STRATEGEN

A Clean Energy Pathway for Southwestern Pennsylvania

Prepared for the Ohio River Valley Institute.

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Authors

Joe Goodenbery
Eliasid Animas
Jennifer Gorman

Contributed

Erin Childs
Nina Hebel
Thanh Nguyen
Joe Walderman

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Contents

1 | Executive Summary

This report describes the development and analysis of a clean energy pathway for a 10-county region in southwestern Pennsylvania.[1] Due to its abundance of fossil fuel resources, the region has a long history of substantial energy production, often at the expense of local environmental quality and economic diversity. A transition to clean energy provides a compelling opportunity to transform the local energy profile, while ending the region's overreliance on fossil fuels, to reduce emissions and pursue a path of sustainable growth.

To date, the prevailing narrative for decarbonizing this region has centered around the perpetuation of the natural gas industry and costly investments in carbon capture and storage (CCS) technologies and infrastructure. Strategen's analysis provides an alternative focused primarily on zero emissions resources, energy efficiency, increased electrification, and leveraging clean energy imports from outside the region, while minimizing the local need for fossil fuels.

Key Takeaways from this study:

+ A renewables-based pathway, including energy efficiency and clean energy imports from the PJM market, is more cost-effective than continued reliance on fossil fuels. A strategy focused on natural gas and carbon capture will be 13% more costly than the clean energy pathway, which avoids expensive investments in CCS technologies to reduce emissions, while limiting the region's exposure to fuel price volatility and mitigating the risk of stranded fossil fuel assets.
+ In the developed decarbonization pathway, all coal plants and a significant portion of natural gas plants in the region will retire or reduce output by 2035, drastically reducing emissions going forward. A limited portion of natural gas plants may be kept online as capacity or peaking resources and to ensure reliability, though clean dispatchable resources could potentially serve this role in the future, as technology progresses.
+ The clean energy pathway results in a 97% reduction in CO_2 emissions from the power sector by 2050, leading to environmental benefits of nearly $2.7 billion annually. These benefits are greater than those associated with strategies built around natural gas and CCS, furthering the case for the clean energy pathway as a least cost option for energy transition.
+ Deep electrification of the transportation and buildings sectors can directly lower regional CO_2 emissions from these sectors by 95%. The total annual value of environmental and health benefits associated with combined reductions from the power, buildings, and transportation sectors reaches $4.2 billion in 2050, through avoided social costs.
+ Through reduced reliance on natural gas for power generation and in buildings, Strategen's decarbonization pathway will decrease natural gas consumption by 96% and 98%, respectively, for two these sectors by 2050. Lower consumption provides an opportunity to reduce emissions associated with natural gas extraction. The value of these avoided emissions would surpass $1 billion in 2050 alone.
+ Energy efficiency is projected to increase over time, reducing regional electricity load by an average of 2.6% each year of the study period. Combined with electrification, the clean energy pathway results in overall load growth of 33% by 2050.

1. The study region includes Allegheny, Armstrong, Beaver, Butler, Fayette, Greene, Indiana, Lawrence, Washington, and Westmoreland counties.

+ Efficiency measures not only reduce load, emissions, and the need for additional generation, but also lead to local job creation and savings for consumers. Expenditures on efficiency and resulting residential bill savings support 12,416 total jobs in 2035, and 15,353 total jobs by 2050. Compared to both power generation and fossil fuel extraction, energy efficiency has a greater potential for local economic development, leading to more, higher-paying jobs served by workers and suppliers within the region.

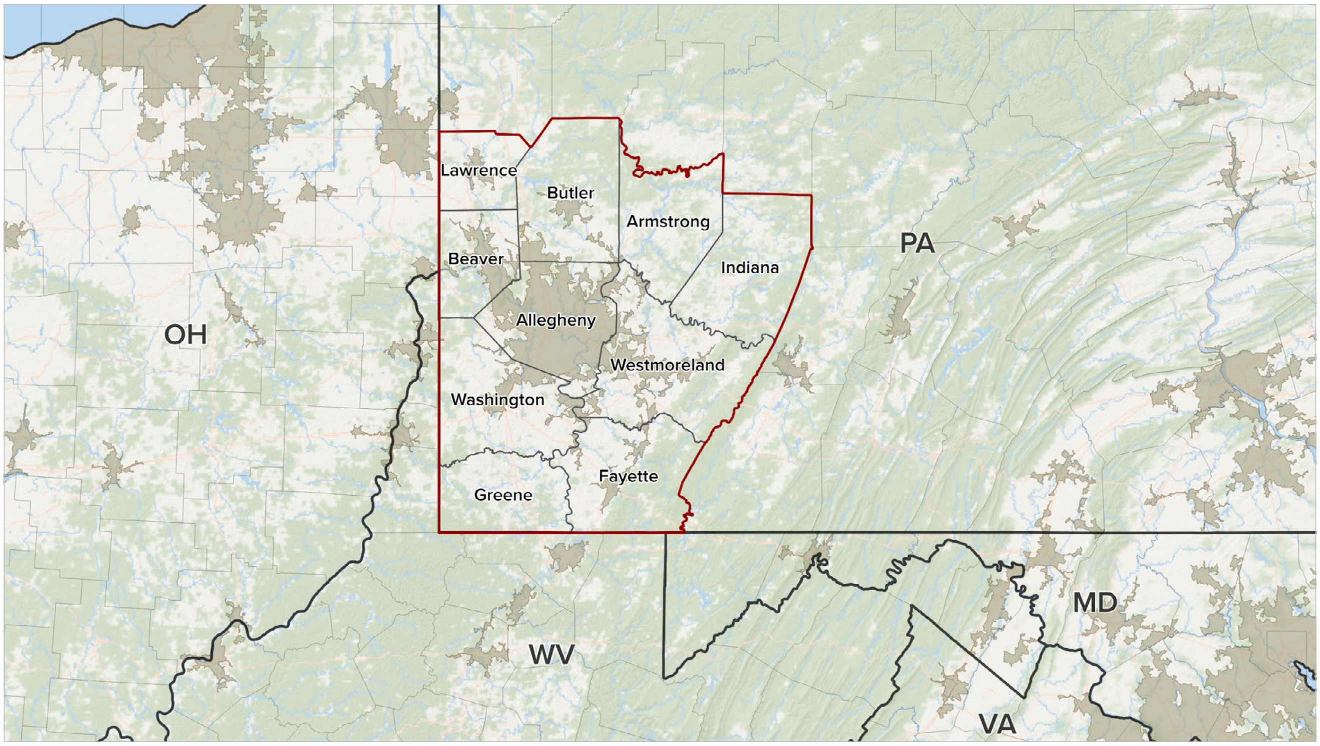

Figure 1: Study Region in Southwestern Pennsylvania

Focusing on the power sector as the backbone of the region's clean energy transition, Strategen conducted analysis to develop a clean, reliable, and cost-effective resource mix for meeting electricity demand, in a manner more consistent with efforts to limit global warming potential to 1.5° Celsius by 2050. The clean energy analysis additionally included deep electrification to transition nearly all fuel usage from the buildings and transportation sectors to further reduce emissions as the power sector decarbonizes over time. Through the use of an in-house dispatch model, Strategen employed data on localized hourly demand, the potential for renewable energy and energy efficiency improvements, import transmission capacity, and cost forecasts to simulate the operation of the electric grid and determine the necessary resource mix for the region, with limited contributions from fossil generation to ensure reliability.

Strategen's analysis found that harnessing the local potential for renewable energy in the region and importing clean energy from the PJM interconnection allows for the retirement of all coal resources by 2035 and nearly all natural gas generation by 2050. For balancing and reliability, there is a need for some natural gas or other dispatchable resources to remain on the system, but even these resources have the potential for future decarbonization through possible advancements in technology.

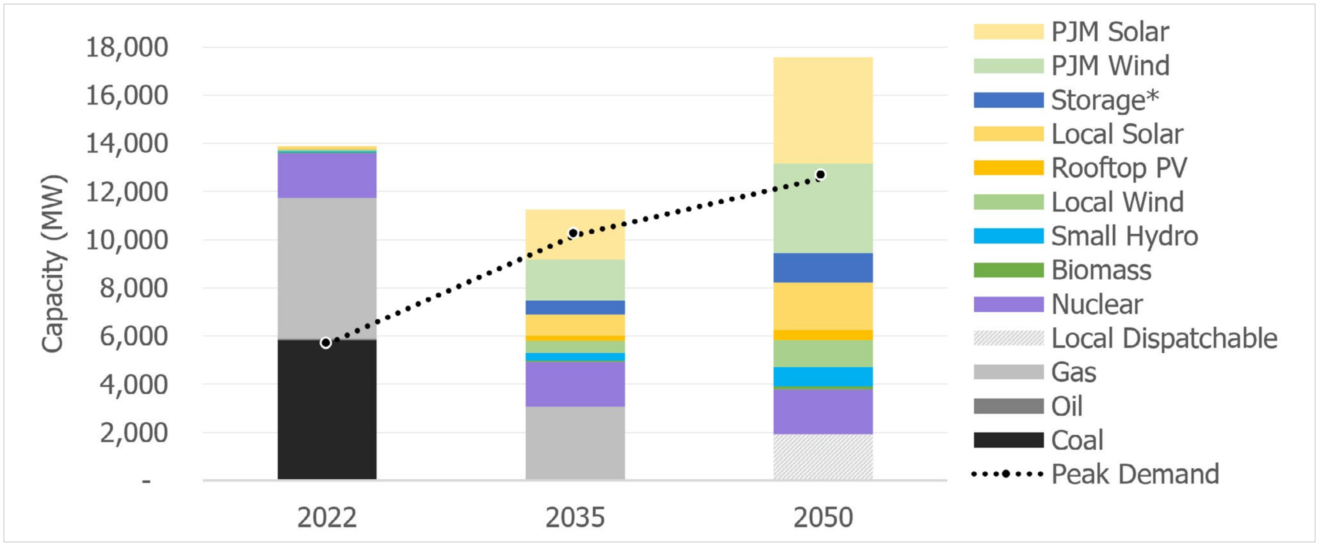

Figure 2: Proposed Changes in Generating Capacity | Source: Strategen analysis

Over time, the region transitions from a net exporter of electricity to a net importer, through the ability to leverage cleaner resources from areas rich in renewable potential via the regional PJM energy market.[2] By 2050, approximately 31% of the energy supply is expected to come from outside of the region. At the same time, electrification, net of increased energy efficiency, results in a 33% growth in load, with the majority met by zero emissions resources, including wind, solar, hydroelectric and nuclear power. Of these resources, solar and wind would experience the largest expansion, increasing demand for land and workers locally and within the PJM region.[3]

2. PJM allows for the buying and selling of wholesale power between regional generators and resellers, including electric utilities, competitive power providers, and electricity marketers. The PJM Interconnection coordinates the movement of electricity through all or parts of 13 states, including Pennsylvania.

3. By 2050, an estimated 63 square miles of direct land use would be necessary to accommodate new solar and wind additions in Strategen's clean energy pathway, with 19 of these square miles located within the 10-county study region. For context, the total direct land use would represent approximately 0.14% of Pennsylvania's land area, in square miles. However, the total extension of renewable energy projects would be larger than the direct land requirements, when including land that would not be directly covered with panels and turbines. For example, in an average solar farm, 90% of the land is directly used, but in a wind farm direct land use is only about 1%, due to spacing needed between turbines. In wind farms, the remaining 99% of the land can be used for other purposes, such as agriculture or conservation. Estimated direct land use was calculated based on modeling results from Princeton University's Net-Zero America project and was benchmarked using information from NREL on the footprint of sampled projects. See: Princeton University, 2021. *Net-Zero America: Potential Pathways, Infrastructure, and Impacts.*

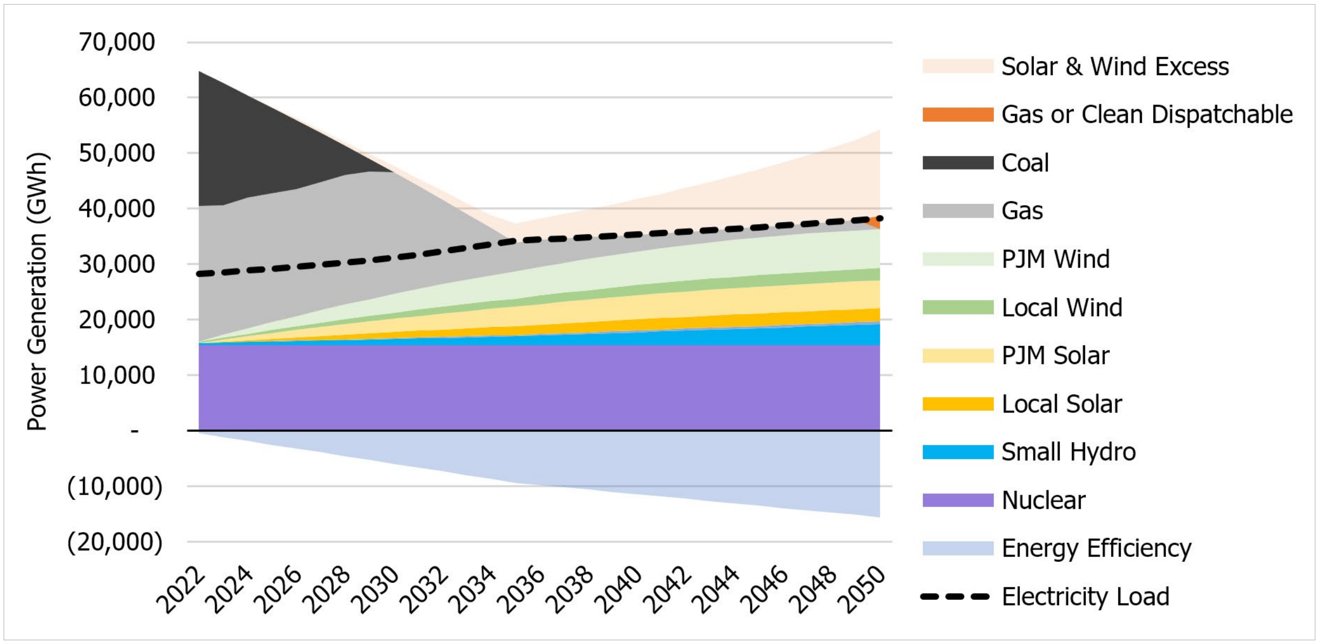

Figure 3: Projected Power Generation by Source | Source: Strategen analysis

Strategen's clean energy pathway for the region is actually lower cost than a pathway that relies on natural gas resources with carbon capture. For this comparison, an alternative scenario was developed, assuming that generation must be local to the region and that natural gas resources were not retired, paired with CCS technology instead. Overall, the clean energy pathway for the power sector is 13% less expensive than a pathway relying on gas and CCS.

