PUMP, BABY, PUMP:

GEOTHERMAL ENERGY IN APPALACHIAN COAL COUNTRY

LILY MATTHEWS

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EXECUTIVE SUMMARY

The EPA estimates that there are more than 250,000 abandoned and inactive mines across the country that have yet to be reclaimed. To manage the associated environmental hazards, it is estimated to cost over $50 billion. The perpetual need to pump mine drainage to the surface and to treat the water is an expensive process that can impose a long-term economic burden. Abandoned coal mines, however, can be reimagined as thermal assets in network geothermal systems, providing heating and cooling for coal-dependent communities. The Appalachian region spans 423 counties across 13 states and is characterized by rugged terrain, abundant fossil fuel reserves, and a history of extraction-based industry. While once the predominant player in U.S. coal production, Appalachia has faced decades of economic decline due to the rise of cheap natural gas following the Shale Revolution and cultural and political reluctance to transition away from coal.

Today, many coal-reliant counties in Kentucky, Pennsylvania, and West Virginia experience high levels of social vulnerability, marked by low incomes, limited job opportunities, and some of the highest household energy burdens in the country. Reliance on aging coal plants for electricity generation and inefficient heating systems at the household level have contributed to high energy costs. Unique to Appalachia is the abundance of abandoned underground coal mines across the region, which present an untapped opportunity for geothermal energy recovery. The Pittsburgh coal seam, one of several coal seams in the Appalachian coal region, is estimated to hold 1.36 trillion gallons of flooded mine water, which can be harnessed as a thermal asset for heating and cooling buildings.

The technical and economic feasibility of using flooded mines for geothermal networks depends on a multitude of factors including the properties of the mine water, the proximity of mines to population centers, the presence of gas utilities capable of transitioning to thermal services, and the energy demand of end users. Two counties, McDowell (WV) and Letcher (KY) have been identified as strong candidates for further site-specific analysis of a network geothermal system. Following the utility-led thermal networks in states like Massachusetts, geothermal systems using mine water could reduce household heating costs by up to 67%, while leveraging utilities' existing infrastructure and cost structures to ensure affordability. By converting an environmental liability into a thermal asset, Appalachia can attract federal investment and generate interest in a region that has long been overlooked as a candidate for economic development. As the coal industry continues to decline, network geothermal offers a way to reimagine Appalachia's history of extraction by "pumping" instead of mining.

1. TECHNOLOGY OVERVIEW

1.1 Heat Pump Systems

A heat pump is a device that provides space heating and cooling in buildings by moving thermal energy from a heat source to a heat sink. As with a refrigerator, heat pumps use electricity to transfer heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. In the cooling months, a heat pump moves heat from the inside of a building to the outdoors, while in the heating months, heat is moved from the cool outdoors to the warm interior of a building.

Compared to heat generating systems, such as a furnace, heat pumps are generally considered more efficient because thermal energy is being transferred rather than generated. Heat pumps are categorized into two main types according to the thermal source: air-source (ASHP) and ground-source (GSHP) or geothermal. Both systems transfer heat from either the ambient air or the ground for use in interior heating or cooling applications.

