Low-Carbon Transition Strategies for the Southeast

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EVOLVED ENERGY RESEARCH

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DDPP DEEP DECARBONIZATION PATHWAYS PROJECT

Low-Carbon Transition Strategies for the Southeast

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Version 1

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Introduction

This report explores unique opportunities and challenges for the Southeast region (Alabama, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee) in the broader context of the transformative changes to the U.S. energy system that are required to reduce carbon dioxide (CO_2) emissions to net-zero emissions in 2050. The scale and rate of physical changes to the U.S. energy system will be significant, and the Southeast will play a critical role in enabling a national transition. The implications of these changes for the region will be far-reaching, offering opportunities to grow new industries and jobs, as well as the chance to deploy climate mitigation and adaption policies that help to ensure an equitable energy transition.

There are two central questions about the Southeast region in this report: how does the physical energy infrastructure in the Southeast region need to evolve to enable a low carbon transition, and what are key decarbonization opportunities and challenges in the Southeast from a societal perspective? Answers to these questions can support regional stakeholders' efforts to develop a shared vision of pathways to deep decarbonization, and advance discussions in states across the region. This study explores these questions in three sections. The first section provides context about the national pathways to deep decarbonization, which provides the basis for a Southeast regional exploration. The second section lays out the regional analysis approach and provides an in-depth exploration of Southeast-specific topics. The final section considers broader implications of the physical changes for policymakers, long-term planners, and stakeholders within the region.

Low Carbon Transition in the U.S.

Deep decarbonization of the U.S. economy will entail large scale infrastructure changes across multiple sectors. To understand the scope of these changes, it is critical to understand how both demand for, and supply of energy may evolve to support a low-carbon future. This study builds on previous national analysis of decarbonization, including deep decarbonization studies that examined the requirements for reducing greenhouse gas (GHG) emissions by 80% below 1990 levels by 2050 ("80 x 50"),[1] as well as a recent study examining the changes necessary to stabilize the atmospheric concentration CO_2-equivalent at 350 ppm by 2100.[2] These previous studies found that achieving mid-century GHG reduction targets is technically feasible, economically affordable[3], and attainable using alternative technologies.

The primary requirements of a transition to net-zero CO_2 emissions by 2050 are the construction of energy infrastructure characterized by high energy efficiency, low-carbon electricity, replacement of fossil fuel combustion with decarbonized electricity and other low-carbon fuels,

[1] Pathways to Deep Decarbonization in the United States (2014) and Policy Implications of Deep Decarbonization in the United States (2015). Both studies are available at http://usddpp.org/

[2] Study available at https://www.ourchildrenstrust.org/350-ppm-pathways

[3] The 350ppm study found that the scenarios that meet the carbon constraint have a net increase in the cost of supplying and using energy equivalent to about 2% of GDP, up to a maximum of 3% of GDP, relative to the cost of a business-as-usual baseline, and a total energy system cost as a fraction of GDP comparable or below spending in the last 50 years. These cost figures neglect potential economic benefits of avoided climate change or reduced pollution. See the study for more details.

and carbon capture, along with the policies needed to achieve this transformation. Based on these requirements, there are critical milestones along the pathway to deep decarbonization of the U.S. The key actions by decade below provide a policy-outcome blueprint[4] for the physical transformation of the energy system. Such a blueprint is essential because of the long lifetimes of infrastructure in the energy system and the carbon consequences of investment decisions made today. Additional blueprints are needed to support climate adaptation, which is not explicitly addressed here, and significant study is also needed around equity issues to ensure that the low carbon transition does not adversely impact disadvantaged communities or augment existing inequities.

2020's

- Large-scale electrification of transportation and buildings needs to begin in earnest to enable the very high electrification by the 2040s.
- Switch electricity system dispatch away from coal and to natural gas while the deployment of new renewable generation and transmission-system reinforcements both continue to accelerate.
- Electricity markets begin significant reforms to prepare for major changes load, from electrification and load flexibility, as well as a resource mix dominated by renewables.
- End new investments in infrastructure to transport fossil fuels (e.g., pipelines).
- Launch pilot projects for new technologies that will need to be deployed at scale after 2030, such as carbon capture for large industrial facilities.

2030's

- Achieve maximum rates of renewable generation build-out, which will need to be sustained in the following decades.
- Effect significant build-out of electrical energy storage as storage prices continue to fall, and the volume of renewable energy increases.
- Attain levels of near 100% of new sale shares for key electrified technologies (e.g., light-duty electric vehicles).
- Begin large-scale production of advanced biofuels.
- Deploy large scale carbon capture on industrial facilities.

2040's

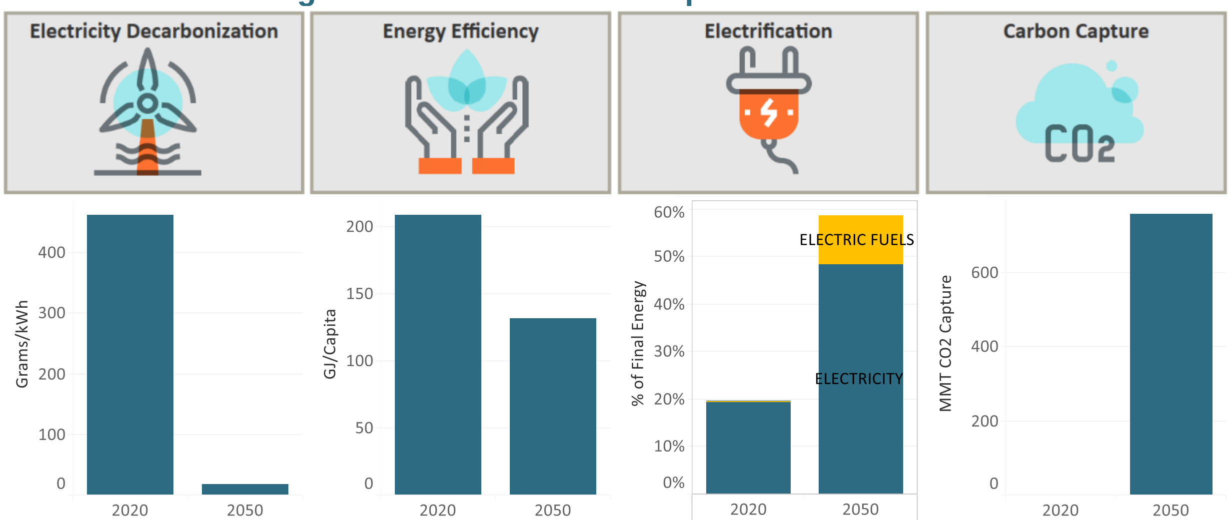
- Achieve near-complete electrification of key end-uses, like light-duty vehicles and heating services in buildings, replacing direct fuel combustion with clean electricity.
- Extend nuclear generation at the end of its plant lifetime or replace it with new low- and zero-carbon generation technologies.
- Fully deploy advanced biofuel production with carbon capture to decarbonize end-uses where electrification is not a viable strategy.
- Deploy bioenergy with carbon capture and storage (BECCS) or direct air capture (DAC) to achieve net-zero greenhouse gas emissions

[4] The list is based current knowledge and forecasts of future costs, capabilities, and events. It is critical to revisit and update this type of blueprint as events unfold, technology improves, energy service projections change, and our understanding of climate science evolves.

The analysis behind this blueprint is based on a **Deep Decarbonization Pathway (DDP)** scenario, which limits CO_2 emissions from fossil fuel combustion and industrial process emissions in the U.S. to net-zero[5] by mid-century. This analysis focuses on energy CO_2 emission reductions while acknowledging that non-energy and non-CO_2 emissions are expected to increase in relative importance as the transformation of the energy system advances.[6] The DDP achieves these emission reductions while providing the same energy services for daily life and industrial production as the Annual Energy Outlook (AEO), the Department of Energy's long-term forecast. The scenarios were modeled using two sophisticated analysis tools, EnergyPATHWAYS and RIO, which provide a high level of sectoral, temporal, and geographic detail to ensure scenarios account for such things as the inertia of infrastructure stocks and the hour-to-hour dynamics of the electricity system, in fourteen electric grid regions of the U.S.[7] The changes in energy mix and emissions for the scenarios were calculated relative to a high-carbon **Reference** scenario based on the AEO.

U.S. Energy Infrastructure Transformation for Net-Zero CO_2

Figure 1 Four Pillars of Deep Decarbonization



The DDP achieves its emissions target through four principal strategies ("four pillars") shown in Figure 1: (1) **electricity decarbonization**, the reduction in emissions intensity of electricity generation by roughly 95% below today's level by 2050; (2) **energy efficiency**, the reduction in energy required to provide energy services such as heating and transportation, by about 40% below today's level; (3) **electrification**, converting end-uses like transportation and heating[8] from

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[5] In this context, DAC and bioenergy with carbon capture and storage are able to provide negative emissions that can be used to offset remaining energy and industrial emissions.

[6] Abatement of non-CO_2 emissions is a critical topic for deep decarbonization but falls outside the scope of this analysis. Other analysis give a much more detailed treatment of non-CO_2 GHG mitigation, including recent work by the Environmental Protection Agency: https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases

[7] See the technical appendix for more detail on the analytical tools and methodology.

[8] High electrification of buildings is the most cost-effective approach to decarbonizing the sector, but there are other viable pathways to net-zero CO_2 in 2050 involve higher levels of natural gas in buildings. These alternative pathways are expected to be more costly, potentially significantly more costly.

fossils fuels to low-carbon electricity, so that electricity triples its share from just under 20% of current end uses to nearly 60% in 2050; and (4) **carbon capture**, the capture of CO_2 that would otherwise be emitted from power plants, industrial facilities, and fuel production, along with direct air capture, rising from nearly zero today to more than 700 million metric tons in 2050. The captured carbon may be stored or utilized for the production of synthetic renewable fuels.

Achieving this transformation by mid-century requires an aggressive deployment of low-carbon technologies. The scale of the infrastructure buildout for the U.S. is indicated in Figure 2, and key actions between 2020 and 2050 include:

- Electrifying virtually all passenger vehicles and natural gas use in buildings.
- Increasing low-carbon electricity generation capacity by more than seven-fold, primarily with low-cost solar and wind power, which grows by more than ten-fold, to meet greater load from electrified end-uses.
- New types of energy infrastructure will be created to work in tandem with a high-renewables electricity system to enable net-zero emissions. This new infrastructure includes large-scale industrial facilities for carbon capture and storage, the production of biofuels with negative net-lifecycle CO_2, hydrogen production from electrolysis using excess renewable electricity and from biomass, as well as synthetic fuel production which utilizes hydrogen and captured carbon.