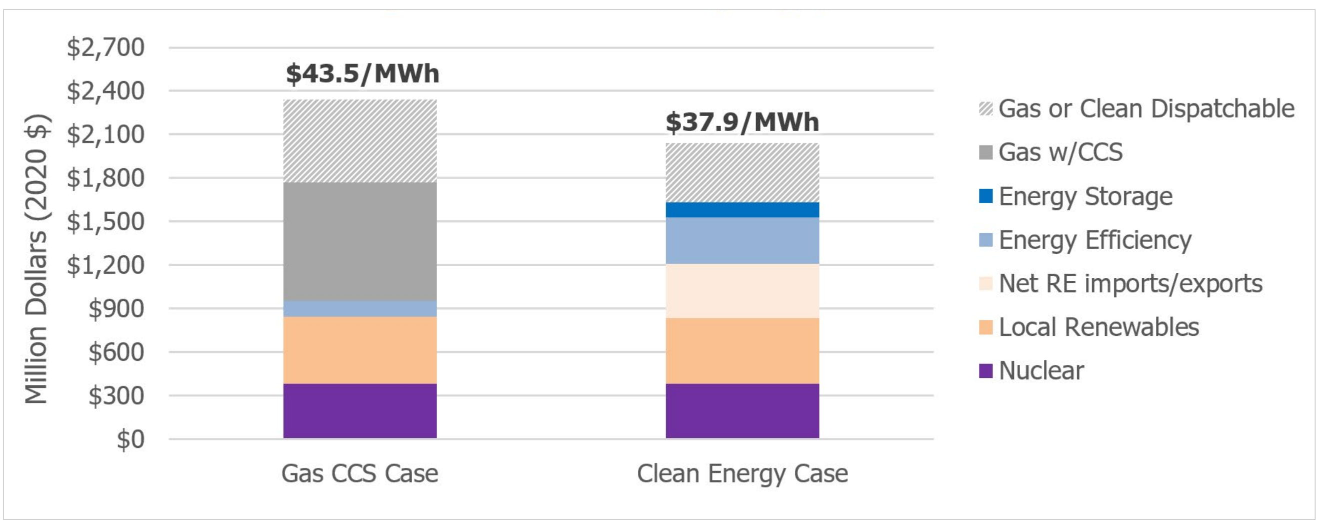

Figure 4: Cost of Electricity Supply in 2050 | Source: Strategen analysis

The clean energy pathway reduces emissions drastically, cutting CO_2 emissions by 92% by 2035 and 97% by 2050. The reductions result in environmental and health benefits of more than $2 billion in 2035, reaching $2.7 billion annually by 2050. These environmental benefits are greater than those associated with the alternative case built around natural gas and CCS, further underscoring the finding that a clean energy transition minimizing the use of fossil fuels would be the least cost pathway for southwestern Pennsylvania.

Through electrification, the clean energy pathway additionally reduces CO_2 emissions from the buildings and transportation sectors by 46% in 2035 and 95% by 2050, resulting in annual environmental and health benefits valued at $572 million and $1.5 billion in 2035 and 2050, respectively. In total, reductions in CO_2 from the power, buildings, and transportation sectors lead to annual benefits of $4.2 billion in 2050, through avoided social costs.[4]

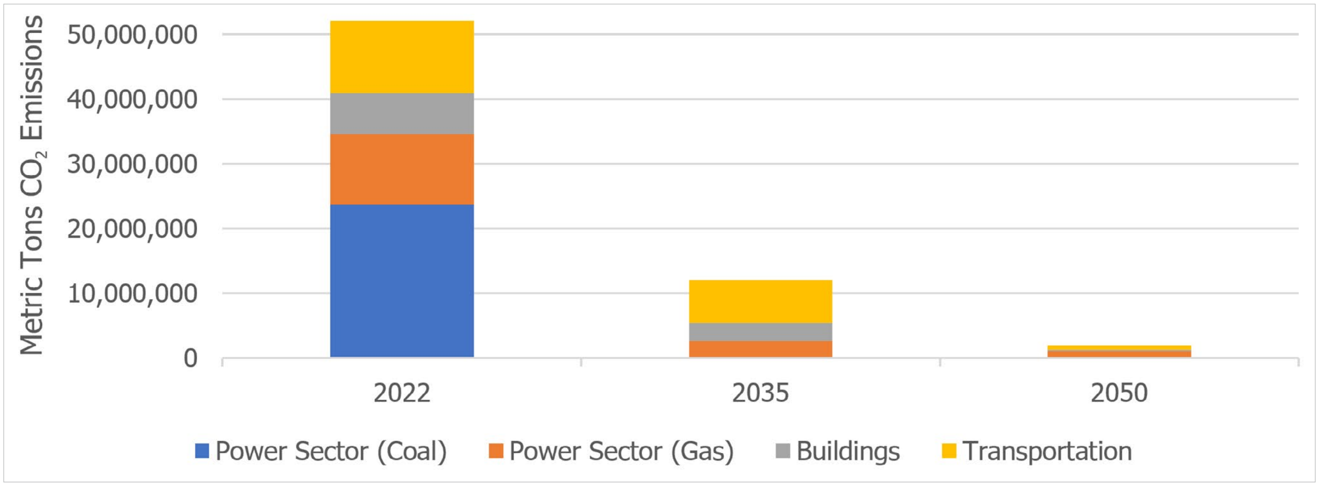

Figure 5: CO_2 Emissions from Targeted Sectors | Source: Strategen analysis

Furthermore, the developed clean energy pathway reduces the region's reliance on natural gas for power generation and in buildings, resulting in decreases in overall consumption of natural gas from these two sectors of 96% and 98%, respectively, by 2050. This drop in demand, which reaches 500 billion cubic feet annually by the end of the study period, provides the potential opportunity to lower emissions from natural gas extraction. Treated as a corresponding decrease in natural gas production in the region, the value of these avoided emissions and associated damages totals more than $1 billion in 2050.

From an economic development perspective, Strategen's proposed decarbonization pathway offers further advantages for the local economy. Energy efficiency improvements provide a particularly strong opportunity, as the region transitions away from fossil fuels, generating economic activity in labor-intensive sectors and leading to job creation in industries served by the local workforce. Strategen conducted analysis to explicitly estimate the job creation potential from energy efficiency improvements included in the clean energy pathway for the region, using local multipliers from the U.S. Bureau of Economic Analysis, finding that expenditures on efficiency and resulting residential bill savings support 12,416 total jobs in 2035, and 15,353 total jobs by 2050.

	2035	2050	Annual Average
Spending on Implementation	5,733	3,486	5,204
Bill Savings	6,683	11,867	6,927
Total	**12,416**	**15,353**	**12,131**

Table 1: Job Creation from Energy Efficiency Investments | Source: Strategen analysis, using RIMS II multipliers from the Bureau of Economic Analysis

4. This analysis assumed a social cost of carbon of $67 per metric ton in 2035 and $85 per metric ton in 2050 (2020$), and employed a discount rate of 3%. U.S. Environmental Protection Agency, 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.

Energy efficiency provides tremendous value not only as a cost-effective alternative to utility scale generation, but also as a compelling driver for local economic development. Compared to electric power generation and fossil fuel extraction, energy efficiency has greater potential for local, sustainable growth. Analysis of multiplier data for the 10-county region shows that efficiency investments create more jobs than these industries, and that the jobs created offer higher wages.[5] Moreover, most efficiency improvements, such as upgrades in lighting, insulation, doors and windows, or heating and cooling systems, can be performed by local workforce, supporting jobs for contractors and suppliers within the region. This is especially true for rural or exurban areas.[6] In contrast, industries such as natural gas extraction have often relied heavily on workers and suppliers from out of state. Energy efficiency therefore offers a particularly attractive option for a region where job growth and personal income have significantly trailed national growth rates since the beginning of the natural gas boom.[7]

Southwestern Pennsylvania carries a disproportionate socio-economic and environmental burden from the energy industry, but a power sector decarbonization pathway for southwestern Pennsylvania that leverages clean energy imports from the PJM market and is focused on renewable energy, existing nuclear, energy storage, and energy efficiency has the potential to transform the region and shift away from its reliance on fossil fuels. The clean energy pathway designed by Strategen results in cost savings, emissions reductions, and local economic development, laying the groundwork for sustainable prosperity in the 10-county region.

5. Using RIMS II multipliers from the U.S. Bureau of Economic Analysis, the jobs multiplier calculated for energy efficiency is 59% higher than the multiplier for oil and gas extraction, 122% higher than the multiplier for coal mining, and 151% higher than the multiplier for electric power generation, transmission, and distribution. Furthermore, the multiplier for labor income associated with energy efficiency industries is 10%, 51%, and 46% higher than the income multipliers for oil and gas extraction, coal mining, and electric power generation, respectively.

6. Natural Resources Defense Council, 2018. *Clean Energy Sweeps Across Rural America.*

7. Over the 2008 to 2019 period, 22 counties in Ohio, Pennsylvania, and West Virginia that produce 90% of Appalachian natural gas trailed the national rates for job, personal income, and population growth. The Ohio River Valley Institute, 2021. *Destined to Fail: Why the Appalachian Natural Gas Boom Failed to Deliver Jobs & Prosperity and What It Teaches Us.*

2 | Background and Scope

Pennsylvania has long been a leader in fossil energy production, given its extensive reservoirs of coal, oil, and natural gas. The commonwealth is the country's second-largest producer of natural gas, behind only Texas, accounting for 22% of national production.[8] Pennsylvania is also the third-largest coal-producing state, with almost 8% of national coal production annually.[9] Virtually all of these fossil resources are extracted from the region west of the Appalachian Mountains. In this area, over 200 years of fossil fuel extraction have resulted in abandoned mines and orphaned wells across the landscape, many of which release methane and other chemicals into the air, soil and water.[10] Additionally, Pennsylvania is a major consumer of fossil fuels for the industrial, transportation, buildings, and power sectors. As a result, the Commonwealth ranks fourth in the nation in carbon dioxide emissions,[11] further suggesting a need for an energy transition.

This study focuses on a collection of 10 counties, defined here as southwestern Pennsylvania, that contain both the Pittsburgh metro area and the core of the fuel-rich Appalachian region in the commonwealth.[12]

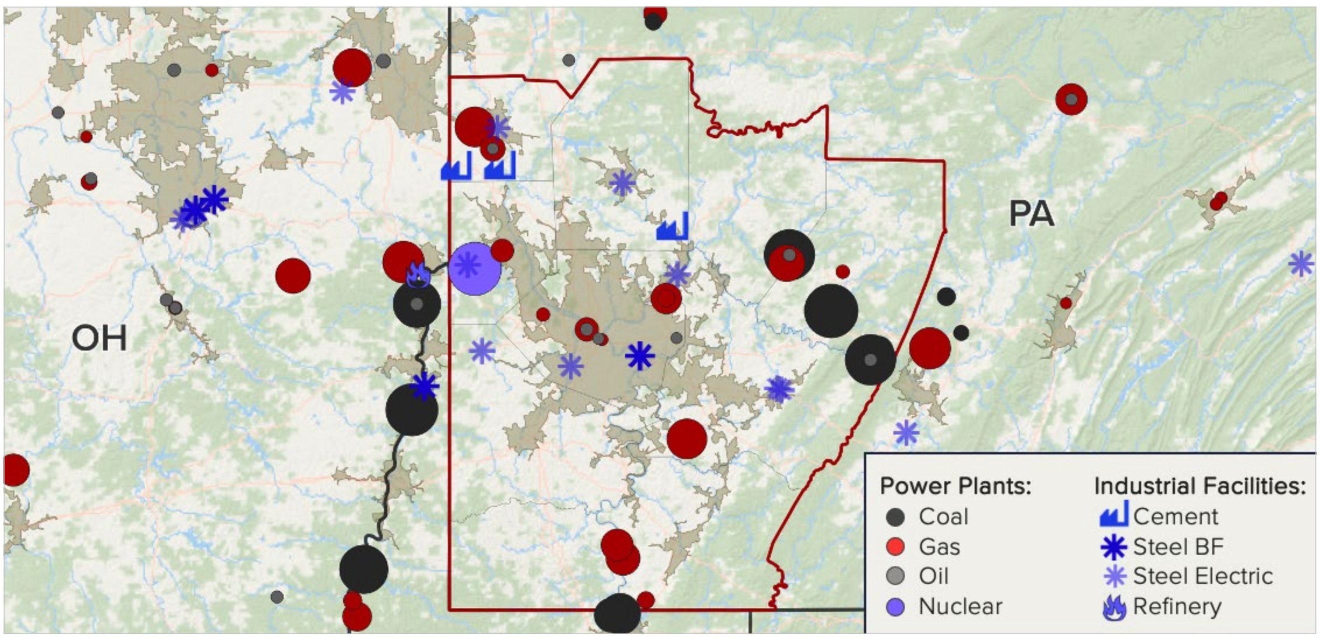

Figure 6: Major Emission Sources in Southwestern Pennsylvania | Source: Strategen with data from EPA and Homeland Infrastructure Foundation-Level Data

8. U.S. Energy Information Administration (EIA), 2022. *Natural Gas Annual Supply and Disposition by State.*
9. EIA, 2022. *Annual Coal Report 2021.*
10. The region's long history of fossil fuel production through coal mining and well drilling has left a deeply problematic environmental landscape. While a handful of coal mines remain open in the southwestern corner of the commonwealth, natural gas has taken over as the primary driver of the region's energy economy. There are at least 400,000 wells in the region that require capping and maintenance to prevent leakage of methane and other pollutants.
Map of oil and gas wells: https://gis.dep.pa.gov/PaOilAndGasMapping/OilGasWellsStrayGasMap.html
Map of abandoned coal mines: https://mapmaker.millersville.edu/pamaps/AbandonedMines/
11. EIA, 2019. *Pennsylvania State Profile and Energy Estimates.*
12. The ten counties discussed in this report include Allegheny, Armstrong, Beaver, Butler, Fayette, Greene, Indiana, Lawrence, Washington, and Westmoreland.

Southwestern Pennsylvania is home to 19% of Pennsylvania's population[13] and has anchored energy production in the United States since the 19th century. Electric power is one of the primary industries in the region. About 72% of the energy that is produced in the study area is generated from fossil fuels, while 26% is from nuclear, and only 2% is produced from renewable sources. In 2021, southwestern Pennsylvania generated approximately 60 TWh of electricity, equal to twice the energy consumed in the region. This large surplus of production translates to substantially higher emissions, placing a disproportionate environmental burden on a region that has long been a net exporter of energy.