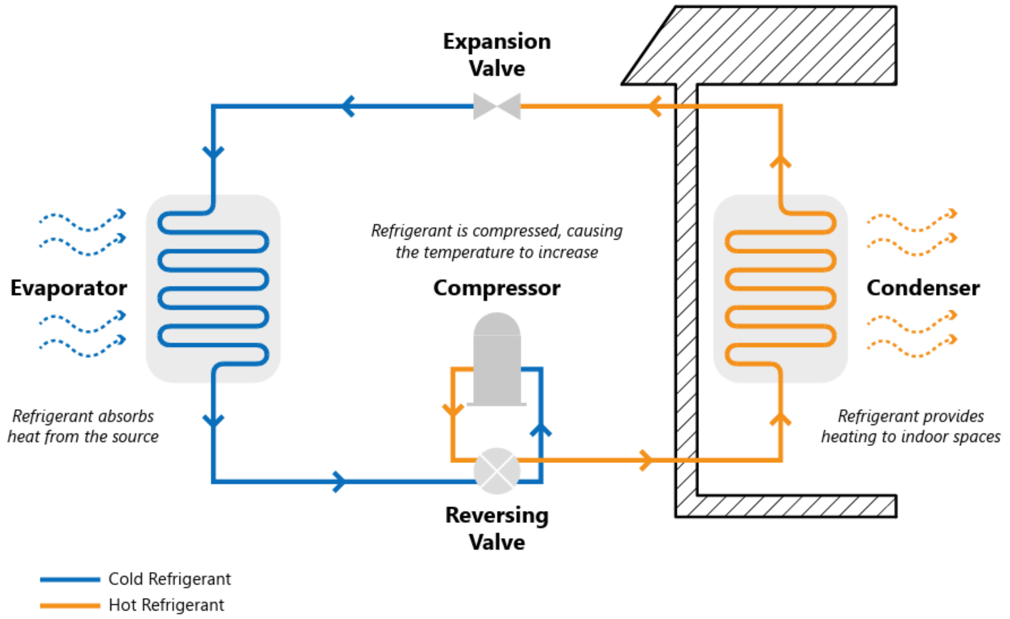


FIGURE 1: HEAT PUMP PROVIDING SPACE HEATING

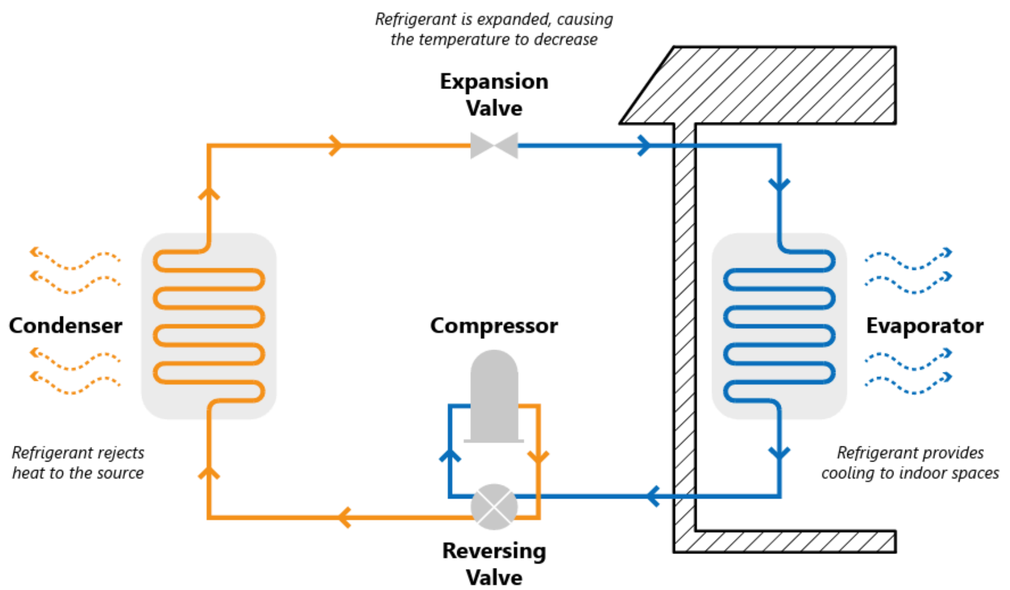


FIGURE 2: HEAT PUMP PROVIDING SPACE COOLING

1.2 Ground-Source Heat Pumps

A GSHP provides heating and cooling using the ground, groundwater, or surface water as a thermal source. To utilize heat from the thermal sources, a GSHP system has a network of piping, known as a GSHP loop, that runs through one or more boreholes, wells, or trenches, or sits directly in a body of water. A circulating fluid, usually water or water with antifreeze solution, is moved through the GSHP loop to facilitate the transfer of heat. GSHP systems take advantage of the relatively constant temperature of the shallow earth, which depending on the location, remains constant within a range of around 40 to 70 °F year-round. Despite seasonal temperature differences, the near-surface temperature remains constant, allowing for the efficient exchange of thermal energy that can provide heating in the winter and cooling in the summer. Because the efficiency of a heat pump declines as the difference between ambient outdoor and indoor air temperatures increases, GSHPs, which have a thermal source less susceptible to annual fluctuations in temperature, yield better performances than ASHPs.

Typically, the GSHP loop transfers thermal energy to a single end user through a heat pump unit installed within the building served or a central utility plant. A water-to-air or water-to-water heat pump exchanges heat from the GSHP loop with the heating and cooling distribution systems of the building, allowing for a transfer of thermal energy. Water-to-air heat pumps are usually coupled with a central forced-air distribution system that uses fans and ductwork to circulate the air that has been heated or cooled by the heat pump throughout the building. Similarly, water-to-water heat pumps are coupled with hydronic systems that distribute fluid that has been heated or cooled by the heat pump to terminal units such as radiators, radiant panels, and baseboard convectors. It is important to note that the fluid distributed through a hydronic system is separate from the circulating fluid within the GSHP loop.

GSHP systems can be grouped into three further categories based on the thermal source used:

- A ground-couple heat pump (GCHP) exchanges thermal energy with the ground using a series of vertical boreholes or horizontal trenches.

- A surface-water heat pump (SWHP) exchanges thermal energy with certain surface water bodies (i.e. lakes, ponds, rivers) that maintain a relatively stable water temperature throughout the year.

- A groundwater heat pump (GWHP) system exchanges thermal energy with existing groundwater sources (i.e. aquifers) using one or more wells.

Note: A GWHP can be configured in an open-loop system where groundwater is directly removed from an aquifer and is pumped through an intermediate heat exchanger.

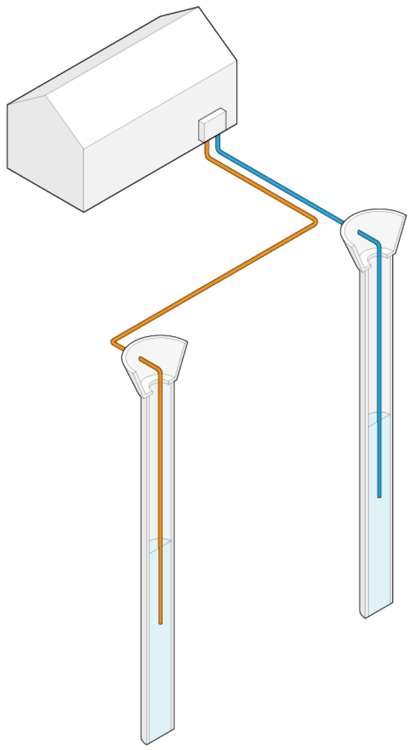
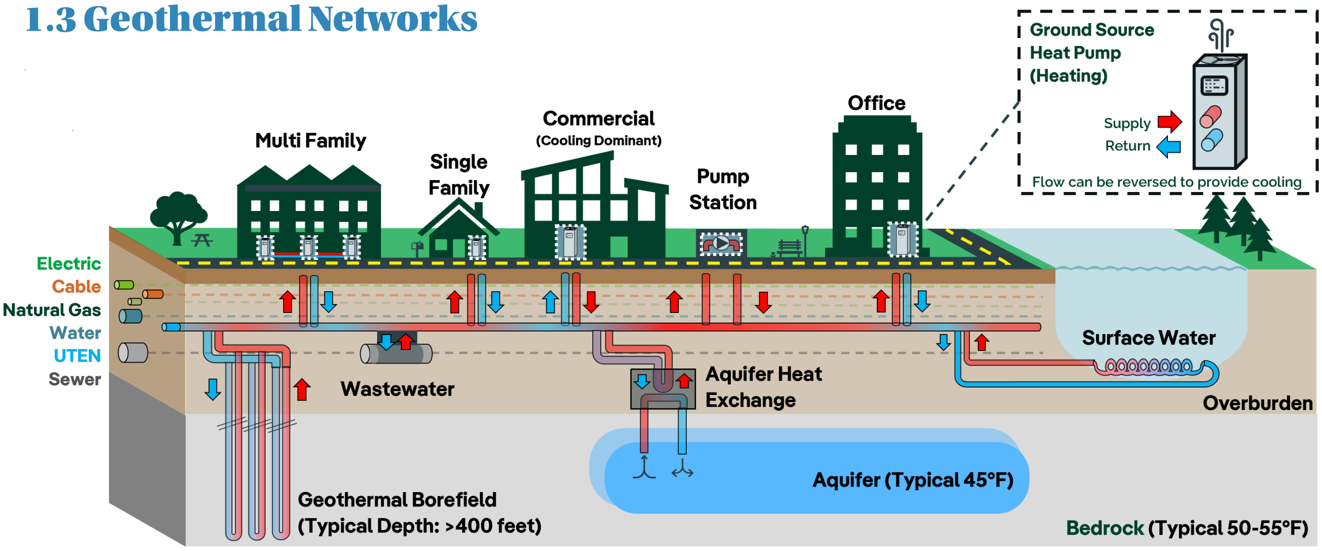


FIGURE 3: CONVENTIONAL OPEN-LOOP GWHP SYSTEM

1.3 Geothermal Networks



A geothermal network connects buildings and a load balancing source, such as a borehole, solar thermal, or wastewater heat exchange, in an ambient-temperature loop which operates at a microgrid or utility scale. Individual buildings are connected to the thermal loop through water-source heat pumps, allowing for heating and cooling throughout the year. Traditionally, district energy systems provide heating and cooling by distributing supply generated at a central location to individual buildings through a network of pipes. A central utility plant may generate heating with a boiler or combined heat and power engine (CHP) that produces both electricity and heat simultaneously. Generally, cooling is provided by chillers that operate on-site. Contranstingly, geothermal network systems operate in an interconnected system where each building can act as a consumer or producer of heat. For example, a brewery may inject waste heat into the geothermal network, providing heating for nearby residences. This bi-directional flow of energy to and from individual sources enables “thermal load cancelling” in which heat is transferred from producers to consumers so that the temperature of the thermal loop and the thermal environment of the surrounding soil do not change significantly.