Figure 2 Low-Carbon Energy Infrastructure Growth

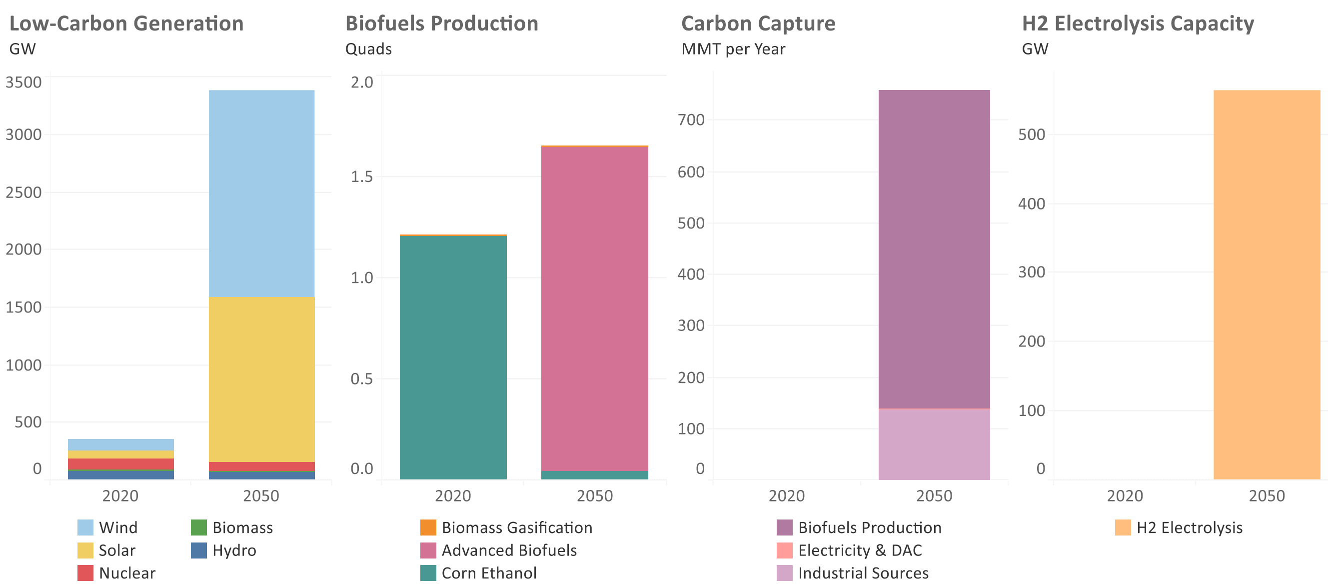
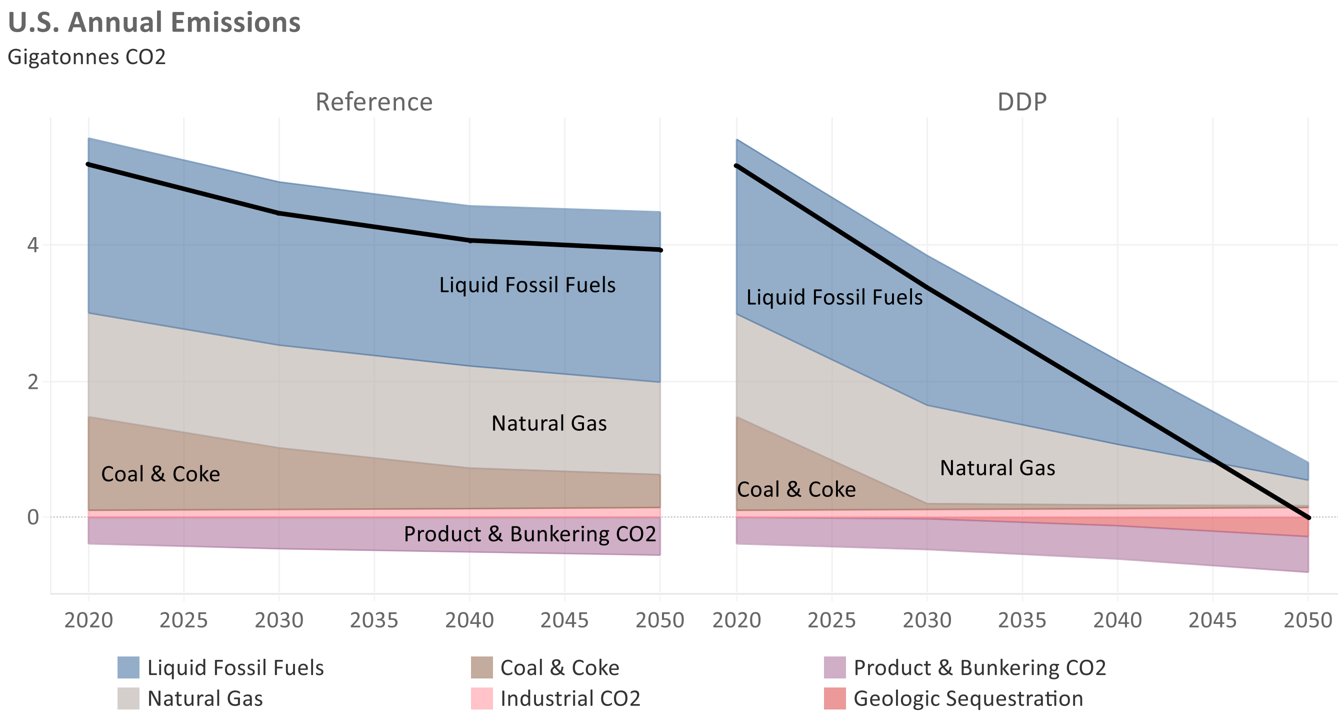


Figure 3 shows that a DDP scenario achieves steep reductions in net fossil fuel CO_2 emissions to reach net-zero emissions by 2050. Variations on the DDP which explore alternative pathways where policy or external factors constrain the set of potential technologies (e.g., limited biomass or a 100% renewable electricity requirement) are more difficult or more costly relative to the base DDP case with all options available, which is our focus here.

Figure 3 Energy-Related CO_2 Emissions[9]



For the U.S. as a whole, there is a clear pathway for the transformation of the energy infrastructure that can enable a net-zero CO_2 economy by 2050. While a national blueprint for the evolution of energy supply and energy demand is a central component for reducing GHG emissions, there are also critical questions about adaption, land use, and how enabling policies will balance a variety of objectives to enable an equitable transition. The following section explores not only the transformation of the Southeast energy infrastructure but key opportunities and challenges, including some of the critical questions around policy and implementation, which will impact a range of outcomes in the region from the future of nuclear energy, to equity, to soil tilling practices.

[9] Product CO_2 represents feedstocks into industrial processes where the CO_2 is sequestered in a final product, principally plastics. Bunkering CO_2 represents emissions which occur in international waters which don't count toward U.S. emission inventories. Both categories offset fuel combustion counted in other categories.

Low Carbon Transition in the Southeast

A Regional Perspective

Although the underlying analysis of this report is for the U.S. as a whole, there are significant regional variations in energy demand and supply that provide valuable insights for the Southeast. This report offers details on how the actions required for national deep decarbonization align with regional geographical boundaries, and the unique opportunities for a given region in contrast to the rest of the country. These insights can illuminate key considerations for a collection of states that are likely to share similar resource potential, act as a common market for key technologies, and already coordinate on large-scale energy infrastructure (e.g., electric transmission).

Regions typically share comparable renewable energy resource potential, biomass production capability, and have tightly coupled electrical systems which depend on some level of regional coordination for long-term planning. They also represent a common market for critical consumer technologies such as electric heat pumps and electric vehicles. For example, the states in the Southeast have comparable cooling and heating requirements that affect the performance of heat pumps, as well as utilities that cross state borders. These commonalities for states within a region make a regional-level analysis a valuable exercise and enable a discussion about critical long-term planning and policy questions that are a unique concern for the region.

Insights about these unique considerations for each region can empower organizations to advance decarbonization efforts within the states they operate. A common understanding of the region’s role in a national effort to decarbonize can serve as a starting point for a shared vision for a pathway to 2050, supporting the long-term planning and implementation work to transform energy use across multiple states. These regional organizations bring a depth of experience and expertise on critical topics for constituents and policymakers who can advance this long-term planning and implementation work. Regional analysis supports these organizations to do the work they are uniquely positioned to do, shaping implementation plans, and ensuring long-term planning is incorporating the critical components of a successful decarbonization effort for the region. With a coherent shared vision of the energy transition, stakeholders are better positioned to explore how to make the transition equitable and the best avenues for pairing adaption efforts with mitigation efforts.

Key Questions

For this study, the Southeast region was taken to consist of the following six states: Alabama, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee, as shown in Figure 4.[10] The Southeast region makes up approximately 12% of the nation's population and energy-related CO_2 emissions. Historically, there has been limited policy ambition to decarbonize the energy sector and improve efficiency relative to other regions of the U.S., such as the West Coast and the Northeast. However, recent initiatives have sought to reduce emissions in the region, such as North Carolina's Clean Energy Plan and Duke Energy's goal of net-zero carbon emissions by 2050.[11]

Figure 4 Southeast Region

Although municipalities and states within the Southeast have varied levels of political ambition for reducing GHG emissions, the region as a whole is likely to face unique challenges as the country transitions from a fossil to a net-zero carbon energy economy. Relative to other regions in the U.S., the Southeast is expected to face some of the most severe climate change-related impacts. Projections indicate that the region will incur the largest economic damages in the U.S. (Figure 5), with local economies facing increased heat-related mortality, lower crop yield, and declines in labor productivity.[12] The region is also home to a significant number of industries that

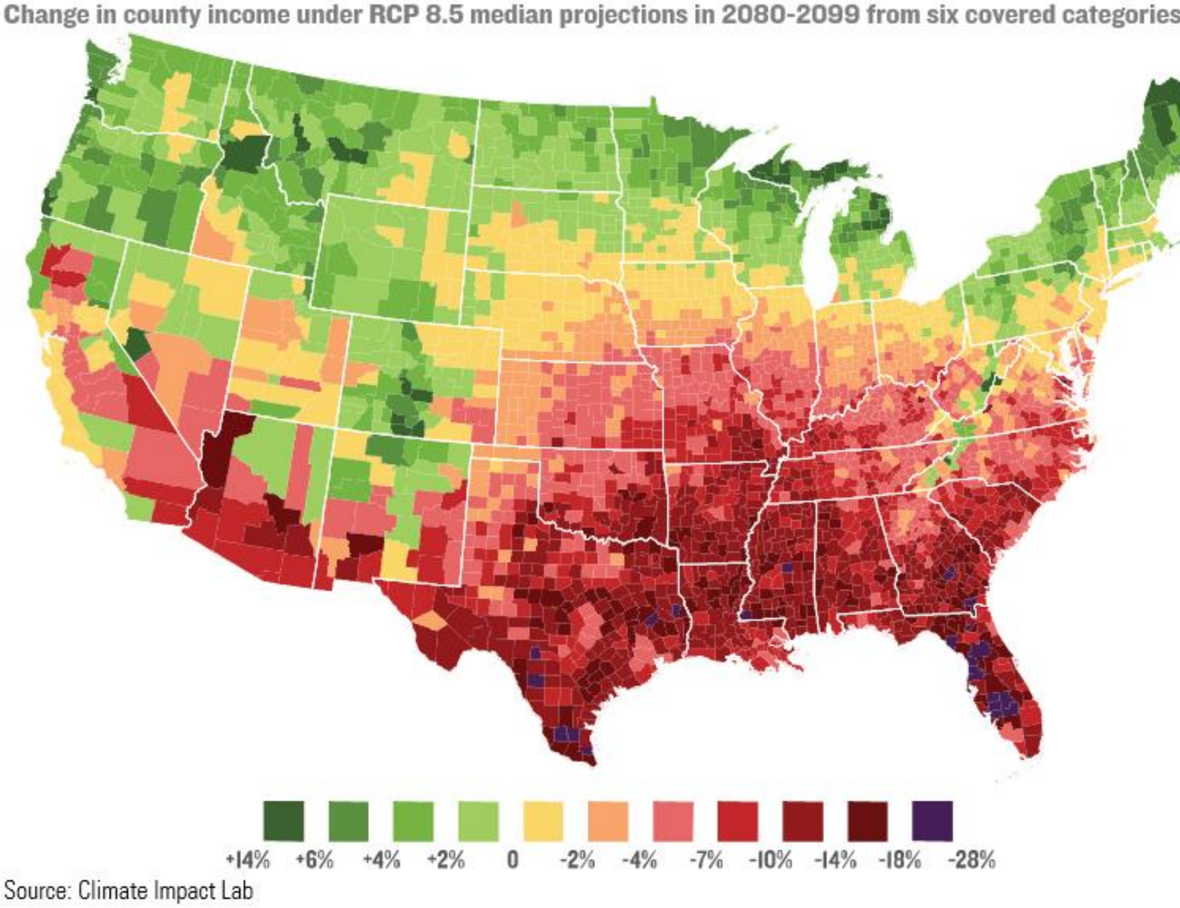
[10] Florida was not included in this study because its decarbonization challenges are sufficiently distinct from the rest of the Southeast region to call for a separate study, which the authors are currently preparing.

[11] North Carolina Clean Energy Plan: https://deq.nc.gov/energy-climate/climate-change/nc-climate-change-interagency-council/climate-change-clean-energy-16. Duke Energy's net-zero goal: https://news.duke-energy.com/releases/duke-energy-aims-to-achieve-net-zero-carbon-emissions-by-2050

[12] See https://riskybusiness.org/report/national/ and https://rhg.com/research/hotter-poorer-and-more-unequal/

face uncertain changes under an energy transformation, such as the automotive and agricultural industries.

Figure 5 Economic Damages from Climate Change by 2100[13]



Jurisdictions and organizations within the region are building momentum to confront these challenges and plan for a transition to deep decarbonization and the associated near-term implementation. This momentum, together with existing organizations that are focused on confronting the range of issues posed by climate change, presents an opportunity for this study to accelerate the discussion in the Southeast.

This study seeks to address two central research questions for the Southeast region:

(1) How do energy supply and demand, investment, and infrastructure across the region need to evolve to enable a low carbon transition?; and

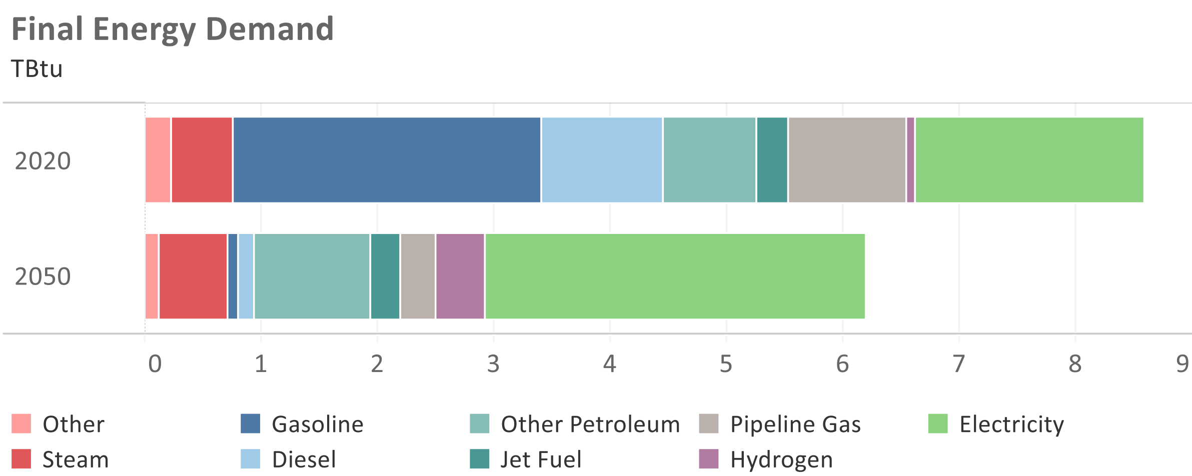
(2) What are key decarbonization opportunities and challenges in the Southeast, and how do they interact both within and outside the region?