Fossil fuel extraction and related industries, such as steel and petrochemicals, are also deeply rooted in the region's economy and culture. Virtually all major fossil energy companies are present in the region, although most are headquartered elsewhere. A global energy transition that will directly affect this region's energy-driven industries, however, is already underway.

In response to the targets set in the 2015 Paris Agreement,[14] many state governments have set their own goals and made commitments to reduce carbon emissions. Unfortunately, current commitments may still fall short of the changes needed to limit global temperature increase to 1.5° Celsius above pre-industrial levels, which was outlined as a goal in the Paris Accords.

Executive Order 2019-01, signed by Pennsylvania's governor in 2019, set a net greenhouse gas emissions goal of 26% reductions from 2005 levels by 2025 and 80% by 2050.[15] As of 2019, Pennsylvania had achieved reductions of nearly 18%, but emissions rose slightly the following two years.[16] Meeting Pennsylvania's eventual goals, and those set through the Paris Agreement, will require deeper reductions in greenhouse gas emissions throughout the commonwealth. The 10-county region, which produces power sector emissions at a rate nearly double the Pennsylvania average,[17] will need to transition substantially. To ensure the long-term prosperity of southwestern Pennsylvania, a well-designed pathway towards decarbonization, centered around the energy industry, is therefore imperative for the environmental and economic health of the region.

2.1 | Existing Decarbonization Plans

Several groups, including the Allegheny Conference on Community Development, the Roosevelt Project, and the Labor Energy Partnership, have put forth potential decarbonization pathways that either include or focus on southwestern Pennsylvania. Although the pathway developed by the Allegheny Conference has particularly dominated regional dialogue, all three studies follow a framework perpetuating the region's reliance on the natural gas industry and requiring significant investments in costly technologies and infrastructure to achieve emissions reductions.

13. U.S. Census Bureau, 2019. *Quick Facts Pennsylvania Population Estimates.*

14. The Paris Agreement is a United Nations international treaty for which countries have established goals towards limiting climate change.

15. PA Executive Order 2019-01: Commonwealth Leadership in Addressing Climate Change and Promoting Energy Conservation and Sustainable Governance. https://www.oa.pa.gov/Policies/eo/Documents/2019-01.pdf

16. Pennsylvania Department of Environmental Protection, 2022. *2022 Pennsylvania Greenhouse Gas Inventory Report.*

17. In 2019, the power sector in the 10-county region emitted 10.2 million tons of CO_2e on a per-capita basis, while the average rate from the power sector in the commonwealth of Pennsylvania was 5.7 million tons. Energy Task Force of the Allegheny Conference on Community Development, 2022. *Our Region's Energy Future: A strategy for accelerating decarbonization, investment and inclusive growth in the Pittsburgh region.*

In 2021, the Allegheny Conference on Community Development created an Energy Task Force with a focus on creating a regional decarbonization strategy for the 10-county region that makes up southwestern Pennsylvania.[18] The Allegheny Conference Energy Task Force is co-chaired by representatives from Shell Polymers Pennsylvania Chemicals and the PNC Financial Services Group. Members of the Task Force include representatives from electric utilities, natural gas utilities, the manufacturing sector, the chemical and materials industry, energy developers, equipment providers, financial services, and the legal field.[19]

The plan[20] proposed by the Allegheny Conference is focused on the development of an emissions reduction pathway consistent with limiting global warming to 2° Celsius, which is insufficient to meet the Paris Agreement goals. In developing this pathway, the Allegheny Conference noted that two critical sectors for emissions reductions include industrial production, which produces 27 million tons of CO_2e in the region each year, and the energy production sector, which produces 26 million tons CO_2e annually. Combined, these sectors account for 76% of the emissions in southwestern Pennsylvania.

The Allegheny Conference Energy Task Force members were surveyed to understand key actions they saw as having the highest priority for decarbonization. The highest priorities identified by the Task Force were the deployment of hydrogen, decarbonization of industry and power through carbon capture and storage, and deployment of low-carbon power generation sources. The decarbonization pathway set forth by the Allegheny Conference assumes the retirement of coal plants by 2035, but is otherwise centered around the expansion of the natural gas industry and therefore relies heavily on costly carbon, capture, and storage (CCS) technology for reducing power sector emissions. The report suggests that CCS deployment will cover 23% of total emission reductions from the region, but it does not specifically account for the substantial costs and challenges associated with building out the infrastructure necessary to support a network of carbon capture, transport, and storage.

A separate decarbonization study, released by the Roosevelt Project, identifies 13 counties, including the 10-counties comprising southwestern Pennsylvania, as a region facing a critical energy sector transition.[21] The study states that the region has built diverse strengths that will be in high demand in a low-carbon transition, but suggests that fossil fuels, particularly natural gas, will be an important part of the region's energy future, along with CCS and hydrogen. The report further focuses on expanded usage of natural gas as a means to lower greenhouse gas emissions in the short term, due to its lower carbon intensity, relative to coal.

Another report, published by the Labor Energy Partnership, focuses on policies and regulations that can expedite the creation of CO_2 transportation and storage infrastructure to support rapid and deep decarbonization of both the industrial and power sectors, as well as new technologies like direct air capture and bioenergy with carbon capture and sequestration. The study notes that such measures can play a potential role in the Ohio River Valley, which includes southwestern Pennsylvania.[22] As with the other previously developed pathways, this study proposes solutions involving continued investments in fossil fuel resources, which run the risk of becoming stranded assets, and does not achieve a net zero pathway.

18. The 10-county region identified by the Allegheny Conference is the same region that is discussed in Strategen's clean energy pathway for southwestern Pennsylvania.

19. The Allegheny Conference Energy Task Force includes members from Eaton, Columbia Gas, PPG, Westinghouse Electric Company, Oriden, United States Steel Corporation, the University of Pittsburgh, Hillman Family Foundations, Aquatech International Corporation, Carnegie Mellon University, ATI, Duquesne Power and Light, FirstEnergy, Covestro, Peoples Natural Gas, Harbison Walker International, Wabtec Corporation, In-2-Market, Mitsubishi Electric Power Products, and Babst, Calland, Clements, and Zomnir.

20. Energy Task Force of the Allegheny Conference on Community Development, 2022. *Our Region's Energy Future: A strategy for accelerating decarbonization, investment and inclusive growth in the Pittsburgh region.*

21. Ansolabehere, S., Araujo, K., He, Y., Hu, A., Karplus, V., Li, H., Thom, E., et al. *A Low Carbon Energy Transition in Western Pennsylvania.*

22. Labor Energy Partnership, 2021. *Building to Net Zero: A U.S. Policy Blueprint for Gigaton-Scale CO_2 Transport and Storage Infrastructure.*

2.2 | Vision for a Clean Energy Pathway

Existing energy pathways proposed for southwestern Pennsylvania have been centered around a continued reliance on natural gas, paired with substantial investments in carbon capture technologies and infrastructure to reduce associated emissions. In contrast to this prevailing narrative, Strategen developed an alternative clean energy pathway, which outlines a compelling opportunity to transition the region's energy mix away from fossil fuels to pursue a path of sustainable growth and improved environmental quality. The decarbonization pathway for southwestern Pennsylvania proposed by Strategen is underpinned by four key pillars:

+ **Focus on Zero Emissions Resources:** Southwestern Pennsylvania can limit the development and usage of generation powered by fossil fuels by focusing instead on clean energy resources, such as wind, solar, hydropower, storage, and existing nuclear, with the aim of reducing power sector emissions in a manner more consistent with efforts to limit global warming towards 1.5°C by 2050. While existing renewable energy resources are scarce in the region, electric transmission can become available as fossil-fueled plants are phased-out, creating opportunities to develop local clean energy resources and maintain reliability. Further, energy storage can provide value in shifting and balancing load, as well as emergency and ancillary services
+ **Leverage Imports from Outside the Region:** The 10-county region can benefit by leveraging clean energy imports from the wider PJM market to procure energy for reliability and when local supply is constrained. This strategy will provide southwestern Pennsylvania with greater access to renewable energy imported from regions rich in technical potential from diverse sources.
+ **Invest in Energy Efficiency:** Incremental investments in energy efficiency reduce the need for additional generation, help avoid negative fossil energy externalities, and provide economic benefits to the community through bill savings and local job creation.
+ **Support Deep Electrification:** As part of a larger economy-wide decarbonization strategy, deep electrification of the buildings and transportation sectors can reduce emissions as the power sector decarbonizes over time.

A decarbonization pathway for southwestern Pennsylvania focused on zero and low emissions generation, clean energy imports from the wider PJM territory, increased electrification, and increased energy efficiency measures provides a "no regrets" strategy to reduce the region's reliance on fossil fuels. This strategy will limit the need for costly infrastructure associated with carbon capture and other investments that perpetuate the use of fossil resources, while avoiding the potential for future stranded costs and reducing the region's exposure to fuel-price volatility.

The proposed pathway is also intended to align the region with federal policies and incentives. The Inflation Reduction Act, for example, benefits early investments in clean energy and includes additional benefits for energy projects sited in areas and communities that have historically been exposed to the socio-economic and environmental burdens associated with fossil fuel energy.

3 | Analysis Approach and Methodology

The power sector is the backbone of Strategen's decarbonization analysis, to achieve the vision of an alternative clean energy pathway, with reduced reliance on fossil fuels and costly carbon capture technology. Zero-emissions resources such as wind, solar, storage, and nuclear are mature technologies, capable of meeting much of the study area's energy needs. There is existing potential to develop some of these resources locally, and access to the PJM market allows for additional clean generation to be imported, while reducing the region's energy burden.

Transitioning energy demand from both the buildings and transportation sectors through electrification provides an avenue for deeper decarbonization. Energy efficiency measures can offset increases in electricity load and provide a clean and cost-effective alternative to utility scale generation. Strategen's analysis was designed as a high-level assessment of these opportunities to transition the region towards a cleaner future, in a manner more consistent with efforts that aim to limit global warming potential, ideally to 1.5° Celsius.

To model the 10-county region and develop a clean energy pathway, Strategen employed a five-step methodology to define the future energy needs and opportunities for the region:

1. Load profile definition
2. Electrification & energy efficiency assessment
3. Energy supply assessment
4. Power dispatch simulation
5. Costs and benefits valuation

Strategen's analysis incorporates recent, publicly available data from reputable sources in the energy and environmental sectors, including the National Renewable Energy Laboratory (NREL), the U.S. Environmental Protection Agency (EPA), Princeton University's Net-Zero America project, and the Pennsylvania Public Utility Commission. It should be noted that this analysis does not incorporate capacity expansion or production cost modeling, and therefore the resulting resource mix is not fully optimized to produce a lowest possible cost solution. Rather, the analysis provides reliable guidance towards the development of a feasible power sector pathway with minimal reliance on fossil fuel resources. Further optimization through more detailed modeling analysis would offer the ability to identify a clean energy solution that is lower cost than that the pathway proposed in this report.

3.1 | Load Profile Definition

This step of the analysis involves defining the region's energy demand and projecting it through 2050, to compare it to available generation resources and ultimately balance electricity supply and demand using diverse clean technologies. To define the baseline electricity load, Strategen's analysis incorporated energy profiles from NREL's Demand-Side Grid Model,[23] which enables the estimation of electricity and fuel demand in the ten-county region, from different subsectors, at the hourly level.

23. NREL's Demand-Side Grid Model provides comprehensive energy load data sets at high temporal, geographic, sectoral, and end-use resolution. Available at: https://www.nrel.gov/analysis/dsgrid.html

NREL's model employs a bottom-up approach that leverages data on residential and commercial building stock, industrial facilities, and energy usage variations by climate zone, sample year, and demographic characteristics. These data sets can support analysis of numerous demand-side, technology-driven changes, such as energy efficiency, electrification, and operational flexibility. Additionally, the electricity use data are time-synchronized with solar and wind data sets, which is ideal for conducting power systems analysis.[24] Strategen employed the data from NREL to develop a baseline load profile for the region, to be used as a starting point, with the effects of electrification and energy efficiency implemented each year of the study period.[25]

3.1.1 | Residential Load

Residential load data used in Strategen's analysis is based on NREL's ResStock model,[26] a physics-based simulation developed to represent energy use and energy savings potential for residential building stocks. The model features large public and private data sources, statistical sampling, detailed sub-hourly building simulations, and high-performance computing.

In the baseline year, residential load accounts for 40% of total electricity consumption and 87% of residential and commercial fuel consumption in the 10-county region. Electric demand in the study area peaks during the winter, driven primarily by residential load. Almost 98% of residential fuel usage is for space and water heating, and therefore fuel demand is concentrated in the winter months, with minimal use in the summer. The peak for residential fuel use is nearly four times the size of the peak for residential power.[27]

3.1.2 | Commercial Load

Strategen's analysis sources data on commercial load from NREL's ComStock model.[28] This model combines building characteristics from the DOE's Commercial Prototype Building and Commercial Reference Building Models with a variety of additional public- and private-sector data sets. Collectively, this information provides high-fidelity building stock representation with a wide diversity of various building characteristics.

Initially, commercial load accounts for 24% of electricity consumption and 13% of residential and commercial fuel consumption in the region. As expected, power demand from commercial buildings is nearly flat, featuring little variation throughout the year. Fuel usage comes from three main categories, with space heating, water heating, and the powering of equipment comprising 58%, 13%, and 29% of demand, respectively.

3.1.3 | Industrial Load

The remaining 36% of the electricity load comes from the industrial sector, which has a more defined demand pattern over weekdays but is relatively constant throughout the year. Strategen did not model changes related to industrial sector electrification or efficiency, and therefore fuel usage in this sector was not incorporated into the analysis for the region.

24. A city-scale version of the Demand-Side Grid Model was developed for NREL's groundbreaking Los Angeles 100% Renewable Energy Study (LA100). The study was conducted to explore pathways that the nation's second-largest city could take to achieve its goal of a 100% clean energy future.
25. Based on recent growth trends in the 10-county region, and load forecasts from local utilities, Strategen assumes no substantive growth in load, other than that associated with modeled electrification and energy efficiency measures, outlined in Section 4.2.
26. ResStock is a U.S. Department of Energy (DOE) model that has been developed and maintained by NREL since 2014. Available at: https://resstock.nrel.gov
27. Fuel usage is measured in kWh, for purposes of this comparison.
28. ComStock is a DOE model of the U.S. commercial building stock, developed and maintained by NREL. Available at: https://comstock.nrel.gov

Strategen's analysis employed county-level industrial load data from NREL,[29] which is sourced from the U.S. Environmental Protection Agency and directly from large greenhouse gas emitters in the region. NREL's approach to the industrial sector differs from the residential and commercial sectors. The industrial sector is unique in that large greenhouse gas emitters report at the facility level. These are treated individually, but the information on the smaller units is approximated by NREL based on the North American Industrial Classification System (NAICS) codes and employment, and NREL's statistical samples and calibration.