To move thermal energy to where it is needed, electricity-powered pumps are required to circulate fluid throughout the system. The idea is to balance heating- and cooling-dominant building uses–residential and commercial, respectively– to improve the overall efficiency of the thermal network. A geothermal network could start as a single street-scale GSHP system and expand as neighboring streets are connected. With a larger network connecting buildings with increasingly diverse heating and cooling loads, the system becomes increasingly efficient.

Notably, geothermal networks are not constructed thousands of feet underground where temperatures reach hundreds of degrees. Instead, these systems take advantage of relatively constant temperatures of shallow bedrock. At a shallow depth, geothermal networks can utilize existing right-of-way (ROW) corridors owned and operated by utilities. By repurposing existing ROW corridors for natural gas infrastructure, geothermal networks can be connected to individual buildings to provide heating and cooling while leveraging utilities’ capital financing, existing workforce, and customer base. Adjacent properties such as yards, parks, parking lots, and water bodies are also suitable for siting GSHP infrastructure for geothermal networks. While the capital costs of installing a geothermal network are relatively high, particularly for drilling boreholes, the nature of district energy systems allows for the cost to be distributed amongst a large number of consumers. This sharing of capital costs can result in more equitable deployment than the installation of GSHP systems at an individual building scale.

Residential natural gas customers are already experiencing increases in energy bills. Largely driven by the increasing efficiency of household appliances and a transition towards heat pumps, natural gas use per residential gas customer has fallen by 51% between 1971 and 2023. In 2022, annual sales in heat pumps for homes rose above 4 million units in 2022, overtaking sales of gas-powered furnaces for the first time. As more residents move towards heat pumps, the cost of distributing natural gas is shared amongst fewer and fewer customers, further increasing energy bills for those reliant on gas for heat. The recent increase in household energy bills can also be attributed to a surge in construction-related expenditures by natural gas utilities. Since 2011, annual construction expenditures have risen sharply, with a 50% increase from $32.7 billion to $49.1 billion between 2022 and 2023. Expansions in pipeline capacity, evolving federal and state safety and emissions regulations, and the renovation of old natural gas infrastructure has contributed to these increased expenditures. An analysis of household heating bills in MA suggests that network geothermal yields lower energy costs than natural gas, offering a low-cost alternative in the long-run.

Compared to an ASHP or a household GSHP system, the network effect of an interconnected geothermal system yields higher resilience and efficiency. When a new building is added to a network geothermal system, the ability to predict and manage power flow becomes more accurate, helping the system become more resilient in high-stress situations.

Additionally, by providing cooling, large-scale thermal energy networks can reduce demand for electricity during summer peaks. Assumed to have a COP of 6, network geothermal flattens the future electricity demand peak compared to other electrification scenarios. And unlike solar and wind, geothermal energy provides a stable, constant source of energy, mitigating strain on the electrical grid. By reducing strain on the grid, the potential for power outages is reduced, helping utility customers avoid the long-term costs of adding new capacity.

It is important to note, however, that the performance and feasibility of a geothermal network may vary considerably based on unique site conditions such as thermal properties of the ground, building loads, and existing underground infrastructure. Comprehensive assessment of these conditions is necessary to determine the feasibility of implementation. Further, the efficiency of a geothermal network is dependent on the efficiency of the individual buildings connected to the system. Efficiency upgrades such as installing high quality insulation may be necessary to reduce customer energy bills and increase the performance of the GSHP system.

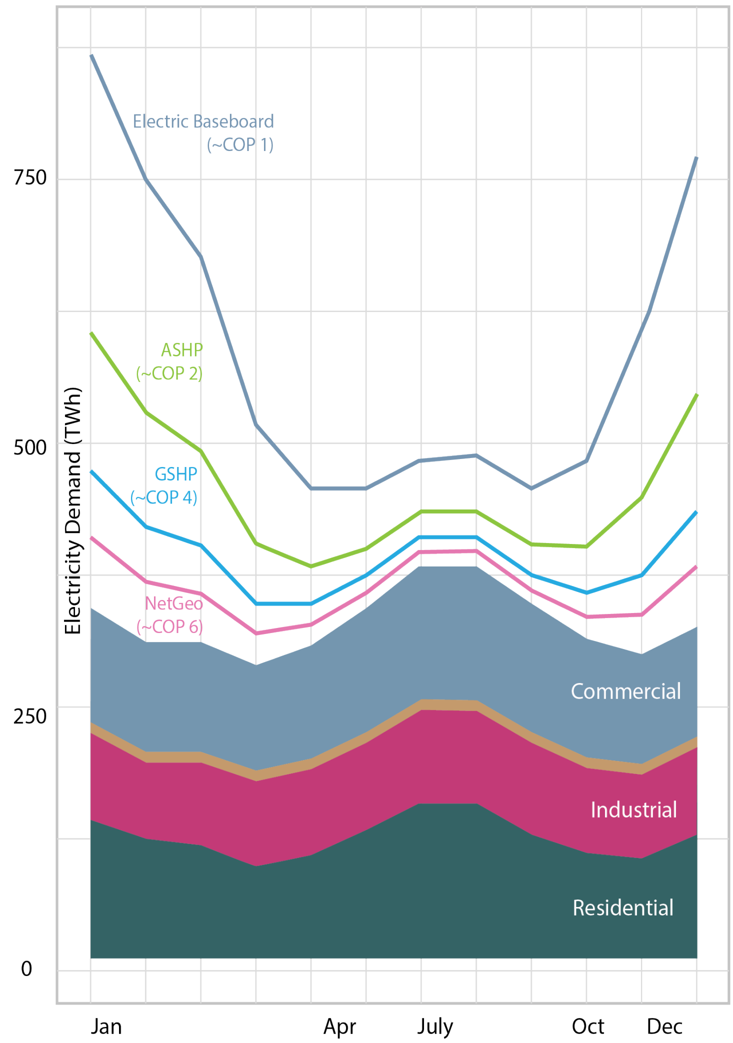


FIGURE 4: FUTURE U.S. SEASONAL ELECTRIC PEAKS UNDER DIFFERENT ELECTRIFICATION SCENARIOS

2. ABANDONED MINES AS A THERMAL ASSET

As the old adage goes, "if it can't be grown, it must be mined", mining is a ubiquitous activity. To reach resources from underground deposits, infrastructure such as shafts and extensive galleries are necessary. While in operation, pumps are installed to dewater the mines, controlling groundwater and providing a dry environment necessary for efficient and safe extraction. Once mining activity has stopped, the underground cavities often fill with water. Mining reservoirs are particularly susceptible to flooding because the mining process creates fractures in the surrounding geology, allowing for infiltration of water from surface accumulations, aquifers, bed separation cavities, solution cavities, and old mine workings.

Due to the potential environmental and health hazards of mine drainage, mines are required to be monitored and pumped to maintain water at a safe level. If water mine water exceeds critical limits, mine drainage will leech into the surrounding environment, contaminating drinking water and posing a serious public health issue. With more than 250,000 abandoned and inactive mines across the country that have yet to be reclaimed, the EPA estimates that it will cost $50 billion to manage the associated environmental hazards (this figure includes the clean-up costs of not just coal mines, but mines used to extract metals and other minerals).