[13] Figure source: Rhodium Group (2017), "Hotter, Poorer and More Unequal", available at: https://rhg.com/research/hotter-poorer-and-more-unequal/

The Southeast Today and in 2050

The national results presented in the previous section provide context for exploring key considerations for the Southeast as a region in a broader transition to a decarbonized economy. Figure 6 shows the types of energy the region relies on today in contrast to the changes by 2050. The figure presents final energy demand, energy used in the delivery of end-use services, such as heating or transportation, for 2020 and in 2050 for the DDP scenario. End-use electrification (fuel switching) and energy efficiency transform the total and composition of final energy demand. Total final energy demand is more than 25% below today by mid-century despite increases in population and economic activity, while electricity's share increases to about half of end-use consumption. Liquid fuels (e.g., diesel and gasoline fuel) and pipeline gas consumption dramatically decrease as fossil fuel-consuming equipment (e.g., internal combustion engine vehicle; gas furnace) is replaced by efficient, electric equipment (e.g., electric vehicle; heat pump).

Figure 6 Final Energy Demand in the Southeast for the DDP Scenario

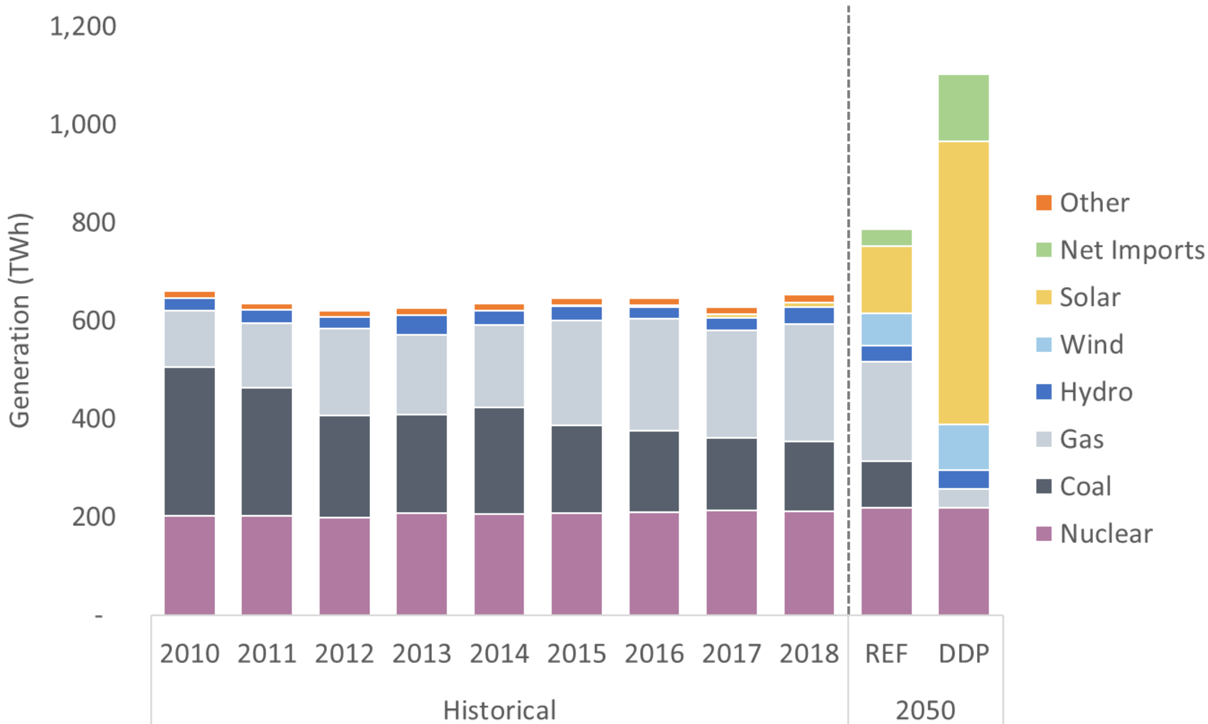


Today, the electric power sector is responsible for a disproportionate share of the region's energy-related CO_2 emissions. Power plants burning fossil fuels made up 41% of the Southeast's energy CO_2 emissions in 2016 versus 35% for the country as a whole.[14] During the past decade, the region's power sector has already transformed, particularly from coal-to-gas switching, as shown in Figure 7. The power sector would need to accelerate this transformation by 2050 via (a) doubling electricity generation from today to meet increased end-use consumption; (b) eliminating coal-fired electricity generation; (c) limiting gas-fired generation; (d) maintaining its nuclear fleet; (e) transitioning primarily to solar generation; and (f) importing wind generation from neighboring regions ("Net Imports" in the figure). This transition from a thermal- to renewable-dominated electricity mix is necessary to support economy-wide emissions reductions. In contrast, the business-as-usual trajectory continues to rely on gas-fired generation

[14] EIA Energy-Related Carbon Dioxide Emissions by State, 2005-2016, available at: https://www.eia.gov/environment/emissions/state/analysis/

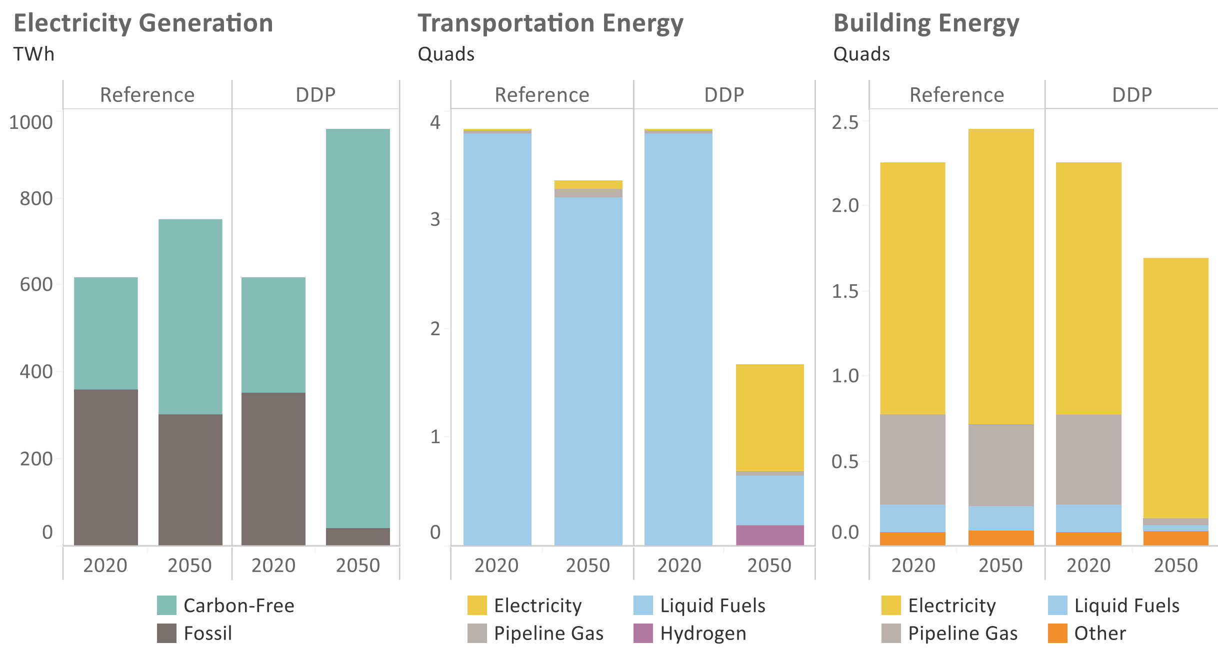
and adds renewables, primarily solar, at a level where they are an economical complement to coal and gas-fired generation.

Figure 7 Historical and 2050 Electricity Generation in the Southeast



At a high level, the transition of the Southeast's energy infrastructure to a deeply decarbonized energy system is similar to the U.S. as a whole. The critical elements of the Southeast transition are shifting the electricity mix from fossil to carbon-free generation and pursuing electrification and energy efficiency in transportation and buildings to the extent possible. Figure 8 illustrates the energy transition for electricity generation and transportation and building energy demand in the Southeast. Carbon-free resources grow from roughly 40% in 2020, due to a large amount of nuclear generation, to more than 95% of electricity in the region generation by 2050. Buildings and transportation are the key drivers of the major change in final energy demand shown in Figure 6. Total energy demand decreases, as more efficient electric technologies displace fuel-combustion technologies. Biofuels play a critical role in decarbonizing fuel use that is not displaced by electricity, accounting for more than 45% of liquid fuels in 2050 compared to less than 4% in 2020.

Figure 8 Overview of Southeast Energy Transition



Critical Issues for the Southeast

The analysis in the prior section shows the Southeast following a deep decarbonization pathway parallel to that of the U.S. as a whole, but the region plays a unique role in some facets of the transition and faces distinct challenges when compared to the rest of the country. From renewable resource endowments and differences in climate to unique regional considerations for an equitable transition, the Southeast will see significant opportunities but also face important policy and planning decisions on a pathway to deep decarbonization. The following sections explore key decarbonization topics for the Southeast in greater detail:

- **Bountiful solar, but limited wind**: the Southeast's renewable resource endowments push the region to rely heavily on local solar with wind generation imported from outside the region.
- **Continuing the coal phaseout**: deep decarbonization accelerates the phase-out of coal-fired electricity generation that is already underway, and the role of gas as a replacement resource evolves from today to mid-century.
- **Nuclear relicensing trade-offs**: the Southeast's nuclear fleet has continuously supplied about one-third of electricity generation for the past decade, and there is an operating nuclear reactor in each of the six states of the region. Relicensing reactors in the region to continue operations through 2050 could support deep decarbonization, and nuclear retirements will raise trade-offs for other resource additions.
- **Rethinking building energy use**: the region has historically been behind in energy efficiency deployment, but deep decarbonization presents an opportunity to re-imagine policy and move towards fuel switching. The region's hot and humid climate makes it ideal for electrifying residential and commercial buildings without significant electric transmission and distribution peak load impacts.
- **EVs and jobs:** with numerous manufacturing facilities that support the automotive industry inside the region, the Southeast is uniquely positioned to propel the massive electrification effort for cars and trucks.
- **Advanced biofuels**: an abundant supply of biomass feedstocks in the region could be utilized to develop advanced biofuels to develop new related industries that support national decarbonization.

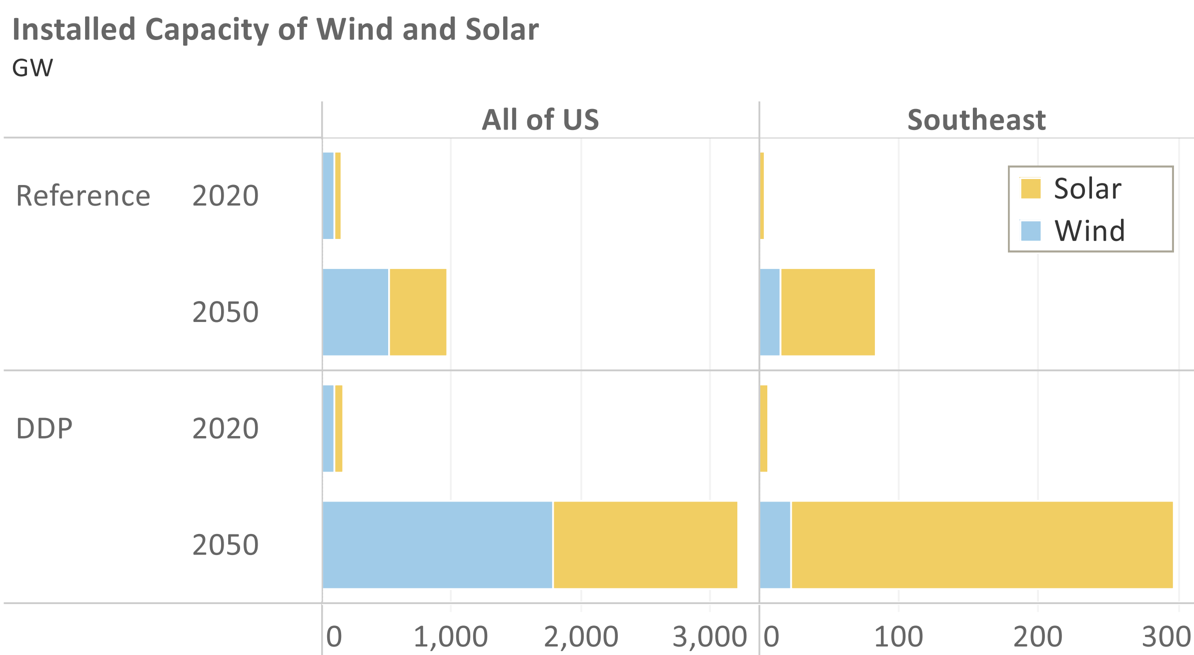
Each of the sections below offers a deeper dive into each of these topics, specifically examining how the Southeast will play a unique role in the national transition as well the opportunity for the Southeast and critical questions for enabling the changes.