3.2 | Electrification and Energy Efficiency Assessment

Building on the developed electricity demand profile for the region discussed in the previous section, Strategen's clean energy pathway features additional analysis and incorporation of deep electrification of the buildings and transportation sectors, and the inclusion of energy efficiency improvements, both of which impact the projected load over the study period. Taken together, electrification and efficiency measures result in overall load growth of 33% by 2050.

3.2.1 | Building Electrification

Electrification of residential and commercial buildings within the 10-county region is a critical step towards decarbonization throughout the economy, as energy needs are shifted from fossil fuels to power generated by zero- and low-emission resources. With a large majority of the region's building stock currently served by natural gas, this transition will require a substantial effort over time.

According to data from the U.S. Census Bureau, more than 70% of households in the 10-county region are served by natural gas.[30] For these residential buildings, the rate of electrification, and the resulting impact on electricity load, in Strategen's analysis was centered on the assumption that household heating systems and other equipment would be converted based on life expectancies from the U.S. Energy Information Administration (EIA).[31] The current age of household heating equipment, water heaters, and appliances in the region was estimated using data for Pennsylvania from EIA's Residential Energy Consumption Survey (RECS),[32] and over the period equipment was replaced as it aged, with initial replacement commencing in 2025.[33] For commercial buildings, detailed data on equipment age in the region were not available, so the timeline for electrification was based on the high electrification trajectory from the Princeton University Net-Zero America pathways report.[34] Employing this methodology, 90% of commercial buildings in the region are fueled by electricity by 2050.

29. NREL, 2019. *Sector-Specific Methodologies for Subnational Energy Modeling.*

30. U.S. Census Bureau, 2019. American Community Survey, House Heating Fuel. Accessed September 2022. https://data.census.gov/cedsci/table?q=heating&g=0500000US42003,42005,42007,42019,42051,42059,42063,42073,42125,42129&tid=ACSDT1Y2019.B25040. Within the 10 counties, 71.6% of households rely on natural gas as the primary heating source, with 7.1% and 2.0% reliant on kerosene/fuel oil and propane, respectively.

31. EIA, 2022. *Assumptions to the Annual Energy Outlook: Residential Demand Module.*

32. EIA, 2020. *2020 Residential Energy Consumption Survey (RECS) Microdata.* Accessed September 2022. https://www.eia.gov/consumption/residential/data/2020/index.php?view=microdata

33. Space heating equipment, water heaters, and other appliances were replaced at separate rates, based on their respective ages. Due to limited availability on data for all types of equipment, clothes dryers were used as a proxy for all other appliances and it was assumed that these appliances were replaced at the same rate as dryers. Heating systems fueled by natural gas and propane were replaced after surpassing 20 years, while fuel oil heating was replaced after 25 years. All water heaters were replaced when entering the 15-19 year age range, and all other appliances were similarly replaced at an age of 15-19 years or older.

34. Princeton University, 2021. *Net-Zero America: Potential Pathways, Infrastructure, and Impacts.* The rate of electrification for commercial buildings was estimated by Strategen, consistent with the E+ High Electrification scenario.

As residential and commercial buildings are electrified, load within the region was increased over the period, commensurate with the shares of building stock converted each year.[35] It was assumed that all building heating system replacements involved conversion to cold climate electric heat pumps. Heat pumps provide an opportunity for significant improvements in efficiency, and new electric loads associated with heating were therefore adjusted, to reflect a 50% reduction in total energy usage, consistent with efficiency gains cited by the U.S. Department of Energy.[36]

3.2.2 | Transportation Electrification

Strategen's clean energy pathway includes increased electrification of the transportation sector, in line with trends toward growing adoption of zero-emissions vehicle (ZEVs). There are currently 1,938,561 vehicles registered in the 10-county region, 96% of which are light-duty and 4% are classified as medium- or heavy-duty (MHDV).[37] For the decarbonization analysis, it was assumed that, by 2035, all new sales of light-duty vehicles would be ZEVs, with annual milestones along the way, consistent with California's ZEV mandates.[38] The projected rate of adoption was based on a stock turnover rate of 6.25% annually, assuming an average lifetime for passenger vehicles of 16 years.[39] Following this methodology, the fleet of light-duty vehicles in the study region were fully transitioned to ZEVs by 2050.

For MHDVs, growth in ZEV sales and adoption through 2030 were modeled based on California's proposed Advanced Clean Truck Rule,[40] with accelerated stock turnover assumed for subsequent years, based on analysis from NREL,[41] which helps to increase ZEV penetration.[42] In Strategen's clean energy pathway, 96% of MHDVs across all classes were transitioned to ZEVs by 2050.

35. The underlying dataset from NREL includes usage of natural gas, propane, and fuel oil converted to kWh of electricity, which were then added to the baseline load each year.

36. U.S. Department of Energy, Energy Saver. *Heat Pump Systems.* Accessed November 2022. https://www.energy.gov/energysaver/heat-pump-systems. Strategen's analysis assumes that efficiency savings associated with heat pump conversions reduce heating loads by 50% initially, and 60% by 2050, to account for future advancement in technology. These efficiency gains were modeled separately from energy efficiency improvements.

37. Pennsylvania Bureau of Motor Vehicles, 2021. *Report of Registrations for Calendar Year 2021.*

38. This methodology is influenced by California's Advanced Clean Cars I Regulation and proposed Advanced Clean Cars II Regulation, which would mandate that all new passenger cars, trucks, and SUVs sold in the state would be zero emissions by 2035, with annual milestones of 14.5%, 17%, 19.5%, 22%, 35%, 43%, 51%, 59%, 68%, 76%, 82%, 88%, and 94% for years 2022 through 2034, respectively. See: California Air Resources Board. *Final Regulation Order, Section 1962.2, Title 13, California Code of Regulations.* See also: California Air Resources Board. *Advanced Clean Cars Regulation I and II.* Accessed November 2022. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii

39. Keith, David & Houston, Samantha & Naumov, Sergey, 2019. *Vehicle Fleet Turnover and the Future of Fuel Economy.*

40. California Air Resources Board. *Advanced Clean Truck Rule.*

41. National Renewable Energy Laboratory, 2022. *Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis.*

42. The majority of vehicle turnover involves transitioning to battery electric vehicles (BEVs), but fuel cell electric vehicles also play a role in the ZEV transition for MHDVs, representing 10% of rigid truck sales, 15% of bus sales, and 44% of truck trailer sales by 2050. Buses include vehicles classified as School Bus, Omni Bus, Bus, ARP Bus, and Transit Bus. Truck tractor numbers are determined as trucks with a gross vehicle weight rating (GVWR) of 26,001 lbs. or more that travel over 50,000 miles annually. Of the trucks with this weight rating, 55% were assumed to meet this milage criteria, while the remaining 45%, along with all trucks with a GVWR between 14,001 and 26,000 lbs., were designated as rigid trucks. See: Union of Concerned Scientists, 2019. *Ready for Work.*

The division of vehicles into four classes, consisting of light-duty, buses, rigid trucks, and truck tractors, had implications for the resulting impacts on total electricity load in the region, as these vehicle classes are associated with different average fuel efficiencies and annual miles traveled, which ultimately affect their projected energy usage. Further, each class sees different levels of FCEV adoption, which also impacts energy usage. To determine the electricity load added annually, the number of ZEVs on the road each year in each class was multiplied by the average vehicle miles traveled[43] and the kWh per mile efficiency[44,45] for each corresponding vehicle class.[46]

As ZEVs are integrated into the fleet and introduced to the electric grid, they offer the potential to provide demand flexibility, by shifting the timing of charging towards off-peak periods. Strategen's analysis incorporated a high-level assumption that less than 10% will have the flexibility to shift to off-peak charging. In actual practice, thoroughly developed initiatives that fully leverage vehicle-to-grid capabilities, such as time-of-use tariffs and other demand response programs, can further improve reliability and reduce both the need for and costs associated with additional capacity procurement.

3.2.3 | Energy Efficiency

In addition to load growth through electrification of the buildings and transportation sectors, Strategen's clean energy pathway includes increased implementation of energy efficiency measures over the study period. The projected adoption of efficiency improvements was estimated for the region based on a study prepared for the Pennsylvania Public Utility Commission on the market potential for energy efficiency in the commonwealth.[47] For the clean energy pathway, it was assumed that the region would adopt levels of efficiency consistent with estimates of economic potential, meaning that all technically feasible and cost-effective measures would be implemented.[48] This methodology results in an average annual reduction in load of 2.6% each year, due to energy efficiency improvements.

3.3 | Energy Supply Assessment

To meet the future load profile outlined in the previous section, Strategen conducted analysis to determine the necessary capacity and generation from resources to supply the region. This process involved first defining the current generation fleet, and then modeling potential capacity retirements and additions. The existing fleet was based on the boundaries for the 10-county region, but wider territories throughout the commonwealth and the PJM Interconnection were considered for siting of future resources, to allow for the import of additional clean generation, and to reduce the region's energy and environmental burden.

43. U.S. Department of Energy, Alternative Fuels Data Center, 2020. *Average Annual Vehicle Miles Traveled by Major Vehicle Category.* https://afdc.energy.gov/data/widgets/10309

44. Gao Z. et al., 2017. *Energy Consumption and Cost Savings of Truck Electrification for Heavy-Duty Vehicle Applications.*

45. U.S. Department of Transportation, Federal Transit Administration, 2018. *Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses.*

46. The production source of hydrogen to power FCEVs and the potential impact of FCEVs on the 10-county region's electricity load were not modeled as part of this analysis.

47. Pennsylvania Statewide Evaluation Team and Optimal Energy, 2020. *Pennsylvania Act 129 – Phase IV Energy Efficiency and Peak Demand Reduction Market Potential Study Report.*

48. Energy efficiency adoption specific to the study region was calculated based on estimates of economic potential for the electric distribution companies (EDCs) operating in the 10 counties. The percentage reductions from baseline electric sales for the relevant EDCs were applied to load within the 10-county study region, for years 2022 through 2030. It was assumed that annual efficiency improvements decline each year for the 2031 to 2050 period, based on the trajectory of estimates for the previous 5 years (2026 to 2030), to account for future reductions in energy efficiency potential, as measures are implemented over time. To avoid double counting of efficiency gains, energy efficiency improvements were applied only to existing electricity load, rather than new loads added through electrification.

The energy supply assessment also considered the locational variation in energy output from renewable resources. Strategen used hourly generation profiles modeled in NREL's System Advisor Model for over 20 sample regions.[49] These regions were selected based on the location of active interconnection requests across the PJM territory. PJM's interconnection queue includes all proposed renewable resources under study for possible interconnection to the grid.[50]

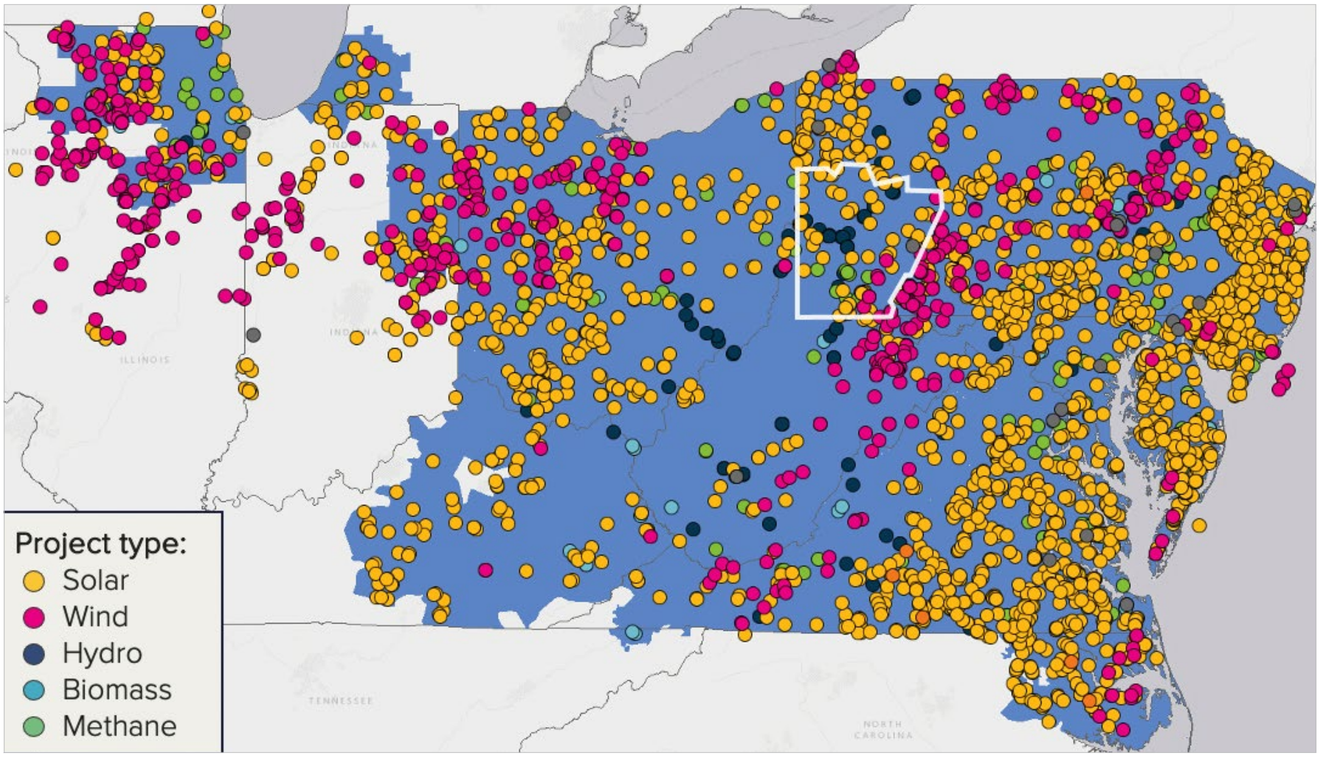

Figure 7: Currently Proposed Renewable Energy Projects in PJM | Source: PJM Interconnection Queue

Current generating capacity located within the 10-county region includes 5.84 GW of coal plants, 5.84 GW gas, 1.9 GW nuclear, 140 MW of oil and other fossil fuels, and approximately 160 MW of renewable energy resources.[51] In 2021, these resources collectively generated 58,220 TWh, nearly double the actual consumption of electricity within the region. In Strategen's decarbonization pathway, this surplus afforded an opportunity to initially scale back generation from fossil resources, but the eventual retirement of the region's coal fleet, and most of the gas-fired resources, combined with an assumption that no new fossil plants would be developed in the region at all, created a need for new clean generation resources. However, the retirement of existing coal and gas plants also provided interconnection availability for the siting of local resources and transmission capacity to import clean energy from outside the study area. Indeed, the current gap between local generation and consumption of electricity suggests an existing transmission capacity of up to 8.5 GW.