The ongoing need to pump mine drainage to the surface and to treat the water is an expensive process that can impose a long-term economic burden. For example, the Maritnika mine in Marion County, WV has been closed for years, with both surface and groundwater flow into the inactive mine void. To prevent mine water from being discharged into the tributaries of the Tygart River, costs adding up to $900,000 per year must be incurred to pump and treat the water. While costs associated with treating mine water are eye watering, by using existing pump infrastructure and capitalizing on the high water yields of deep coal mine shafts, abandoned mines can be reimagined as thermal assets–presenting an opportunity to offset land cleanup costs while simultaneously protecting community health and enhancing environmental remediation.

The most common application of a geothermal heat pump system using mine water is an open loop system. Extraction of mine water can occur at depths as shallow as 100 feet or as deep as over 2,000 feet, making the efficiency of the operation highly site-specific. Mine water is pumped through a heat exchanger, which is located at the surface or in the gallery of the shaft, and is discharged after the transfer of thermal energy is complete. The presence of a heat exchanger allows the mine water, which is often corrosive or toxic, to be isolated from the heat pump with an additional loop. Pumping water from a vertical shaft can lead to stratification breakdown, or the mixing of water with different temperatures. This can lead to declines in the efficiency of heat extraction, thereby degrading the quality of the thermal resource.

To avoid altering the temperature of the mine water, reinjection can occur at a separate location. It is worth noting that additional requirements may be necessary to reopen a shaft and discharge water back into the environment following the removal of energy. In the U.S., a Class V Injection Well Permit may be required to discharge water back into the mine reservoir. In a closed-loop system, the heat exchanger sits directly in the mine water and a circulating fluid is moved through the system to facilitate the transfer of heat without ever contacting the mine water.

Many coal mines are located in remote areas with settlements developed as a direct result of mining activity. These communities are often situated in areas with rugged terrain or harsh climates, unsuitable for the development of large towns and cities, and are, therefore, heavily reliant on the continuation of the mining operation. The strong dependence of mining communities on coal for employment and the importation of fuel, yields great social and economic vulnerability. For remote mining communities, network heating using geothermal provides an opportunity to decrease reliance on fuel importation and to promote economic revitalization. Further, as an extraction industry, pumping geothermal energy from abandoned coal mines has many parallels to the coal industry. Solutions in Appalachia should focus on the unique strengths of the region. For example, with a workforce highly knowledgeable on the coal mining industry, network geothermal projects can leverage many skills that are transferable to installing and overseeing a new energy system in a challenging geography.

In states such as WV where politicians and the Public Service Commission have doubled down on coal, intermittent sources of energy such as solar and wind are seen as a direct threat to coal employment and a deeply rooted culture in the coal industry. Particularly in WV, the coal industry is entrenched in the political landscape. Governor Jim Justice owns coal mines in the state and the family of Joe Manchin, a highly influential Senator, has made its fortune in coal. Faced with the inevitable decline of coal as a predominant source of fuel, geothermal energy may be more politically attractive than intermittent sources such as solar and wind that fail to capture the unique strengths of the Appalachian coal region. For example, WV ranked 45th in solar power potential by state, an index based on the average number of hours of peak direct sunlight per year.

Furthermore, network geothermal systems can be regulated by gas utilities that transition to become a "thermal utility" and own all of the associated infrastructure such as the pipes and pump station. By allowing utilities heavily reliant and entrenched in coal energy to have regulatory ownership of a geothermal network, the political viability of the technology is seen as more favorable. As noted by HEET, a nonprofit working towards nation-wide adoption of network geothermal systems, the Trump Administration has shown interest in "geothermal" as an energy source in-line with the extractive nature and the "drill, baby, drill" culture of the fossil fuel industry.

While many schools and universities have interest in network geothermal applications, the same approach can be used to provide heating and cooling to commercial or industrial parks. Geothermally heated and cooled greenhouses, aquaculture farms, data centers, breweries, industrial processing facilities, and commercial spaces have the potential to provide employment opportunities for nearby communities. Project Oasis, a campaign based in Southwest Virginia, has promoted the use of geothermal energy on abandoned mine lands for data center cooling. It is estimated that using geothermal energy, data centers could save over $1 million annually in reduced electric costs and municipal water purchases. Further, geothermal energy provides an opportunity for a more efficient land use operation, as current renewable energy projects for data centers utilize solar energy, which requires a large amount of land–approximately six to ten acres per MW.

A regional analysis of Southwest Virginia found that a large data center in the area could create 2,000 jobs during construction, 40 direct, and 59 additional permanent jobs. The project would produce $233 million in economic activity during construction, and over $50 million in annual economic activity once operations begin. As a highly energy and capital intensive process, mine sites are often well connected to roads and electric transmission lines, making it much easier to connect the thermal asset to both the grid and nearby population centers. With the potential to generate employment and spur economic growth, network geothermal projects in the coal-reliant communities of the Appalachian region should be explored.

3. CASE STUDIES

3.1 Space Heating: Park Hills, Missouri

A thermal recovery system located in a closed, flooded lead mine provides an 8,100 square-foot municipal building in Park Hills, Missouri with space heating. Two 400-foot wells are located within the mine, which provides water at a temperature of 57 °F. With submersible pumps fitted in each well, heat is extracted through an open loop system. A plate and frame heat exchanger interfaces with nine heat pumps, providing thermal energy to distribute throughout the building. Despite a large initial capital investment of $132,400, with capacity of 112 kW, the system had a payback period of just 4.6 years.

3.2 Space & DHW Heating: Shettleston, Glasgow, Scotland

Located in the Ell Coal Seam, the Shettleston Colliery produced coal from 1872 until its abandonment in 1923. In 1999, an open loop ground source heat system was implemented to extract thermal energy from mine water in a 328 foot borehole. The 54 °F mine water is pumped through a water-to-water heat pump, which heats the water to 131 °F. Once heated, the water is stored in an insulated tank until use. The water is then distributed to domestic hot water storage cylinders at 16 houses. The wastewater from the thermal energy system is discharged in a shallow re-injection borehole at 37 °F.