Bountiful Solar, but Limited Wind

A solar-heavy resource endowment shapes the future electricity mix

Over the past decade, the U.S. has seen significant installations of wind and solar plants. This trend has been driven by several policy and technology factors, including state-level renewable portfolio standards (RPS) and sizable reductions in capital cost. Continued deployment of wind and solar resources is a predicate of national deep decarbonization, including approximately 1,400 GW of solar and 1,800 GW of wind installed by 2050. As shown in Figure 9, this is nearly three times the projected quantity expected under existing policy, and wind and solar make up more than 80% of the nation's electricity generation by mid-century.

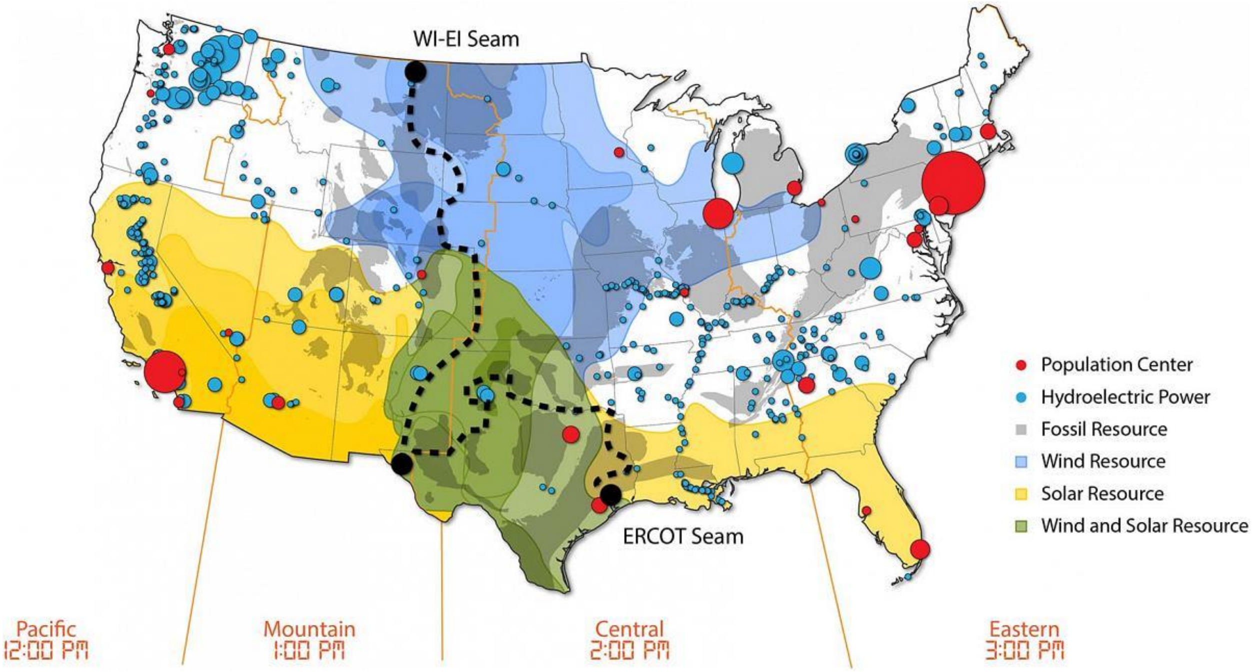
Figure 9 Installed Capacity of Renewables



In the Southeast, nearly all renewable installations are solar resources (275 GW of installed capacity by 2050), and solar makes up 45% of total electricity generation in the region. The Southeast relies much more heavily on solar as compared to the U.S. as a whole because the region has an abundance of high-quality solar resources at low-cost, whereas its onshore wind resource is poor, as evident by the limited number of operating wind plants in the region.[15] Figure 10 depicts wind and solar resource quality across the U.S., and the Southeast includes a swathe of high-quality solar resources, but low-quality wind. As a result, most onshore wind in the DDP scenario is developed across the Great Plains and Midwest regions, where capacity factors are high.

[15] As of December 31, 2018, there is a single 208 MW operating wind plant in North Carolina and 29 MW in Tennessee.

Figure 10 U.S. Wind and Solar Resource Quality Map[16]



Relying highly on solar for electricity generation brings balancing challenges to deliver clean energy during hours when the sun is not shining. To address these challenges, the Southeast relies on significant imports of onshore wind from the lower-Midwest. By 2050, imports of wind generation meet more than 10% of the load in the Southeast, bringing the combined share of (local) solar and (local and remote) wind to more than 60% of the total generation. Significant new inter-regional transmission lines are required to deliver out-of-region, high-quality wind to the Southeast, and the transmission capacity between portions of the Midwest and Southeast increases five-fold by 2050. The concept of delivering high-quality wind to the Southeast via long-distance transmission is not new. For example, the Plains & Eastern Clean Line proposed to deliver wind generation in Oklahoma to the Tennessee Valley Authority's balancing area.[17]

Key Questions for Renewables Development

The transition to an electricity system where renewables supply two-thirds of load represents a significant change for the Southeast, which has historically relied on thermal generation. The scale of development brings opportunities for significant new employment, tax revenue, reductions in air pollution, and improvements to human health, but will also decrease employment in fossil industries in the region. Realizing this opportunity in the Southeast depends on addressing several key implementation questions and uncertainties:

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[16] Map is from NREL Interconnection Seam Study, available at: https://www.nrel.gov/analysis/seams.html

[17] Plains & Eastern Clean Line Transmission Project: https://www.energy.gov/nepa/eis-0486-plains-eastern-clean-line-transmission-project

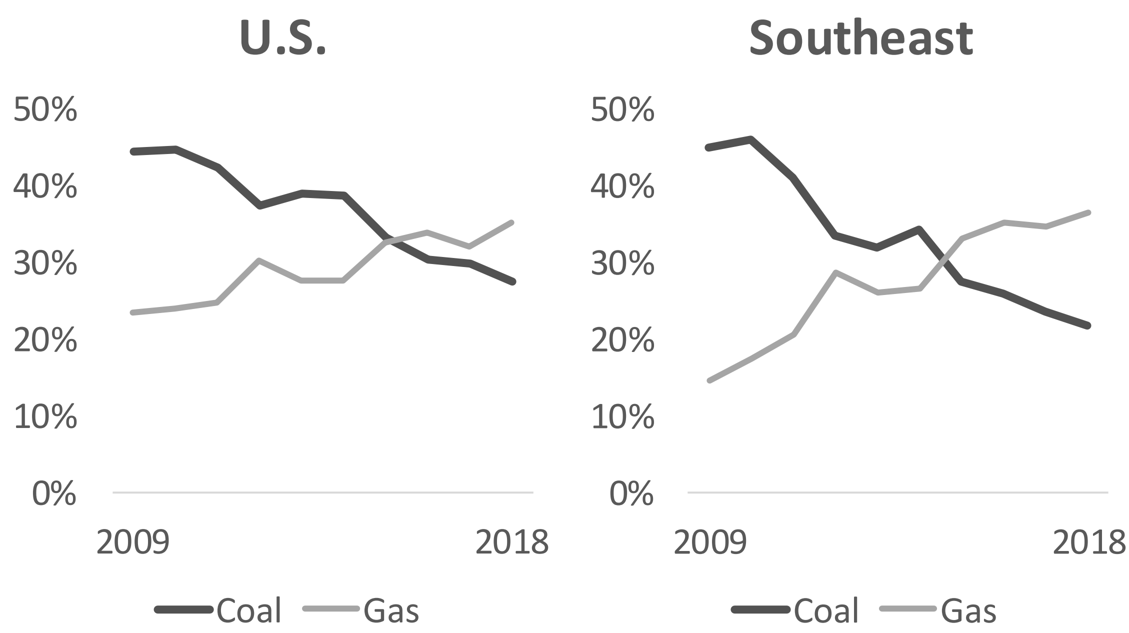
- **How will the region permit and develop solar at the necessary scale and rate?** Our analysis implies more than 10,000 MW of solar installed per year between 2020 and 2050. Anticipating this development requires forward-looking permitting and consideration in environmental and energy planning. The actual deployment will require new supply chains and a sizable labor force. Solar power is already economic in many jurisdictions in the region, and early policy steps to enable the ramp-up of solar power are no regrets actions.
- **How will new intra- and inter-regional transmission be developed?** New transmission is necessary within the region to deliver solar PV to load, as well as significant inter-regional transmission between the lower-Midwest and Southeast to realize high-quality wind. The inter-regional transmission is a critical enabling step to balancing a high-solar, low-carbon electricity system in the Southeast. New transmission development has proven challenging throughout the U.S., but for the Southeast, it represents a “fork in the road” decision point for developing a decarbonized electricity system. Robust and inclusive long-term planning processes and policy support will be critical for enabling new transmission development.
- **How is planning affected if new inter-regional transmission is not realized**? To date, projects across the U.S. to deliver remote, high-quality wind to load centers have often failed. The Southeast is constrained by its renewable resource quality and will need to depend on remote wind to decarbonize electricity generation at least-cost. If the region is unable to access these resources, it may require offshore wind or other clean sources at significantly higher costs.
- **How will transmission costs, which support solar generation, be allocated?** The results show that new transmission to import wind from outside the region is part of the least-cost decarbonized electricity system for the Southeast. However, the analysis provides limited insight as to the best approach to allocating the cost of transmission among consumers who will benefit from its deployment. Questions of cost allocation are central to an equitable pathway to deep decarbonization and will be critical enablers of a high-solar with transmission electricity system.

Continuing the Coal Phaseout

All Southeast Coal Retires and Gas Plants Have a New Role Supporting Solar

During the past decade, a significant quantity of coal-fired power plants across the country has retired in the face of environmental regulations and challenging economics largely driven by lower natural gas prices. Retirements have decreased the share of electricity generation from coal, declining from 45% in 2009 to below 30% by 2018, as shown in Figure 11. During this period, gas-fired power plants have replaced the decline in energy and capacity from coal-fired resources, including existing plants operating at higher capacity factors as well as new gas-fired plants. This trend is more pronounced in the Southeast, where coal’s share has been cut in half since 2009, and gas has effectively replaced all of the energy. This coal-to-gas shift is responsible for most emissions reductions in the Southeast's power sector to date.

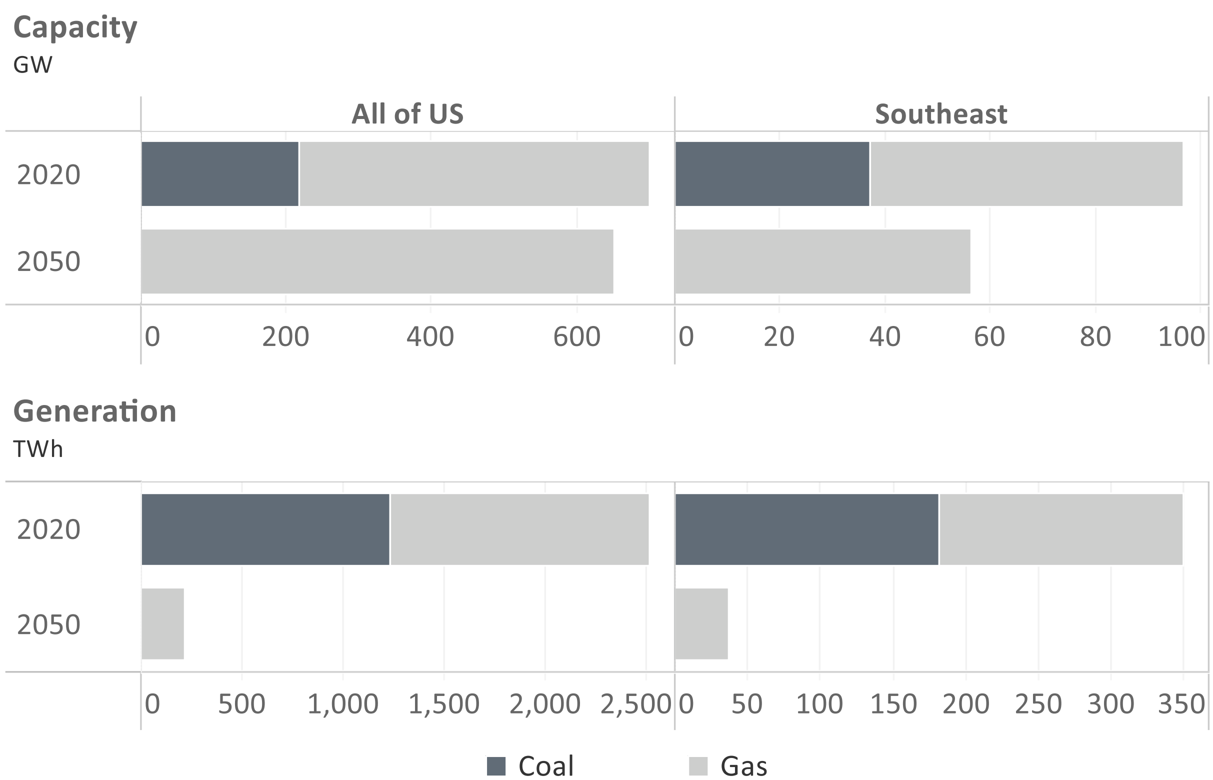
Figure 11 Historical Share of Total Electricity Generation from Coal and Gas



Under business-as-usual conditions, the trend from the past decade is projected to continue with the U.S. expected to retire about two-thirds of existing coal-fired resources, and gas-fired resources replace both the capacity and energy from these retirements. However, under deep decarbonization, carbon-free resource additions change the role of the remaining fossil-fired thermal resources, as shown in Figure 12. Carbon-free resources replace the energy of retired coal-fired resources, which all go offline before 2050. The *capacity* from these retired coal-fired resources is largely replaced by new gas-fired resources to maintain resource adequacy. However, the gas-fired fleet runs very infrequently, such as during challenging system conditions with high loads and low renewable production, at capacity factors of less 5%. With such low utilization rates, these plants are not a significant source of emissions, but these plants could run on low- or zero-carbon fuels like methane derived from biomass and power-to-gas or a blend of hydrogen depending on the plant's design.

