon intensity of the grid, lowering the avoided emissions from retrofitting as every unit of power saved is now equivalent to less CO2. This model uses the ratio of CO2 intensities to scale the known CO2 reduction from retrofitting cases. This interaction was modeled using the following quantities and formula on MATLAB2. Figure S4 shows the matrix used to conceptualize this relationship, with the results plotted in Figure S5

- **ΔE**: Emissions reduction from retrofitting cases, relative to baseline [$MMTCO_2$]
- **I_b**: Baseline CO_2 intensity of grid power [$MMTCO_2$/GWh]
- **I_s**: Drawdown scenario CO_2 intensity of grid power [$MMTCO_2$/GWh]
- **ΔS:** Emissions reduction from combined retrofitting-solar fields cases, relative to baseline [$MMTCO_2$]

$$\Delta S = \Delta E \cdot Is/Ib$$

The results in Figure S3 are somewhat predictable based on the modelling process used. It is worth noting that this model assumes the carbon savings from retrofits are a direct result of home energy reduction alone, disregarding non-energy contributions such as refrigerant use, etc.

Interaction between Rooftop Solar and Solar Fields. The grid is only capable of handling a finite amount of intermittent solar generation due to several factors, including limitations of energy storage causing issues of over- and under-generation throughout periods of varying solar resources (night vs day, winter vs summer, etc.). Therefore, two solar technologies with large technical potentials are not able to coexist, or “fit” into the same energy space, as is the issue with rooftop solar and large-scale solar generation. In this interaction, the upper generation limit is defined to be the independent technical potential of solar fields, the current highest potential for carbon reduction from a solar technology modeled in this project. If the sum of rooftop and large-scale solar is less than this limit, no changes are required, and this combination can coexist. As these two technologies both replace the same conventional generation sources, a unit amount of energy generated from large-scale solar is assumed to be environmentally equivalent to that generated from rooftop solar. This interaction was modeled using the following quantities and formulae on MATLAB3. Figure S6 shows the matrix used to conceptualize this relationship, with the results plotted in Figure S7.

- **ΔS:** Emissions reduction from combined rooftop solar-solar fields cases, relative to baseline [$MMTCO_2$]
- **ΔE_{LS}**: Emissions reductions from large-scale solar cases, relative to baseline [$MMTCO_2$]
- **ΔE_{RS}**: Emissions reductions from rooftop solar cases, relative to baseline [$MMTCO_2$]
- **ΔE_{max}**: Emissions reductions from the independent large-scale solar technical case, relative to baseline [$MMTCO_2$]
- **ΔE_{total}**: Sum of emissions reductions from the independent large-scale solar and independent rooftop solar case, relative to baseline [$MMTCO_2$]

$$\Delta E_{total} = \Delta E_{LS} + \Delta E_{RS}$$

If ΔE_{total} is more negative than ΔE_{max}:

$$\Delta S = \Delta E_{RS} + \Delta E_{max} - \Delta E_{total}$$

If ΔE_{total} is less negative than ΔE_{max}:

$$\Delta S = \Delta E_{RS}$$

Figure S7 displays a few overlapping CO2 savings forecasts. The large-scale technical case acts as our upper limit for solar overall. By definition, no new rooftop solar is allowed to be introduced when large-scale solar is growing at its technical potential. This causes an overlap at zero as seen by the red/yellow line. The achievable scenario for large-scale solar is small enough that it can accommodate the development of rooftop solar at its achievable potential alongside it. Therefore, the rooftop solar achievable scenario does not require any reduction and overlaps with the curve plotted independently of large-scale solar, i.e., when large-scale solar is at its baseline as shown by the black/teal line. The technical potential scenario for rooftop solar is large enough that it requires significant reduction in order to accommodate the achievable scenario for large-scale solar. Therefore, the solid teal line diverges from the original logistic curve (solid black) after 2023.

MATLAB Script for EV-Large Scale Solar

```
close all
clc
clear
load('EVSolarData.mat');

%% Conversion

% Desired unit: MMT CO2
% 1 BkWh = 1000 GWh
% 1 tCO2/GWh = 1000 tCO2/1000GWh
% 1 MMTCO2 = 1e6 tCO2

elec_LDV_b=elec_LDV_b*1000; %GWh
elec_LDV_A=elec_LDV_A*1000; %GWh
elec_LDV_T=elec_LDV_T*1000; %GWh

I_elec_A=I_elec_A./1e6;     %MMTCO2/GWh
I_elec_b=I_elec_b./1e6;     %MMTCO2/GWh
I_elec_T=I_elec_T./1e6;     %MMTCO2/GWh


%% Matrix Calculation

year=[2017:2030];
MMT_EVA_SolarA=(elec_LDV_A-elec_LDV_b).*I_elec_A+(MMT_LDV_A-MMT_LDV_b);
MMT_EVA_SolarT=(elec_LDV_A-elec_LDV_b).*I_elec_T+(MMT_LDV_A-MMT_LDV_b);
MMT_EVT_SolarA=(elec_LDV_T-elec_LDV_b).*I_elec_A+(MMT_LDV_T-MMT_LDV_b);
MMT_EVT_SolarT=(elec_LDV_T-elec_LDV_b).*I_elec_T+(MMT_LDV_T-MMT_LDV_b);
MMT_EVA_Solarb=(elec_LDV_A-elec_LDV_b).*I_elec_b+(MMT_LDV_A-MMT_LDV_b);
```

```
MMT_EVT_Solarb=(elec_LDV_T-elec_LDV_b).*I_elec_b+(MMT_LDV_T-MMT_LDV_b);
MMT_EVb_SolarA=elec_LDV_b.*I_elec_A-elec_LDV_b.*I_elec_b;
MMT_EVb_SolarA(1:4)=0;
MMT_EVb_SolarT=elec_LDV_b.*I_elec_T-elec_LDV_b.*I_elec_b;
MMT_EVb_SolarT(1:4)=0;


%% Display

close all
figure(1)
hold on
c=plot(year,MMT_EVA_SolarA,year,MMT_EVA_SolarT,year,MMT_EVA_Solarb,year,MMT_EVT_SolarA,year,MMT_EVT_SolarT,year,MMT_EVT_Solarb)
set(c(1:end),'linewidth',3);
a=plot(year,MMT_EVb_SolarA,'r-')
a.LineWidth=3;
b=plot(year,MMT_EVb_SolarT,'k:')
b.LineWidth=3;
xlabel('Year')
ylabel('MMT CO2 Reduced')
legend('EV Achievable, if Solar Achievable','EV Achievable, if Solar Technical',...
'EV Achievable, if Solar Baseline','EV Technical, if Solar Achievable',...
'EV Technical, if Solar Technical',EV Technical, if Solar Baseline',...
'EV Baseline, if Solar Achievable',...
'EV Baseline, if Solar Technical','location','southwest')
grid on
set(gca,'FontSize',14)
title('MMT CO2 Reduction from EV and Solar Farms Relative to Baseline')
```

2. MATLAB Script for Retrofitting-Solar Fields

```
close all
clc
clear
%% Load Data
load("RetroSolarData.mat");

%% Calculate each case combination

S_b_R_b=zeros(1,14);       % E.g. S_b_R_b signifies "Solar-baseline, Retrofitting-baseline
S_b_R_a=MMT_ach;
S_b_R_t=MMT_tech;
S_a_R_b=MMT_base.*(I_ach./I_base);
S_a_R_a=MMT_ach.*(I_ach./I_base);
S_a_R_t=MMT_tech.*(I_ach./I_base);
S_t_R_b=MMT_base.*(I_tech./I_base);
S_t_R_a=MMT_ach.*(I_tech./I_base);
S_t_R_t=MMT_tech.*(I_tech./I_base);
year=[2017:1:2030];

%% Plot

figure(1)
hold on
d=plot(year,S_t_R_a,year,S_a_R_a,year,S_b_R_a,year,S_t_R_t,year,S_a_R_t,year,S_b_R_t);
```

```
set(d(1:end),'linewidth',3);
a=plot(year,S_a_R_b,'k-')
a.LineWidth=3;
xlabel('Year')
ylabel('MMT CO2 Reduced')
xlim([2017,2030]);
ylim([-15,1]);
legend('Retrofit Achievable, if Solar Technical',...
  'Retrofit Achievable, if Solar Achievable',...
  'Retrofit Achievable, if Solar Baseline',...
  'Retrofit Technical, if Solar Technical',...
  'Retrofit Technical, if Solar Achievable',...
  'Retrofit Technical, if Solar Baseline',...
  'Retrofit Baseline, all cases','location','southwest')
grid on
set(gca,'FontSize',14)
title('MMT CO2 Reduction from Retrofit and Solar Fields Relative to Baseline')
```

Interactions Between EV Penetration and Carbon Intensity of the Electric Grid. General assumptions:

Georgia Fleet of LDVs (passenger cars, light trucks, vans, SUVs): 8,200,000 vehicles [Ref 1, GA DOT 2020]
Georgia Electric Power consumption in 2030 129 B kWh [Ref 2]
Grid supplied electricity efficiencies for SERC SE [Refs 3-7]:

- Generation, annual average (0.377)
- Transmission, annual average (0.944)
- Wall-charging, average of class 2 chargers (0.87)

Baseline 2030 scenario
Number of EVs: 24,217 vehicles (about the same as in 2019, no new sales) [Ref 1]
Total estimated electric power generation requirement by EVs (authors estimate based on above assumptions):

$$\frac{0.11\ BkWh}{(0.944)\cdot(0.87)} = 0.13\ BkWh$$

Achievable 2030 scenario
Number of EVs: 308,826 vehicles (about 3.7% of the Georgia fleet) (author's model)
Total estimated electric power generation requirement by EVs (authors estimate based on above assumptions):

$$\frac{1.90\ BkWh}{(0.944)\cdot(0.87)} = 2.3\ BkWh$$

This annual generation requirement could then be expected to meet in a variety of modes. For the purposes of simplicity and comparison, we assess two representative cases, reflecting a range of hourly capacity needs (equal and on-peak):

Equal allocation in an hourly fashion, and assumed to be needed at any given hour, effectively at full capacity, including coincident with the greatest summer peak plus the 15% margin. This would imply an additional demand purely due to EV growth as follows:

$$\frac{2.3\ BkWh}{8760\ h/yr} \approx 263\ MW$$

Since 263 MW < 600 MW (excess reserve capacity of the grid), this level of EV growth under this charging assumption would be acceptable and still permit compliance with electric power reserve protocols.

In a second scenario, we allocate the additional demand incurred by EVs to half of the year's hours, and consider that so-called "managed charging" (i.e., timed to avoid unintended adverse effects) is not implemented. This means the capacity requirements may be called upon during peak hours, implying the effective grid demand may be doubled as follows:

$$\frac{2.3\ BkWh}{4380\ h/yr} \approx 526\ MW$$

Since 526 MW < 600 MW, this level of EV growth under this more conservative charging assumption would be acceptable and still permit compliance with electric power reserve protocols.

Technical 2030 scenario
Number of EVs: 680,911 vehicles (about 8.3% of the Georgia fleet) (author's model)
Total estimated electric power generation requirement by EVs (authors estimate based on above assumptions):

$$\frac{3.48\ BkWh}{(0.944)\cdot(0.87)} = 4.2\ BkWh$$

Again, this annual generation requirement can be allocated in two representative ways as above. If allocated in an hourly fashion, an additional demand purely due to EV growth is estimated as :

$$\frac{4.2\ BkWh}{8760\ h/yr} \approx 480\ MW$$

Again, under this scenario 480 MW < 600 MW (excess reserve capacity), implying that this level of EV growth remains acceptable.

However, when allocating the additional demand incurred by the technical potential scenario of EV growth to half of the year's hours, and consider that so-called "managed charging" (i.e., timed to avoid unintended adverse effects) is not implemented. This means the capacity requirements may be called upon during peak hours, implying the effective grid demand may be doubled as follows:

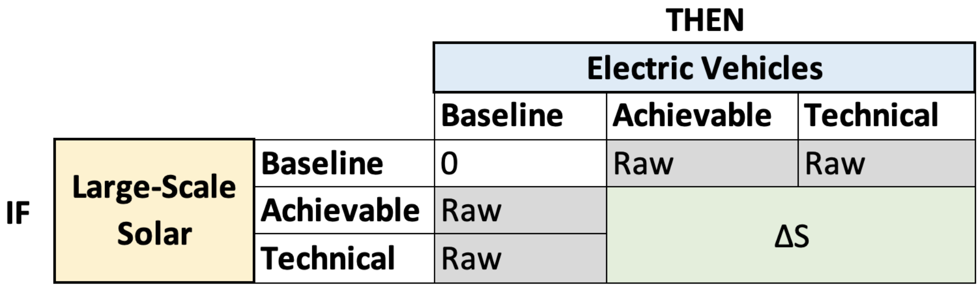
$$\frac{4.2\ BkWh}{4380\ h/yr} \approx 960\ MW$$

Under this scenario 960 MW > 600 MW, meaning capacity may exceed excess reserve capacity by more than 50%, implying that this level of EV growth would be unacceptable in this 2030 scenario, as it would violate electric power reserve protocols. While it is possible that this condition could potentially be if managed charging were effectively implemented, this first-order example of a real-world capacity forecast for the Georgia grid demonstrates one of the potential grid-demand risks of deep EV deployment.

Finally, even if reserve capacity concerns are navigated, a potential concern remains around CO2 intensity of the generating mix. Naturally, if a utility must meet increasing levels of generation, it will be forced to deploy an increasing number of dispatchable generating units, the largest fraction of which are fossil powered (i.e., coal or natural gas). As a result, the marginal emissions of the grid (i.e., hourly rate of CO2/kWh), will almost always be greater than the annual average, or pure off-peak average. The implication of the above in view of our current understanding of the 2030 generation mix for GA is that CO2 reductions derived from EVs will plateau or even reverse under certain high penetration scenarios (such as the Technical potential scenario).

Supplementary Information Figures

Fig. S1. Drawdown Georgia Solutions for 2030



THEN

		Electric Vehicles		
		Baseline	Achievable	Technical
IF Large-Scale Solar	Baseline	0	Raw	Raw
	Achievable	Raw	ΔS	
	Technical	Raw		

Fig. S2. Matrix used to conceptualize the data used for the 9 combined EV-Solar cases. "Raw" signifies independent, unprocessed data.

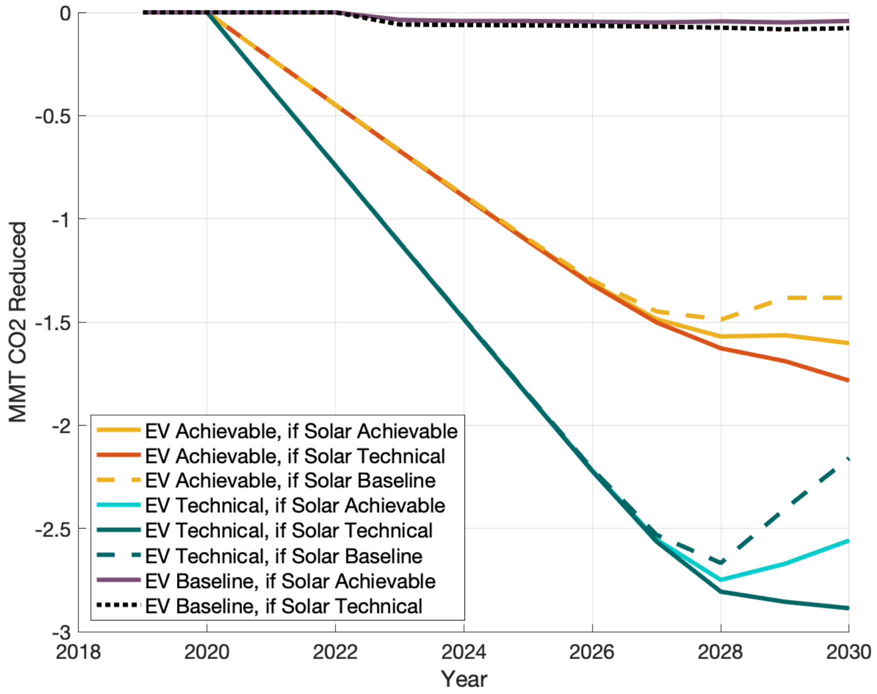
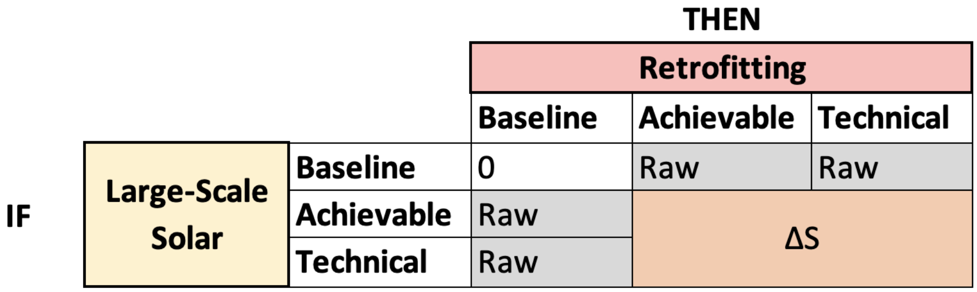


Fig. S3. Carbon Emissions from EV-Solar Fields Cases, Relative to Baseline



THEN

			Retrofitting		
			Baseline	Achievable	Technical
IF	Large-Scale Solar	Baseline	0	Raw	Raw
		Achievable	Raw	ΔS	
		Technical	Raw		

Fig. S4. Matrix used to conceptualize the data used for the 9 combined Retrofitting-Solar cases.