ABOVE: INSTALLATION OF INFRASTRUCTURE IN HEERLEN

3.3 Thermal Energy Network: Heerlen, Netherlands

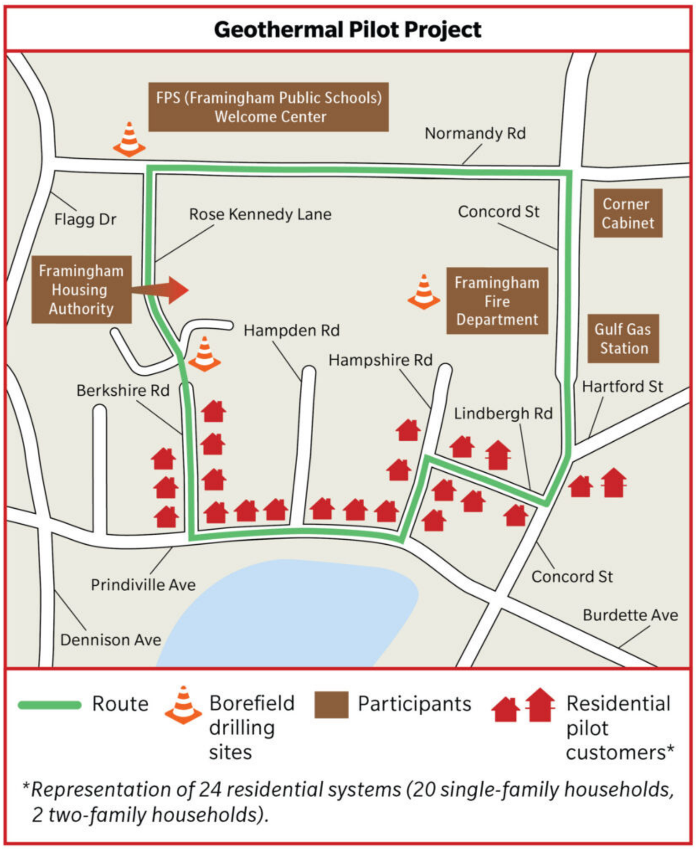
With funding from the European Union and the Dutch government, the city of Heerlen drilled five wells, approximately 2,297 feet in depth, to extract thermal energy from retired coal mines. The water temperature from the wells ranged from between 86-95 °F or 61-66 °F. During the initial build out of the heating and cooling network in 2008, approximately 538,196 square feet of floor space in buildings were served. As more buildings were added to the network, the geothermal capacities of the mine were no longer able to supply adequate heating and cooling. In 2013, Mijnwater BV created an innovative solution to this issue. The company connected buildings to each other, constructing a 5th Generation District Heating and Cooling Network (5GDHC) that supplies 20 TJ/year of heating and 20 TJ/year of cooling to 2,690,978 square feet of offices, businesses, supermarkets, residential and public buildings. The interconnection of buildings has enabled half of the energy consumed by users for heating and cooling to be generated by the customers themselves. For example, a school is heating from the waste heat generated by a pension data center. While the retired coal mines are no longer the primary source of thermal energy, the wells now act as an inter-seasonal storage solution, conserving heat produced by air conditioners in the summer to heat buildings in the winter. Through a network of heat pumps and storage solutions, the 5GDHC was able to reduce the urban energy demand of a city of 86,832 people by 50%.

3.4 Thermal Energy Network: Framingham, Massachusetts

In 2020, the Massachusetts Department of Public Utilities approved a network geothermal pilot project in the city of Framingham. The project was driven by HEET, a nonprofit organization with a focus of building out network geothermal systems by transitioning natural gas utilities to thermal utilities. Eversource Energy, the natural gas utility in the area, paid for the construction and installation of the geothermal system, in addition to covering the cost of equipment installed in individual homes and businesses. Of the capital budget, approximately 30% went towards drilling boreholes, another 30% was used for building conversions and the installation of heat pumps, while the remaining costs included construction of the pumphouse, civil work, etc.

To learn how to install the infrastructure for the network geothermal system, natural gas contractors required only one day of training. As Bill Akley, President of Gas Distribution, noted, “Operating, constructing, and maintaining an underground geothermal network has a lot of parallels to what our industry and our employees do every day. This project, for us, is enabling our group of dedicated employees to see a way that we can provide different services in a different way.” Natural gas sales-people were also retrained to aid in customer acquisition for the pilot project. Eversource employees went door-to-door, offering participants a low, monthly fixed charge for access to the geothermal network – a majority of residents bought into the program. With easily transferable skills, the natural gas contractors were able to install pipes for the network geothermal system next to existing natural gas pipes and natural gas sales-people acquired a customer base.

Following a year of construction, the system now serves 135 residential and commercial customers with ground-source heating and cooling. Studies on the project have shown that the thermal environment of the soil surrounding the network geothermal system has not changed significantly, and that there is no evidence of an adverse impact on the tree canopy of Framingham. With the success of the initial build-out, Eversource Energy has received Department of Energy (DOE) funding for Phase II of the project. While the pilot in Framingham was a retrofit project, HEET and Eversource have announced a new construction network geothermal project in South Plymouth. For this project, boreholes will be drilled before the construction of a new housing subdivision.



ABOVE: EVERSOURCE ROUTE MAP OF PILOT PROJECT

4. GEOTHERMAL IN APPALACHIA

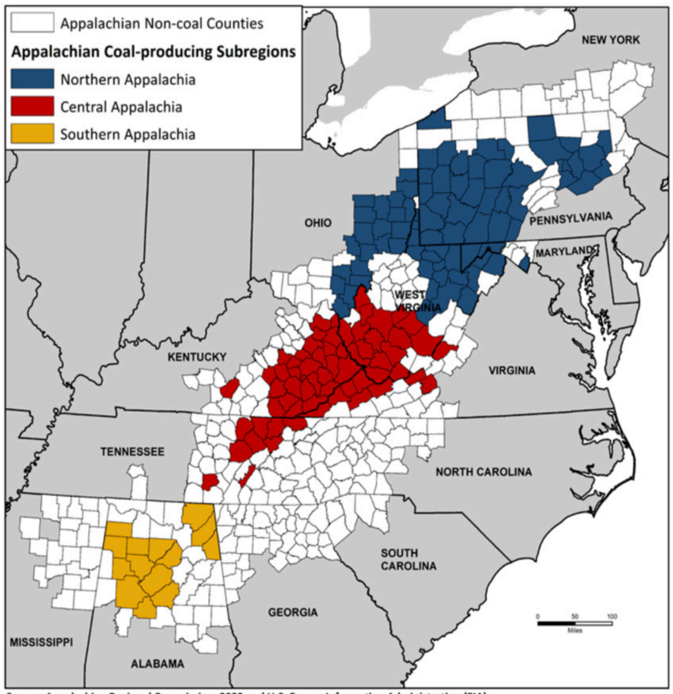
4.1 Geography

The Appalachian mountain range stretches over 1,500 miles from Northern Mississippi to Southern New York, with peaks rising above 6,000 feet. 423 counties across 13 states are considered part of the Appalachian region, which is home to 26.4 million residents. Parts of the mountain range sit atop a Marcellus shale play, an organic-rich formation that has enabled decades of natural gas and coal extraction. While the region has abundant underground carbon stores, the rugged terrain has led to the development of highly isolated communities with a strong dependence on the fossil fuel industry.

4.2 History and Mining Culture

As the primary producer of U.S. coal throughout the 19th and 20th centuries, the Appalachian region played a crucial role in the industrialization of the country. In recent decades, the region has had an increasingly important role in natural gas production, continuing a long history of energy extraction. Despite being endowed with rich resources, the region's extractives-based economy has left communities especially vulnerable to the volatility of boom-and-bust cycles. For example, the oil price spike of the 1970s increased demand for cheaper coal, but was followed by a sharp drop in oil prices in the 1980s that caused a bust cycle in the U.S. coal sector. Coal production is clustered in areas where mining serves as the anchor of the local economy and culture, meaning that shifts in the broader energy market can produce acute, localized economic shocks. As a result, many coal-dependent communities have disproportionately faced impacts of boom-and-bust cycles compared to the wider U.S. economy. The long-term decline of the coal industry over the past 50 years has only deepened the economic and social challenges of many Appalachian communities.