The story in the Southeast parallels the national changes, with the overall size of the gas fleet in 2050 being roughly the same as today, but generation is 80% lower. Gas plants in the Southeast play a critical role in supporting the solar for a reliable grid. These plants primarily operate during non-solar hours in the winter to meet morning and evening electric heating loads rather than operating as a "baseload" resources and have capacity factors on the order of 7%.

Figure 12 Coal- and Gas-fired Resources: Capacity and Generation for the DDP Scenario



A variation on the DDP scenario where all fossil fuels are displaced by renewable generation and renewable fuels (100% RE) offers additional support for the importance of thermal capacity to balance high renewable systems. This alternative pathway burns no fossil fuels in 2050 and has 40% more renewable capacity than the DDP scenario at a 5% higher societal cost for the energy system over 30 years. In the Southeast, to support balancing an electricity system with an even higher level of solar renewables, the 100% RE pathway includes more energy storage and 60% more gas capacity than the DDP case. These gas plants run on a fuel that is a mixture of biomass-derived renewable gas and synthetic natural gas produced from a power-to-gas process and produce 60% less energy from gas plants than the DDP scenario. This larger amount of gas-fired capacity is critical for a small number of hours to ensure there is a sufficient supply of electricity to maintain reliability. In all other hours, the plants remain idle and ready to support reliability. Without this gas generation that burns clean fuels in the 100% RE pathway, the cost to ensure reliability for the electricity system would increase dramatically.

Key Questions for Completing the Transition Away from Coal

The Southeast's coal fleet has already shrunk during the past decade, and gas-fired resources have largely replaced their energy. Deep decarbonization necessitates the complete retirement of the regions' coal fleet before 2050 and a new role for gas-fired resources, having them run at very low capacity factors and potentially burn decarbonized fuels. Significant concerns exist about the evolving role of gas-fired generation, including the possibility that if the gas assets are online, they will run at high capacity factors burning fossil natural gas, or “carbon lock-in,” and the potential for stranded gas-fired assets.

State-level carbon policy represents an opportunity to ease this transition and address the range of concerns around this topic. Policy approaches like a stringent cap on emissions (either the electricity sector or economy-wide), and a clean electricity policy (e.g., RPS) would limit gas plant operations to reliability events and avoid “carbon lock-in.” Fears about new gas plants becoming stranded assets can be addressed through mechanisms such as a shorter depreciation life, or different regulatory approaches for compensating for reliability services.

Managing the transition away from coal-fired resources raises several considerations:

- **How quickly should coal plants be retired?** The rate of retirement and the need for replacement resources depends on a variety of factors, including relative coal and gas fuel prices, the cost of new renewables, the need for capacity services partially driven by the level of solar and other renewable penetration, and the willingness to build new gas plants. One potential option is to delay the retirement of existing coal for reliability but only run these units infrequently (e.g., only during peak season). Many existing coal plants are uneconomic compared to new renewable resources, and a no-regrets approach suggests retirement sooner rather than later.
- **How do we ensure new resources are built for the long-term**? Retiring coal resources is an obvious and necessary strategy to reduce emissions, but replacing their contribution towards resource adequacy is complex. Within the Southeast, integrated planning processes will likely identify the need for new gas plants and other replacement resources, as well as defining the critical reliability services each resource will provide during the transition to a deeply decarbonized grid.
- **What is an equitable approach to managing the impacts on jobs and communities as coal plants close?** While the retirement of coal generation will yield benefits for decarbonization, potential cost savings, and improved air quality, it will have major impacts on the communities that rely on the coal plants and the mines that supply those plants. These impacts are also an important consideration for an equitable transition.

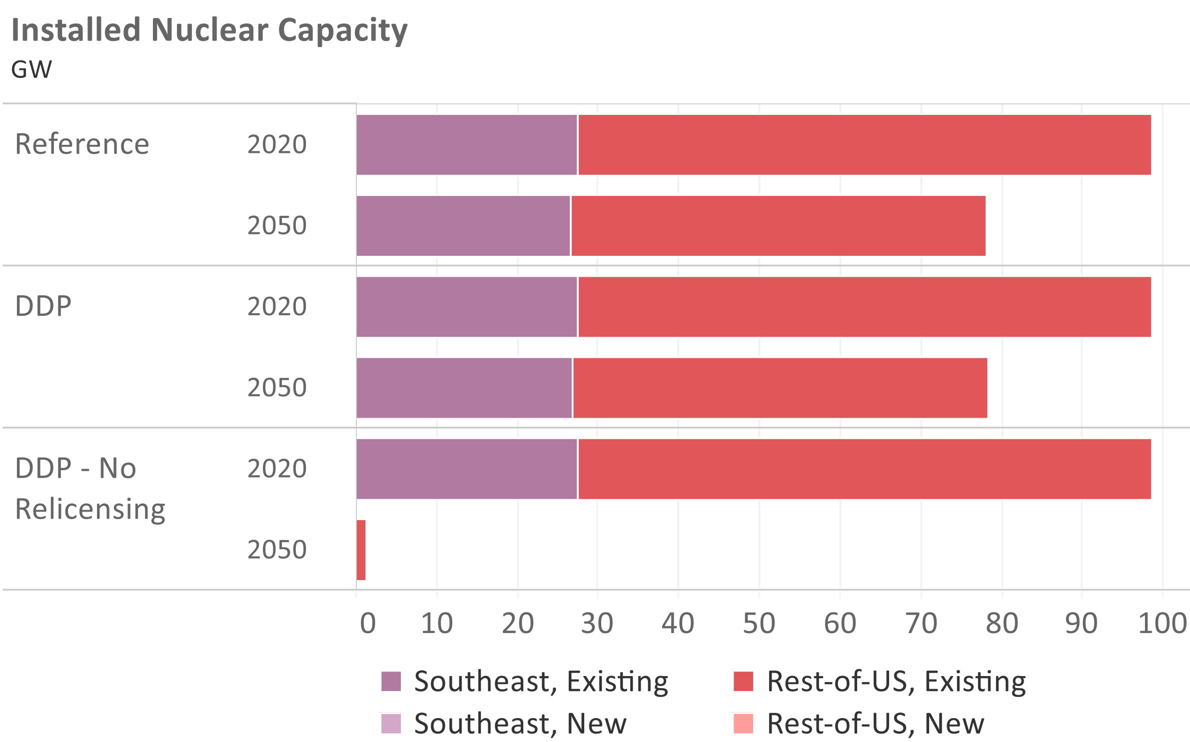
Nuclear Relicensing Trade-offs

Relicensing Could Lower the Cost of Decarbonization

The U.S. nuclear fleet has supplied approximately 20% of the country’s electricity generation for the past two decades, and it is a sizable source of existing low-carbon generation. Nuclear power has a more prominent role in the Southeast, where it has continuously supplied about one-third of electricity generation, and there is an operating nuclear reactor in each of the six states of the region. Preserving the existing nuclear fleet has been identified as a key strategy for supporting a decarbonized electricity system through 2050 at low cost, and many reactors require relicensing decisions prior to 2050. Recent experiences in countries and regions such as Germany, Japan, and California highlight the challenge of simultaneously closing nuclear power plants and reducing emissions.

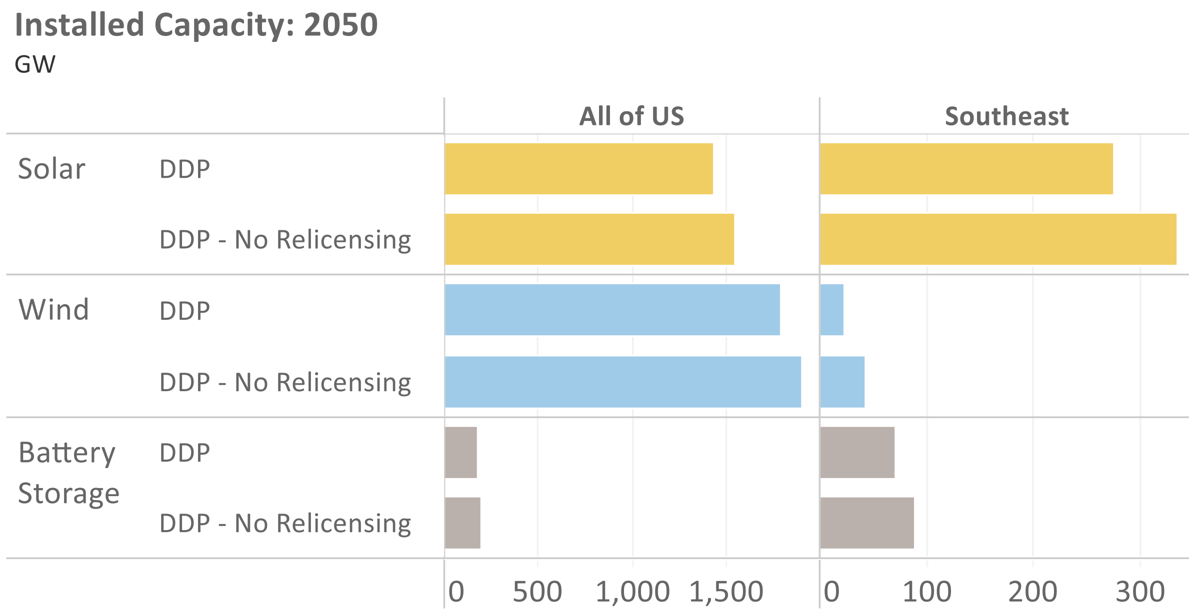
In a deep decarbonization context, the size of the U.S. nuclear fleet of 2050 is about four-fifths the size of the fleet today, due to relicensing and a small amount of planned nuclear plant additions, as shown in Figure 13. If nuclear relicensing is not allowed, the "DDP – No Relicensing" sensitivity, effectively all nuclear plants will retire by 2050. In the Southeast, it is cost-effective to retain nearly all reactors, and their output supplies 15% of all generation by 2050, down from 30% in 2020 on account of substantial load growth. The lack of high-quality wind resources in the region improves the economics of existing nuclear plants relative to other carbon-free resources since they provide a significant source of energy during non-daylight hours. The fact that existing nuclear is part of a least-cost, low-carbon resource mix highlights the imperative to plan for extending nuclear through 2050 if possible.

Figure 13 U.S. Nuclear Fleet



If existing nuclear plants are not able to be relicensed, the retirement of nearly all nuclear capacity will drive the need for other resource additions, principally more renewables and energy storage, incurring a higher societal cost for the energy system. Figure 14 compares the installed capacity in 2050 for the DDP scenario against the DDP – No Relicensing sensitivity, which does not allow new nuclear and prevents relicensing. For the country as a whole, wind, solar, and battery storage increase by five to ten percent. In the Southeast, greater historical dependence on nuclear energy drives greater increases in renewable additions to replace the lost energy and capacity from nuclear. The region requires an additional 60 GW of solar, 20% more, along with an additional 20GW of wind, nearly doubling the DDP scenario, and roughly 20 more GW of batteries (+25%). This sensitivity has a 1% higher societal energy system cost than the DDP scenario through 2050 for the whole U.S., with the Southeast likely bearing larger share of the cost increase than other regions on account of the scale of the changes within the Southeast.