49. NREL System Advisor Model. Available at: https://sam.nrel.gov/

50. PJM Interconnection Queue. Map of PJM renewable energy projects. Accessed August 2022, at: https://mapservices.pjm.com/renewables/

51. S&P Market Intelligence. Data from EPA.

3.3.1 | Power Plant Retirements

Strategen's power supply analysis assumed the gradual retirement of coal plants and an age-based retirement for natural gas plants. Coal unit retirements were modeled as inputs to the analysis, with the eight existing units shutting down at a rate of one unit each year, over the 2023 to 2030 period, beginning with the oldest units. Seven of these units were installed between 1967 and 1977, meaning that even the newest would reach a 50 year lifetime by 2027. The eighth unit, a waste coal steam turbine, was installed in 2004 and Strategen's analysis assumed this unit would retire by 2030.

Power plants fueled by natural gas and oil were assumed to shut down upon reaching the average retirement age for each generating technology. This methodology resulted in retirement at 44 years for oil plants, 30 years for gas combined cycle (CC) units, 36 years for gas combustion turbines (GT), 56 years for gas steam turbines (ST), and 35 years for all other fossil fuel technologies.[52]

The region's existing nuclear plant, Beaver Valley, was assumed to continue operation through the entire study period. Strategen modeled the plant's energy output and accounted for capacity outages from maintenance and refueling, but did not include any potential costs associated with future repowering.

3.3.2 | Local Renewable Resources

Strategen's analysis of local renewable resource availability focused on hydro, wind and solar. To inform these analyses, the analysis incorporated research and geographical data from NREL, DOE and the Oak Ridge National Laboratory related to the technical and economic potential of each resource type in the study area. While the region is rich in hydro and wind potential, tax benefits can unlock the potential for solar in the area as well.

Hydropower, specifically from small runoff-dams and existing but non-powered dams (NPD), can potentially become a valuable source of clean energy for the region. Though output from hydropower is limited in flexibility, it generally aligns with seasonal changes in local demand, peaking in the winter and spring months. An assessment from NREL examined the technical and economic potential of small hydro at the state level, including considerations of site accessibility, transmission proximity, land use, and environmental sensitivity. This study estimated that Pennsylvania has nearly 2 GW of economic potential for small hydro, capable of producing 8,370 GWh annually.[53]

To determine the share of this potential assigned to the 10-county region, Strategen employed data from Oak Ridge National Laboratory to calculate the proportional potential for each county, based on the existing capacity of non-powered dams in the state.[54] This analysis resulted in 1,630 MW and 6,830 GWh of economic potential for hydropower in the study region. Based on current incentives for clean energy, Strategen's modeling assumed that 50% of this potential would be achievable by 2050.

52. S&P Market Intelligence, 2019. *Average age of US power plant fleet flat for 4th-straight year in 2018.* Average fossil fuel plant retirement ages. https://www.spglobal.com/marketintelligence/en/news-insights/trending/gfjqeFt8GTPYNK4WX57z9g2
53. NREL, 2012. U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis.
54. Oak Ridge Lab, 2012. US Hydropower Potential from Existing Non-powered Dams (greater than 1MW).

The data from Oak Ridge National Laboratory also allowed for the identification of local seasonal variations in small hydro generation, which were incorporated in later steps of the analysis.

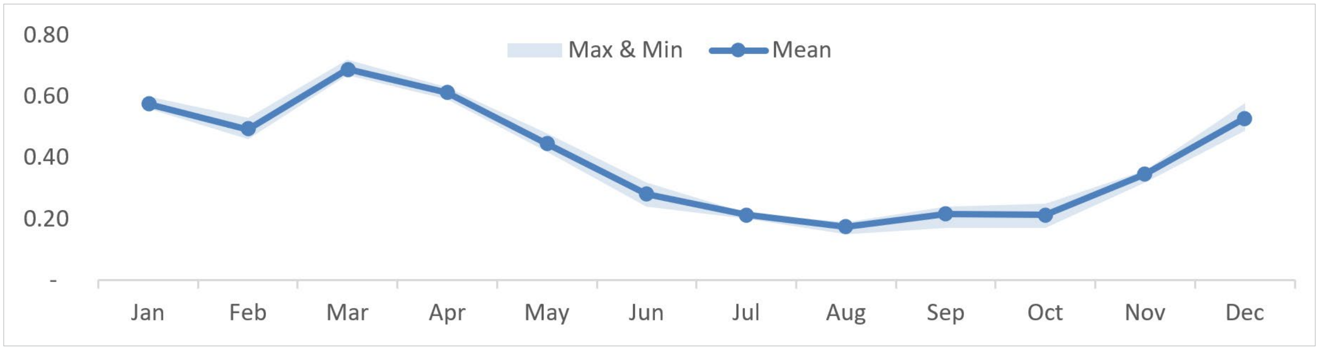

Figure 8: Average Hydropower Generation Profile | Source: Strategen with data from Oak Ridge National Laboratory

Wind power is a valuable resource in the region, and while the Pittsburgh metro area has limited geographic area for turbines, the neighboring counties closer to the mountains have tremendous potential to provide abundant and low-cost energy from wind-powered resources. To access this localized potential, Strategen relied on wind supply curves developed by NREL.[55] These data characterize the quantity and quality of land-based and offshore wind resources for three different levels of physical and regulatory constraints. Using geographic information systems (GIS) software, Strategen used the most limited of these three scenarios to identify areas where abundant wind resources could be developed economically. Through this analysis, it was determined that 2,260 MW of wind capacity could be developed in the region, with 50%, or 1,130 MW, achievable by 2050.

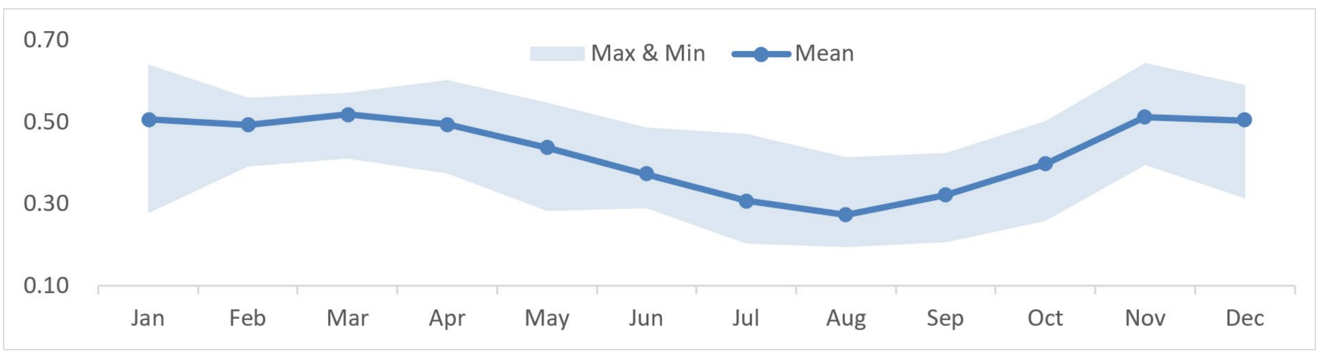

Figure 9: Average Wind Generation Profile | Source: Strategen with data from NREL

Solar potential in the region is lower than in other areas of the country, resulting in a lower capacity factor, which directly impacts the cost of solar energy. Moreover, generation from solar is more abundant during summer months, when regional demand is lowest, further impacting utilization of the resource. Taking these limitations into account, Strategen calculated and included the potential for both utility-scale solar and rooftop-solar in modeling clean energy supply for the region.

55. NREL website. Wind Supply Curves. Accessed September 2022, at: https://www.nrel.gov/gis/wind-supply-curves.html

In assessing the region's potential for utility-scale solar, Strategen employed a similar methodology to the approach taken for wind, relying on supply curves from NREL.[56] This analysis determined that the study region and its neighboring areas have the potential to for the development of 19,250 MW of utility-scale solar. Given the lower efficiency of this resource in the 10-county region, Strategen assumed that 10% of this overall capacity could be deployed by 2050.

For consideration of rooftop-solar, Strategen relied on research from NREL that quantified the technical potential of photovoltaic (PV) systems deployed on rooftops in the continental United States, and estimated how much energy could be generated by installing PV on all suitable roof areas.[57] Strategen's analysis assumed that 10% of the assessed technical potential in the region could be developed by 2050, resulting in 425 MW of rooftop-solar capacity.

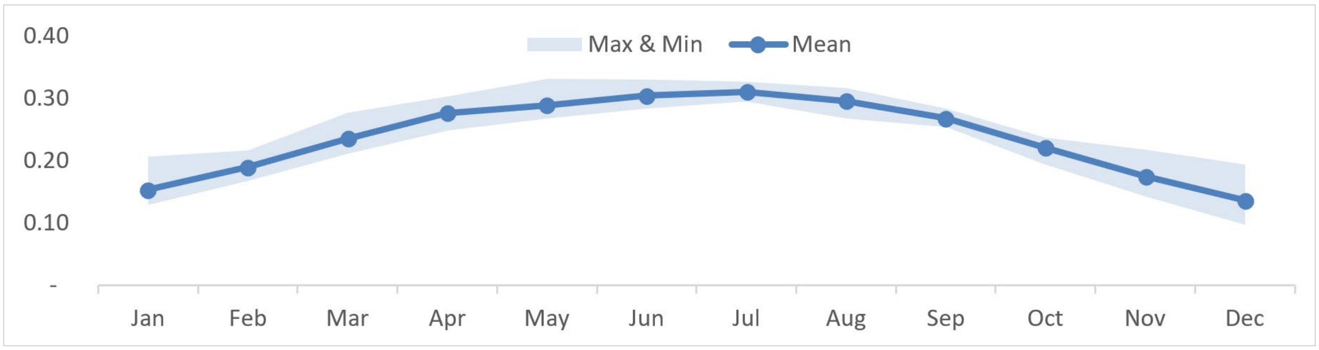

Figure 10: Average Solar Generation Profile | Source: Strategen with data from NREL

3.3.3 | PJM Imports

As mentioned earlier, the retirement of older coal and natural gas power plants would provide considerable transmission capacity previously used for exporting energy. This capacity can be used to import clean energy from other areas within the PJM Interconnection. To assess the renewable generating capacity that could be developed elsewhere in the interconnection and imported to the study region, Strategen relied on analysis from Princeton University's Net-Zero America project, which modeled multiple pathways for the U.S. to achieve net zero emissions targets.[58]

Using results from Princeton's modeling, Strategen quantified the amount of renewable energy that could be deployed in the PJM territory and then calculated the share that could be allocated to serve the study region. This analysis was based on the proportion of current electricity demand in the region, relative to the PJM Interconnection. Applying this proportion, calculated at 3.5%, resulted in approximately 8,800 MW of solar, 5,260 MW of land-based wind, and 2,180 MW of offshore wind capacity by 2050. Based on the transmission capacity expected to be available, Strategen assumed that 50% of that renewable capacity could be contracted and imported into the 10-county region. The clean energy pathway therefore allocated 4,417 MW of solar and 3,718 MW of wind from PJM to serve the study region.

56. NREL. Solar Supply Curves. Accessed September 2022, at: https://www.nrel.gov/gis/solar-supply-curves.html
57. NREL, 2016. *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment.* NREL's analysis estimated the potential for small, medium, and large buildings, providing data available at the zip code level.
58. Princeton University, 2021. *Net-Zero America: Potential pathways, infrastructure and impacts.*

3.4 | Power Dispatch Simulation

To simulate the energy dispatch of future supply resources, Strategen applied the developed renewable energy profiles and proposed resource capacity in each year to the expected demand profiles, using an in-house dispatch tool. The tool resolves any imbalances between clean energy supply and regional demand by estimating the need for additional flexible, reliable, and dispatchable energy resources, such as imports, natural gas turbines, batteries, or other long duration storage technologies.

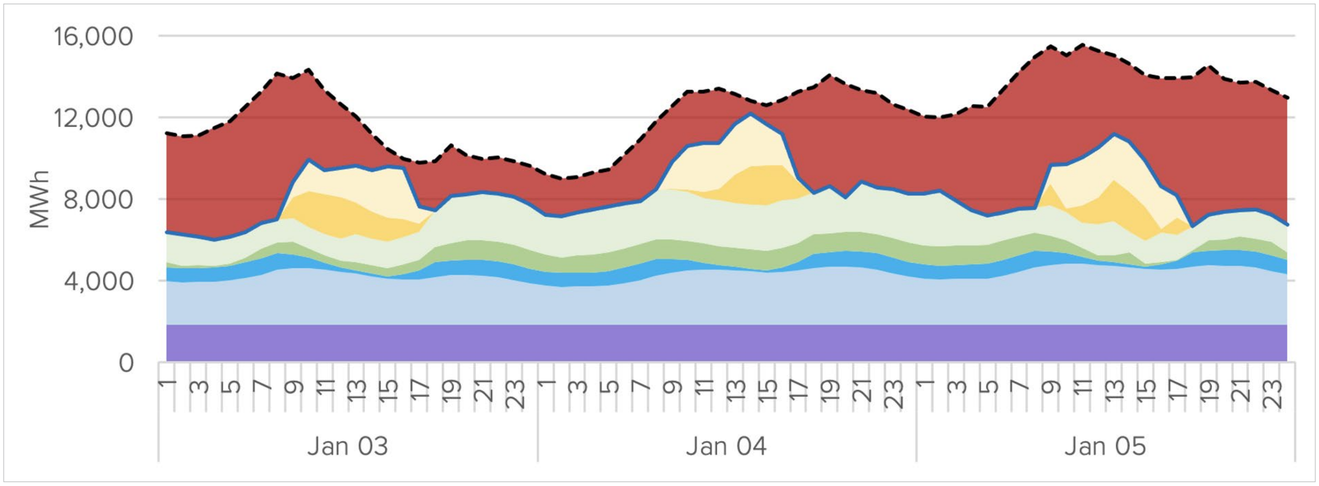

Figure 11.1: Modeled Dispatch for Sample Days, 2050 (peak winter days) | Source: Strategen analysis