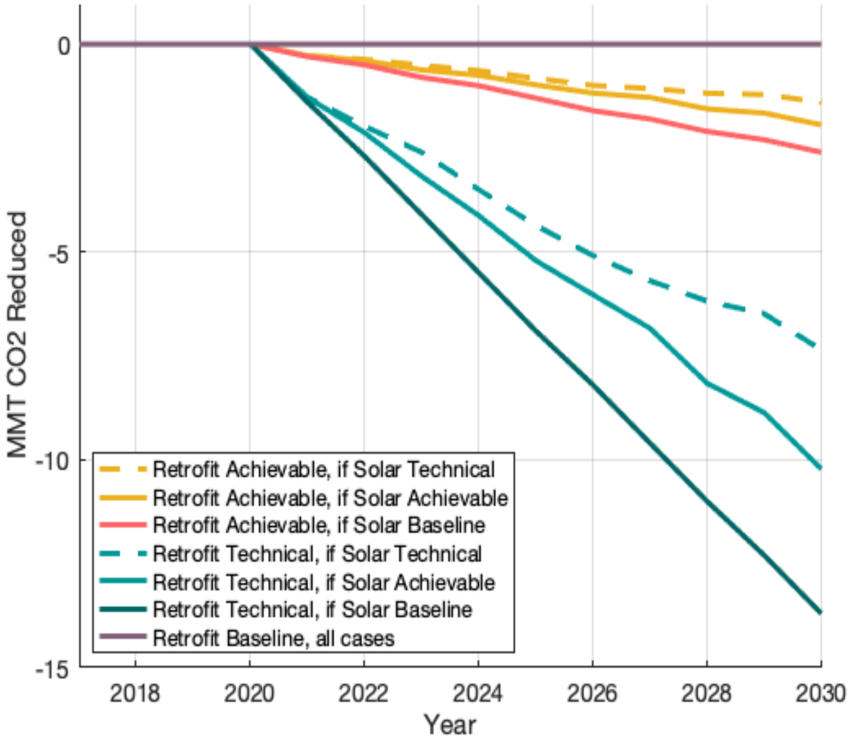
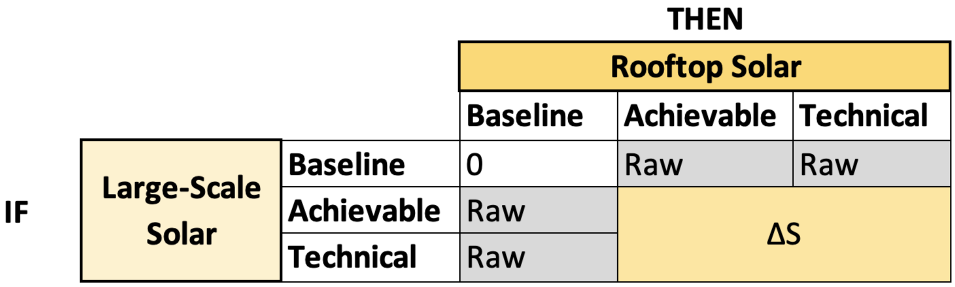


Fig. S5. Carbon Emission from Retrofits- Solar Fields Achievable Cases, Relative to Baseline



			THEN		
			Rooftop Solar		
			Baseline	Achievable	Technical
IF	Large-Scale Solar	Baseline	0	Raw	Raw
		Achievable	Raw	ΔS	
		Technical	Raw		

Fig. S6. Matrix used to conceptualize the data used for the 9 combined Large-Scale Solar-Rooftop Solar cases. “Raw” signifies independent, unprocessed data.

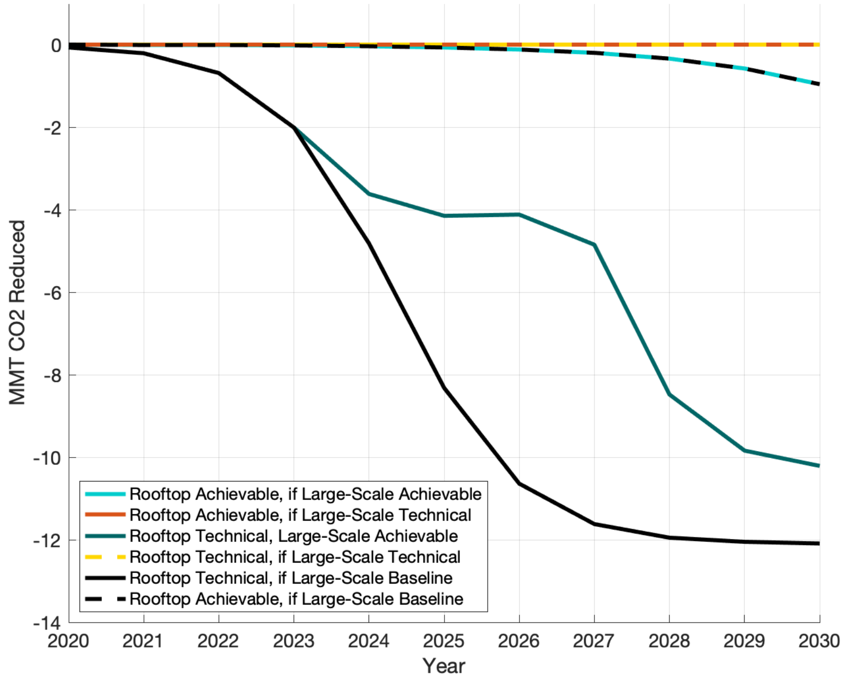


Fig. S7. Carbon Reductions from Large-Scale Solar + Rooftop Solar Cases, Relative to Baseline.

Supplementary Information Tables

State	Nature of Goal	Carbon Sequestration	Equity Focus	Both
California	California has a target of reaching net zero carbon dioxide emissions by 2045, which was set in 2018. The state also set a target in 2005 to reduce GHG emissions 80% below 1990 levels by 2050. In 2006, the state enacted a statutory target to reduce GHG emissions to 1990 levels by 2020 and in 2016, it set a statutory target to reduce GHG emissions 40% below 1990 levels by 2030. (6)	Yes	Yes	Yes
Colorado	Colorado has statutory targets to reduce GHG emissions 26% by 2025, 50% by 2030, and 90% by 2050, all compared to 2005 levels, which were set in 2019. (7)	No	Yes	No
Connecticut	Connecticut has an interim statutory target to reduce GHG emissions 45% below 2001 levels by 2030, which was enacted in 2018. Additionally, the state has statutory targets to reduce GHG emissions at least 10% below 1990 levels by 2020 and 80% below 2001 levels by 2050, which were enacted in 2008. (8)	Yes	Yes	Yes
Delaware	Delaware has a target to reduce GHG emissions 30% below 2008 levels by 2030, which was enacted in 2014. (9)	Yes	No	No
Louisiana	Louisiana has targets to reduce net GHG emissions 26-28% by 2025 and 40-50% by 2030, compared to 2005 levels, which were set in 2020. The targets also aim for net-zero GHG emissions by 2050. (10)	No	No	No
Maine	Maine has a target of achieving net-zero GHG emissions by 2050, and statutory targets to reduce GHG emissions 45% below 1990 levels by 2030 and 80% below 1990 levels by 2050. All three targets were enacted in 2019. (11)	Yes	No	No
Maryland	Maryland has a statutory target to reduce GHG emissions 40% below 2006 levels by 2030, which was enacted in 2016. (12)	Yes	No	No
Massachusetts	Massachusetts has a target to reduce GHG emissions 85% below 1990 levels and reach net-zero GHG emissions by 2050, which was set in 2020. The state also has statutory targets to reduce GHG emissions 25% below 1990 levels by 2020 and 80% below 1990 levels by 2050, which were enacted in 2008. (13)	Yes	Yes	Yes

Michigan	Michigan has a target to achieve economy-wide carbon neutrality by no later than 2050 and to maintain net negative GHG emissions thereafter, which was set in 2020. In 2019, the state also set a target of reducing GHG emissions 26-28% below 2005 levels by 2025. (14)	Yes	Yes	Yes
Minnesota	Minnesota has statutory targets to reduce GHG emissions 30% below 2005 levels by 2025 and 80% below 2005 levels by 2050, which were enacted in 2007. (15)	Yes	No	No
Montana	Montana set a target in 2019 to achieve economy-wide GHG neutrality at a date to be determined. In 2020, the state announced its target to reach economy-wide GHG neutrality between 2045-2050. (16)	Yes	No	No
Nevada	Nevada enacted statutory targets in 2019 to reduce GHG emissions 28% by 2025 and 45% by 2030 compared to 2005 levels, and reach zero or near-zero by 2050. (17)	No	No	No
New Hampshire	New Hampshire has targets to reduce GHG emissions 20% below 1990 levels by 2025 and 80% below 1990 levels by 2050, which were enacted in 2009. (18)	Yes	No	No
New Jersey	New Jersey has targets to reduce GHG emissions to 1990 levels by 2020 and 80% below 2006 levels by 2050, which were enacted in 2007. (19)	Yes	No	No
New Mexico	New Mexico has a target to reduce GHG emissions 45% below 2005 levels by 2030, which was enacted in 2019. (20)	No	No	No
New York	New York has statutory targets to reduce GHG emissions 40% below 1990 levels by 2030 and no less than 85% below 1990 levels by 2050, which were enacted in 2019. The targets also aim for net-zero GHG emissions by 2050. (21)	Yes	Yes	Yes
North Carolina	North Carolina has a target to reduce GHG emissions 40% below 2005 levels by 2025, which was enacted in 2018. (22)	No	Yes	No
Oregon	Oregon has targets of reducing GHG emissions 45% below 1990 levels by 2035 and 80% below 1990 levels by 2050, which were set in 2020. Additionally, the state has statutory targets of reducing emissions 10% below 1990 levels by 2020 and 75% below 1990 levels by 2050, which were enacted in 2007. (23)	Yes	Yes	Yes

Pennsylvania	Pennsylvania has targets to reduce GHG emissions 26% below 2005 levels by 2025 and 80% below 2005 levels by 2050, which were enacted in 2019. (24)	No	No	No
Rhode Island	Rhode Island has statutory targets to reduce GHG emissions 10% by 2020, 45% by 2035, and 80% by 2050, all compared to 1990 levels, which were enacted in 2014. (25)	No	No	No
Vermont	Vermont has statutory targets to reduce GHG emissions 26% below 2005 emissions by 2025, 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050, which were enacted in 2020. (26)	Yes	No	No
Virginia	Virginia has a statutory target to achieve net-zero GHG emissions across all sectors by 2045, which was enacted in 2020. (27)	Yes	No	No
Washington	Washington has statutory targets to reduce GHG emissions 45% by 2030, 70% by 2040, and 95% by 2050, all compared to 1990 levels, which were enacted in 2020. The targets also aim for net-zero GHG emissions by 2050. (28)	No	Yes	No
Total		15	9	6

Table S1. Summary of State-Level Climate Goals and Plans

Solutions	Data Sources	Modelling Achievable Potential	Modelling Technical Potential
Cogeneration (29-45)	Hampson, et al. (2016), U.S. DOE (2020), experts' advice, GT-NEMS modeling	We modeled the baseline forecast for electricity generation and industrial cogeneration using the GT-National Energy Modeling System (GT-NEMS), which is the primary modeling tool run by the U.S. Energy Information Administration (USEIA, 2009; 2018). GT-NEMS uses the 2018 version of NEMS. The achievable potential was estimated taking into account the installed capacity of industrial facilities and a percentage of the technical potential, as advised by experts. The percent of technical potential is smallest for enterprises with the smallest installed capacities of 50-500 KW (at 10%) and largest for enterprises with the largest installed capacity >20 MW (50%). Assuming a 75% capacity factor, industrial facilities with an additional total 835 MW nameplate installed capacity would generate 5,484 GWh /year. In 2030, it is assumed that 388 tCO2 will be emitted per GWh of electricity generated in Georgia (GT-NEMS modelling). At this projected carbon intensity, 2.13 MtCO2 could be avoided in 2030 by adding 5,484 GWh of zero-carbon electricity We assessed CO_2 emissions reductions and other pollutant and public health impacts using customized spreadsheets. For further details see Brown and Sanmiguel Herrera (2020).	Hampson, et al. (2016) estimates the CHP technical potential of individual industrial and commercial sites located in the U.S. Technical potential is calculated in terms of CHP electrical generation capacity that could be installed at existing industrial and commercial facilities based on the estimated electric and thermal needs of the site. The analysis focuses on sites with CHP technical potential of 50kW or higher. According to Hampson, et al. (2016), Georgia has the technical potential to grow its CHP capacity from 42 sites in 2018 to 9,374 sites with a total capacity of 5,110 MW, which are judged by DOE to be cost-effective. Of this technical potential, the state has 2,725 MW of industrial on-site potential mainly from the textiles, paper, food processing, chemicals and wood sectors, and 2,371 MW of commercial on-site potential primarily from colleges and universities, commercial buildings, schools, hospitals and military sectors (Hampson et al., 2016). Assuming a 75% capacity factor, industrial and commercial facilities with a total 5,107 MW nameplate installed capacity would generate 33,555 GWh /year. In 2030, it is assumed that 388 tCO2 will be emitted per GWh of electricity generated in Georgia. At this projected carbon intensity, 13.02 MtCO2 could be avoided in 2030 by adding 33,555 GWh of zero-carbon electricity (source of carbon intensity: GT-NEMS modelling). An Excel spreadsheet model was developed to complete a financial analysis of two typical CHP configurations implemented in Georgia: (1) a topping cycle with a gas turbine (GT) combined with a boiler/steam turbine (ST), and (2) a bottoming cycle with a reciprocating engine and gas turbine. Use of CHP in several industries were evaluated, based on the type of CHP system most appropriate to the industry's characteristics, and informed by expert advice. Installation and O&M costs were estimated taking into account the achievable installed capacity of industrial facilities and the costs that correspond to the prime mover of the selected configuration.
Demand Response (46-90)	Data internal to GT-NEMS (US EIA, 2018); Lazard	We model the baseline forecast for demand response using Georgia Tech's version of the National Energy Modeling System (GT-NEMS). The baseline	Modelled using GT-NEMS, by assuming a maximum 20% demand shift. In addition, In the technical potential scenario, GT-NEMS further incentivizes DR by reducing the cost of storage