Figure 14 Nuclear Relicensing Effect on Solar, Wind, and Battery Capacity



Key Questions for Maintaining the Nuclear Fleet

Despite very high penetrations of local solar and remote wind generation, the existing nuclear fleet plays an important role in a low-carbon electricity system. Relicensing existing reactors represents an opportunity for the region to achieve deep decarbonization at least cost and utilize the existing nuclear resources to support the integration of high levels of renewables. There are several considerations for planning for an electricity system with and without these nuclear resources:

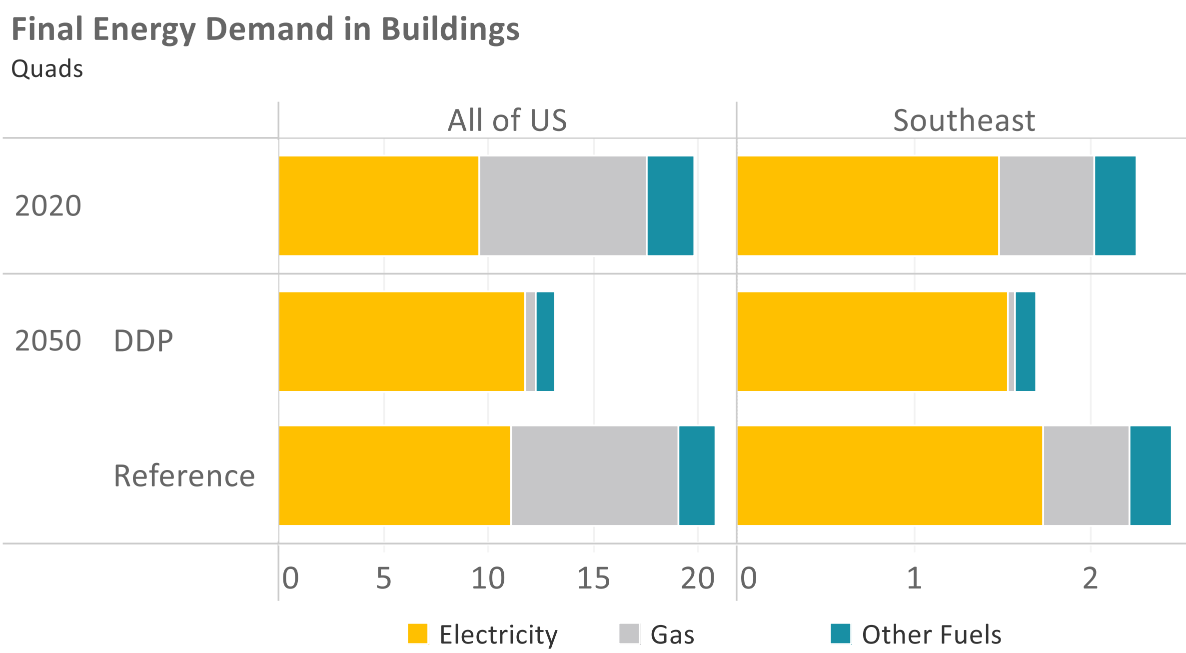
- **How much nuclear will retire in the region?** Decision making around nuclear retirement and relicensing is complex and often contentious. The cost of relicensing is one of many factors that informs the future of existing of nuclear generation. States may take different approaches to nuclear retirements for the plants within their borders.
- **What will replace nuclear energy where retirement occurs?** What factors will shape resource procurement decisions if or when retirements occur? Within the Southeast, nuclear retirements will drive the need for significant additions of zero-carbon resources, but resource endowment limitations and inter-region transmission constraints will impact these decisions. Will policy that manages nuclear retirement also guide what resources can replace nuclear energy?

Rethinking Building Energy Use

Aggressive Efficiency Could Reduce Building Energy Consumption

Significant improvements in residential and commercial building energy efficiency help slash emissions and offset potential increases in energy use from population and economic growth over the next three decades. Final energy consumption in buildings in the DDP scenario is made more efficient through three strategies: (1) electrification of heating services primarily for space and water heating; (2) efficiency improvements for electric end-uses, such as lighting, ventilation and appliances; and (3) improving building envelopes to reduce space conditioning demand. The culmination of these three strategies is a reduction in overall energy demand in 2050 relative to today and an increase in electricity's share of the total energy demand, as shown in Figure 15. Nationally, energy consumption from buildings decreases by more than 30% between today and 2050, and electricity represents almost 90% of end-use consumption by 2050. This shift is primarily due to the adoption of highly efficient electric heat pumps and heat pump water heaters.

Figure 15 Building Energy Demand



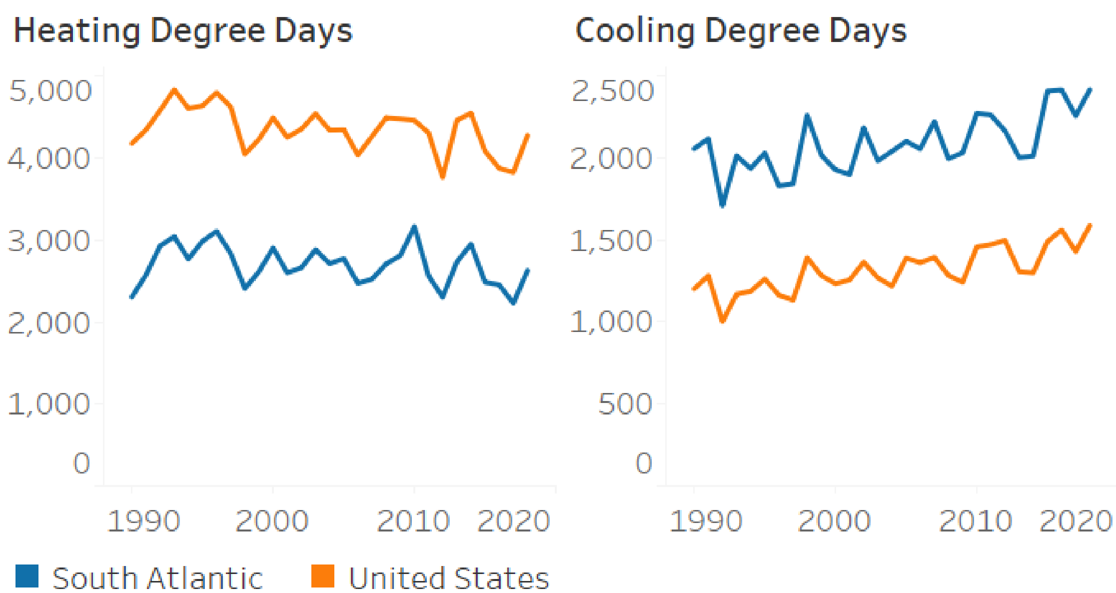
In the Southeast, which has historically lacked strong energy efficiency programs, significant improvements in building energy efficiency are possible. Overall, building energy consumption is 30% below business-as-usual levels in 2050 and 25% below 2020 levels, despite the population increasing by 20% and commercial floorspace increasing by 40%. Electric resistance heating systems are more prevalent in the region to meet heating needs, and replacing these heating systems with heat pump technology an unlock significant end-use efficiency gains. In addition to reducing energy use for heating, heat pumps help reduce energy use for cooling and are ideal in the region due to the humid climate and relatively mild winters.

Southeast Climate is Well-Suited for Electrification

A critical strategy for improving efficiency and decarbonizing buildings is fuel-switching to electricity. Buildings are significant consumers of energy to meet heating and cooling service requirements. Currently, most space and water heating requirements are provided by boilers and furnaces consuming fossil fuels (e.g., natural gas and heating oil). Electrification is a critical strategy to decarbonize buildings at a low cost. In the U.S., this is primarily achieved through the adoption of electric air source heat pumps (ASHP).

However, the energy demand for heating and cooling services varies widely across the country due to regional climate. Figure 16 shows heating degree-days (HDD) and cooling degree-days (CDD) since 1990 for the United States and South Atlantic census division, which includes many states in the Southeast. National HDD are approximately 60% higher than the South Atlantic during this period due to colder temperatures in regions such as the Northeast and Midwest. Higher HDD translates into higher heating service demand and energy use. In contrast, national CDD is approximately 40% below the South Atlantic due to more moderate summer temperatures. Year-to-year variations in HDD and CDD explain changes in electricity and natural gas consumption to heat and cool buildings.

Figure 16 Heating and Cooling Degree-Days, 1990-2018[18]



Concerns have been raised about building electrification in colder climates due to the performance of heat pumps when outdoor temperatures decrease and whether electric transmission and distribution (T&D) peaks will sharply increase. With lower heating and higher cooling service demands than the national average, the Southeast is an ideal region for electrification since there is potential for energy savings in the summer, and the winter impacts on electric T&D are moderate. Nearly 45% of existing homes in the South census region are

[18] HDD and CDD data is from the U.S. Energy Information Administration's Monthly Energy Review. Available at: https://www.eia.gov/totalenergy/data/monthly/

already all-electric, and the region's climate allows that share to increase substantially.[19] A large portion of electric heating in the region is provided by electric resistance heating, which can create winter peaking systems during infrequent cold snaps. Shifting to air-source or geothermal heat pump systems, where feasible, can support further efficiency gains and has the potential to mitigate T&D peaks on winter peaking systems in the region.

Key Questions for Realizing Efficiency Gains and Wholesale Building Electrification

Unlocking significant increases in energy efficiency is a critical strategy for the Southeast to reduce emissions and manage energy costs. Investments in efficient and low-carbon end-use technologies will increase significantly during the next three decades with residential and commercial customers adopting heat pump space and water heaters, high-efficiency appliances (e.g., refrigerators, ventilation, etc.), LED lighting and building shell improvements.

Electrification is a central component of the reductions in energy use from buildings and provides a co-benefit of reducing air pollution. The region's heating and cooling needs make it ideal for large scale heat pump deployment. However, states have typically restricted funding for energy efficiency programs to only support the adoption of technologies of the same energy source (e.g., ASHP can only replace an electric resistance furnace, but not a gas furnace). Southeast states could open energy efficiency to electrification by allowing consumers to switch energy sources (e.g., from gas to electricity). Building shell upgrades and air sealing measures will also be important enablers of building electrification to ensure new ASHP can be sized appropriately to operate at high efficiencies for both heating and cooling.

Realizing these opportunities for efficiency gains raises a variety of questions on how to overcome historical barriers to energy efficiency and reimagine policy going-forward. Large-scale switching from natural gas to electricity in the region's buildings also raises several implementation and business model questions.

- **How can energy efficiency policy evolve to address carbon reduction**? Significant increases in energy efficiency are essential for managing cost and reducing emissions in the Southeast, and evolving energy efficiency policies represent "fork in the road" decision points for deep decarbonization in the region. Given the limited historical role of energy efficiency programs in the region, there may be opportunities to deploy novel efficiency policies in the Southeast as there are fewer barriers from changing existing approaches. One critical area for updates is fuel-switching. Utility programs will need to be able to incentivize fuel-switching to ASHP as well as potential building efficiency measures to ensure newly installed heat pumps can perform as designed. Extensive changes to efficiency policy to accelerate deployment would break from a trend of modest impacts, and enable substantial energy and cost savings across the region.
- **How will electrification be rolled out?** Switching out existing gas-fired furnaces, or electric resistance heating, and central air conditioners with highly efficient heat pumps

[19] https://www.eia.gov/todayinenergy/detail.php?id=39293

will take decades to implement. There are open questions about how to be best incentivize this change even if heat pumps are already economic from a societal perspective. One potential implementation is to start by requiring new buildings to be all-electric, which is critical given the region's growing population and economy.

- **How to manage potential equity and distributional implications of electrification?** Fuel switching to electricity will represent a significant change from the current systems we have today to support low-income customers with utility services. The change will have major impacts on households where energy costs represent a significant portion of their income. A range of important issues will need to be addressed, including electric rate design, local resiliency as well as programs to support low-income customers as they move from a combination of natural gas and electric service to electric only.
- **What is the role of gas utilities and programs focused on gas efficiency?** Gas utility programs have typically focused on improving the efficiency of gas appliances, which is at odds with large scale electrification. Additionally, gas sales are likely to decline significantly on account of building electrification. Lower throughput for gas utilities may pressure these entities to raise rates and present challenges to the gas utility business. While it will take time to increase the penetration of ASHP, resolving questions around the role of the gas utility is a "fork in the road" issue for avoiding stranded assets on the gas system.
- **How will cost-effectiveness tests change?** Codes, standards, and incentives are typically based on cost-effectiveness tests. Enabling large-scale deployment of efficiency measures, including fuel switching, will require a new cost-effectiveness framework that accounts for the overall energy consumption of all fuels and carbon emissions. In addition, the flexibility from newly electrified loads could represent a significant benefit by helping to manage electric transmission and distribution costs.