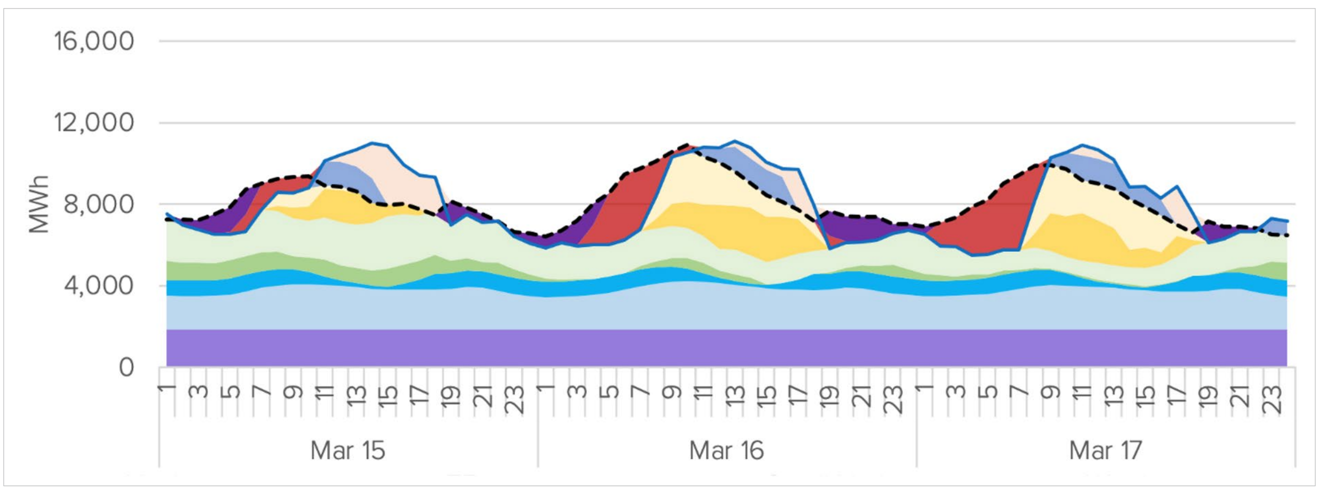

Figure 11.2: Modeled Dispatch for Sample Days, 2050 (shoulder season days) | Source: Strategen analysis

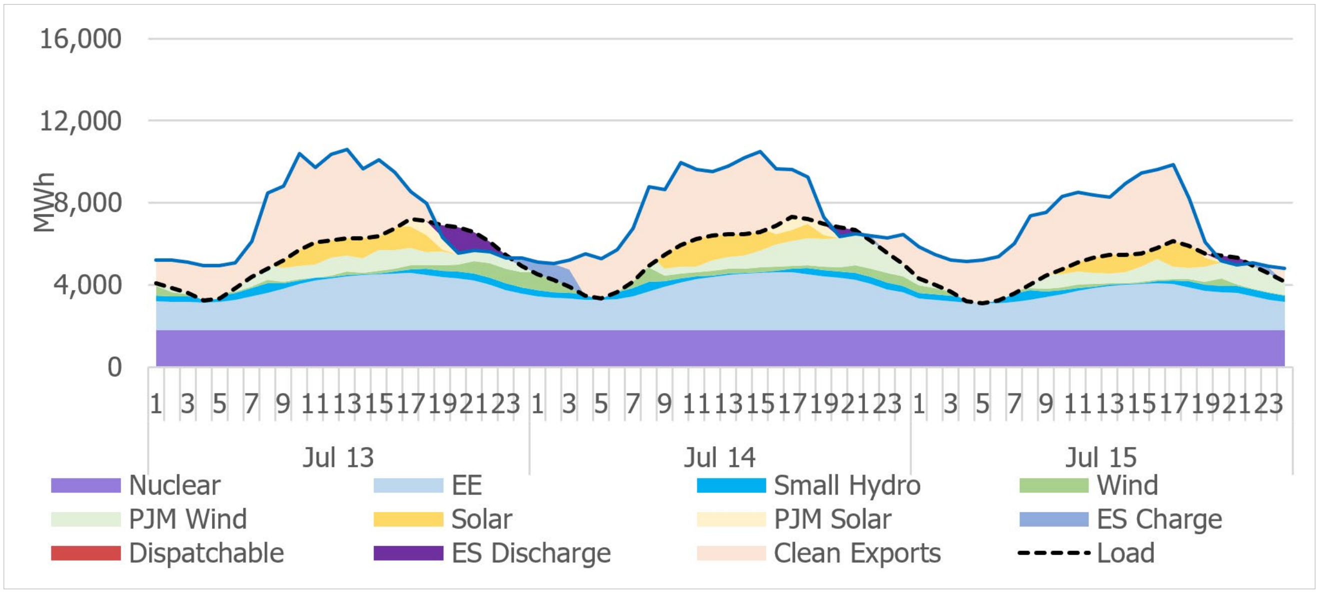

Figure 11.3: Modeled Dispatch for Sample Days, 2050 (summer days) | Source: Strategen analysis

While several technologies can provide flexibility to the system, there are cost and availability considerations that were modeled exogenously. Because the dispatch tool does not perform full cost optimization, the analysis employed a calibration process to incorporate exogenous feedback on cost-effectiveness to value different mixes of resources in the southwestern Pennsylvania system.[59] This process allowed Strategen to identify cases where incremental capacity of each resource had diminishing returns in terms of serving load using clean energy and avoiding excess generation.

Additional analysis was conducted to adjust the load and generation profiles for resources with incremental flexibility. That is, less than 10% of hydro generation and electric vehicle charging loads were granted the ability to shift to more opportune hours, varying on a monthly basis. Though not explicitly modeled in this analysis, advanced vehicle to grid capabilities would be expected to further reduce capacity needs in the region.

Energy storage capacity was determined through an iterative modeling process to avoid diminishing returns associated with increased capacity and durations. This analysis was performed with a focus on integrating renewable generation by only allowing storage to charge from excess renewables. As a result, other storage applications, such as energy arbitrage, ancillary services, and back-up power were not quantified, but those value streams would be expected to further benefit the proposed clean energy portfolio.

As noted earlier, this dispatch analysis did not involve the use of capacity expansion or production cost modeling, and therefore the resulting resource and generation mix was not fully optimized over the study period. Rather, multiple scenarios were tested to understand the impacts associated with different resource solutions, with a focus on designing a portfolio that significantly reduces power sector emissions in the region in a cost-effective manner, with limited use of fossil fuel generation.

59. A full least-cost optimization would potentially allow for the identification of an equally clean, but lower cost, portfolio slightly more optimal than the one arrived at through Strategen's modeling tool.

3.5 | Cost Calculations

To calculate the cost of electricity, Strategen assumed that all the resources could be contracted through their useful life using power purchase agreements, meaning that the region would be subject to the annualized cost of deploying each asset and would be entitled to use or trade all of the energy generated.[60] For each year, the analysis determined the levelized cost of energy, using price projection data from NREL, based on the capacity that would be deployed annually to build the resulting 2035 and 2050 portfolios.[61]

NREL's Annual Technology Baseline (ATB) includes forecasts of the capital, financial, and variable costs associated with each category of energy technology, and preset parameters on resource lifetimes and efficiency, which allow for the calculation of levelized costs.[62] The ATB was data was employed using resource utilization factors specific for the selected locations and generation profiles in the region and in PJM, reflecting the relative cost and performance variations of these resources. The cost analysis also assumed the use of incentive and production credits from the recently passed Inflation Reduction Act, including those for CCS.[63] For energy storage, the dispatch and cost analysis examined incremental durations, from 4 to 10 hours, through the study period.

60. This approach assumed the offtake and payment for all renewable generation regardless of its hourly alignment with demand.
61. As discussed in Section 4, in later years, Strategen's analysis also included a broad category of "dispatchable energy" necessary for balancing load. The costs for these resources were approximated using power price forecasts for the region from EIA. These annual prices were adjusted to reflect seasonal variations and a transition towards a more pronounced winter peak in the region. EIA, 2022. *Annual Energy Outlook.*
62. NREL, 2022. *Annual Technology Baseline.* Accessible at: https://atb.nrel.gov/electricity/2022/index
63. The Inflation Reduction Act of 2022 extends the investment tax credit (ITC) and production tax credit (PTC) for clean generation technologies and provides additional credits for projects sited in "energy communities", such as brownfield land, coal communities, and energy areas where employment and tax revenues are associated with the extraction, processing, transport, or storage of fossil fuels. Many sites in the study region in southwestern Pennsylvania are eligible under at least one of these criteria.

4 | Impacts

This section presents the impacts associated with Strategen's power sector analysis, including the resulting capacity and generation mix for the 10-country region and a comparison of total per-MWh costs to serve electricity load by 2050 for the clean energy pathway versus an alternative scenario focused on natural gas paired with carbon capture. In addition, this section discusses the ultimate impact on emissions and the value of those reductions, as well as the economic development potential and job impacts associated with energy efficiency investments as a driver of local economic growth.

4.1 | Power Sector Impacts

4.1.1 | Resulting Capacity and Generation Mix

In Strategen's analysis, natural gas generating capacity is reduced from 5.8 GW to 1.9 GW, while utilization of these gas power plants drops from 48% to 10% by 2050. Remaining natural gas capacity is not equipped with CCS technology at any point in the study period. In the interim years, generation from natural gas resources displaces generation from coal, but the clean energy scenario was modeled to eliminate all exports of electricity powered by fossil fuels by 2035. By the end of the period, the remaining gas capacity is only dispatched consistently during the winter and serves as a peaking resource during the remainder of the year. Though not explicitly modeled in this analysis, the remaining natural gas generation capacity is expected to be maintained as a reserve for reliability, a service also provided by energy storage and import capacity.

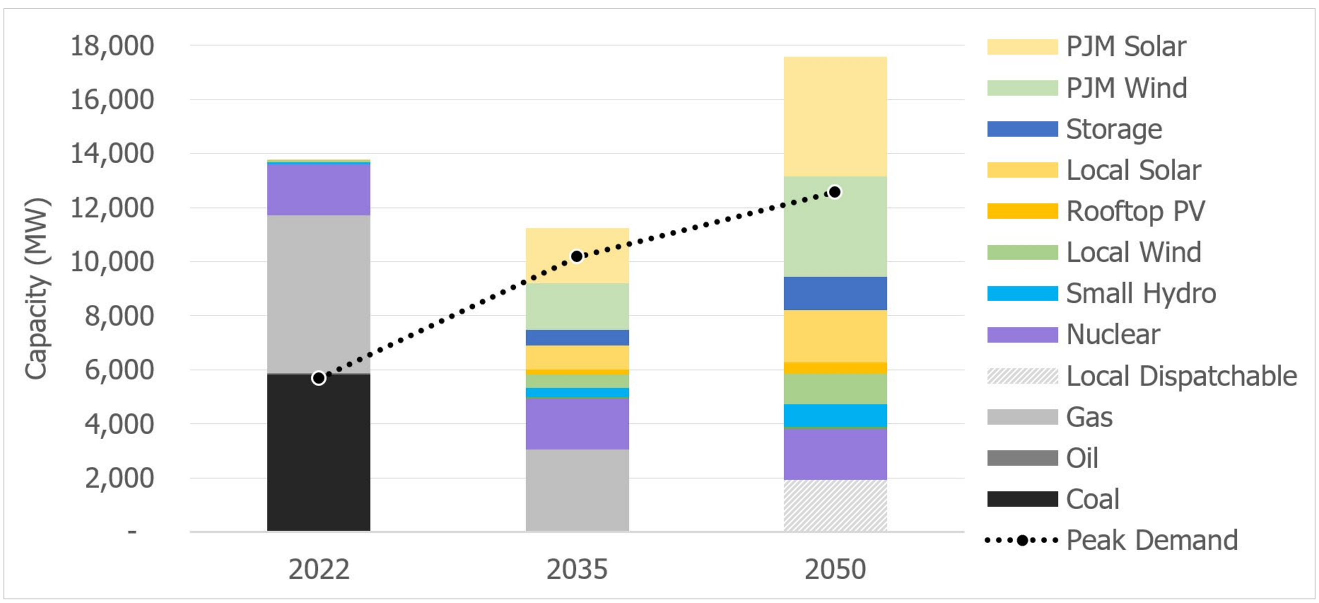

Figure 12: Proposed Changes in Generating Capacity | Source: Strategen analysis

The analysis resulted in an 85% renewable power supply by 2035 and 95% renewable portfolio by 2050. The remaining 5% in 2050 was assumed to be provided by a mix of clean and fossil resources providing dispatchable energy through imports and remaining natural gas plants in the region, to ensure reliability. This remaining gas infrastructure could potentially be retrofitted to employ hydrogen or CCS, or replaced with other forms of seasonal energy storage, as future technology allows. Strategen's modeling did not assume a particular preference for any of these future options, but the dispatch analysis found that such solutions would be necessary for achieving a resource mix that is 100% clean by 2050.

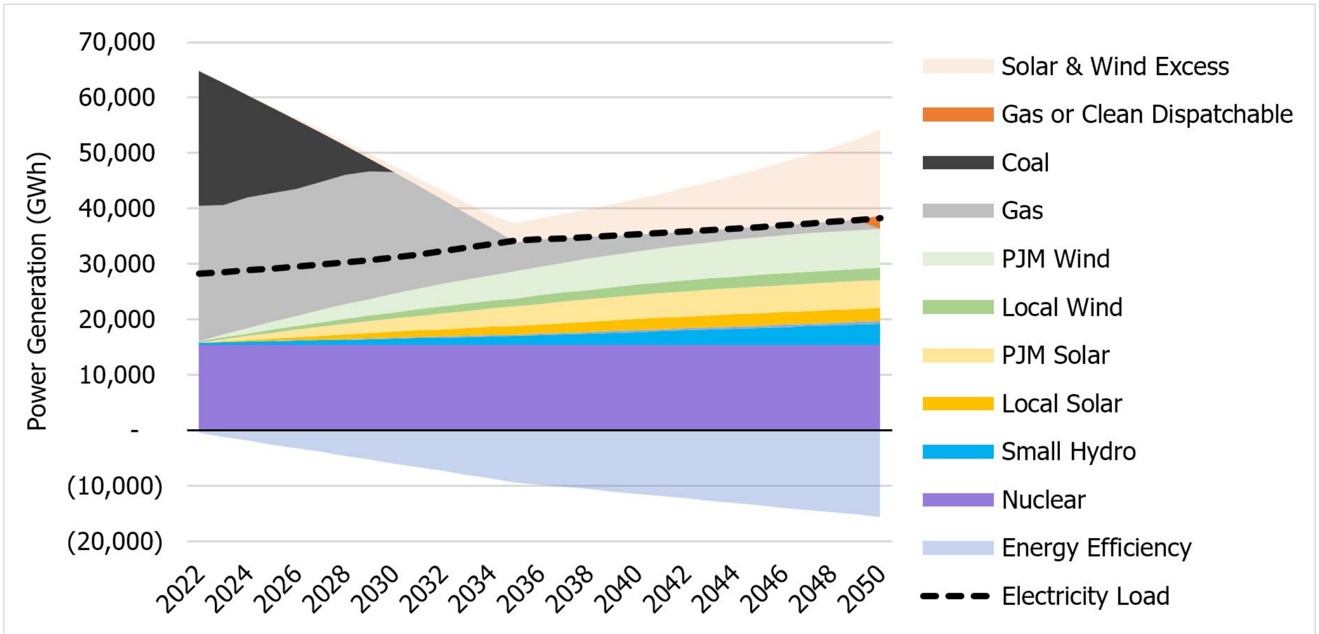

Figure 13: Projected Power Generation by Source | Source: Strategen analysis

Over time, the region transitions from a net exporter of electricity to a net importer, through the ability to leverage clean energy resources from areas rich in renewable potential through the wider PJM system. By 2050, approximately 31% of the energy supply is expected to come from outside of the region. Electrification, combined with increased energy efficiency measures, results in a 33% growth in load, with the majority met by zero emissions resources, including wind, solar, hydroelectric power, and nuclear.