	(2018); BNEF (2020)	forecast allows a 4% shift of demand from on-peak to off-peak hours. This is increased to a maximum of 20% between 2020 and 2030 to estimate the achievable potential scenario. Under this restriction, we estimate that consumers would reduce their on-peak consumption by 10%. For further details, see Brown and Chapman (2020).	by 50%. and by reducing the cost of storage by 50%. (1) Overnight capital cost of \$1238/KW in the technical potential case vs \$2475/KW in the baseline forecast (2) Variable O&M cost of \$4.2/MWh in the technical potential case vs \$8.4/MWh in the baseline forecast (3) Fixed O&M cost of \$20.9/KW in the technical potential case vs \$41.8/KW in the baseline forecast.
Rooftop Solar (91-95)	Google Sunroof dataset of county data based on aerial and satellite imagery, 3-D modelling, and shade (Google Project Sunroof, 2020); data on Solarize participation	To estimate the achievable potential for rooftop solar, we develop a logistic growth function. The function is fitted to the past four years of Solarize participation data. Total annual abatement figures for Solarize were aggregated using the end years of each Solarize campaign, with two ongoing projects in Decatur-Dekalb and Savannah still adding abatement potential in 2020. The logistic curve is also fitted to the estimate of the state's technical potential of 12.1 megatons (see column to the right). The generic logistic growth curve that was fitted to historic growth rates and the technical potential for rooftop solar in Georgia, is specified below. $R_t = \frac{TP}{1 + Ae^{-bt}}$ where: ● R_t = reduction (MtCO$_2$) in year t ● TP = technical potential (MtCO$_2$) ● A and b are the logistic parameter Customized R-based spreadsheets were developed to calculate cost-effectiveness of market penetration using various assumptions about costs and efficiency from the National Renewable Energy Laboratory (Fu et al., 2018). Baseline forecast modeled by GT-NEMS Reference Case. For further details see Brown, M.A., Hubbs, J., Gu, V. and Cha, M-K (2021), Rooftop Solar: Closing the Gap Between the Technically Possible and the Achievable, Working paper.	Analysis of Google Sunroof data by county produced estimates of the rooftop area suitable for solar photovoltaics. Potential electricity generation from these rooftops is based on the capacity factor of existing rooftop solar in Georgia (14.7%) derived from Google Sunroof data on existing installations. To use the per-county estimates to evaluate the total potential by county requires making assumptions about the frequency distribution of the potentially available power within the size bins used in the Google Project Sunroof data. The single-point estimate of available power for rooftops within a capacity size bin is set to its midpoint (e.g., 7.5 KW represents the bin spanning 5-10 KW). Analysis of the data on current installations is used to derive the frequency distributions of the potential for additional solar PV capacity by county. We assume that the nameplate capacity of current installations has the same frequency distribution as the potentially available rooftop space by county provided by Project Sunroof. For the existing installations and the potential installation, we assume there are no installations smaller than 3 kW. We focus on the technical potential for generating electricity on flat and south-facing angled roofs. The resulting 24.3 GW of potential is close to the estimate produced by NREL and published in Lopez, et al. (2012, Table 4). At a capacity factor of 14.7, Georgia has the technical capacity to generate 31,300 GWh of electricity in a year. Based on the GT-NEMS baseline forecast for power generation in Georgia in 2030, 2,580 GWh of new solar electricity generation in that year would displace 1 Megaton of emissions. Thus, 24.3 GW of feasible technical potential rooftop

			solar in Georgia could displace 12.1 megatons of emissions.
Large-Scale Solar (96-103)	Data internal to GT-NEMS (USEIA, Annual Energy Outlook, 2018)	GT-NEMS Reference case was used for the baseline forecast. To estimate the achievable potential for large-scale solar, the Reference case was modified to reflect a carbon tax of $\$10/\text{tCO}_2$, levied on CO_2 emitted by the electricity sector, implemented in 2022, and escalating at 5% per year through 2050. As with the Green New Deal and the Energy Innovation and Carbon Dividend Act of 2019, all carbon tax revenues are recycled back to households on a per capita basis. GT-NEMS models the 22 NERC regions, and we model Georgia as 40.9% of the generation and emissions of the SERC-SE region.[**] Carbon abatement costs are estimated in two ways, which produces a range: by using GT-NEMS outputs of utility resource costs and by reviewing the details of recent power purchase agreements in the U.S. For further details see Brown, M.A, Tudawe, R., and Steimer, H. (2021) "Carbon drawdown potential of utility-scale solar in the United States: Evidence from a case study of Georgia," Working paper. We do not consider the potential impact of agrivoltaics on the achievable potential or cost-effectiveness of solar farms, since this is an emerging approach to regenerative energy. It involves creating a dual purpose for land: producing renewable solar energy and raising small livestock.	To estimate the technical potential for large-scale solar, the Reference case was modified to reflect a carbon tax of $\$15/\text{tCO}_2$, levied on CO_2 emitted by the electricity sector, implemented in 2022, and escalating at 5% per year through 2050. As with the Green New Deal and the Energy Innovation and Carbon Dividend Act of 2019, all carbon tax revenues are recycled back to households on a per capita basis. GT-NEMS models the 22 NERC regions, and we model Georgia as 40.9% of the generation and emissions of the SERC-SE region.[*]

[**] According to S&P data, SERC-SE had 66 GWs of generating capacity in 2018, and 30.5 gigawatt (GW) (46.2%) of this was located in Georgia. SERC-SE generated 254,000 GWh of electricity in 2018, and 104,000 GWh (40.9%) of this total was produced in Georgia. There are also two dams in north Georgia that are owned and operated by the Tennessee Valley Authority. Since hydropower is considered to be nearly carbon-free, we do not make any adjustments for this electricity.

[*] According to S&P data, SERC-SE had 66 GWs of generating capacity in 2018, and 30.5 gigawatt (GW) (46.2%) of this was located in Georgia. SERC-SE generated 254,000 GWh of electricity in 2018, and 104,000 GWh (40.9%) of this total was produced in Georgia. There are also two dams in north Georgia that are owned and operated by the Tennessee Valley Authority. Since hydropower is considered to be nearly carbon-free, we do not make any adjustments for this electricity.

Landfill Methane (104-107)	EPA LMOP LFGcost Spreadsheet	The U.S. Environmental Protection Agency's Landfill Methane Outreach Program Landfill Gas Energy Cost Model (EPA LMOP LFGcost) was used to estimate the achievable potential using 21 candidate landfills in GA totaling 45 MW of nameplate installed capacity.	The U.S. Environmental Protection Agency's Landfill Methane Outreach Program Landfill Gas Energy Cost Model (EPA LMOP LFGcost) was used to estimate the technical potential using 22 candidate landfills in GA totaling 47 MW of nameplate installed capacity.
EVs (108-128)	U.S. DOE Energy Information Administration; U.S. DOE, Alternative Fuels Data Centre; U.S. EPA; U.S. DOT (Household Travel Trends); Other DOT/NHTSA; U.S. DOE, EERE, Vehicle Technologies Office; IRS (Tax credit); GA Tax Code; GA DOT vehicle registration database; DOC (CPI inflation tables); WG authors' publications; Edison Electric Institute; NREL; EPRI; Bloomberg New Energy Finance; Brattle; Others.	Assessed CO_2 emissions reductions and net present value of investments using customized Excel spreadsheets based on input data from open-source publications and resources. For EV 2030 growth projections, plausible estimates were determined based on the best fit of multiple third-party research projections (e.g., DOE/EIA AEO 2019 Reference Case, EPRI Low/Medium Nov 2019, BNEF 2018 EV Outlook, NREL Electrifications Futures, Medium, NAS Midrange PEV, as summarized by BNEF chart below). For GA electricity grid CO_2projections, data from GT- NEMS, Working Group (WG) 1 projections, and open-source data from public reports (e.g., DOE EIA, FERC, EPA) were employed. Other economic indicators use stated assumptions and follow accepted best practices (e.g., discount rates of 3% and 7%, assumed DOC/CPI inflation trends, 2019 Real$, etc. as disclosed in (Simmons, Applied Energy)). For the Achievable Scenario, an EV adoption growth rate corresponding to 21% of new vehicle sales 2030 has been assumed. This corresponds to a total about 310,000 electric vehicles (3.7%) in the Georgia light duty fleet of about 8.2 million vehicles. This level of growth has been inferred from the external sources and economic feasibility. For instance, it represents an approximation based on an average of predicted growth scenarios as per the compiled data shown below. Then, steps were taken to apply this growth trend to the specific case of Georgia, based on compliance with Federal CAFE regulations (DOT/NHTSA and EPA), as well as projections around EV tax credits (Breetz, Energy Policy; Author), existing and future composition of the registered light duty vehicle fleet (GA registered vehicle database, author). An annual turnover of the vehicle stock of between 5-6% for Georgia is assumed, based on recent historical trends from DOT	For the Technical Potential Scenario, an EV adoption growth rate corresponding to 40% of new vehicle sales 2030 has been assumed. This corresponds to a total about 680,000 electric vehicles (8.3%) in the Georgia light duty fleet of about 8.2 million vehicles. This level of growth has been inferred from the external sources. This EV adoption rate represents an approximation based on aggressive growth scenarios as forecasted by the compiled data shown below. Then, steps were taken to apply this growth trend to the specific case of Georgia. For the technical potential scenario, several constraints were relaxed in conjunction with author's independent analyses, including: compliance with Federal CAFE regulations (DOT/NHTSA and EPA), EV tax credits, electric power generation infrastructure, reserve capacity and marginal CO2 emission rates, public and private charging demands, and economic feasibility. An annual turnover of the vehicle stock of between 5-6% for Georgia is assumed, based on recent historical trends from DOT (Household survey).

		(Household survey). Economic feasibility was based on projected price trends for new vehicles and battery prices from the literature, in conjunction with author's independent analyses.	
Energy-Efficient Cars (129-130)	Simmons, et al. (2015); Simmons, (2015) U.S. EPA; www.fueleconomy.gov; U.S. DOT; U.S. DOE EIA; U.S. DOE, Alternative Fuels Data Center; U.S. DOE, EERE, Vehicle Technologies Office; GA DOT vehicle registration database; Edmunds.Com; Kelly Blue Book; WG authors' publications; Others	Assessed CO_2 emissions reductions and net present value of investments using author's benefit cost modeling methodology for incremental cost and efficiency gains. This includes customized Excel spreadsheets based on input data from open-source publications and resources. For future fuel economy standards, and technology adoption projections, current and future US Corporate Average Fuel Economy Regulations (EPA and DOT/NTHSA) as well as market trend analyses were employed. Other economic indicators use stated assumptions and follow accepted best practices. For the achievable scenario, a 1% fuel economy improvement above the regulatory baseline projection was assumed for light duty trucks, and the share of cars is assumed to increase from a 36% baseline in 2020 to 44% in 2030.	For the technical potential scenario, a 2% fuel economy improvement above the regulatory baseline projection was assumed for light duty cars and trucks, and the share of cars is assumed to increase from a 36% baseline in 2020 to 44% in 2030.
Energy-Efficient Trucks (131-183)	Atlanta Regional Commission. Argonne National Laboratory; Birkey, et al. (2017); Curry, et al. (2012); Davis and Boundy (2020); North American Council for Freight Efficiency; NHSTA; Scora, et al. (2020); Simmons, et al. (2015); Smith, et al. (2019); U.S. DOE EIA; U.S. DOE EERE; U.S. DOE NREL; U.S. DOT; U.S. EPA	Assessed CO_2 emissions reductions and net present value of investments using customized Excel spreadsheets based on input data from open-source publications and resources for eleven medium and light-heavy duty vehicle use cases. Weighted average emissions reductions for these use cases was used to estimate emissions reductions for use cases not specifically modeled. For future fuel economy standards, and technology adoption projections EPA and DOT/NTHSA standards and market trend analyses were referenced. Other economic indicators use stated assumptions and follow accepted best practices. The achievable scenario was established to meet a 25% overall reduction in truck fuel consumption by 2030.	The technical potential scenario was established to meet or exceed a 30% overall reduction in truck fuel consumption by 2030. Such a scenario would result in 4.2 MMT/y in CO2 reductions.

	Wang, et al. (2016)		
Mass Transit (184-187)	Atlanta Regional Commission, CALTRANS, Georgia Tech/ORNL Fuel and Emissions Calculator U.S. DOT FTA U.S. EPA	New housing units were estimated based on future population growth projections from the Atlanta Regional Commission. Study adopted projected GHG emissions reductions associated with transit-oriented development developed for CALTRANS. Additional emissions reductions based on electrification of transit buses were estimated using the Georgia Tech/ORNL Fuel and Emissions Calculator (FEC) developed for U.S. DOT FTA. For the achievable scenario, approximately 30% of new households (288,000) in Atlanta would lie within Transit Oriented Development zones. This would result in a reduction of 0.8 MMT/yr compared to the baseline forecast.	New housing units were estimated based on future population growth projections from the Atlanta Regional Commission. Study adopted projected GHG emissions reductions associated with transit-oriented development developed for CALTRANS. Additional emissions reductions based on electrification of transit buses were estimated using the Georgia Tech/ORNL Fuel and Emissions Calculator (FEC) developed for U.S. DOT FTA. For the technical potential scenario, approximately 36% of new households (360,000) in Atlanta would lie within Transit Oriented Development zones. This would result in a reduction of 1.1 MMT/yr compared to the baseline forecast.
Alternative Mobility (188-202)	U.S. DOE Energy Information Administration; U.S. DOE, Alternative Fuels Data Center; U.S. EPA; U.S. DOT (Household Travel Data); Other DOT; Matisoff (2020)	Assessed CO_2 emissions reductions and net present value of investments using customized Excel spreadsheets based on input data from open-source publications and resources. Achievable potential was defined as a 5 – 10% increase in biking / cycling for urban trips <4 miles, and 10 – 20% telecommuting.	Achievable potential was defined as a 42% shift to cycling and walking across all trips and 50% telecommuting.
Recycling (203-214)	U.S. EPA Waste Reduction Model (WARM); R.W. Beck (2005); Shin (2014).	Used published data from literature to estimate average waste stream for Georgia, and the Environmental Protection Agency (EPA)'s Waste Reduction Model (WARM) to calculate the energy savings and CO2 savings from increased recycling. The results were then used to calculate the cost of avoided generation as part of estimating the private costs and benefits of recycling associated with the recycling of paper products, glass, plastics, and metals. The Achievable Scenario represents a 50% improvement in recycling rates to achieve a 20% recycling rate.	The technically achievable scenario represents a 95% improvement in recycling rates to achieve a 33% recycling rate.
Refrigerant Management. (215-238)	EPA's Greenhouse Gas State Inventory and Projection (SIP) Tool; California's High Global Warming Potential Gases	Estimated the current state of refrigerants in Georgia using EPA SIP tool with a linear extrapolation from the 2010-2016 data to create a 2020 baseline. Estimated Georgia's loss rates and inventories associated with the various sectors that use refrigerants using 2015 California refrigerants inventory. Projected potential	The technical potential involves eliminating the leakage of GWP refrigerant leakage from grocery stores. And, in addition to replacing residential air conditioners with SNAP low GWP alternatives, 50% of commercial refrigeration systems would be replaced with 0-GWP alternatives.