EVs and Jobs

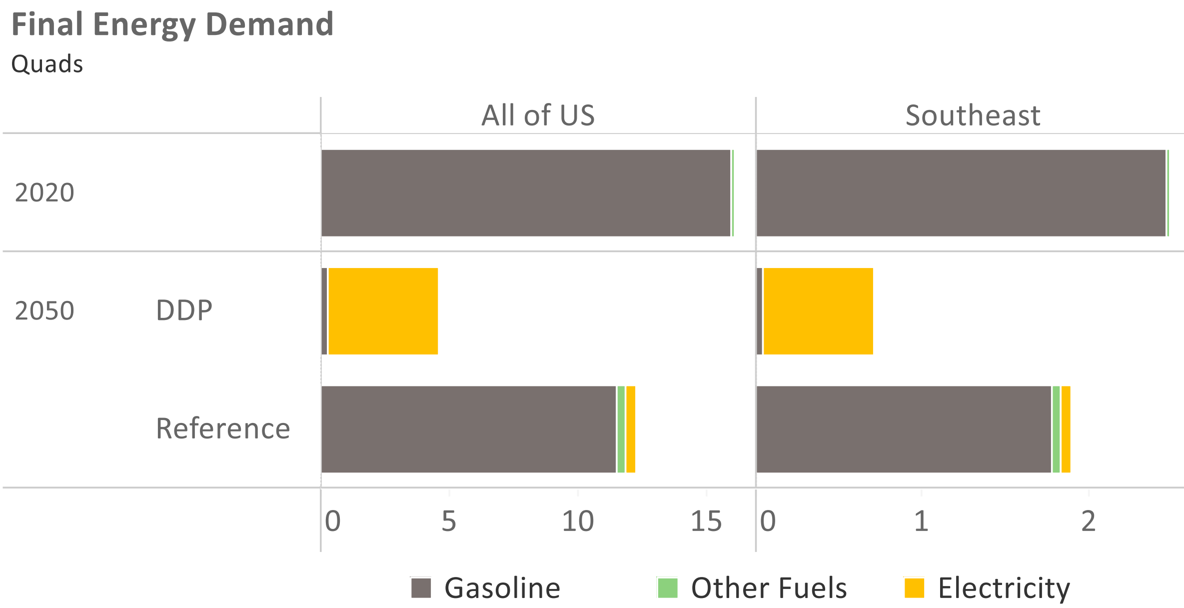
Transition to Electric Vehicles Reduces Energy and Air Pollution

Nationally, emissions from the transportation sector currently represent the largest source of CO_2 emissions. A significant portion of these emissions is from fossil fuel combustion by light-duty vehicles (e.g., passenger transportation). This sub-sector currently consumes nearly 60% of all energy used in the transportation sector, primarily from gasoline consumption to fuel internal combustion engine (ICE) vehicles. Improved urban planning and greater access to public transit can help mitigate some of these emissions while offering a range of co-benefits,[20] but eliminating

[20] This analysis assumes service demand for light-duty vehicles consistent with AEO forecasts, which implies modest increases in public transit ridership and shifting out of light-duty vehicles.

emissions from the remaining light-duty vehicles on the road is necessary to meet national emissions targets.

Figure 17 Light-Duty Vehicle Final Energy Demand



Aggressive adoption of electric vehicles is the preferred strategy for mitigating light-duty vehicle emissions. In the DDP scenario, nearly all passenger cars and trucks on the road are electric by 2050. The impact of shifting from ICE to electric vehicles is the elimination of gasoline demand and an increase in electricity consumption, as shown in Figure 17 , along with much lower energy demand, is due to the greater efficiency of electric powertrains. In the Reference scenario, overall energy demand from light-duty vehicles does decrease due to improvements in fuel economy standards, but the reduction is a fraction of what will be necessary for economy-wide transformation.

The transition to electric vehicles is similar in the Southeast region, where transportation emissions are an even higher share of emissions than nationally. In 2016, the transportation sector accounted for 40% of all energy-related CO_2 emissions in the Southeast versus 37% for the U.S. This reflects the fact the region is heavily car-dependent, and per capita vehicle miles traveled are 20% higher in the Southeast relative to the national average.[21] While the need for a transition from ICE to EVs presents challenges in the region, it also comes with economic opportunities. The Southeast is already home to a significant number of car and truck manufacturing facilities that could supply EVs for the whole country. During the next three decades, the DDP scenario projects that 400 million EVs are sold nationwide to naturally turn

[21] https://www.bts.gov/archive/publications/state_transportation_statistics/state_transportation_statistics_2015/chapter-5/table5_3

turnover cars and trucks from ICE to electric vehicles, and the Southeast could be a major driver for deploying these vehicles at scale.

Key Questions for Developing an Electric Vehicle Manufacturing Industry

The light-duty vehicle transition from gasoline to electric automobiles presents a major opportunity for the Southeast. Existing and potential new manufacturing automotive industries in the region are well-positioned to provide the domestic market for light-duty EVs if they can keep pace with innovations in the space. If manufactures within the region can lead the transition to electric vehicles, the Southeast can maintain its position as a significant producer in the global automotive market.

Remaking the U.S. light-duty vehicle fleet will present challenges, and the Southeast region will need to address key questions to be positioned to lead the automotive manufacturing needed to support these changes:

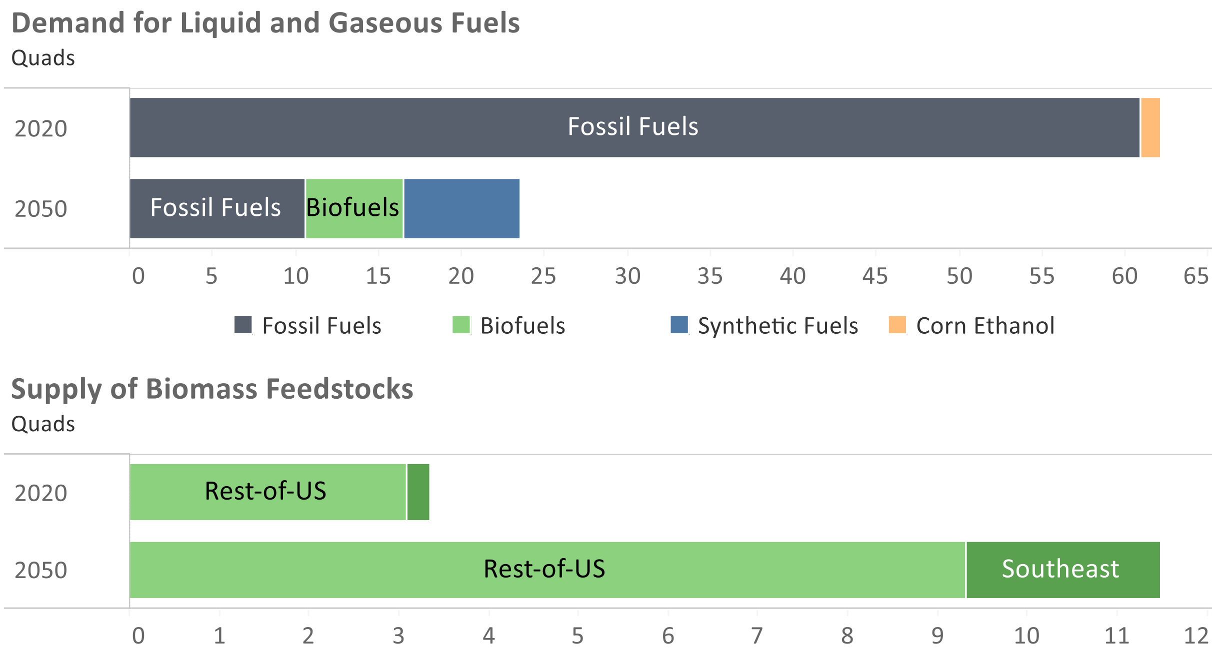
- **How can vehicle manufacturers get ahead and be strategically positioned for this change?** Near-term business pressures are shifting some automakers' focus away from EV development. The pace of the transition for cars and trucks will be rapid if the country is going to meet ambitious 2050 GHG emission reduction targets, and industries in the Southeast will need to continue to prepare for long-term market changes. The question of strategic positioning these companies represents a “fork in the road” decision point.
- **How quickly will demand for EV’s materialize?** Numerous factors influence customer purchase decisions, which can be complicated and weakly tied to the economics of lifetime cost. A range of factors will shape how quickly demand for EVs may materialize, and the rate of EV demand will be a critical factor in how quickly automakers in the Southeast can respond.
- **What role is there for policy?** Given the complexity of customer adoption decisions, policy can play an important role in accelerating EV adoption. Policy has the potential to support higher rates of customer uptake by tackling barriers to EV adoption. These policies might target things like the availability of public charging, including “charging deserts,” which may have equity implications and working to raise awareness of EV’s. Policy support is likely to be particularly important for the Southeast, which is generally more dependent on light-duty vehicles than the U.S. as a whole.

Advanced Biofuels

Shifting Away from Corn Ethanol to Advanced Biofuels

A key strategy for national deep decarbonization is reducing final energy demand for fuels (e.g., pipeline gas, diesel fuel, etc.) as much as possible since the cost of decarbonizing the fuel supply is very high. This is achieved through electrifying end-uses, but some end-uses, such as aviation, are not practical for electrification. Where electrification is not a viable approach, the preferred approach for reducing the carbon intensity of residual fuel demand is the deployment of biofuels.

Figure 18 U.S. Fuel Demand and Biomass Feedstock Supply for the DDP Scenario



This dynamic is illustrated in Figure 18, where the top panel shows demand for liquid and gaseous fuels and its composition of fossil and low-carbon sources. Overall, fuel demand decreases by two-thirds between 2020 and 2050, and 25% of the fuel supply in 2050 is from biofuels. The location of biomass feedstocks used to produce these biofuels is identified in the bottom panel, which shows the Southeast supplying approximately 20% of the country's total, up from 8% in 2020. The region increases biomass feedstock production by more than 7-fold and represents the nation's second-largest supplier behind the Midwest. The estimate of biomass feedstocks, including location and cost, are from the U.S. Department of Energy's Billion Ton Report.[22]

This biomass production has a critical role enabling biofuels to lower emission intensity of residual fuels in the economy. Low- and negative-carbon agricultural practices to produce this biomass could offer an additional emissions reduction benefit, which is not captured in this analysis. The cost of biofuel production of direct replacements for fossil fuels, including industrial feedstocks, is typically lower cost than any other approach to decarbonizing fuels, particularly for fuels that are long hydrocarbons (e.g., heavy fuel oil and lubricants).

This analysis finds that amongst the potential range of biofuels that could be produced with a constrained supply of biomass, advanced biofuels that are direct replacements for heavy refining products for industrial use and hydrogen production with carbon capture are the most

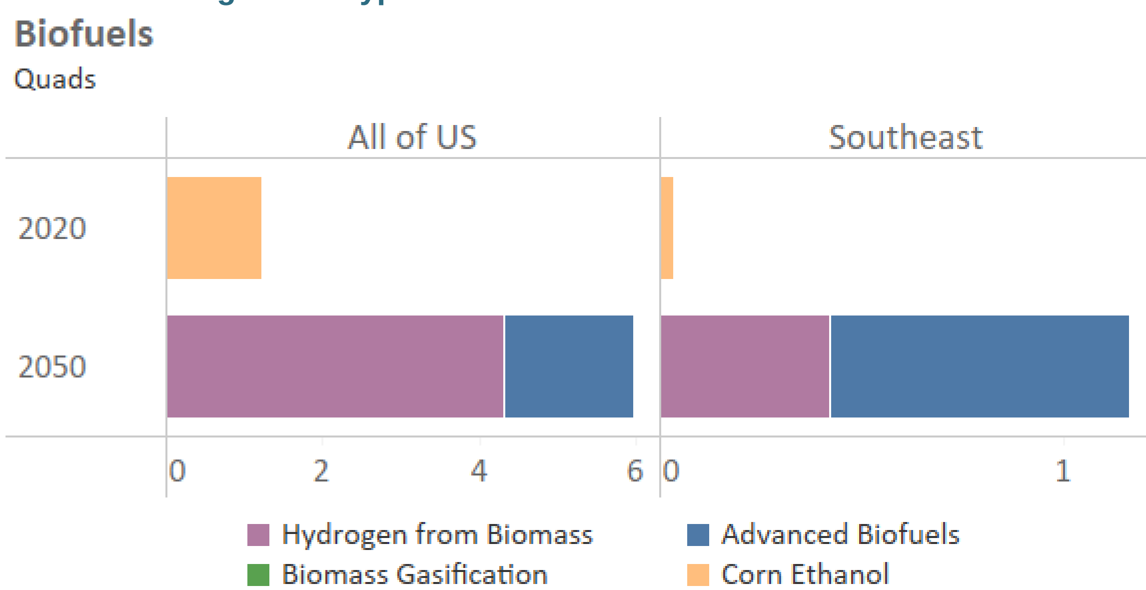
[22] 2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, available: https://www.energy.gov/eere/bioenergy/2016-billion-ton-report

economical options. Whereas biomass to produce renewable natural gas is generally only economical once all other options have been exhausted, as natural gas has low GHG emissions on an energy basis in comparison to liquid fuels, and AEO forecasts suggest it will remain low cost into the future. Biofuels to replace gasoline also play a limited role on account of a 97% reduction in gasoline demand due to electrification of the light-duty vehicle fleet.

Key Questions for Growing a New Southeast Biofuels Industry

A significant increase in biomass production to supply advanced biofuels and produce hydrogen presents a significant opportunity for the region. Today, the national biofuels industry is focused on producing ethanol from corn feedstocks to blend with gasoline. However, in a deep decarbonization context, gasoline fuel demand is nearly eliminated along with corn ethanol production. Instead, other advanced biofuels and hydrogen are produced from other biomass feedstocks other than corn (e.g., herbaceous residues, energy crops, woody residues), as shown in Figure 19. Advanced biofuels act as drop-in replacements for fuels that remain in the economy, and hydrogen has a critical role in a DDP energy system both as a feedstock for the production of synthetic fuels and as a fuel for some industrial and transportation applications. Developing hydrogen-from-biomass production facilities with carbon capture allows for carbon-negative, biomass-derived hydrogen. Notably, the Southeast biofuel production is skewed toward advanced biofuels while the country as a whole produces more hydrogen from biomass than advanced biofuels. The reason for this is the region produces different feedstocks, predominantly woody residues, that are more economical for the production of long-hydrocarbon advanced biofuels than for hydrogen production.