Energy Source	2022	2035	2050
Electricity Load	28,797	34,200	38,255
Coal	24,231	-	-
Gas	24,478	5,240	-
Nuclear	15,393	15,393	15,393
Local Solar	14	1,636	2,357
PJM Solar	-	3,496	5,020
Local Wind	251	1,470	2,241
PJM Wind	-	4,889	7,022
Small Hydro	374	1,585	3,787
Gas or Clean Dispatchable	-	-	2,433
Solar & Wind Excess	-	3,314	15,512
Exported Fossil Energy	36,452	-	-
Energy Efficiency	-508	-9,422	-15,613

Table 2: Projected Power Generation by Source (GWh) | Source: Strategen analysis

4.1.2 | Cost of Energy Comparison

Based on the ultimate capacity and generation mix resulting from the power sector analysis, Strategen calculated the cost of energy supply associated with the designed clean energy pathway. As a basis of comparison, this calculation also included the development of an alternative scenario relying more heavily on natural gas resources, paired with carbon capture technology. This alternative case was intended as a representation of other existing decarbonization plans for the region, discussed in Section 2.1, to allow for direct comparison to Strategen's pathway.[64]

The alternative gas with CCS scenario included all of the same inputs incorporated into the clean energy pathway, with the exception of three key assumptions. First, natural gas resources were not retired in this scenario and were instead paired with CCS technology. Second, the alternative case assumed that the local load would be served primarily by resources from within the study area, with limited imports from outside the region. Third, the levels of energy efficiency were assumed to be one-third lower than the levels assumed in the clean energy case, to reflect lower incremental investments. To determine the relative cost-effectiveness of Strategen's clean energy pathway, compared to a gas-heavy decarbonization pathway, the per-MWh cost of the electricity supply in 2050 was calculated for both scenarios.[65]

64. The Allegheny Conference study, based on the same 10-county study region, did not include a calculation of the cost of energy supply associated with the proposed decarbonization pathway, necessitating the need for Strategen to approximate an alternative case as a proxy, for purposes of cost comparison.
65. Since both scenarios were assumed to have the same levels of electrification, and the same costs of energy outside the power sector, the comparison focused only on the cost of electricity.

Strategen's cost comparison analysis found that, by 2050, the cost of power sector energy supply in the clean energy pathway was 13% less expensive than a pathway relying on natural gas paired with carbon capture.[66] This analysis suggests that a future power sector focused on zero emissions resources, that leverages availability of clean energy imports from the PJM market, can be a cost-effective alternative to the prevailing narrative that decarbonization in the region must be centered around perpetuation of the fossil fuel industry.

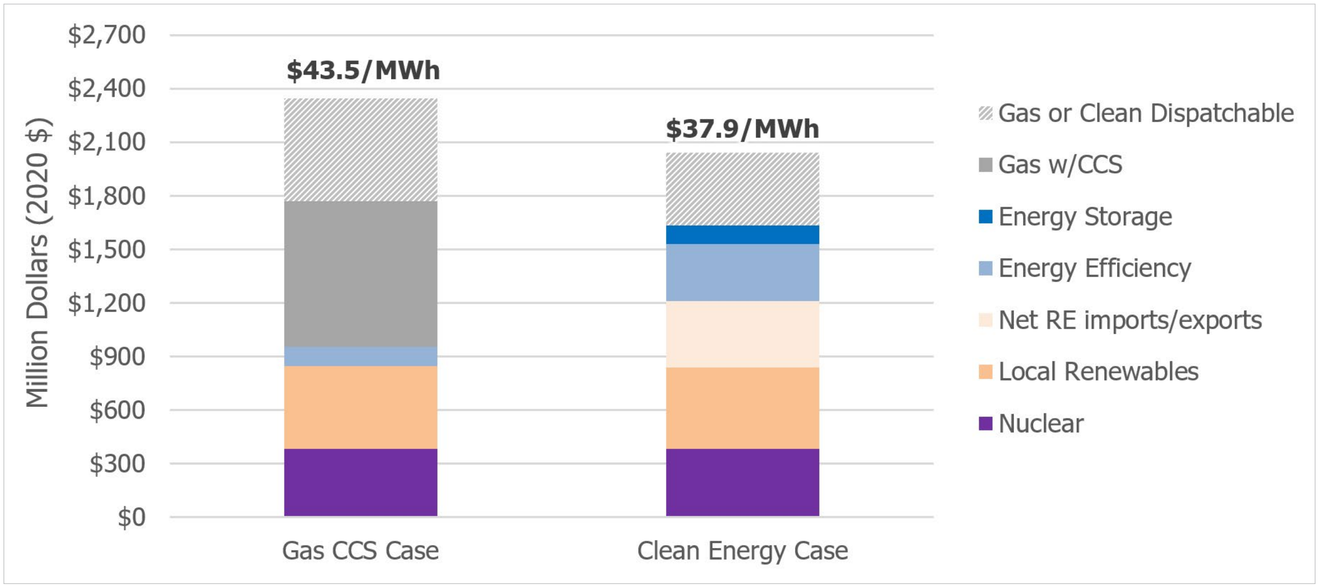

Figure 14: Cost of Electricity Supply in 2050[67] | Source: Strategen analysis

4.2 | Emissions Impacts

The proposed clean energy pathway results in substantial emissions reductions, driven by the retirement of all coal generation by 2030, as well as the scaling back in utilization, and eventual retirement, of the majority of natural gas plants in the region. In Strategen's clean energy case, power sector CO_2 emissions decrease by 92% by 2035 and 97% by 2050.

These reductions lead to annual environmental and health benefits valued at more than $2 billion in year 2035, and by 2050 annual benefits reach $2.7 billion.[68] In the alternative scenario, centered around natural gas and CCS, the annual value of power sector CO_2 emissions reductions totals $2.5 billion in 2050. Thus, the clean energy case is both more economic and provides greater environmental benefits, further underscoring the finding that a clean energy transition minimizing the use of fossil fuels would be the least cost pathway for southwestern Pennsylvania.

66. This analysis assumed a natural gas price of $5.83/MMBtu by 2050, but Strategen performed additional sensitivity analysis, using a natural gas price assumption as low as $3.29/MMBtu, which still found that the developed clean energy case would be 4% less expensive than the scenario relying on natural gas and CCS.

67. Per-MWh costs presented in this figure were calculated under the assumption that the nuclear would continue to run at existing marginal cost levels. Additional sensitivity analysis, including potential refurbishment costs, resulted in costs of $47.75/MWh and $42.16/MWh for the natural gas with CCS and clean energy cases, respectively.

68. The value of these benefits is based on avoided social costs associated with climate change, including human health impacts, changes in agricultural productivity, property damage from natural disasters, disruption of energy services, environmental migration, and lost ecosystem services, among others. This analysis assumed a social cost of carbon of $67 per metric ton in 2035 and $85 per metric ton in 2050 (2020$), and employed a discount rate of 3%. U.S. Environmental Protection Agency, 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.*

Power sector emissions of local pollutants like nitrogen oxides (NOX) and sulfur dioxide (SO2) will also be reduced. These emissions are responsible for health damages near their sources, causing incidences of respiratory illness, cancer, and premature mortality. Allegheny County, the most populated county in the region, is in the top 1% of U.S. counties for cancer risk from toxic air pollutants released from stationary sources, such as power plants and industrial facilities.[69] In the 10-county study region, coal power plants are responsible for 94% of electric sector NOX emissions and 99% of the SO2 emissions. Retirement of all coal resources eliminates most these emissions by 2035, and backing down and retiring natural gas plants in the region further lowers the health and morbidity risks associated with these harmful pollutants in nearby communities.[70]

Through electrification, the clean energy pathway additionally reduces CO_2 emissions from the buildings and transportation sectors by 46% in 2035 and 95% by 2050. These reductions result in annual environmental and health benefits valued at $572 million by 2035 and $1.5 billion by 2050.

	Remaining CO_2 Emissions (metric tons)	**Annual Economic Benefit (2022$)**
Power Sector	1,080,026	$2.7 billion
Transportation Sector	695,085	$936.4 million
Buildings Sector	141,024	$551.8 million
Total	**1,916,135**	**$4.2 billion**

Table 3: Annual Economic Impact of CO_2 Reductions in 2050 | Source: Strategen analysis

In total, the clean energy pathway reduces combined CO_2 emissions from the power, buildings, and transportation sectors by 77% by 2035 and 96% by 2050. The total annual value of the environmental and health benefits associated with these reductions is $4.2 billion in 2050, through avoided social costs.

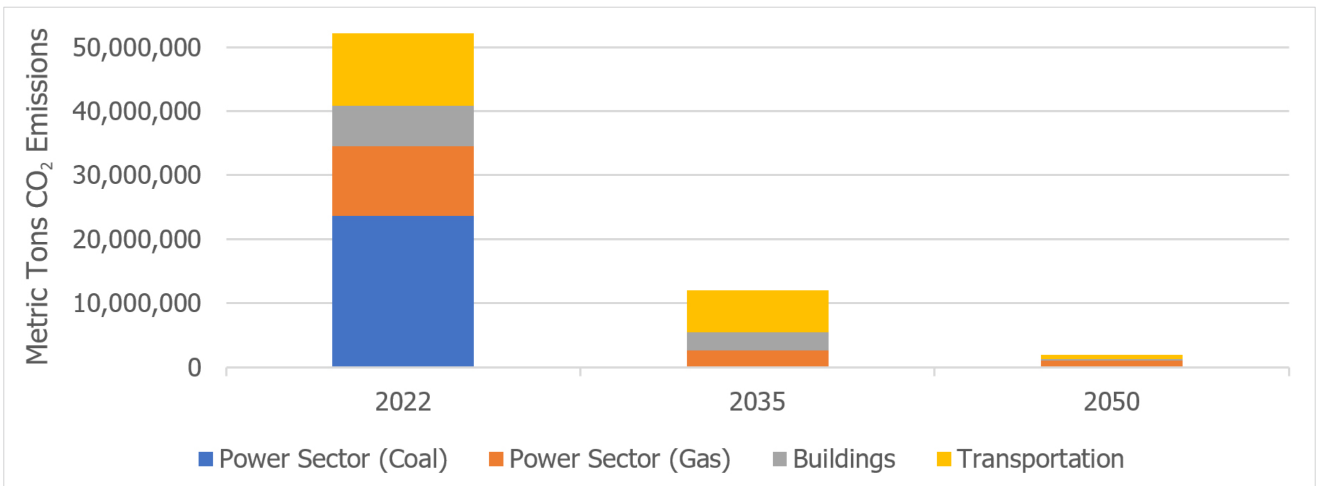

Figure 15: CO_2 Emissions from Targeted Sectors | Source: Strategen analysis

69. Cancer & Environment Network of Southwestern Pennsylvania, 2021. *National Air Toxics Assessment and Cancer Risk in Allegheny County Pennsylvania.* Based on data from the 2014 National Air Toxics Assessment, conducted by the U.S. Environmental Protection Agency.

70. The U.S. Environmental Protection Agency has issued guidance on estimating the benefits associated with decreasing NOX and SO2 emissions, based on the morbidity and mortality of these pollutants as precursors of PM2.5, but accurate modeling of these benefits requires detailed geospatial analysis to determine the size of populations in proximity of emitting sources and to measure their distance. Such analysis was not included in this study. See: U.S. Environmental Protection Agency, 2022. *Technical Support Document: Estimating the Benefit per Ton of Reducing Directly-Emitted PM2.5, PM2.5 Precursors and Ozone Precursors from 21 Sectors.*

Strategen's clean energy pathway additionally leads to lower consumption of natural gas within the region, resulting from the power section transition and electrification of the buildings sector. The analysis found that the decarbonization pathway would decrease natural gas consumed for electricity generation by 90% by 2035 and 96% by 2050, and reduce gas consumption in buildings by 56% in 2035 and 98% in 2050. The overall drop in annual natural gas consumption in the region totals approximately 500 billion cubic feet by the final year of the study period. In turn, lower consumption provides an opportunity to reduce emissions associated with natural gas extraction, through decreased production. A study conducted by researchers at Carnegie Mellon University estimated that the production of natural gas in the Appalachian Basin resulted in air quality and climate damages valued at $2 per thousand cubic feet, through the release of CO_2, methane, and other local pollutants.[71] Applying this methodology, and assuming that reductions in natural gas consumption from the power and buildings sectors would lead to a corresponding drop in production, the additional benefit provided by decreased natural gas production in the clean energy pathway totaled $874 million in 2035 and over $1 billion in 2050.

Further declines in natural gas production would lead to additional emissions reductions, and greater environmental benefits. The transition of industrial uses, such as steelmaking, away from natural gas would lead to similar consumption-driven reductions, enabled through electric arc furnaces or the use of hydrogen for fuel, though CCS may also be necessary to completely decarbonize these industries.[72] Though not modeled as part of this analysis, research from the World Economic Forum, in collaboration with Accenture, concluded that efforts to reduce fugitive and vented methane caused by the natural gas industry can eliminate 70% of associated emissions.[73] Electrification of the extraction process can further reduce emissions from the natural gas sector.

4.3 | Economic Development Impacts

In addition to the cost and environmental benefits outlined earlier in this section, the proposed decarbonization pathway offers further advantages for the local economy. There is evidence to suggest that electricity created from renewable sources creates more jobs per unit of electricity generated than power from fossil fuels,[74] and the growing renewable energy industry is already a major U.S. employer, with clean energy workers outnumbering fossil fuel workers three to one.[75]

A joint analysis from the World Resources Institute, the International Trade Union Confederation, and the New Climate Economy found that investments in clean energy create more jobs than fossil fuel investments, with energy efficiency providing particularly strong economic benefits.[76] For southwestern Pennsylvania, energy efficiency offers a compelling opportunity for significant job creation, as the region transitions away from generating all of its electricity locally. Investments in efficiency create economic activity in labor-intensive sectors, leading to job creation in industries served by the local workforce.