	Emission Inventory 2015 Edition; U.S. EPA GreenChill grocery store data; U.S. EPA Significant New Alternatives Policy (SNAP); Regulatory Impact Analysis from 2016 & 2018 Section 608 Refrigerant Management / ODS regulations	savings using EPA Greenchill store data and SNAP approved low-emitting chemicals to predict possible effects of new technologies. The low-achievable scenario reduces grocery store leakage rates to 13% on average. The high achievable scenario adds a replacement of 20% of residential air conditioners with a SNAP approved low GWP alternative.	
Retrofitting (239-269)	U.S. DOE analyses of state/utility energy efficiency potentials; U.S. DOE SCOUT; Residential Energy Consumption Survey (RECS); Commercial Building Energy Consumption Survey (CBECS)	Baseline delivered energy usage was determined from NEMS. Individual technologies were evaluated for cost-effectiveness based on DOE estimates, peer reviewed literature, and expert input from focus groups._The Achievable scenario utilizes smart thermostats, improved insulation, and LED lighting for the residential sector and retro-commissioning, building automation, and LED lighting for the commercial sector. These technologies were deemed cost-effective with a 12% discount rate. Cumulative retrofit rates are based on the annual energy efficiency potentials observed from various state / utility analyses. The scenario assumes 2% per year market penetration. Typical relative energy savings from the retrofit solutions were estimated from SCOUT. The CO2 savings arising from the energy savings were calculated using Georgia-specific emission factors.	The technically feasible scenario adds high efficiency heat pumps, hybrid heat pump water heaters, and improved insulation in the commercial sector. These technologies create a bundle of cost-effective technologies at an 12% discount rate. It assumes a 5% per year market penetration for all technologies reaching 50% penetration by 2030.
Composting (270-275)	U.S. MSW data and distribution fractions from U.S. EPA (2017) GHG emission factors data from U.S. EPA Waste Reduction Model (WARM) (U.S. EPA, 2020; Weitz et al., 2002) Economic data related to composting obtained from refed.com (ReFed, 2016); U.S. EPA, 1998).	The current and projected organic waste, including food waste, was estimated for Georgia from the U.S. EPA's municipal solid wastes (MSW) data on a per-capita basis. The total organic waste sent to landfills that would otherwise be composted was modeled in a customized excel spreadsheet that accounts for the current rate of composting and combustion of organic wastes in Georgia for baseline projection. Our achievable potential estimates are assumed to evaluate the carbon reduction potential, if 50% of organic wastes are diverted from landfills to composting by 2030.	Technically, all the organic wastes generated in Georgia can be composted, so the technical potential is 100%. The GHG emission reduction potential by composting was calculated based on the total amount of organic wastes sent to landfills. The current organic waste data does not include biosolids from municipal sewer systems and crop residues such as cotton gin wastes and other wastes such as poultry litter generated in Georgia.

		The cost-benefits of composting 50% organic wastes were estimated based on the composting cost data obtained from open literature sources and the estimates from ReFed organization (Refed, 2016).	
Conservation Agriculture (276-283)	Georgia specific historic cropland data obtained from https://www.nass.usda.gov (USDA-NASS, 2019) and conservation adoption practices information from Knowler and Bradshaw (2017). Enterprise budget data obtained from https://agecon.uga.edu/extension/budgets.html (UGA Extension, 2019)	The historic total cropland area, types of crops grown, irrigation types, current conservation practices, current crop rotation information for the state of Georgia were obtained from the USDA National Agricultural Statistical Services (NASS) databases. We developed a spreadsheet-based model to assess the baseline GHG reduction potential due to conservation agricultural practices in Georgia (current annual adoption rate is 1.5%). Although conservation agriculture is a broad term encompassing multiple physical and management practices, we focused in this analysis exclusively on the effects of conservation tillage practices (no-tillage and/or strip-tillage), crop rotation and leaving the residues in the field to prevent soil erosion. For each major crop, the life cycle GHG emissions for conventional and conservation practices were used to estimate the GHG reduction potentials from adoption of conservation agriculture practices. The GHG reduction potentials include the soil carbon sequestrations due to conservation agriculture practices. The achievable potential analysis assumes a 3% annual adoption rate of major row crops grown using conservation tillage practices and its potential to reduce GHG emissions by 2030.	Technically, every acre of the major row crops grown in Georgia (cotton, peanuts, corn and soybean) could adopt conservation agriculture practices, so the technical potential is 100% of all row crops grown in Georgia.
Plant-Rich Diet (284-296)	The U.S. meat consumption rate data was obtained from www.ers.usda.gov (USDA-ERS, 2019) The GHG emission factors data obtained from open literature	We used the Georgia population data to estimate the GHG emission potentials of plant-rich diets. The per capita meat consumption in the U.S. estimated by the U.S. Department of Agriculture (USDA), Economic Research Services (ERS) was used to estimate the current-level of meat consumption rate in Georgia. Open literature per-capita data on the emission factors for animal-rich and plant-rich diets were coupled with	We used the Georgia population data to estimate the GHG emission potentials of plant-rich diet solution. We assumed a technical potential as about 75% of the Georgia population shifts to plant-rich/low-carbon diets.

	sources [Eshel, et al., (2019); Heller et al., (2013); Shepon, et al., (2018); Tilman et al., (2014)] The solution strategies and economic data were obtained from Ranganathan et al., (2016), NAS (2019) and Drew, et al., (2020), Eshel, G., P. Shepon, A., Noor, E. & Milo, (2016).	Georgia population projections to estimate Georgia-specific GHG emission reduction potentials. The baseline analysis assumes that about 2.5% of Georgia's population shifted to plant-rich diets. The achievable potential estimate assumes about 25% of Georgia's population shift to a plant-rich/low-carbon diet by 2030 at an annual adoption rate of 2.5%. The strategic interventions to adopt plant-rich diets proposed by Ranganathan et al., (2016) was applied to estimate the potential cost of adoption or shift to plant-rich diets.	
Reduced Food-Waste (297-306)	The U.S. food waste data obtained from various sources compiled by (ReFED, 2016); (Buzby et al. 2012); (Heller et al. 2014); (Hoover et al. 2017). The economic data and other strategies to reduce regional food wastes information obtained from (ReFED, 2016); (Tilman et al. 2014); (FAO, 2011); (Snyder et al.2018); (CAST, 2018).	U.S. food waste data from open literature sources were used to estimate Georgia-specific food waste tonnage on a per-capita basis. The Georgia specific food-wastes data were further divided into wastes at the consumer and retail levels and losses at the farm and during processing based on the national average values. The potential food waste reduction interventions by the ReFed.com organization were used to compute food wastes that can be preventable and reusable by food banks. The emission factors data for food waste prevention and reuse by the U.S. EPA's WARM model were used to estimate GHG reduction potential specific to Georgia. The food waste reduction by disposal methods such as composting and anaerobic digestions was not considered in our analysis to estimate GHG emission reduction potentials. The achievable potential analysis estimated the GHG emission reduction potential of 20% reduction in food waste by 2030. The economic data related to potential food waste reduction interventions reported by ReFed.com were applied to estimate cost and benefits data.	The technical potential analysis estimated the GHG emission reduction potential, if 50% of food waste can be reduced by 2030.

Afforestation and Silvopasture (307-317)	USDA (2016), Georgia Forestry Commission (2019), Richter et al. (1999), Machmuller et al. (2018), Carey et al. (2016), Crowther et al. (2016), Moore et al. (2011), Georgia Forestry Commission (2019)	The state of Georgia contains 2.8 million acres of pasturelands (Georgia Forestry Commission 2019, USDA 2016). For the Afforestation and Silvopasture solution, we estimated annual CO$_2$e gain in trees and soils if planted in a 50:50 mix of loblolly pine (*Pinus taeda*; the main timber species in the Southeast and the United States) and native hardwood species, as well as if planted exclusively in loblolly pine. To calculate annual amounts of carbon dioxide equivalents (CO$_2$e) stored in living tree biomass per acre, we calculated annual carbon gain in wood and roots, assuming green wood contains 28% carbon (Wang 2010) and converted to CO$_2$e. (Loblolly pine green wood ranges from 25-30% carbon, Wang 2010). For loblolly CO$_2$e annual gain in living biomass, we estimated a rate of 4.6 t CO$_2$e per acre in above and below ground living tree biomass. Hardwood species have lower productivity and growth over the initial years of stand development, so we assumed CO$_2$e accumulation rates in hardwood trees of half that of pines (Christensen and Peet 1981; Mohan et al. 2007, 2009; Schlesinger and Bernhardt 2020). We note that while our current models only include planting trees in Georgia pastures, additional CO$_2$e plus non-carbon benefits including local cooling, biodiversity habitat, and filtering of air and water pollutants would be achieved by planting trees in urban, suburban, and rural lands including parks and yards. To estimate CO$_2$e stored in loblolly-associated soils, we based our calculations on Richter et al. (1999), who measured soil carbon accrual over time in the degraded soils of a 40-year old loblolly stand in South Carolina, which naturally recruited following mid-20th Century agricultural land abandonment. We also supplemented with Machmuller et al. (2018), Carey et al. (2016), and Crowther et al. (2016). The much more chemically labile (easy for microbes to break down) hardwood leaf litter leads to much faster litter decomposition rates which respire CO$_2$ to the atmosphere and reduce carbon stored in the soil litter layer (Schlesinger and Bernhardt 2020). Thus, we assumed	For the technical potential, we assumed 100% of the current 2.8 million acres of pasturelands were planted in mixed loblolly-hardwood tree species (Note: this would convert the land use from pastures to forests, potentially managed for timber and non-timber forest products). Under this scenario, we estimated sequestering an additional 14.3 MtCO$_2$e annually by the year 2030 in living tree biomass and soils. As trees continue to grow and funnel carbon to soils, this annual amount would increase over time. We additionally modeled an "extreme technical potential," which considered planting 100% of current pasturelands exclusively in loblolly pine, one of the most productive temperate forest tree species, and calculated a potential storage rate of 19.5 MtCO$_2$e per year by 2030. Again, as trees continue to grow and funnel carbon to soils, this annual amount would increase over time. However, an important caveat is that high risk is associated with planting a single species due to the risk of pests, pathogens, susceptibility to extreme weather events, etc., so this extreme technical potential should be viewed with caution.

		soil CO_2e accumulation to occur at about a quarter of the rate of that under loblolly pine trees. For the mixed half loblolly and half hardwood planting scenarios, we used an annual CO_2e accumulation rate of 4.8 tCO_2e per acre in living tree biomass and soils. For the loblolly-only planting scenarios, we assumed a CO_2e rate of 6.6 tCO_2e per acre per year in living tree biomass and soils. For the <u>Achievable Potential,</u> we estimated if 20% of the current 2.8 million acres of pasturelands were planted in mixed loblolly-hardwood tree species, an additional 2.8 $MtCO_2e$ would be stored annually by the year 2030 in living tree biomass and soils. As trees continue to grow and funnel carbon to soils, this annual amount would increase over time.	
Coastal Wetlands (318-326)	Georgia Department of Natural Resources Coastal Resources Division (2012), Creswell (2018), United States Global Change Research Program (2018), Edwards, L., J. Ambrose, and L.K. Kirkman. (2013), Aber, J.D. and J.E. Melillo. (2001), Schlesinger, W.H. and E.S. Bernhardt (2020).	The state of Georgia has ~100 miles of coast and the coastal wetlands it has are markedly undeveloped compared with those of other states. Further, with a few small exceptions these wetlands are owned by federal, state and conservation agencies (the exceptions being Jekyll Island, Tybee Island, and St. Simons). The over 429,924 acres of tidal marshes in Georgia comprise the largest amount of healthy tidal wetlands in the U.S. Atlantic seaboard (Seabrook (2006), Edwards et al.(2013), Georgia Department of Natural Resources Coastal Resources Division (2012). Further, Georgia's tidal marshes are among the most productive ecosystems in the world on a per-unit area basis, rivaling those of tropical rainforests (Aber and Melillo (2001), Edwards, et al. (2013), Schlesinger and Bernhardt (2020), Ouyang and Lee (2014). Thus, maintaining Georgia's Coastal Wetlands is an important Drawdown Solution. Carbon sequestration rates were calculated from data in publicly-available and published sources (e.g Georgia Department of Natural Resources Coastal Resources Division (2012), Creswell (2018), U.S. Global Change Research Program (2018). State level economic data were estimated from Creswell (2018)	<u>Technical Potential</u> - By increasing coastal wetland cover by 14% we would increase annual CO_2e storage in the state's coastal wetlands by 0.2 Mt by 2030, for a 2030 total sequestration rate of 1.6 $MtCO_2e$ per year.

		research in Chatham County, GA. Most Coastal Wetland ecosystem carbon storage is belowground, helping protect this carbon from storms and other natural disturbances. Coastal inland land protection is also required to account for inland coastal migration in response to sea level rise (U.S. Global Change Research Program (2018). Additionally, healthy Coastal Wetlands are critical for protecting coastal lands and properties from storms and surges which are becoming increasingly apparent with climate change (Creswell 2018, U.S. Global Change Research Program 2018, Kirwan and Megonigal 2013). We estimate the 429,294 acres of Georgia's tidal wetlands (Seabrook 2006) currently sequester 1.4 MtCO$_2$e annually. Achievable Potential - By increasing coastal wetland cover by 7% we would increase annual CO$_2$e storage in the state's coastal wetlands by 0.1 Mt by 2030, for a 2030 total sequestration rate of 1.5 MtCO$_2$e per year.	
Temperate Forest Protection and Management (327-333)	USDA (2020), Richter et al. (1999), Machmuller et al. (2018), Carey et al. (2016), Crowther et al. (2016), Moore et al. (2011)	To estimate CO$_2$e annually stored in living tree biomass we used data from the USDA Forest Inventory and Analysis data for the state of Georgia between 2007 and 2017 and calculated average annual storage amounts of 27 MtCO$_2$e for Georgia. To estimate annual soil carbon, we relied on FIA soil data and Richter et al. (1999), supplemented with Machmuller et al. 2018, Carey et al. 2016 and Crowther et al. 2016. For calculating annual soil carbon storage on lands with already established forest cover, unlike degraded post-agricultural soil, we estimated a 0-3 Mt CO$_2$e of annual soil carbon storage for the state of Georgia, depending on the initial soil carbon levels, with relatively carbon-rich soils already supporting canopy trees having lower levels of annual new carbon accumulation and sites with depleted soils having higher rates of new soil carbon accumulation upon planting trees (Richter et al. 1999). For the Achievable Potential, we estimated CO$_2$e sequestration in forest trees and soils by increasing the state's	For the Technical Potential, we estimated CO$_2$e sequestration in forest trees and soils by increasing the state's forest cover by 15%, resulting in enhanced annual CO$_2$e storage of 4.3 Mt per year by 2030.

		forest cover by 10%, resulting in enhanced annual CO_2e storage of 2.8 Mt per year by 2030.	