Figure 19 Type of Biofuels Produced: DDP Scenario



The major growth in the production of biomass feedstocks and advanced biofuels will create significant opportunities for new energy infrastructure in the Southeast. Moving to a greater dependence on advanced biofuels produced in the Southeast and the rest of the country can also support greater domestic energy independence and may increase resiliency. A range of national policies has been implemented to advance these objectives in the past, including the Energy Policy Act of 2005, which played an important role in expanding the current ethanol industry, and well-crafted policy that complements decarbonization efforts through 2050 can ensure production of advanced biofuels and hydrogen from biomass support multiple policy objectives.

Demand for advanced biofuels from the Southeast will drive the deployment of new biofuel production facilities in the region. Given that it is cheaper to transport finished biofuels than biomass feedstocks, we expect these new biofuel production facilities to be placed primarily in rural areas with manageable biomass collection costs and potential for low-cost transportation of refined biofuel outputs. This development will create significant opportunities for new economic development in rural areas.

There are critical considerations around realizing these opportunities inside the region:

- **What quantity of biomass that will be available for biofuel production?** While there have been several major studies of the topic of future biomass availability, including the Billion Tons study that this analysis draws on, the range of estimates of future biomass availability is wide. The volume of sustainable biomass production will be determined by several factors, including potential impacts on food prices and ecosystems. Additionally, the impacts of a changing climate on competing land-uses are uncertain, and adaption measures may complement or work against biofuel production in some regions.
- **Will a transition away from ethanol leave opportunities for biofuel development in other portions of the U.S.?** As demand for gasoline declines, existing political and economic interests that have supported historical ethanol production will face important decisions. The timing and implications of a shift away from ethanol to other biofuels will be critical to the transition. Biofuel production has historically been concentrated in the Midwest, and changes to the policies that support ethanol production may focus on new biofuel production largely in the same places that biofuels have been produced to date. Focusing biofuel policy on just the Midwest, rather than recognizing the opportunity in the Southeast and other regions, will slow the national transition and hamper the development of new biofuel industries.
- **Which policies can help realize the benefits of new biofuel production that aren't captured in this analysis?** In the past, biofuel blending standards have been used to support energy independence objectives, and there will be opportunities for well-crafted policies that support the development of advanced biofuels and achieve a range of benefits in addition to decarbonization. Agricultural and land-use practices may support higher levels of carbon sequestration in soils, and policy could be the best means to recognize and incentivize this potential co-benefit. Similarly, economic development and new opportunities in rural areas in the Southeast are both important facets of equity in the energy transition.

A Long-Term Regional Vision is Needed

Deep decarbonization in the Southeast will present significant opportunities for economic growth and new jobs for the region, as well as the possibility of defining and executing a plan for an equitable transition to a net-zero CO_2 emissions economy. The region could become a national leader on planning and decision making around nuclear retirement along with a new role for gas plants to support a renewable dominated system as coal retires. The Southeast can become a major producer of sustainable, zero-carbon advanced biofuels to facilitate national decarbonization efforts and creating jobs and new industries in the process. And the region has the opportunity to redefine high-impact efficiency and fuel-switching policy and programs as states lower energy demand while growing their population and economies. But realizing these opportunities will require a shared, coherent long-term vision for the region, along with effective planning and well-crafted policy to address key questions along the pathway to deep decarbonization and to execute in the near- and mid-term.

Achieving these desirable outcomes on the way to a net-zero emissions target in 2050 requires action today. This analysis highlights two critical implications for near- and mid-term actions in the Southeast to advance deep decarbonization:

(1) long-term planning and cross coordination between sectors and geographies is essential, and builds toward a shared vision of the desired pathway to 2050; and

(2) maintaining a focus on long-term goals is critical when establishing near-term policy to advance decarbonization.

Positioning the region and the nation to successfully address the key questions raised in the previous sections necessitates effective engagement with stakeholders who can act on the above implications. The focus of this analysis is the physical transformation of the energy system and enabling challenges, but its findings can support the local and state-level decision making that will be essential for designing an equitable transition and producing durable outcomes that can sustain decarbonization efforts for the next 30 years and beyond. The following two sections address the implications of this study for planners, policymakers, and advocates in greater detail.

Planning and Coordination Across Sectors and Geographies

A common characteristic across low-cost deep decarbonization pathways is much tighter coupling of electricity to all sectors that consume energy. This is particularly important for end-use electrification of buildings, transportation, and industry. Tighter coupling of electricity with other energy use will drive significant growth in electrical loads; in this analysis, 2050 load more than doubles as compared to 2020. The new loads from electrification will require integrated planning across sectors to ensure that new clean generation resources and electric distribution and transmission system upgrades are developed to meet growing demand. Inter-sector coordination will be critical for planning to enable the transformation necessary to reach a low-cost 2050 system.

Effective long-term planning for the energy system will also necessitate regional coordination. Long-term regional planning will be critical to address new infrastructure needs across the region, as well as new common markets for electrified and highly efficient devices like ASHP. Regional electric planning will face new challenges in developing reliable, high-renewable systems. This challenge will be particularly acute in the Southeast, where there is a bountiful solar resource but limited wind resource to complement solar production when the sun is down. New transmission that connects the Southeast to wind power in the Great Plains is part of a least-cost deep decarbonization pathway, but it depends on navigating the difficulties of inter-regional coordination to enable significant wind imports to support a clean grid in the region.

Utility planners, public utility commissions, state energy offices, advocates for consumers and advocates for an equitable transition all will play an important role in these long-term planning processes. Planning for deep decarbonization will depend on drawing from existing analytical methods along with new approaches for collaborating in long-term planning. Given the scale of changes necessary for achieving emission reduction targets, successful planning efforts need to layout a technical pathway for achieving long-term goals but also engage a broader range of stakeholders to foster a shared vision of a pathway to reaching 2050.

Maintain Focus On Long-Term Goals When Setting Near-Term Policy

A shared vision of the desired 2050 outcomes is a critical ingredient for enabling the breadth of stakeholders in the region to confront the key questions and challenges on a pathway to a deeply decarbonized system. Maintaining a focus on long-term goals for transforming the energy system is essential for developing policies that can advance the Southeast towards the opportunities that the region is uniquely positioned to realize in a national decarbonization effort. With a clear, shared picture of the changes the many stakeholders in the region are working toward, it will be easier to chart a course through issues that seem intractable when the focus is only on incremental changes and near-term outcomes. A common vision will also advance policy discussions around establishing criteria beyond cost-effectiveness, including questions like what is a just transition from today to tomorrow?; and are burdens distributed equitably across communities in the region? Many of these questions are complicated and are likely best answered at a local and state level, and a shared regional vision within these policymaking contexts can support more equitable and durable decarbonization efforts.

Long-term goals should inform near- and mid-term policies. Key areas of focus include policies to accelerate changes required to reach long-term goals and addressing critical issues that long-term planning is likely to offer little insight into, such as equity, fair burden-sharing, and resilient and robust communities. A long-term focus is critical both for policy around energy supply, which already incorporates long-term planning (e.g., integrated resource planning for electric and gas utilities), but also for enabling the customer-side transformation where nearer-term policy has an important role to play hastening demand for electrified technologies and improving energy efficiency. Complete electrification of buildings will require decades of consumer adoption to turn over the building stock by 2050, and policy will likely be needed to help transform the market. Similarly, near-term policies to support the electrification of transportation need to account for the lag between the saturation of new vehicle sales and completely turning over the vehicle stock on the road. Long-term planning helps define what changes are needed, while near- and mid-term policy defines how to achieve those changes together with critical considerations around equity, cost, and benefits not explicitly considered in the long-term planning analysis and economic impacts.

Achieving net-zero emissions by 2050 is technically feasible, economically affordable, and will offer the Southeast a host of new opportunities for economic growth along with more equitable and resilient communities. The Southeast can become a major producer of sustainable, advanced biofuels and develop new high-value industries and jobs support biofuel production as biomass feedstock production increases by seven-fold. The region also has the opportunity to become a national model for setting novel and impactful energy efficiency and electrification policy that can advance equity and decarbonization objectives simultaneously. Southeastern leadership can define national best-practices on decision-making around nuclear retirement and planning for coal retirements and replacement energy from renewables and capacity from energy storage and gas plants producing very little energy and emissions. Automotive manufacturing throughout the region can propel the national transition to electric vehicles, bringing more economic growth to the Southeast. Action starting today is necessary to develop a shared long-term vision, which will become a foundation for establishing near-term policies that begin enabling a pathway to deep decarbonization.

Technical Appendix

The analysis for this report was performed by Evolved Energy Research, using two purpose-built tools developed specifically to explore questions about long-term planning for decarbonization of the energy economy: EnergyPATHWAYS (EP) and the Regional Investment and Operations model (RIO). EP is an energy system demand-side accounting model that simulates the changes in load and demand curves from evolving technologies, policy, and stock rollover constraints by end-use in every sector of the energy economy. RIO is a cutting-edge integrated resource planning model used to find the least-cost investments in the electricity and broader energy systems over time. EP and RIO are used in tandem to explore the evolution of both energy demand and supply in deeply decarbonized systems.

	ENERGY PATHWAYS	RIO
Description	**EnergyPATHWAYS (EP)** Scenario analysis tool used to develop demand-side scenarios across all end-use sectors	**Regional Investment and Operations (RIO)** Tool to develop cost-optimal energy supply portfolios for all fuel types
Track record	Many regional and US wide decarbonization studies, used internationally in Europe and Mexico	Decarbonization studies of the US, Northwest, Mexico, and Europe, as well as investor studies of asset value in future decarbonization scenarios
Application	Scenario design allows for alternative electrification and efficiency measures, which produces: • Annual final energy demand for all fuels (electricity, pipeline gas, diesel, etc.) • Hourly electricity load shape These energy demand parameters are used as parameters for RIO	RIO uses demand projections from EP to produce cost-optimal energy supply portfolios: • Electricity sector capacity expansion • Biomass allocation across fuels • Synthetic electric fuel production • Direct air capture deployment

EnergyPATHWAYS Platform

EnergyPATHWAYS[23] (EP) is a bottom-up energy sector model with stock-level accounting of all energy infrastructure. EP was specifically built to explore a range of potential energy system transformations, and to this end, the model leaves most energy system decisions to the user. Thus, it is appropriate to think of EP as a complex accounting system or simulation model that keeps track of and determines the implications of detailed user scenario decisions. EP is the offspring of an analytical approach that has already proven to be a successful strategy to dramatically change the climate policy discussion at the global, national, and subnational levels. The basic insight is that climate policy was stuck in the realm of short-term, incremental changes discussed in abstract and academic terms and that this failure was reinforced by the analysis and modeling approaches used. The pathways strategy was to force the policy and business worlds to address, head-on, the reality that achieving greenhouse gas targets requires transformation,

[23] EnergyPATHWAYS is an open-source modeling framework maintained by Evolved Energy Research. Databases used in analyses conducted with the EnergyPATHWAYS source code can public or maintained as proprietary. More detail can be found here: https://github.com/energyPATHWAYS/energyPATHWAYS.

not incrementalism; that only a long-term perspective on the kind of infrastructure and technology changes required can prevent short-term investments that result in high-emissions lock-in; and that only an analysis that moves past the abstract focus on tons of CO_2 along an emissions trajectory to a focus on the energy supply and end-use equipment that produces the CO_2 would speak to practical decision-makers in the regulatory, business, and investment worlds.

Regional Investment and Operations Platform

RIO blends capacity expansion and detailed sequential hourly system operations to effectively capture the value each resource type can offer the system as part of an optimally dispatched portfolio. Rather than being a snapshot valuation, either as price taker with static prices or during a single year in time, RIO captures the full set of dynamics over the lifetime of the system or the lifetime of a resource. It is a powerful tool for both planning and asset evaluation applications. Investments that look attractive under current system conditions may not be cost-effective over a lifetime of operations. RIO puts every investment into the lifetime context of future policy, fuel pricing, technology pricing, and demand-side potential. Without this context, large near-term investments are very risky, considering the scale of system change likely to occur over a resource's lifetime. RIO meets the policy goals and reliability constraints of each system modeled while finding the lowest cost solution. Investment dynamics, such as the tipping point between investing in new thermal or building new renewables, or even generating energy from existing thermal resources or investing in renewables, are easily demonstrated by RIO, and elucidate the dynamics driving value for one resource versus another.

Developing Regional Results from National Modeling

Nation-wide results are used in this study to contextualize key considerations for the Southeast as a region in a broader transition to a decarbonized economy, based on a "downscaling" of national and sub-national (e.g., census division) data inputs to the Southeast region. The downscaling approach utilizes a combination of energy demand and supply input data at a variety of geographical resolutions and maps these data together onto one consistent geography. For example, space conditioning data is typically provided by DOE climate zone while industrial energy demand is provided by census region. The analysis draws on a variety of inputs from the U.S. Energy Information Administration's National Energy Modeling System, that produces the AEO, that are remapped to enable a regional analysis. This methodology is effective for addressing the central research for this study, but it is not equivalent to a canonical deep decarbonization pathway for the Southeast. This analysis does not provide state-level detail for the collection of states considered the Southeast for this analysis. Either of these types of analysis would require further study, based on more granular data inputs specific to the states in question rather than depending on a downscaling approach.

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