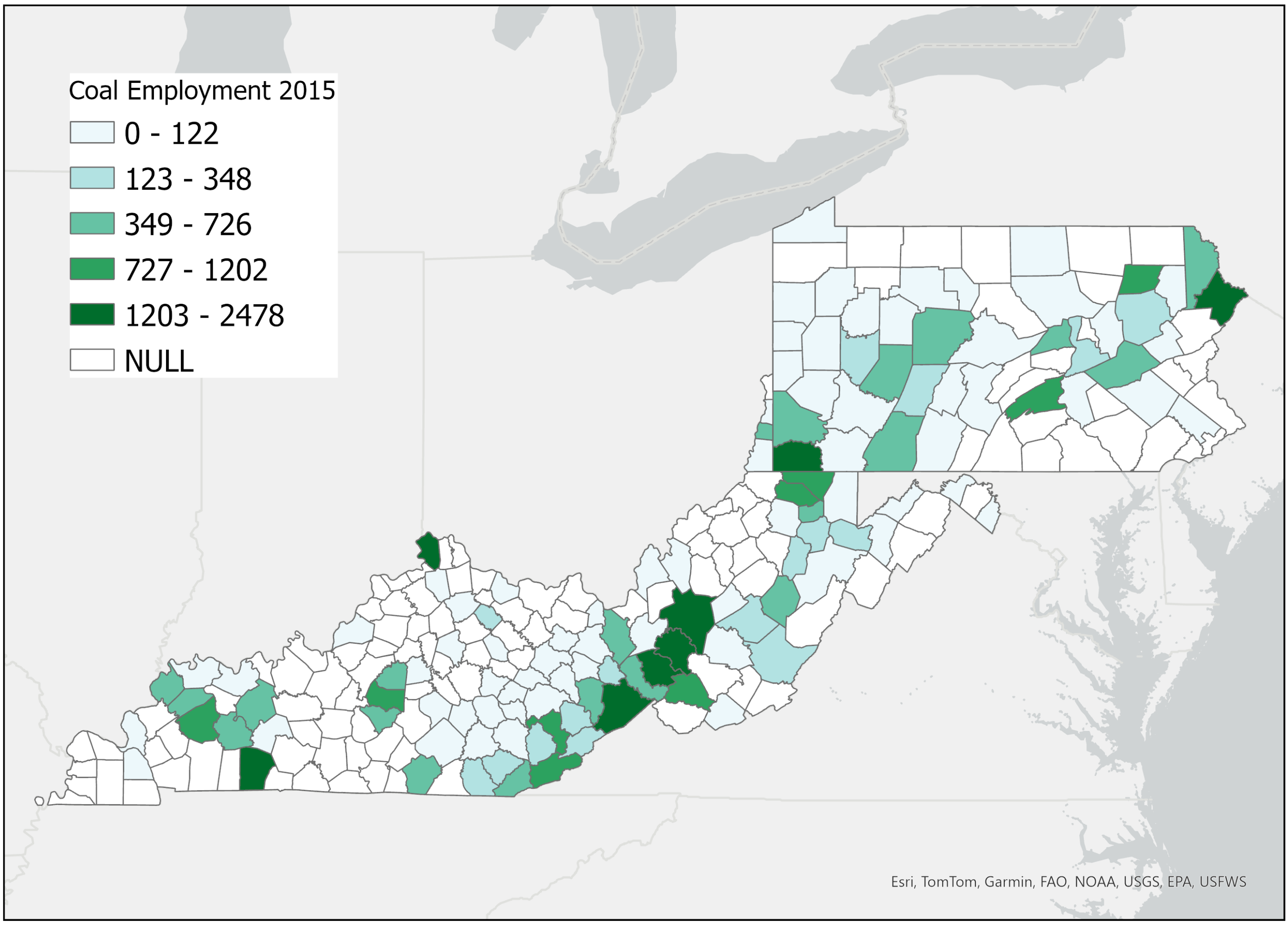
Figure 1: Appalachian Coal-producing Subregions and Appalachian Non-coal Counties



Source: Appalachian Regional Commission, 2022 and U.S. Energy Information Administration (EIA)
Note: Appalachian coal-producing subregions include counties within Apppalachian region, as defined by EIA, that produced at least one thousand short tons of coal in any year from 2000 through 2021.

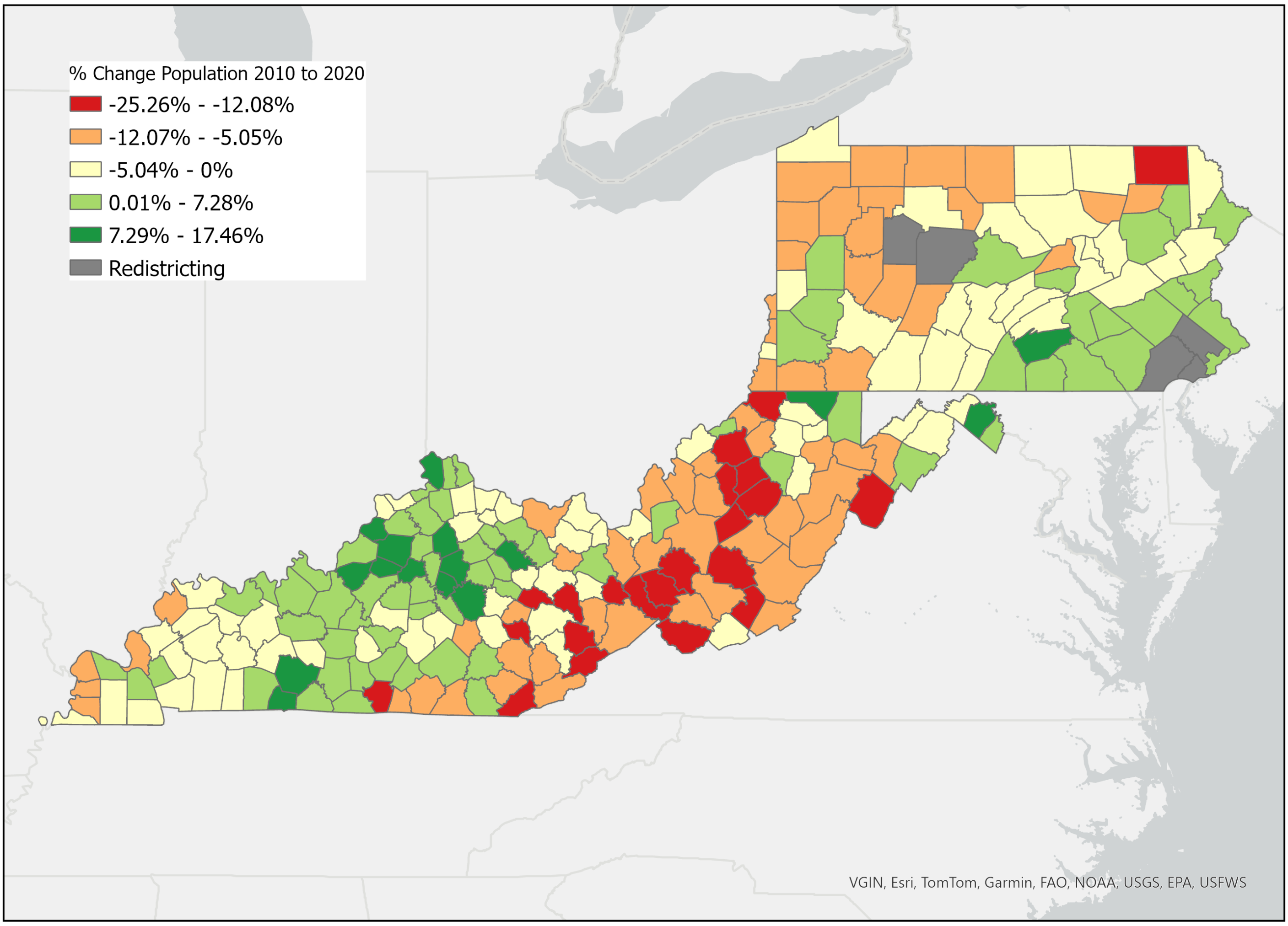
At its peak in the 1940s, the United Mine Workers of America (UMWA), the predominant labor union for mine workers, had close to 500,000 members. Employment in WV followed a similar trend, peaking in 1948 with 125,669 coal miners employed. In the same year, however, the continuous mining machine was introduced, revolutionizing the extraction of coal in underground mines and contributing to a steady decline in coal miner employment in both WV and nation-wide. In the years leading up to 1963, employment nationally fell steadily to 141,646. By 1990, there were fewer miners in WV than there were nurses or telephone solicitors, and Walmart employed more workers in the state than any coal company.