Table S2. Data Sources and Modelling Approaches Used to Estimate the Potentials and Costs of 20 Solutions

	Achievable		Technical
Solution	**Carbon Abatement in 2030 (MT CO2-e)**	**Net Present Value of Abatement Cost (2017\$/tCO$_2$-e)**	**Carbon Abatement in 2030 (MT CO2-e)**
Rooftop Solar	0.85	-118 to -26	12.1
Utility-Scale Solar	11.2	-3.9 to 71.0	21.4
Demand Response	1.95	6.10	1.45
Cogeneration	2.1	-178	13.0
Landfill Methane	1.4	-11.43	1.5
Electric Vehicles	1.4	27. to 144	2.3
Energy-Efficient Cars	1.4	25 to 40	4.1
Energy-Efficient Trucks	3.3	-37.0	4.2
Mass Transit	0.8	116	1.1
Alternative Mobility	1.8 to 3.6	-4.67 to -1.58	21.5
Recycling	2.0 to 4.1	-43 to -21	7.7
Refrigerant Management	0.71	7.61	2.80
Retrofitting	2.6 to 4.0	-0.85 to 2.12	13.7
Composting	0.70	-17.0	1.38
Conservation Agriculture	0.5	1.9 to 6.6	0.7
Plant-Rich Diet	1.13	0 to 8.0	3.44
Reduced Food-Waste	1.8	-336	4.3
Afforestation & Silvopasture	2.8	2.0	14.3 to 19.5
Coastal Wetlands	0.1	1.6	0.2
Temperate Forests	2.8	2.0	4.3

Table S3. Abatement Potential and Costs from 20 Solutions Implemented in Georgia in 2030

Solution	Scenario	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cogeneration	Achievable	0	-0.2	-0.4	-0.6	-0.9	-1.1	-1.3	-1.5	-1.7	-1.9	-2.1
	Technical	0	-1.3	-2.6	-3.9	-5.2	-6.5	-7.8	-9.1	-10.4	-11.7	-13
Demand Response	Achievable	0	1	2	-0.2	-3.8	-2.3	-2.8	-3.8	-2.1	-3.2	-1.7
	Technical	0	-0.8	1.8	-1.6	-2.9	-5.7	-3.6	-4.7	-3.8	-5.2	-1.5
Rooftop Solar	Achievable	0	0	0	0	0	-0.1	-0.1	-0.2	-0.3	-0.6	-0.9
	Technical	-0.1	-2.1	-5.1	-8	-8.9	-9.4	-9.6	-9.9	-10.3	-11.8	-12.1
Large Scale Solar	Achievable	0.2	-3.9	-9.1	-11.7	-14.1	-14.7	-15.1	-15.1	-12.2	-13.8	-11.2
	Technical	-0.2	-4.2	-10.2	-16.1	-17.8	-18.8	-19.2	-19.9	-20.6	-23.6	-21.4
Landfill Methane	Achievable	0	-0.1	-0.3	-0.4	-0.6	-0.7	-0.8	-1	-1.1	-1.3	-1.4
	Technical	0	-0.2	-0.3	-0.5	-0.6	-0.8	-0.9	-1.1	-1.2	-1.4	-1.5
Electric Vehicles	Achievable	0	0	-0.1	-0.1	-0.1	-0.1	-0.4	-0.6	-0.9	-1.2	-1.4
	Technical	0	-0.2	-0.3	-0.5	-0.7	-0.8	-1.1	-1.4	-1.7	-2	-2.3
Energy-Efficient Cars	Achievable	0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.5	-0.7	-0.9	-1.1	-1.4
	Technical	0	-0.3	-0.7	-1	-1.4	-1.7	-2.2	-2.7	-3.1	-3.6	-4.1
Energy-Efficient Trucks	Achievable	0	-0.5	-0.9	-1.4	-1.8	-2.3	-2.5	-2.7	-2.9	-3.1	-3.3
	Technical	0	-0.5	-1	-1.5	-2	-2.5	-2.8	-3.2	-3.5	-3.9	-4.2
Mass Transit	Achievable	0	-0.1	-0.1	-0.2	-0.3	-0.4	-0.5	-0.5	-0.6	-0.7	-0.8
	Technical	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.9	-1	-1.1
Alternative Mobility	Achievable	0	-0.2	-0.4	-0.5	-0.7	-0.9	-1.1	-1.3	-1.4	-1.6	-1.8
	Technical	0	-2.2	-4.3	-6.5	-8.6	-10.8	-12.9	-15.1	-17.2	-19.4	-21.5
Recycling	Achievable	0	-0.3	-0.6	-0.9	-1.2	-1.6	-1.9	-2.2	-2.5	-2.8	-3.1
	Technical	0	-0.8	-1.5	-2.3	-3.1	-3.8	-4.6	-5.4	-6.1	-6.9	-7.7
Refrigerant Management	Achievable	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7
	Technical	0.3	0	-0.3	-0.6	-0.9	-1.3	-1.6	-1.9	-2.2	-2.5	-2.8
Retrofitting	Achievable	0	-0.3	-0.5	-0.8	-1	-1.3	-1.6	-1.8	-2.1	-2.3	-2.6
	Technical	0	-1.4	-2.7	-4.1	-5.5	-6.9	-8.2	-9.6	-11	-12.3	-13.7
Composting	Achievable	0	-0.1	-0.1	-0.2	-0.3	-0.34	-0.4	-0.47	-0.55	-0.62	-0.69

	Technical	0	-0.1	-0.3	-0.4	-0.5	-0.67	-0.81	-0.95	-1.09	-1.23	-1.38
Conservation Agriculture	Achievable	0	-0.1	-0.1	-0.2	-0.2	-0.3	-0.34	-0.38	-0.42	-0.46	-0.5
	Technical	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.54	-0.58	-0.62	-0.66	-0.7
Plant Rich Diet	Achievable	0	-0.1	-0.2	-0.3	-0.4	-0.53	-0.65	-0.77	-0.87	-1	-1.13
	Technical	0	-0.3	-0.6	-0.9	-1.3	-1.61	-1.95	-2.3	-2.7	-3	-3.4
Reduced Food Waste	Achievable	0	-0.2	-0.3	-0.5	-0.7	-0.9	-1	-1.2	-1.4	-1.6	-1.8
	Technical	0	-0.4	-0.8	-1.3	-1.7	-2.1	-2.6	-3	-3.5	4	-4.5
Afforestation & Silvopasture	Achievable	0	-0.1	-0.2	-0.4	-0.5	-0.7	-1.1	-1.5	-2	-2.4	-2.8
	Technical	0	-0.7	-1.4	-2.2	-2.9	-3.6	-5.7	-7.9	-10	-12.2	-14.3
Coastal Wetlands	Achievable	0	0	0	0	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
	Technical	0	0	0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2
Temperate Forest Protection & Management	Achievable	0	0	-1.2	-1.4	-1.6	-1.8	-1.9	-2	-2.2	-2.4	-2.6
	Technical	0	0	-2.8	-3	-3.3	-3.5	-3.6	-3.7	-3.9	-4.1	-4.3

Table S4. Abatement Potential, by Year

Year	Summer Peak	Peak + 15%	Installed Capacity	Excess	Excess
	MW	MW	MW	MW	%
2019	16,300	18,750	20,300	1,550	7.6
2029	17,150	19,700	20,300	600	3.0

Table S5. Forecasted capacity of Georgia Power, for subject years

References

1. Hawken, Paul. (2017). *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming* (Penguin Press).
2. Brown, M.A., Beasley, B., Atalay, F., Cobb, K.M., Dwivedi, P., Hubbs, J., Iwaniec, D.M., Mani, S., Matisoff, D., Mohan, J.E., Oxman, M., Rochberg, D., Rodgers, M., Shepherd, M., Simmons, R., Taylor, L., Toktay, L.B., and Mullen, J. (2021) Translating a Global Emissions Reduction Framework for Sub-National Climate Action: A Case Study from the State of Georgia. *Environmental Management,* forthcoming.
3. Leiserowitz, A., Maibach, E., Rosenthal, S., Kotcher, J., Bergquist, P., Ballew, M., Goldberg, M., & Gustafson, A. (2019) Climate Change in the American Mind: November 2019. Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication.
4. World Resources Institute, CAIT 2.0. (2014) *Climate Analysis Indicators Tool: WRI's Climate Data Explorer.* Washington, DC: World Resources Institute. Available at: https://www.wri.org/data/climate-watch-us-states-greenhouse-gas-emissions
5. U.S. Environmental Protection Agency (EPA). (2018) EPA-2 database. Available at: https://www.epa.gov/ghgemissions/overview-greenhouse-gases
6. Government Accountability Office, (2017) THE 2017 Climate Change Scoping Plan Update: The Proposed Strategy for Achieving California's 2030 Greenhouse Gas Target. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2020/07/CA_2017_Scoping_Plan.pdf
7. Governor of Colorado Office. (2019) Polis Administration's: Roadmap To 100% Renewable Energy by 2040 and Bold Climate Action. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2020/06/CO_2019_Action_Plan.pdf
8. Governor's Council on Climate Change. (2018) Building a Low Carbon Future for Connecticut: Achieving a 45% GHG Reduction by 2030. . Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2020/06/CT_2018_Action_Plan.pdf
9. ICF. (2020) Delaware Climate Action Plan Supporting Technical Greenhouse Gas Mitigation Analysis Report. Delaware Department of Natural Resources and Environmental Control. Available at: https://decaptransfer3.wpengine.com/wp-content/uploads/2020/09/DNREC-Technical-Report_FINAL-9-3-20-CLEAN.pdf
10. Governor's Office of Coastal Activities. (2021) Louisiana Climate Initiatives Draft Partial Final Report. Office of the Governor Available at: https://gov.louisiana.gov/assets/docs/CCI-Task-force/CITF_Draft.Partial.Final.Report.for.Public.Comment.pdf
11. Department of Environmental Protection. (2004) A Climate Action Plan for Maine 2004. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/ME_2004_Action_Plan.pdf
12. Maryland Department of the Environment. (2015) Greenhouse Gas Emissions Reduction Act Plan Update. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/MD_2015_Action_Plan.pdf
13. Executive Office of Energy and Environmental Affairs. (2015) Massachusetts Clean Energy and Climate Plan for 2020. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/MA_2015_Action_Plan.pdf
14. Michigan Department of Environment, Great Lakes and Energy. (2020) Michigan Healthy Climate Plan. Government of Michigan. Available at: https://www.michigan.gov/climateandenergy/0,4580,7-364-98206---,00.html
15. Minnesota Environmental Quality Board. (2015) Climate Solutions and Economic Opportunities: A foundation for Minnesota's state climate action planning. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/MN_2015_Action_Plan.pdf

16. Montana Climate Solutions Council. (2020) Montana Climate Solutions Plan. Available at: https://deq.mt.gov/Portals/112/DEQAdmin/Climate/2020-09-09_MontanaClimateSolutions_Final.pdf
17. State of Nevada Climate Initiative. (2020). Nevada's 2020 State Climate Strategy. Available at: https://climateaction.nv.gov/wp-content/uploads/2021/01/NVClimateStrategy_011921.pdf
18. Department of Environmental Services. (2009) The New Hampshire Climate Action Plan A Plan for New Hampshire's Energy, Environmental and Economic Development Future. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/NH_2009_Action_Plan.pdf
19. New Jersey Department of Environmental Protection. (2009) Meeting New Jersey's 2020 Greenhouse Gas Limit: New Jersey's Global Warming Response Act Recommendations Report. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/NH_2009_Action_Plan.pdf
20. New Mexico Interagency Climate Change Task Force. (2019) New Mexico Climate Strategy Initial Recommendations and Status Update. Available at: https://www.climateaction.state.nm.us/documents/reports/NMClimateChange_2019.pdf
21. Department of Environmental Conservation. (2010) Climate Action Plan Interim Report. Available at: https://www.dec.ny.gov/energy/80930.html
22. North Carolina Department of Environmental Quality. (2019) North Carolina Clean Energy Plan: Transitioning to a 21st Century Electricity System. Available at: https://files.nc.gov/ncdeq/climate-change/clean-energy-plan/NC_Clean_Energy_Plan_OCT_2019_.pdf
23. Oregon Environmental Council. (2020) Oregon Climate Action Plan. Available at: https://oeconline.org/wp-content/uploads/2020/04/OCAP-Fact-Sheet-FINAL_FINAL-FINAL.pdf
24. Pennsylvania Department of Environmental Protection. (2019) Pennsylvania Climate Action Plan: Strategies and Actions to Reduce and Adapt to Climate Change. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2020/06/PA_2019_Action_Plan.pdf
25. RI Executive Climate Change Coordinating Council. (2016) Rhode Island Greenhouse Gas Emissions Reduction Plan. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/RI_2016_Action_Plan.pdf
26. Vermont Climate Action Commission (2018) Executive Order No. 12-17 Report to the Governor. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2020/06/VT_2018_Action_Plan.pdf
27. Governor's Commission on Climate Change. (2008) Final Report: A Climate Change Action Plan. Available at: https://rga.lis.virginia.gov/Published/2009/RD19/PDF
28. Carbon Emissions Reduction Taskforce. (2014) Report to the Washington State Governor's Office. Center for Climate and Energy Solutions. Available at: https://www.c2es.org/site/assets/uploads/2018/11/WA_2014_Action_Plan.pdf
29. Brown, Marilyn A. and Valentina Sanmiguel Herrera. (2021) "Cogeneration: A High-Impact Carbon Reduction Solution Requiring Innovative Policy Support", working paper.
30. Brown, M. A. (2017). Commercial cogeneration benefits depend on market rules, rates, and policies. *Environmental Research Letters,* 12 (3)(031003).
31. Brown, M. A., Cox, M., & Baer, P. (2013). Reviving manufacturing with a federal cogeneration policy. *Energy Policy,* 52, 264-276.
32. Exelon. (2019). Albany Green Eenergy Retrieved from https://www.exeloncorp.com/locations/power-plants/albany-green-energy
33. Global, B. I. (2015). Procter & Gamble, Constellation celebrate development of $200 million biomass energy plant in Georgia. *PPI Pulp & Paper News Service*.
34. Hampson, A., Tidball, R., Fucci, M., & Weston, R. (2016). *Combined Heat and Power (CHP) Technical Potential in the United States*. Retrieved from US Department of

Energy: https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf

35. Maize, K. (2020). “Combined Heat and Power: A Sleeping Giant May Be Waking” Power Magazine, https://www.powermag.com/combined-heat-and-power-a-sleeping-giant-may-be-waking/
36. Patel, Sonal. (2017). “Global Developments Giving CHP a Much-Needed Boost,” Power Magazine. https://www.powermag.com/global-developments-giving-chp-a-much-needed-boost/
37. U.S. Department of Energy (USDOE). (2016a). *Combined Heat and Power Technology Fact Sheet Series, Gas Turbines*. Retrieved from https://www.energy.gov/sites/prod/files/2016/09/f33/CHP-Gas%20Turbine.pdf
38. USDOE. (2016b). *Combined Heat and Power Technology Fact Sheet Series, Reciprocating Engines*. Retrieved from https://www.energy.gov/sites/prod/files/2016/09/f33/CHP-Recip%20Engines.pdf
39. USDOE. (2016c). *Combined Heat and Power Technology Fact Sheet Series, Steam Turbines*. Retrieved from https://www.energy.gov/sites/prod/files/2016/09/f33/CHP-Steam%20Turbine.pdf
40. USDOE. (2017). *Combined Heat and Power Technology Fact Sheet Series, Overview of CHP Technologies*. Retrieved from https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Overview_of_CHP_Technologies.pdf
41. USDOE. (2020a). Combined Heat and Power Basics. Retrieved from https://www.energy.gov/eere/amo/combined-heat-and-power-basics
42. USDOE. (2021). Combined Heat and Power Installations in Georgia. U.S. Department of Energy Combined Heat and Power and Microgrid Installation Databases. Retrieved from: https://doe.icfwebservices.com/state/chp/GA
43. USDOE, & EPA. (2012). *Combined Heat and Power: A Clean Energy Solution*. Retrieved from https://www.energy.gov/sites/prod/files/2013/11/f4/chp_clean_energy_solution.pdf
44. U.S. Energy Information Administration (USEIA) (2013). *An Introduction to Spark Spreads*. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=9911
45. Balijepalli, Murthy; Pradhan, Khaparde (2011). "Review of Demand Response under Smart Grid Paradigm." IEEE PES Innovative Smart Grid Technologies.
46. Bloomberg New Energy Finance. Electric Vehicle Outlook 2020. https://about.bnef.com/electric-vehicle-outlook/
47. Asadinejad, A., Tomsovic, K. (2017) Optimal use of incentive and price based demand-side response to reduce costs and price volatility. Electric Power Systems Research (144) http://dx.doi.org/10.1016/j.epsr.2016.12.012
48. Braithwait, Steven, and Michael O'Sheasy, 2002, "RTP Customer Demand Response—reEmpirical Evidence on How Much Can You Expect" In Electricity Pricing in Transition, A. Faruqui, and K. Eakin eds., Kluwer Academic Publishers: Dordecht, Netherlands.
49. The Brattle Group, The National Potential for Load Flexibility: Value and Market Potential Through 2030 (Jun. 2019), at 1, 13, https://brattlefiles.blob.core.windows.net/files/16639_national_potential_for_load_flexibility_-_final.pdf.
50. Brown, M.A. and O. Chapman. (2021) “Demand Response as a Carbon Reduction Policy: Evidence from the Southeastern U.S. State of Georgia”, working paper.
51. Brown, M. A., Zhou, S., & Ahmadi, M. (2018) Smart grid governance: An international review of evolving policy issues and innovations. *Wiley Interdisciplinary Reviews: Energy and Environment*, https://onlinelibrary.wiley.com/doi/full/10.1002/wene.290.
52. California Energy Commission. (2019). "The Value Proposition for Cost-Effective, Demand Responsive-Enabling, Non-residential Lighting System Retrofits in California Buildings." CEC-500-2019-041