71. Mayfield, EN., et al., 2019. *Cumulative Environmental and Employment Impacts of the Shale Gas Boom.*

72. Even without any local consumption at all, natural gas production in the study area would likely remain substantial, driven by exports to areas outside of the region. Such production levels will continue to cause severe health and environmental impacts, absent additional interventions. Although severance taxes can generate valuable revenues for local areas, more aggressive measures that accurately account for the full costs of environmental damages, such as the $2 per thousand cubic feet tax on production suggested by the researchers at Carnegie Mellon University, may be more effective for incentivizing deeper emissions reductions.

73. The World Economic Forum and Accenture, 2022. *Net-Zero Industry Tracker.*

74. Union of Concerned Scientists, 2017. *Benefits of Renewable Energy Use.*

75. Forbes, 2019. *Renewable Energy Job Boom Creates Economic Opportunity as Coal Industry Slumps.*

76. World Resources Institute, International Trade Union Confederation, and The New Climate Economy, 2021. *The Green Jobs Advantage: How Climate-Friendly Investments Are Better Job Creators.* The analysis found that investments in energy efficiency create 2.8 times as many jobs as fossil fuel investments.

4.3.1 | Employment Analysis for Energy Efficiency Investments

The economic development impacts of energy efficiency investments can be quantified through analysis using economic multipliers, which track how spending in an industry flows through the economy, stimulating activity across multiple sectors, measured through direct, indirect, and induced effects. Direct impacts are those occurring in industries receiving the initial investments, while indirect impacts are created for industries in the supply chain. Induced impacts result from workers in both the direct and indirect industries spending income in the economy. Every dollar invested generates direct, indirect, and induced activity, and economic multipliers help quantify the magnitude of these impacts.

To determine the job creation potential associated with energy efficiency investments in southwestern Pennsylvania, RIMS II multipliers[77] from the U.S. Bureau of Economic Analysis (BEA), specific to the 10-county region, were employed to estimate how many jobs will be created for every $1 million spent on efficiency improvements. Although BEA's economic multipliers are available at the industry level, investments in energy efficiency are made in multiple industries, and therefore a unique multiplier was calculated, weighted based on the expected distribution of expenditures across relevant economic sectors.[78] The associated economic sectors and the share of energy efficiency spending allocated to each sector are provided in Table 4.

RIMS II Code	Economic Sector	Allocation for Weighting
333120	Construction Machinery Manufacturing	33.30%
4B0000	All Other Retail	33.30%
322110	Pulp Mills	0.85%
333415	Air Conditioning, Refrigeration, and Warm Air Heating Equipment Manufacturing	6.20%
334111	Electronic Computer Manufacturing	0.25%
335110	Electric Lamp Bulbs and Part Manufacturing	11.70%
335210	Small Electrical Appliance Manufacturing	0.05%
335220	Major Household Appliance Manufacturing	0.25%
2211A0	Electric Power Generation, Transmission, and Distribution	2.05%
541800	Advertising, Public Relations, and Related Services	2.65%
811200	Electronic and Precision Equipment Repairs and Maintenance	1.20%
811300	Commercial and Industrial Machinery and Equipment Repairs and Maintenance	1.90%
33399A	Other General Purpose Machinery Manufacturing	6.30%

Table 4: Spending Allocation on Energy Efficiency by Sector | Source: Strategen, based on methodology from the Natural Resources Defense Council and ICF

77. The Regional Input-Output Modeling System (RIMS II) multipliers, developed by the U.S. Bureau of Economic Analysis, measure the effects of local demand shocks on total gross output, value added, earnings, and employment.

78. Relevant sectors and shares for the allocation of energy efficiency spending are based on a methodology adopted by the Natural Resources Defense Council (NRDC) and ICF International. See: Natural Resources Defense Council, 2014. *Retail Electric Bill Savings and Energy Efficiency Job Growth from the NRDC Carbon Standard: Methodology Description.* NRDC's paper referenced economic sectors from the IMPLAN model. In cases where the economic sectors from BEA's RIMS II multipliers differ slightly from those in IMPLAN, Strategen selected a parallel sector from the RIMS II database.

The expenditures associated with implementing the levels of energy efficiency featured in the clean energy pathway were calculated based on estimates developed by the Lawrence Berkeley National Laboratory (LBNL) for program administrator and customer costs, per kWh saved.[79] For Pennsylvania, LBNL estimates the total cost of saved electricity is $0.042/kWh.[80] Using these costs, the total investment in energy efficiency was determined and applied to the weighted economic multiplier, to estimate the number of jobs created through dollars spent on efficiency measures for each year. These impacts include direct jobs in industries where implementation spending occurs, as well as indirect jobs in other industries linked through the supply chain, and jobs in industries supported through workers in the direct and indirect industries spending in the local economy.

In addition to the economic impacts created through expenditures and implementation, energy efficiency measures also have the potential to stimulate activity through household bill savings. That is, reduced energy consumption resulting from efficiency leads to lower energy bills, which means that households spend less of their disposable income on energy. This increased household disposable income, when spent elsewhere in the local economy, can contribute to further job creation. These jobs can be quantified using the RIMS II multiplier for households, which determines the induced impacts associated with increased household spending in the region.[81]

Energy bill savings were calculated by multiplying the cumulative kWh saved through energy efficiency deployment for each year by the average Pennsylvania retail electric rate.[82] According to the American Public Power Association, average rates in regulated states increased by 5.3% from 1997 to 2021,[83] and this escalation rate was used to project the Pennsylvania retail electric rate out to 2050. Conservatively, it was assumed that commercial and industrial bill savings would not be invested back at the local level, and therefore the RIMS II multiplier for household spending was applied only to residential bill savings.

In the clean energy pathway, expenditures on energy efficiency savings and cumulative residential bill savings support 12,416 total jobs in 2035, and 15,353 total jobs by 2050.[84]

	2035	2050	Annual Average
Spending on Implementation	5,733	3,486	5,204
Bill Savings	6,683	11,867	6,927
Total	**12,416**	**15,353**	**12,131**

Table 5: Job creation resulting from energy efficiency investments | Source: Strategen analysis, using RIMS II multipliers from the Bureau of Economic Analysis

79. Lawrence Berkeley National Laboratory (LBNL), 2018. *The Cost of Saving Electricity Through Energy Efficiency Programs Funded by Utility Customers: 2009-2015.*
80. The total cost of saved energy includes both the program costs and the costs incurred by customers. This analysis modeled the impact of the total investments in energy efficiency, without regard to the source of funding.
81. Increases in household income and spending are not directly related to industry changes and therefore, by definition, do not include direct and indirect impacts.
82. Based on data from EIA, this value was $0.097/kWh, as of 2020.
83. American Public Power Association. *Retail Electric Rates in Regulated and Deregulated States, 2021 Update.* Accessed November 2022.
84. Jobs reported are not additive across multiple years. That is, the analysis calculates the number of jobs supported for a given year, based on spending occurring in that year.

4.3.2 | Comparison of Energy Efficiency as an Economic Driver

As shown through the jobs analysis, energy efficiency has the potential to be a substantial driver of local economic growth. This potential is particularly strong in comparison to other energy-related industries that are traditionally associated with job creation in the area. For example, based on the RIMS II data for the 10-county study region in southwestern Pennsylvania, the jobs multiplier calculated for energy efficiency is 59% higher than the multiplier for oil and gas extraction, 122% higher than the multiplier for coal mining, and 151% higher than the multiplier for electric power generation, transmission, and distribution. With job creation potential more than 2.5 times greater than that associated with power production, energy efficiency provides tremendous value not only as a cost-effective alternative to utility scale generation, but also as a compelling driver for economic development. If the region transitions away from overproduction of power for exports, as outlined in the clean energy pathway, investments in energy efficiency can help offset potential job losses during the transition to a cleaner, lower-emissions economy.[85]

Likewise, energy efficiency has the potential for increased job quality and higher wages. Again, based on the RIMS II data from the Bureau of Economic Analysis, the multiplier for labor income associated with energy efficiency industries is 10%, 51%, and 46% higher than the income multipliers for oil and gas extraction, coal mining, and electric power generation, respectively. This means that investments in efficiency measures support not just more jobs, but also higher-paying ones as well.

Investments in energy efficiency offer additional advantages for local job creation. Most efficiency improvements, such as upgrades in lighting, insulation, doors and windows, or heating and cooling systems, can be performed by the local workforce, supporting jobs for contractors and suppliers within the region. In contrast, industries such as natural gas extraction have often relied heavily on workers and suppliers from out of state,[86] and prior research has additionally found that job growth and personal income in Appalachian counties with high levels of natural gas production have significantly trailed national growth rates.[87]

85. Closing of gas wells may additionally provide opportunities to transition the fossil fuel workforce.

86. For example, it was reported that initially 70% of Marcellus workers came from out of state. See: *Marcellus Shale Education & Training Center, 2011. Pennsylvania Marcellus Shale Economic Impact Study.*

87. The Ohio River Valley Institute, 2021. *Destined to Fail: Why the Appalachian Natural Gas Boom Failed to Deliver Jobs & Prosperity and What It Teaches Us.*

5 | Findings and Recommendations for Further Analysis

Southwestern Pennsylvania carries a disproportionate socio-economic and environmental burden from the energy industry, but a power sector decarbonization pathway for southwestern Pennsylvania that leverages clean energy imports from the PJM market and is focused on renewable energy, existing nuclear, energy storage, and energy efficiency has the potential to transform the region and shift away from its reliance on fossil fuels. The clean energy pathway designed by Strategen results in cost savings, emissions reductions, and local economic development, laying the groundwork for sustainable prosperity in the 10-county region.

5.1 | Summary of Findings

Strategen's analysis found that a renewables-based pathway, including energy efficiency and clean energy imports from the PJM market is more cost-effective than continued reliance on fossil fuels. Decarbonization strategies that focus on natural gas and carbon capture will be 13% more costly than the clean energy pathway, which avoids expensive investments in CCS technologies to mitigate emissions, while limiting the region's exposure to fuel price volatility and mitigating the risk of stranded fossil fuel assets. Even before accounting for health and environmental impacts, a pathway centered around zero emissions energy can provide a more economical solution for decarbonization in the region.

In the decarbonization pathway developed by Strategen, all coal plants and a significant portion of natural gas plants in the region will retire or reduce output by 2035, drastically reducing emissions going forward. A limited portion of natural gas plants may be kept online as capacity or peaking resources and to ensure reliability, though clean dispatchable resources could potentially serve this role in the future, as technology progresses. The clean energy pathway results in a 97% reduction in CO_2 emissions from the power sector by 2050, leading to environmental benefits of nearly $2.7 billion annually.

Deep electrification of the transportation and buildings sectors in the region will directly lower CO_2 emissions from these sectors by 95%. The total annual value of environmental and health benefits associated with combined CO_2 reductions from the power, buildings, and transportation sectors reaches $4.2 billion in 2050. Through reduced reliance on natural gas for power generation and in buildings, Strategen's decarbonization pathway will also decrease natural gas consumption by 96% and 98%, respectively, for these two sectors by 2050. Lower consumption provides an opportunity to reduce emissions from natural gas extraction. Given a corresponding drop in natural gas production in the region, the value of these avoided emissions and associated damages would total more than $1 billion in 2050 alone.

In Strategen's analysis, energy efficiency is projected to increase over time, reducing regional electricity load by an average of 2.6% each year of the study period. Combined with electrification, the clean energy pathway results in overall load growth of 33% by 2050. Efficiency measures not only reduce load, emissions, and the need for additional generation, but lead to local job creation and savings for consumers. Using multipliers from the U.S. Bureau of Economic Analysis, Strategen finds that expenditures on efficiency and resulting residential bill savings support 12,416 total jobs in 2035, and 15,353 total jobs by 2050. Compared to both power generation and fossil fuel extraction, energy efficiency has a greater potential to result in increased economic development, evident through higher multipliers and increased economic activity served by local workers and suppliers within the region.

Based on these findings, a clean energy transition is both possible and imperative for southwestern Pennsylvania, and Appalachia more broadly. As part of a larger coordinated effort, the region can pursue a path to advance the development of renewable resources, accelerated electrification, and heavy investments in energy efficiency, while shifting away from a continued reliance on fossil fuels. Energy storage resources can help integrate and balance generation from local renewables, and the PJM market offers additional opportunity for resource diversity through the import of clean power from areas rich in renewable potential, and dispatchable energy to enhance reliability. The analysis and measures outlined in this report provide a pathway for southwestern Pennsylvania to transform the local energy profile and position the region for cleaner and more sustainable growth.

5.2 | Recommended Further Analysis

The analysis and resulting clean energy pathway described in the previous sections presents an alternative to the prevailing narrative that further investments centered around perpetuating the use of fossil fuels provide the only option for decarbonization in southwestern Pennsylvania. As shown through Strategen's modeling, there is a tremendous opportunity to transition the region towards cleaner energy resources, particularly as part of a larger effort throughout Appalachia. The following recommendations outline additional steps for analysis to further strengthen the case for, and feasibility of, a clean energy transition in southwestern Pennsylvania:

+ **Decarbonization Pathways for the Industrial Sector:** The clean energy pathway focused primarily on the power sector, with additional analysis to decarbonize buildings and transportation through electrification. Given the prevalence of industrial processes requiring fossil fuels as inputs, such as steelmaking and cement manufacturing, within the 10-county region, similar pathways should be developed to reduce emissions in these industries, as part of an economy-wide effort to limit global warming. For steelmaking, pathways to transition away from fossil fuels would likely involve hydrogen, CCS, or full conversion to electric arc furnaces, but in-depth analysis is needed to accurately model both the environmental and economic development benefits associated with these solutions.
+ **Modeling the Economic Value of Energy Efficiency:** As shown in Strategen's economic impact analysis, investments in energy efficiency provide value from an economic development perspective and offer greater potential for local job creation than utility-scale power generation and fossil fuels extraction. Such benefits are in addition to the value of efficiency as a cost-effective and low-emissions option for meeting energy demand. However, this full range of benefits is not traditionally taken into account when making resource planning decisions, and as a result, energy efficiency is both undervalued and underutilized. Analysis to more accurately quantify the economic development value associated with energy efficiency would help inform modeling and planning analyses, and potentially allow for the inclusion of these benefits in estimating total resource costs.

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