The story told by production levels, however, is quite different. The drastic increase in above ground "surface mining" or "strip mining" operations in the 1970s allowed for cheap and fast extraction through the use of heavy machinery that required little labor. In the following decades, strip mining evolved into the process of mountaintop removal (MTR), a highly controversial practice in which explosives are used to blow off mountaintops to access the coal seams below. Despite significant environmental destruction caused by blasting mountaintops and filling streambeds, MTR enabled extraction of coal at rates 2.5 times higher than underground mines. In WV, mechanization and use of MTR allowed for more coal to be produced in 1977 with one-seventh the number of mine workers employed at the height of "pre-mechanization" years in 1948.



The "Shale Revolution" of the early 2000s is arguably the largest single force leading to the demise of the coal industry. The technological breakthrough of combining hydraulic fracturing and horizontal drilling enabled the extraction of oil and natural gas from previously unreachable tight oil formations. The breakthrough rendered natural gas cheap and plentiful, leading many utilities to convert their coal plants to burn natural gas, or retiring them entirely. Coupled with the increased efficiency of new natural gas fired combined cycle combustion turbines, natural gas began to drive down prices in wholesale electricity markets, pushing coal plants "out of the money".

In October of 2004, the first productive natural gas well in the Marcellus shale play, the Renz 1 well, was drilled by Range Resources in western Pennsylvania. Within six years, natural gas changed the domestic energy industry by becoming the fuel of choice for generating electricity at baseload power plants. Considering all dynamics in the electricity markets, the drop in natural gas prices was found to be responsible for nearly half of the decline in U.S. domestic coal consumption between 2011 and 2017. Other contributing factors were lower than expected demand for electricity (26%) and growth in renewable energy (18%). In a region with many communities highly dependent on coal production, the rise of the natural gas industry and steady employment declines has led to emigration from many coal-reliant counties.