53. California ISO. (2020). “Business Requirements Specification, Energy Storage and Distributed Energy Resources Phase 3 (ESDER 3)”. Doc ID: GNFDMDEHU6BB-46-53.
54. Cappers, P., J. MacDonald, C. Goldman. (2013). "Market and Policy Barriers for Demand Response Providing Ancillary Services in U.S. Markets." Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-6155E.
55. Christensen, Toke Haunstrup, et al. (2020). The role of competences, engagement, and devices in configuring the impact of prices in energy demand response: Findings from three smart energy pilots with households. *Energy Policy*, 137.
56. Damisa, Nwulu, and Sun. (2018). A robust energy and reserve dispatch model for prosumer microgrids incorporating demand response aggregators. J. Renewable Sustainable Energy 10, 055301; https://doi.org/10.1063/1.5039747
57. Endemann, B., Frank, K., Hinckley E., Metz P. (2020) “FERC Issues Landmark Order NO. 2222 To Facilitate the Participation Of Distributed Energy Resources In Wholesale Markets,” *The National Law Review*. https://www.natlawreview.com/article/ferc-issues-landmark-order-no-2222-to-facilitate-participation-distributed-energy
58. Faruqui, A. (2012) "Direct load control of residential air conditioners in Texas," Public Utility Commission of Texas, Austin.
59. Faruqui, A., and Hledik, R. (2018). “Reinventing Demand Response for the Age of Renewable Energy.” The Brattle Group.
60. Federal Energy Regulatory Commission (FERC). 2019. *2019 Assessment of Demand Response and Advanced Metering.* https://www.ferc.gov/legal/staff-reports/2019/DR-AM-Report2019.pdf.
61. Gagnon, P. J., and L. A. Bird, (2017). "How to Estimate Demand Charge Savings from PV on Commercial Buildings," National Renewable Energy Laboratory (NREL), Golden, CO.
62. Georgia Power. 2019. Integrated Resource Plan. PDF File. Atlanta, January 31, 2019. https://eteconline.org/news/doe-celebrates-georgia-powers-first-smart-neighborhood/
63. Hernández D, Y. Jiang, D. Carrión, D. Phillips D, and Y. Aratani. (2016). “Housing hardship and energy insecurity among native-born and immigrant low-income families with children in the United States.” Journal of children & poverty 22(2):77-92.
64. Ingram, Andrew. (2020). “Grid Integration Research. Presentation at Georgia Institute of Technology, March 2020.
65. Interagency Working Group (2018) Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf
66. Johnstone, P, Kivimaa, P. (2018) Multiple dimensions of disruption, energy transitions and industrial policy. Energy Research & Social Science, 37, 260-265.
67. Keilty, Kristina. (2018). “Washing with Cold Water: Are You Up for the Challenge? A CBSM Strategy for Engaging Low and Moderate Income Populations.” 2018 ACEEE Summer Study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing. https://aceee.org/files/proceedings/2018/index.html#/paper/event-data/p402
68. King, J. 2018. "Energy Impacts of Smart Home Technologies," *Report A1801,* 2018.Lazard. Levelized Cost of storage.
69. Lazard’s Levelized Cost of Storage Analysis. Version 4.0. November 2018. https://www.lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf
70. Minnesota Department of Commerce and Michaels Energy. (2013). "Demand Response and Snapback Impact Study." COMM/OES-04042011-40697.
71. Muller, Nicholas Z. (2013) “Using Index Numbers for Deflation in Environmental Accounting.” Environmental and Development Economics (19): 466-486. doi:10.1017/S1355770X1300048X

72. North American Electric Reliability Corporation (NERC). (2018) “Long-Term Reliability Assessment 2018.” NERC, Atlanta. Report.
73. O’Connell, N., Pinson, P., Madsen, H., O’Malley, M. (2014) Benefits and challenges of electrical demand response: A critical review. *Renewable and Sustainable Energy Reviews*, 39, 686-699.
74. Parrish, B., Heptonstall, P., Gross, R., Sovacool, B. (2020). A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response. *Energy Policy* (138).
75. Parrish, B., Gross, R., Heptonstall. (2019). On demand: Can demand response live up to expectations in managing electricity systems? *Energy Research & Social Science,* 51, 107-118.
76. Peláez, Guille and Rick Nunno. (2017). "Protecting the Grid from the Impacts of Climate Change." Environmental and Energy Study Institute (EESI). Available at: https://www.eesi.org/articles/view/protecting-the-grid-from-the-impacts-of-climate-change.
77. Parrish, B., Heptonstall, P., Gross, R., Sovacool, B. (2020). A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response. *Energy Policy* (138).
78. Ryan, D., Long, R., Lauf, D., and Ledbetter, M. (2010). Water heater market profile. Technical report, U.S. Department of energy.
79. Smith, A. M., & Brown, M. A. (2015). Demand response: A carbon-neutral resource? *Energy*, 85, 10-22.
80. Todd, A., P. Cappers, and C. Goldman. (2013) "Residential customer enrollment in time-based rate and enabling technology programs," Lawrence Berkeley National Laboratory.
81. U.S. Energy Information Administration (USEIA) (2009). The National Energy Modeling System: An Overview 2009. https://www.eia.gov/outlooks/aeo/nems/overview/pdf/0581(2009).pdf.
82. USEIA (2018). Assumptions to AEO2018, Sections by Module. https://www.eia.gov/outlooks/archive/aeo18/assumptions/.
83. USEIA, Office of Energy Analysis (2018). Annual Energy Outlook 2018: with projections to 2050.
84. U.S. Department of Energy. (2006). "Benefits of demand response in electricity markets and recommendations for achieving them." *US Dept. Energy, Washington, DC, Tech. Report*.
85. U.S. Environmental Protection Agency (EPA). (2013). "Application of Life- Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles." EPA 744-R-12-001.
86. Winskel, M. (2018) Beyond the disruption narrative: varieties and ambiguities of energy system change. Energy Research & Social Science, 37, 232-237.
87. Valentine, S.V., Brown, M.A., Sovacool, B. K. Empowering the Great Energy Transition: Policy for a Low-Carbon Future (Columbia University Press) 2019.
88. Vekony, A. (2020). The Opportunities of Solar Panel Recycling. Retrieved November 02, 2020, from https://www.greenmatch.co.uk/blog/2017/10/the-opportunities-of-solar-panel-recycling
89. Woolf, T., E. Malone, L. Schwartz, J. Shenot. (2013). "A Framework for Evaluating the Cost-Effectiveness of Demand Response." Lawrence Berkeley National Laboratory.
90. Xu, Xiaojing and C. Chen. (2019). “Energy Efficiency and Energy Justice for U.S. Low-income Households: An Analysis of Multifaceted Challenges and Potential.” Energy Policy, vol 128, 763-774, doi: 10.1016/j.enpol.2019.01.020.
91. Brown, M.A, Hubbs, J., Gu, V. and Cha, M-K. (2021) “Rooftop Solar: Closing the Gap Between the Technically Possible and the Achievable” Working paper.
92. Fu, R., Feldman, D., and Margolis, R. (2018) U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72399

93. Google Project Sunroof data explorer (March 2020), www.google.com/get/sunroof
94. Lopez, A., Roberts, B., Heimiller, D., Blair, N., & Porro, G. (2012). *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis*. http://www.osti.gov/bridge
95. Solar Crowd Source. https://www.solarcrowdsource.com/
96. Bolinger M, Seel J, Robson D. Lawrence Berkeley Natl. Lab (2019) Utility-Scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2019 Edition; 2019 [cited 2020 Nov]. Available from: https://eta-publications.lbl.gov/sites/default/files/lbnl_utility_scale_solar_2019_edition_final.pdf.
97. Brown, M.A, Tudawe, R., and Steimer, H. (2021) “Carbon drawdown potential of utility-scale solar in the United States Evidence from a case study of Georgia,” working paper.
98. Georgia Power. You Can Solar Too. Southern Company [Internet]. 2020 [cited 2020 May 30]. Available from: https://www.georgiapower.com/communitysolar.
99. Lopez A, Roberts B, Heimiller D, Blair N, Porro G. U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis National Renewable Energy Laboratory [Internet]. 2012 [cited 2020 May]. NREL/TP-6A20-51946. Available from: https://www.nrel.gov/docs/fy12osti/51946.pdf.
100. Mayes F, Namovicz C. Southwestern states have better solar resources and higher solar PV capacity factors. U.S. EIA [Internet]. 2019 [cited 2020 March]. Available from: https://www.eia.gov/todayinenergy/detail.php?id=39832.
101. Lopez A, Roberts B, Heimiller D, Blair N, Porro G. U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis National Renewable Energy Laboratory [Internet]. 2012 [cited 2020 May]. NREL/TP-6A20-51946. Available from: https://www.nrel.gov/docs/fy12osti/51946.pdf.
102. Millstein, D, Wiser R, Bolinger M, Barbose G. The climate and air-quality benefits of wind and solar in the United States. Nature Energy, 2017; 2, DOI:10.1038/nenergy.2017.134. https://doi.org/10.1038/nenergy.2017.134.
103. NREL [Internet]. Sharing the Sun: Understanding Community Solar Deployment and Subscriptions; c2020 [cited 2020 Dec 3]. Available from: https://www.nrel.gov/docs/fy20osti/76853.pdf.Wiser RH, Bolinger M, Seel J. Lawrence Berkeley Natl. Lab [Internet]. Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals; 2020 [cited Dec 2020]. Available from: https://eta-publications.lbl.gov/sites/default/files/solar_life_and_opex_report.pdf.
104. EPA. (2020). Landfill Methane Outreach Program (LMOP). Retrieved from https://www.epa.gov/lmop/landfill-technical-data
105. S&P Energy Database. (2019). S&P Global Market Intelligence Retrieved from https://www.spglobal.com/marketintelligence/en/index. https://www.spglobal.com/marketintelligence/en/index
106. U.S. EIA. (2020a). Electricity Data Browser Retrieved from https://www.eia.gov/electricity/data/browser/
107. U.S. EIA. (2020b). *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020*. Retrieved from https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf
108. Georgia Department of Transportation, State vehicle registration database. Information about 2020 Georgia fleet provided under confidential contract.
109. Estimated Georgia electric power demand/generation forecasted in 2030 (129 BkWh). This came from NEMS, or DOE/EIA- Marilyn, do you have this?
110. U.S. Energy Information Administration (EIA), Electric Power Annual 2013. U.S. DOE, 2015, Washington, DC. http://www.eia.gov/electricity/annual/pdf/epa.pdf (accessed September, 2015).
111. Evans, A., Strezov, V., Evans, T. Assessment of sustainability indicators for renewable energy technologies, Renewable and Sustainable Energy Reviews 2009; 13(5): 1082-1088

112. Simmons, Richard A. "A techno-economic investigation of advanced vehicle technologies and their impacts on fuel economy, emissions, and the future fleet." Purdue Diss. (2015).
113. U.S. Environmental Protection Agency. eGRID 2012, Version 1.0 2010 data files. Washington, DC. Released February 2014. http://www.epa.gov/cleanenergy/energy-resources/egrid/ (accessed September 2015).
114. Forward, E., Glitman, K., and David, R. An assessment of level 1 and level 2 electric vehicle charging efficiency. Vermont Energy Investment Corporation Transportation Efficiency Group (2013).
115. Vejdan, Sadegh, Santiago Grijalva, and Rich Simmons. "Assessment of Grid-Scale Energy Storage Scenarios for the Southeast: Benefits, Costs and Implications." (2020).
116. Bloomberg New Energy Finance BNEF (compilation chart), with source data cited in the legend
117. NEMs modeling for electric power growth through 2030
118. DOE/EIA: Electric Power Annual (2019); EIA-860; EIA-923
119. DOE/FERC 714; FERC Form 1
120. Georgia Power Integrated Resource Plan for 2019
121. DOT Summary of Travel Trends, 2017 National Household Travel Survey
122. DOT/NHTSA and EPA: Corporate Average Fuel Economy CAFE Regulations https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy
123. Miotti, M., Supran, G. J., Kim, E. J., & Trancik, J. E. (2016). Personal vehicles evaluated against climate change mitigation targets. *Environmental science & technology*, *50*(20), 10795-10804.
124. Kittner, Noah, Felix Lill, and Daniel M. Kammen. "Energy storage deployment and innovation for the clean energy transition." *Nature Energy* 2, no. 9 (2017): 17125.
125. Bloomberg New Energy Finance: Sustainable Energy in America Factbook, 2019.
126. Q12019 U.S. Energy Storage Monitor, Wood Mackenzie Power & Renewables. March 2019
127. Breetz, H. L., & Salon, D. (2018). Do electric vehicles need subsidies? Ownership costs for conventional, hybrid, and electric vehicles in 14 US cities. *Energy Policy*, *120*, 238-249.
128. Simmons, R. A., Shaver, G. M., Tyner, W. E., & Garimella, S. V. (2015). A benefit-cost assessment of new vehicle technologies and fuel economy in the US market. *Applied Energy*, *157*, 940-952.
129. Simmons, Richard A., et al. "A benefit-cost assessment of new vehicle technologies and fuel economy in the US market." *Applied Energy* 157 (2015): 940-952.
130. Simmons, Richard A. "A techno-economic investigation of advanced vehicle technologies and their impacts on fuel economy, emissions, and the future fleet." Purdue Diss. (2015).
131. Birky, A. K., Laughlin, M., Tartaglia, K., Price, R., Lim, B., and Lin, Z. (2017). “Electrification
132. Beyond Light Duty: Class 2b-3 Commercial Vehicles.” Electrification Beyond Light Duty,
133. Oak Ridge National Laboratory, U.S. Department of Energy.
134. Curry, T., Liberman, I., Hoffmann-Andrews, L., and Lowell, D. (2012). “Reducing Aerodynamic
135. Drag & Rolling Resistance from Heavy-Duty Trucks: Summary of Available Technologies and Applicability to Chinese Trucks.” The ICCT, <https://theicct.org/sites/default/files/publications/AERO_RR_Technologies_Whitepaper_FINAL_Oct2012.pdf> (Nov. 16, 2020).
136. Davis, S. C., and Boundy, R. G. (2020). Transportation Energy Data Book Ed. 38.
137. Transportation Energy Data Book, U.S. Department of Energy, <https://tedb.ornl.gov/wp-content/uploads/2020/02/TEDB_Ed_38.pdf> (Oct. 2020).
138. Lascurain, M. B., Franzese, O., Capps, G. J., Siekmann, A., Thomas, N., LaClair, T. J., Barker, A.
139. M., and Knee, H. E. (2012). “Medium Truck Duty Cycle Data from Real-World Driving

140. Environments: Final Report.” Medium Truck Duty Cycle Data from Real-World Driving
141. Environment. Office of Energy Efficiency and Renewable Energy, <https://www.osti.gov/biblio/1081995-medium-truck-duty-cycle-data-from-realworlddriving-environments-final-report> (Oct. 2020).
142. North American Council for Freight Efficiency (2020) ,“Medium-Duty Electric Trucks: Cost of Ownership.” (2020) , <https://nacfe.org/emerging-technology/medium-duty-electric-trucks-costof-ownership/> (Nov. 30, 2020).
143. Reinhart, T. E. (2016). “Commercial medium- and heavy-duty truck fuel efficiency technology study – Report #2.” (Report No. DOT HS 812 194). Commercial medium- and heavy-duty truck fuel efficiency technology cost study. National Highway Traffic Safety Administration.<https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812194_commercialmdhdtruckfuelefficiency.pdf> (Nov. 2020)
144. Scora, G., Boriboonsomsink, K., Durbin, T. D., Johnson, K., Yoon, S., Collins, J., and Dai, Z. (2019). “Variability in Real-World Activity Patterns of Heavy-Duty Vehicles by Vocation.” SAGE Journals, EPA, <https://journals.sagepub.com/doi/pdf/10.1177/0361198119844247> (Oct. 2020).
145. Simmons, R. A., Shaver, G. M., Tyner, W. E., and Garimella, S. V. (2015). “ A Benefit-cost Assessment of New Vehicle Technologies and Fuel Economy in the U.S. Market." Applied Energy 157 (2015): 940-52.
146. Smith, D., Graves, R., Ozpineci, B., Jones, P. T., Lustbader, J., Kelly, K., Walkowicz, K., Birky, A., Payne, G., Sigler, C., and Mosbacher, J. (2019). “Medium- and Heavy-Duty Vehicle Electrification: An Assessment of Technology and Knowledge Gaps.” Medium- and Heavy-Duty Vehicle Electrification, Oak Ridge National Laboratory (ORNL) and National Renewable Energy Laboratory (NREL), <https://info.ornl.gov/sites/publications/Files/Pub136575.pdf> (Nov. 2020).
147. U.S. EIA. (2020) Annual Energy Outlook 2020 with projections to 2050. Annual Energy Outlook 2020, U.S. Energy Information Administration <https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf> .
148. U.S. NREL. (2019) Drive Cycle Analysis Tool - DriveCAT: Transportation Research. NREL.gov, National Renewable Energy Laboratory.https://www.nrel.gov/transportation/drivecycle-tool/index.html.
149. U.S. EPA and U.S. NHTSA. (2016) Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles— Phase 2. DOT,https://www.govinfo.gov/content/pkg/FR-2016-10-25/pdf/2016-21203.pdf.
150. U.S. EPA. (2020) Greenhouse Gases Equivalencies Calculator - Calculations and References. EPA, Environmental Protection Agency. https://www.epa.gov/energy/greenhousegases-equivalencies-calculator-calculations-and-references.
151. Wang, L., Duran, A., Kelly, K., Konan, A., Lammert, M., and Prohaska, R. (2016) The Evaluation of the Impact of New Technologies for Different Powertrain Medium-Duty Trucks on Fuel Consumption. NREL, https://www.nrel.gov/docs/fy17osti/66306.pdf.
152. Atlanta Regional Commission. (2020) Population and Employment Forecasts. Available at: https://atlantaregional.org/atlanta-region/population-employment-forecasts/.
153. Active Living Research – ALR (2016). Moving Towards Active Transportation: How Policies Can Encourage Walking and Bicycling. Research Review.
154. Parker, T., M. McKeever, G.B. Arrington, and J. Smith-Heimer. (2002) Statewide Transit-Oriented Development Study: Factors for Success in California. Final Report, California Department of Transportation (CALTRANS), Report number: dot_38272_ds1.
155. U.S. EPA Environmental Financial Advisory Board. (2014) Meeting Summary of the EFAB Workshop on Transit-Oriented Development for Sustainable Communities. U.S. EPA. Available at: https://www.epa.gov/sites/production/files/2014-10/documents/tod_report.pdf

156. Active Living Research – ALR. (2016) Moving Towards Active Transportation: How Policies Can Encourage Walking and Bicycling. Research Review.
157. Atlanta Regional Commission – ARC. (2015) The Atlanta Region's Plan – Transportation Assessment.
158. Brynjolfsson, E., Horton, J., Rock, D., Ozimek, A., Sharma, G., and Tu Ye, H. (2020) COVID-19 and Remote Work: An Early Look at US Data. MIT.
159. Buehler, R. and Pucher, J. (2012a). Cycling to work in 90 large American cities: new evidence on the role of bike paths and lanes. Transportation 39(2), 409–432.
160. Buehler, R. and Pucher, J. (2012b). Walking and Cycling in Western Europe and the United States – Trends, Policies and Lessons, TRB News, 280, 34-42.
161. Bushell, M.A., Poole, B.W., Zegeer, C.V. and Rodriguez, D.A. (2013). Costs for Pedestrian and Bicyclist Infrastructure Improvements: A Resource for Engineers, Planners, and the General Public. UNC Highway Safety Research Center, prepared for the Federal Highway Administration.
162. Buehler, R. and Pucher, J. (2012a). Cycling to work in 90 large American cities: new evidence on the role of bike paths and lanes. Transportation 39(2), 409–432.
163. Buehler, R. and Pucher, J. (2012b). Walking and Cycling in Western Europe and the United States – Trends, Policies and Lessons, TRB News, 280, 34-42.
164. Dill, J. and Carr, T. (2003). Bicycle commuting and facilities in major US cities: if you build them, commuters will use them-another look. Transportation Research Record, 1828, 116–123.
165. Dill, J. and Voros, K. (2007). Factors Affecting Bicycling Demand: Initial Survey Findings from the Portland, Oregon, Region. Transportation Research Record, 2031, 9-17.
166. FHWA National Household Transportation Survey (2017). Available online at: https://nhts.ornl.gov
167. Gallup (2017). State of the American Workplace.
168. Global Workplace Analytics (2017). 2017 State of Telecommuting in the U.S. Employee Workforce.
169. Harms, L. and Kansen, M. (2018). Cycling Facts – Netherlands Institute for Transport Policy Analysis. Ministry of Infrastructure and Water Management.
170. Kneebone, E. and Holmes, N. (2015). The growing distance between people and jobs in metropolitan America. Brookings Institute Metropolitan Policy Program.
171. Cui, H. and Sosic, G. (2019). Recycling common materials: Effectiveness, optimal decisions, and coordination mechanisms. *European Journal of Operational Research*, 274, 1055-1068.
172. Environmental Research & Education Foundation – EREF (2019). Analysis of MSW Landfill Tipping Fees – April 2018 (rev. 10/2019).
173. Georgia Forestry Commission – GFC (2018). 2018 Economic Benefits of the Forest Industry in Georgia. Report prepared by Enterprise Innovation Institute – Georgia Institute of Technology.
174. Gradus, R., Homsy, G.C., Liao, L. and Warner, M.E. (2019). Which US municipalities adopt Pay-As-You-Throw and curbside recycling? *Resources, Conservation & Recycling*, 143, 178-183.
175. Lakhan, Calvin. "Exploring the relationship between municipal promotion and education investments and recycling rate performance in Ontario, Canada." *Resources, Conservation and Recycling* 92 (2014): 222-229.
176. Morris, J. and DeFeo, W. (1999). Practical Recycling Economics: Making the Numbers Work for Your Program. Prepared for New Jersey Department of Environmental Protection – Division of Solid and Hazardous Waste.
177. RDC-Environment & Pira International (2003). Evaluation of costs and benefits for the achievement of reuse and recycling targets for the different packaging materials in the frame of the packaging and packaging waste directive 94/62/EC – Final consolidated report.

178. R.W. Beck (2005). Georgia Statewide Waste Characterization Study – Final Report. Georgia Department of Community Affairs.
179. Shin, D. (2014). Generation and Disposition of Municipal Solid Waste (MSW) in the United States – A National Survey, MS Thesis, Columbia University, Earth Engineering Center.
180. Skumatz, L and Green, J. (2002). Evaluation the Impacts of Recycling/Diversion Education Programs–Effective Methods and Optimizing Expenditures, for Iowa DNR.
181. The Recycling Partnership (2020). 2020 State of Curbside Recycling Report.
182. U.S. EPA Waste Reduction Model (WARM). V15. 1999.
183. 10 Years of Progress - U.S. EPA's GreenChill Partnership. (2018, December 20). Retrieved June 10, 2020, from https://www.epa.gov/greenchill/10-years-progress-us-epas-greenchill-partnership
184. Average Supermarket's Greenhouse Gas Impacts. (2016, December 12). Retrieved June 10, 2020, from https://www.epa.gov/greenchill/average-supermarkets-greenhouse-gas-impacts
185. California Air Resources Board. (n.d.). Retrieved June 10, 2020, from https://ww2.arb.ca.gov/node/3335/about
186. California Air Resources Board. (n.d.). Retrieved June 10, 2020, from https://ww2.arb.ca.gov/our-work/programs/refrigerant-management-program/about
187. Download the State Inventory and Projection Tool. (2020, February 26). Retrieved June 10, 2020, from https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool
188. Emission Inventory Methodology and Technical Support Document: California's High Global Warming Potential Gases Emission Inventory 2015 Edition. (April 2016). California Air Resources Board. https://ww3.arb.ca.gov/cc/inventory/slcp/doc/hfc_inventory_tsd_20160411.pdf
189. EU legislation to control F-gases. (2017, February 16). Retrieved June 10, 2020, from https://ec.europa.eu/clima/policies/f-gas/legislation_en
190. Fior Market Research LLP. (2020, February 27). Global Low GWP Refrigerants Market is Expected to Reach USD 35.7 Billion by 2025 : Fior Markets. Retrieved June 10, 2020, from https://www.globenewswire.com/news-release/2020/02/27/1991491/0/en/Global-Low-GWP-Refrigerants-Market-is-Expected-to-Reach-USD-35-7-Billion-by-2025-Fior-Markets.html
191. Goetzler, W., Sutherland, T., Rassi, M., and Burgos, J. (2014). Research & Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants. Prepared for the U.S. Department of Energy Building Technology Office.
192. GreenChill Partnership. (2020, June 05). Retrieved June 10, 2020, from https://www.epa.gov/greenchill
193. Industry Market Research, Reports, and Statistics. (n.d.). Retrieved June 10, 2020, from https://www.ibisworld.com/industry-statistics/number-of-businesses/supermarkets-grocery-stores-in-georgia-united-states
194. Jancer, M. (2019, October 18). Everything You Should Know About Fixing Your Car's A/C. Retrieved June 10, 2020, from https://www.popularmechanics.com/cars/car-technology/a23081914/car-ac-myths-repair-r12-vs-r134s/
195. Protection of Stratospheric Ozone: Revisions to the Refrigerant Management Program's Extension to Substitutes, 85 Fed. Reg. 14150 (April 10, 2020).
196. Protection of Stratospheric Ozone: Listing of Substitutes Under the Significant New Alternatives Policy Program, 85 Fed. Reg. 35874 (proposed June 12, 2020).
197. Reducing Hydrofluorocarbon (HFC) Use and Emissions in the Federal Sector through SNAP. (2020, April 08). Retrieved June 10, 2020, from https://www.epa.gov/snap/reducing-hydrofluorocarbon-hfc-use-and-emissions-federal-sector-through-snap

198. Refrigerant Transition & Environmental Impacts. (2018, April 20). Retrieved June 10, 2020, from https://www.epa.gov/mvac/refrigerant-transition-environmental-impacts
199. Residential Energy Consumption Survey (RECS), 2015, Commercial Building Energy Consumption Survey (CBECS), 2012 (updated 2016), Highway Statistics 2018, Table 7.3.2, Georgia Department of Revenue Annual Statistical Report (2000-2018)
200. Revised Section 608 Refrigerant Management Regulations. (2020, May 04). Retrieved June 10, 2020, from https://www.epa.gov/section608/revised-section-608-refrigerant-management-regulations
201. Technical Support Document: Analysis of the Economic Impact and Benefits of Final Revisions to the National Recycling and Emission Reduction Program (2016). Prepared for U.S. Environmental Protection Agency Office of Atmospheric Programs.
202. Transitioning to Low-GWP Alternatives in Unitary Air Conditioning. (2016, December 12). Retrieved July 07, 2020, from https://www.epa.gov/ozone-layer-protection/transitioning-low-gwp-alternatives-unitary-air-conditioning.
203. U.S. Convenience Store Count | NACS. (n.d.). Retrieved June 10, 2020, from https://www.convenience.org/Research/FactSheets/ScopeofIndustry/IndustryStoreCount
204. Understanding ROI on CO2 Refrigeration Systems: White Paper. (2015). Retrieved June 10, 2020, from https://www.hillphoenix.com/white_papers/deco2ded-understanding-roi-co2-refrigeration-systems/
205. US approves hydrocarbon fridges. (2017, November 23). Retrieved June 10, 2020, from https://www.coolingpost.com/world-news/us-approves-hydrocarbon-fridges/
206. What Is Refrigerant and How Does It Help Your Air Conditioner? (2019, July 22). Retrieved June 10, 2020, from https://www.aireserv.com/about/blog/2016/june/what-is-refrigerant-and-how-does-it-help-your-ai/
207. Bibee, D.V., Johnson, K.L., and Nelson, D.R. (2010). Air Sealing Existing Homes with Foam-in-a-Can Rivals Energy Cost Benefits of CFLs. Proceedings of the ASHRAE Buildings XI Conference.
208. Electric Power Research Institute – EPRI (2019). U.S. Energy Efficiency Potential Through 2040 - Summary Report. 3002014926, Final Report, July 2019.
209. Energy Information Administration (EIA), Annual Energy Outlook 2018. Available online at: https://www.eia.gov/outlooks/aeo/
210. ENERGY STAR (2007). Building Upgrade Manual – Chapter 5: Retrocommissioning.
211. ENERGY STAR (2020). Smart Thermostats Key Product Criteria. Available online at: https://www.energystar.gov/products/heating_cooling/smart_thermostats/key_product_criteria
212. ENERGY STAR (2020). ENERGY STAR Certified Heat Pump Water Heaters. Available online at: https://www.energystar.gov/products/water_heaters/high_efficiency_electric_storage_water_heaters/benefits_savings
213. ENERGY STAR (2020). ENERGY STAR Most Efficient 2020 — Central Air Conditioners and Air Source Heat Pumps. Available online at: https://www.energystar.gov/products/most_efficient/central_air_conditioners_and_air_source_heat_pumps
214. ENERGY STAR (2020). Methodology for Estimated Energy Savings from Cost-Effective Air Sealing and Insulating. Available online at: https://www.energystar.gov/campaign/seal_insulate/methodology
215. Fernandez, N., Katipamula, S., Wang, W., Xie, Y., Zhao, M. and Corbin, C. (2017). Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction. Prepared for the U.S. Department of Energy, Report No. PNNL-25985.
216. Garrison, N., Horowitz, C. and Lunghino, C.A. (2012). Looking Up: How Green Roofs and Cool Roofs Can Reduce Energy Use, Address Climate Change, and Protect Water Resources in Southern California. NRDC Report R:12-06-B.

217. Haq, G. and Weiss, M. (2018). Time preference and consumer discount rates – Insights for accelerating the adoption of efficient energy and transport technologies. Technological Forecasting and Social Change, 137, 76-88.
218. Hoyt, T., Arens, E. and Zhang, H. (2014). Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings. Building and Environment, doi:10.1016/j.buildenv.2014.09.010.
219. Jadun, P., McMillan, C., Steinberg, D., Muratori, M., Vimmerstedt, L. and Mai, T (2017). Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. National Renewable Energy Laboratory. NREL/TP-6A20-70485.
220. Jamasb, T. (2007). Technical Change Theory and Learning Curves: Patterns of Progress in Energy Technologies. The Energy Journal, 28(3), 51-72.
221. Keegan, P., 2013. Help My House Program Final Summary Report, s.1: Central Electric Power Cooperative and The Electric Cooperatives of South Carolina.
222. Langevin et al. (2019). Assessing the Potential to Reduce U.S. Building CO2 Emissions 80% by 2050, Joule, 3, 1-22.
223. Mullen, J.D. and Lamsal, M. (2013). Green Roof Adoption in Atlanta, Georgia: The Effects of Building Characteristics and Subsidies on Net Private, Public, and Social Benefits. Environmental Science & Technology, 47, 10824-10831.
224. Murphy, Sharon (2015). Assessing the Effectiveness of Extensive Green Roofs at Improving Environmental Conditions in Atlanta, Georgia. Thesis, Georgia State University.
225. Nadel, S. and Ungar, L. (2019). Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050. American Council for an Energy-Efficient Economy.
226. National Action Plan for Energy Efficiency - NAPEE (2008). Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy Makers. Energy and Environmental Economics, Inc. and Regulatory Assistance Project.www.epa.gov/eeactionplan
227. National Renewable Energy Laboratory – NREL (2020). Residential Energy Efficiency Potential – Georgia. Available online at: https://resstock.nrel.gov/factsheets/GA
228. Nexant (2018). Georgia Power Company Energy Efficiency Potential Study. Methodology and Findings – presented to DSM Working Group, March 2018.
229. Relf, G., Baatz, B. and Nowak, S. (2017). 2017 Utility Efficiency Scorecard. American Council for an Energy-Efficient Economy.
230. Relf, G., Cooper, E., Gold, R., Goyal, A. and Waters, C. (2020). 2020 Utility Efficiency Scorecard. American Council for an Energy-Efficient Economy.
231. SCOUT – Department of Energy (2020). Available online at: https://scout.energy.gov
232. Thomas, V.M., Mlade, J., Borin, S., Tindall, N., Okwo, A. and Dhamodharan, A. (2014). Reducing Greenhouse Gas Emissions in Atlanta. Report, Georgia Institute of Technology, Atlanta, GA.
233. U.S. Environmental Protection Agency – USEPA (2009). Clean Energy – Lead by Example Guide: Strategies, Resources, and Action Steps for State Programs. State and Local Climate and Energy Program.
234. U.S. Department of Energy - USDOE (2011). Advanced Energy Retrofit Guide, Practical Ways to Improve Energy Performance – Office Buildings, prepared by Pacific Northwest National Laboratory and PECI, Report. No. PNNL-20761.
235. U.S. Department of Energy - USDOE (2020). Estimating Costs and Efficiency of Storage, Demand, and Heat Pump Water Heaters. Available online at: https://www.energy.gov/energysaver/estimating-costs-and-efficiency-storage-demand-and-heat-pump-water-heaters

236. U.S. Department of Energy - USDOE (2020). Energy Efficiency Potential Studies Catalog. Available online at: https://www.energy.gov/eere/slsc/energy-efficiency-potential-studies-catalog
237. Wilson, E., Christensen, C., Horowitz, S. Robertson, J. and Maguire, J. (2017). Energy Efficiency Potential in the U.S. Single-Family Housing Stock. National Renewable Energy Laboratory – U.S. Department of Energy, Report No. NREL/TP-5500-68670.
238. Platt, B and N. Goldstein. (2014). State of composting in the U.S. BioCycle, July 2014: 19-27. Available online at: https://ilsr.org/wp-content/uploads/2014/07/biocycle-stateofcomposting-us-article-july-2014.pdf
239. ReFED. (2016). A roadmap to reduce U.S. food waste by 20 percent. Available online at: https://www.refed.com/downloads/ReFED_Report_2016.pdf.
240. U.S. EPA. (2017). Sustainable Materials Management (SMM) - Materials and Waste Management in the United States Key Facts and Figures. *Environment and Conservation.*Washington DC. Available at: *https://www.epa.gov/smm*
241. U.S. EPA (1998). An Analysis of Composting As an Environmental Remediation Technology. EPA530-R-98-008. https://www.epa.gov/sites/production/files/2015-09/documents/analpt_all.pdf
242. U.S. EPA (2020). Waste Reduction Model (WARM). V15., Washington DC. Available at: https://www.epa.gov/warm
243. Weitz, K. A., Thorneloe, S. A., Nishtala, S. R., Yarkosky, S., & Zannes, M. (2002). The Impact of Municipal Solid Waste Management on Greenhouse Gas Emissions in the United States. *Journal of the Air & Waste Management Association, 52*(9), 1000-1011. doi:10.1080/10473289.2002.10470843
244. Knowler, D., & Bradshaw, B. (2017). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy, 32(1), 25–48. https://doi.org/10.1016/j.foodpol.2006.01.003
245. Derpsh, R., Friedrich, T., Kassam, A., and Hongwen, L. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. Int J Agric & Biol Eng, 3(1), 1-25.
246. Gordon, H. (2013). Basic economic analysis using T-Charts. Economics Technical Note No.: TN 200-ECN-1. Natural Resources Conservation Service (NRCS), United States Department of Agriculture (USDA).
247. Lal, R. (2015). Sequestering carbon and increasing productivity by conservation agriculture. Journal of Soil and Water Conservation, 70(3), 55A–62A.
248. Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine,R. E., Penning de Vries, F. W.& Morison, J. I. (2006). Resource-conserving agriculture increases yields in developing countries.Environmental science & technology,40(4), 1114-1119.Retrieved from http://www.julespretty.com/wp-content/uploads/2013/09/7.-Pretty-et-al-EST-2006-Vol-40-4-pp-1114-19.pdf
249. University of Georgia (UGA)-Extension. (2019). Crop budgets. Athens, GA. Available at: https://agecon.uga.edu/extension/budgets.html
250. USDA-NASS. (2019). Crops and Plants - Quickstats data. Washington D.C.: USDA National Agricultural Statistics Service. Available at: https://www.nass.usda.gov
251. U.S. EPA. (2018). Advancing Sustainable Materials Management: Facts and Figures Report. Retrieved from https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/studies-summary-tables-and-data-related
252. Drew, J., Cleghorn, C., Macmillan, A., and Mizdrak, A. (2020). Healthy and Climate-Friendly Eating Patterns in the New Zealand Context. Environmental Health Perspectives, 128(1).
253. Eshel, G., P. Sttainier, A. Shepon and A. Swaminathan. (2019). Environmentally optimal, nutritionally sound, protein and energy conserving plant based alternatives to U.S. meat. Scientific Reports, 9:10345.

254. Eshel, G., P. Shepon, A., Noor, E. & Milo, (2016). R. Environmentally Optimal, Nutritionally Aware Beef Replacement Plant-Based Diets. Environ. Sci. Technol. 50, 8164–8168.
255. Heller, M.C., G.A. Keoleian and W.C. Willett. (2013). Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: a critical review. Environ. Sci. Technol. 47, 12632–12647.
256. National Academies of Sciences, Engineering, and Medicine (NAS). (2019). Sustainable Diets, Food, and Nutrition: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/25192.
257. Ranganathan, J., Daniel Vennard, Richard Waite, Brian Lipinski, Tim Searchinger, Patrice Dumas, Agneta Forslund, Hervé Guyomard, Stéphane Manceron, Elodie Marajo-Petitzon, Chantal Le Mouël, Petr Havlik, Mario Herrero, Xin Zhang, Stefan Wirsenius, Fabien Ramos, Xiaoyuan Yan, Michael Phillips and Rattanawan Mungkung. (2016). "Shifting Diets for a Sustainable Food Future." Working Paper, Installment 11 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute. Accessible at https://www.wri.org/publication/shifting-diets
258. Shepon, A., Eshel, G., Noor, E. & Milo, R.(2018). The opportunity cost of animal based diets exceeds all food losses. Proc. Natl. Acad. Sci. USA 115.
259. Tilman, D., Clark, M. (2014). Global diets link environmental sustainability and human health. Nature 515, 518–522 (2014). https://doi.org/10.1038/nature13959
260. Sabaté, J., and Soret, S. (2014). Sustainability of plant-based diets: back to the future. American Journal of Clinical Nutrition, 100(1), 476S-82S.
261. Springmann, M., Wiebe, K., Mason-D'Croz, D., Suler, T.B., Rayner, M., and Scarborough, P. (2018). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Plant Health, 2.
262. Tantamango-Bartley, Y., Jaceldo-Siegl, K., Fan, J., and Fraser, G. (2013). Vegetarian Diets and the Incidence of Cancer in a Low-risk Population. Cancer Epidemiology, Biomarkers & Prevention, 22(2).
263. Tonstad, S., Stewart, K., Oda, K., Batech, M., Herring, R.P., and Fraser, G.E. (2013). Vegetarian diets and incidence of diabetes in the Adventist Health Study-2. Nutrition, Metabolism & Cardiovascular Diseases, 23, 292-299.https://doi.org/10.1038/nature13959
264. USDA-ERS. (2018). Livestock, Dairy and Poultry Outlook in 2018. Retrieved from https://www.ers.usda.gov/publications/pub-details/?pubid=91042
265. Buzby, J. C. and J. Hyman. (2012). Total and per capita value of food loss in the United States. Food Policy 37(5): 561–570.
266. Council for Agricultural Science and Technology (CAST). (2018). Food Loss and Waste—A paper in the series on The Need for Agricultural Innovation to Sustainably Feed the World by 2050. Issue Paper 62. CAST, Ames, Iowa.
267. Hanson, C. and P. Mitchell (2017). *The Business Case for Reducing Food Loss and Waste: A report on behalf of Champions,* March 2017
268. Heller, M.C., Keoleian, G.A. (2014). Greenhouse Gas Emission Estimates of U.S. Dietary Choices and Food Loss: GHG Emissions of U.S. Dietary Choices and Food Loss. J. Ind. Ecol. n/a-n/a. doi:10.1111/jiec.12174
269. Hoover, D and L. Moreno. (2017). Estimating quantities and types of food waste at the city level. NRDC report – R-17-09-B. Natural Resources Defense Council (NRDC), U.S.
270. Food and Agriculture Organization of the United Nations (FAO). 2011. Global food losses and food waste: Extent, causes, and prevention. Rome, Italy: United Nations. Available at www.fao.org/fileadmin/user_upload/ags/publications/GFL_web.pdf
271. ReFED. (2016). A roadmap to reduce U.S. food waste by 20 percent. Available online at: https://www.refed.com/downloads/ReFED_Report_2016.pdf.

272. Ruggen, Martine M. (2013). "What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice," *Agric & Food Secur* 2, 13 https://doi.org/10.1186/2048-7010-2-13
273. Snyder, A., Shumaker, K., and Nelsen, N. (2018). Ensuring Food Safety as Demand for Improved Food System Efficiency Increases. Journal of Extension, 56(7).
274. Tilman, D., Clark, M. (2014). Global diets link environmental sustainability and human health. Nature 515, 518–522. https://doi.org/10.1038/nature13959
275. Carey J, Tang J, Templer P, Kroeger KD, Crowther TW, Burton AJ, Duke JS, Emmett B, Frey SD, Heskel MA, Jiang L, Machmuller MB, Mohan JE, Panetta AM, Reich PB, Reinsch S, Wang X, Allison SD, Bamminger C, Bridgham S, Collins SL, de Datox G, Eddy WC, Enquist BJ, Estiarte M, Harte J, Henderson A, Johnson BR, Larsen KS, Luo Y, Marhan S, Melillo JM, Peñuelas J, Pfeifer-Meister V, Poll C, Rastetter E, Reinmann AB, Reynolds LL, Schmidt IK, Shaver GR, Strong AL, Suseela V, and Tietem A. 2016. Temperature response of soil respiration largely unaltered with experimental warming. Proceedings of the National Academy of Sciences (PNAS) 113(48): 13797-13802. www.pnas.org/cgi/doi/10.1073/pnas.1605365113
276. Christensen, N.L. and R.K. Peet. 1981. Secondary forest succession on the North Carolina Piedmont. Pp. 230-245 IN: West, D.C., H.H. Shugart, and D.B. Botkin (eds.) *Forest Succession: Concepts and Applications*. Springer-Verlag, New York.
277. Crowther, T., Todd-Brown, K., Rowe, C. et al. (2016) Quantifying global soil carbon losses in response to warming. Nature 540, 104–108
278. Georgia Forestry Commission (2019). Sustainability Report for Georgia's Forests: January 2019. Dry Branch, GA. 25 pgs.
279. Machmuller, M.B., Ballantyne, F., Markewitz, D. et al. (2018) Temperature sensitivity of soil respiration in a low-latitude forest ecosystem varies by season and habitat but is unaffected by experimental warming. Biogeochemistry 141, 63–73.
280. Mohan, J.E., J.S. Clark, and W.H. Schlesinger. (2007) Long-term CO_2 enrichment of a forest ecosystem: Implications for forest regeneration and succession. *Ecological Applications* 17(4): 1198-1212.
281. Mohan, J.E., R.M. Cox, and L.R. Iverson. (2009) Composition and carbon dynamics of forests in northeastern North America in a future, warmer world. *Canadian Journal of Forest Research* 39(2): 213-230.
282. Richter, Daniel D., Daniel Markewitz, Susan E. Trumbore, and Carol G. Wells (1999) Rapid accumulation and turnover of soil carbon in a re-establishing forest. Nature 400: 56-58.
283. Schlesinger, W.H. and E.S. Bernhardt. (2020) *Biogeochemistry: An Analysis of Global Change*, 4th edition. Academic Press. 762 pp.
284. U.S. Department of Agriculture. (2016) *Georgia's Land: Its Use and Condition Fourth Edition*, Natural Resource Conservation Service, Athens, Georgia and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. 27 pp.
285. Wang, H-J. (2010). *Projecting Carbon Pools in Aboveground Woody Accumulations and Harvested Wood in Loblolly Pine Plantations of the Southern United States: From Stand-level to Regional Scales*. PhD Dissertation from Virginia Polytechnic Institute and State University, Blacksburg, VA. 128 pp.
286. Creswell, Courtney (2018). Costs and Benefits of Land Use Adaptation with Projections of Coastal Wetland Migration. M.S. Thesis under the direction of Craig E. Landry, University of Georgia. Athens, GA. 54 pgs.
287. Aber, J.D. and J.E. Melillo (2001). Terrestrial Ecosystems, 2nd edition. 556 pg. Academic Press, USA.
288. Edwards, L.E., J. Ambrose, and L.K. Kirkman (2013). Salt marshes and brackish tidal marshes pgs. 567-575 in: *The Natural Communities of Georgia*. University of Georgia Press, Athens, GA 30602.

289. Georgia Department of Natural Resources Coastal Resources Division (2012). Results of the National Wetlands Inventory and Landscape-level Functional Assessment, Brunswick, GA. 90 pgs.
290. Kirwan, M. L., & Megonigal, J. P. (2013). Tidal wetland stability in the face of human impacts and sea-level rise. *Nature*, *504*(7478), 53.
291. Ouyang, X., and Lee, S.Y., 2014. Updated estimates of carbon accumulation rates in coastal marsh sediments. Biogeosciences, 11: 5057-5071.
292. Schlesinger, W.H. and E.S. Bernhardt. (2020) *Biogeochemistry: An Analysis of Global Change*, 4th edition. Academic Press. 762 pp.
293. Seabrook, C. 2006. Tidal Marshes IN: New Georgia Encyclopedia https://www.georgiaencyclopedia.org/articles/geography-environment/tidal-marshes.
294. U.S. Global Change Research Program (USGCRP) (2018) Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report [Cavallaro, N., G. Shrestha, R. Birdsey, M. A. Mayes, R. G. Najjar, S. C. Reed, P. Romero-Lankao, and Z. Zhu (eds.)]. Washington, DC, https://doi.org/10.7930/SOCCR2.2018).
295. Carey J, Tang J, Templer P, Kroeger KD, Crowther TW, Burton AJ, Duke JS, Emmett B, Frey SD, Heskel MA, Jiang L, Machmuller MB, Mohan JE, Panetta AM, Reich PB, Reinsch S, Wang X, Allison SD, Bamminger C, Bridgham S, Collins SL, de Datox G, Eddy WC, Enquist BJ, Estiarte M, Harte J, Henderson A, Johnson BR, Larsen KS, Luo Y, Marhan S, Melillo JM, Peñuelas J, Pfeifer-Meister V, Poll C, Rastetter E, Reinmann AB, Reynolds LL, Schmidt IK, Shaver GR, Strong AL, Suseela V, and Tietem A. 2016. Temperature response of soil respiration largely unaltered with experimental warming. Proceedings of the National Academy of Sciences (PNAS) 113(48): 13797-13802. www.pnas.org/cgi/doi/10.1073/pnas.1605365113
296. Crowther, T., Todd-Brown, K., Rowe, C. et al. (2016) Quantifying global soil carbon losses in response to warming. Nature 540, 104–108.
297. Georgia Forestry Commission (2019). Sustainability Report for Georgia’s Forests: January 2019. Dry Branch, GA. 25 pgs.
298. Machmuller, M.B., Ballantyne, F., Markewitz, D. et al. (2018) Temperature sensitivity of soil respiration in a low-latitude forest ecosystem varies by season and habitat but is unaffected by experimental warming. Biogeochemistry 141, 63–73.
299. Moore, R., T. Williams, E. Rodriguez, and J. Hepinstall-Cymmerman. 2011. Quantifying the value of non-timber ecosystem services from Georgia’s private forests. Final Report submitted to the Georgia Forestry Foundation. Forsyth, GA. 44 pgs.
300. Richter, Daniel D., Daniel Markewitz, Susan E. Trumbore, and Carol G. Wells (1999) Rapid accumulation and turnover of soil carbon in a re-establishing forest. Nature 400: 56-58.
301. U.S. Forest Service Forest Inventory and Analysis. Washington, DC. https://www.fia.fs.fed.us/