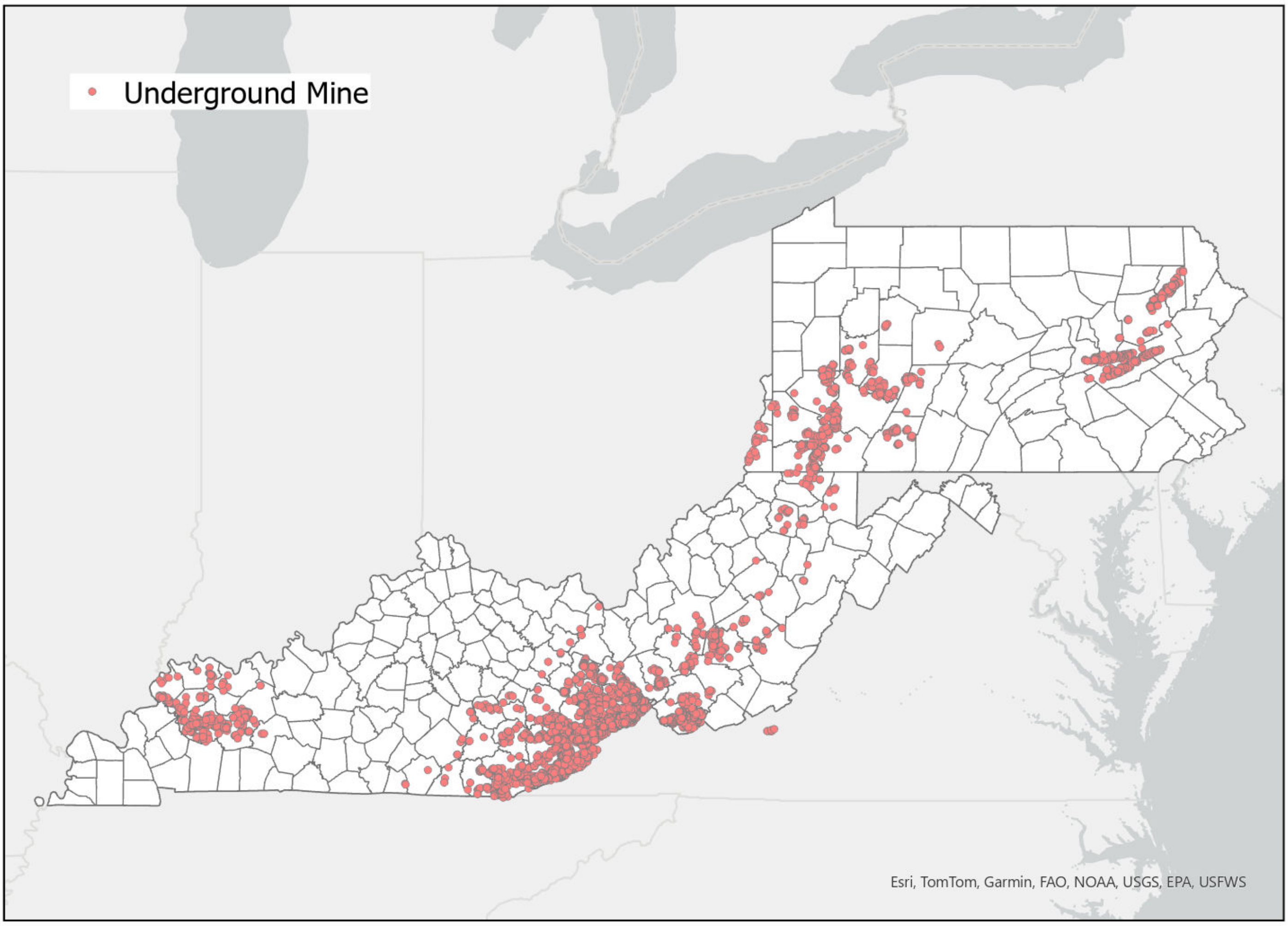


4.3 Abundance of Abandoned Mines

The EPA reports that a majority of abandoned mine lands remain idle and have never been considered for any type of reuse. Of the 1,200 underground coal mines in the Pittsburgh coal seam, one of several coal seams in the Appalachian coal region, only twelve are currently active. The remaining coal mines have either been closed, and are flooded, flooding, or free draining. It is estimated that the volume of underground flooding in the coal mines of the Pittsburgh seam is 1.36 trillion gallons, or enough to fill over two million Olympic-sized swimming pools. Only about 77% of the water discharged throughout the basin passes through a treatment plant. A sizable amount of the remaining 23% is pumped and treated, however, offering enough thermal energy to heat and cool up to 3.74 million square meters of interior space, or approximately 20,000 homes. The mining companies or municipalities with access to the closed flooded mines often lack the resources or expertise to generate a site-specific feasibility study of geothermal energy recovery, however. As a result, private firms or academic researchers are often contracted to perform studies.

Appalachian Counties with the most Underground Mines (reported as number of mine portals):

1. Pike, KY (1,654)
2. Floyd, KY (1,230)
3. Schuylkill, PA (1,209)
4. Letcher, KY (816)
5. McDowell, WV (792)
6. Carbon, PA (742)
7. Harlan, KY (583)
8. Fayette, WV (379)
9. Lackawanna, PA (377)
10. Perry, KY (373)

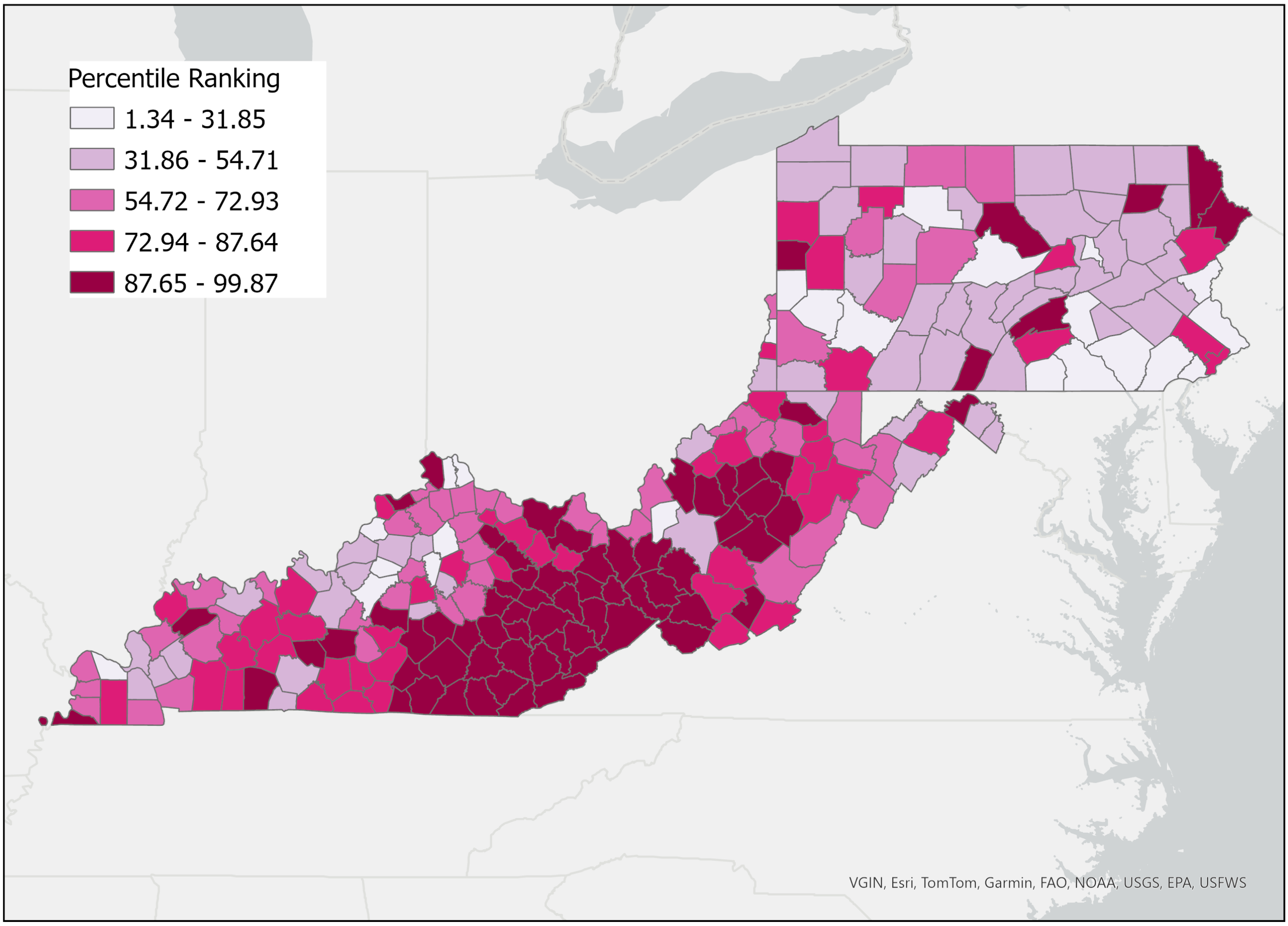


4.4 Social Vulnerability

Compared to counties across the nation, coal producing sub-regions in Appalachia report high social vulnerability scores. The National Renewable Energy Laboratory (NREL) developed a Social Vulnerability Index (SVI) to help jurisdictions identify underserved areas and target investments towards communities with vulnerable populations. Using U.S. Census data, NREL developed the SVI which is calculated by combining the scores of four categories: socioeconomic status, minority status & language, household composition & disability, and housing type & transportation. The scores displayed on the map refer to a percentile ranking, depicting how a county compares to other counties in the country. For example, a percentile ranking of 75 indicates that the county scores higher than 75% of other counties in the country. 62 counties in Appalachian Kentucky, Pennsylvania, and West Virginia have a percentile ranking of 90 or higher.

Appalachian Counties with Highest SVI Scores:

1. Wolfe, KY (99.87)
2. McCreary, KY (99.78)
3. Clay, KY (99.65)
4. Leslie, KY (99.33)
5. Owsley, KY (99.24)
6. McDowell, WV (99.11)
7. Breathitt, KY (99.08)
8. Knott, KY (99.04)
9. Martin, KY (99.01)
10. Harlan, KY (98.89)

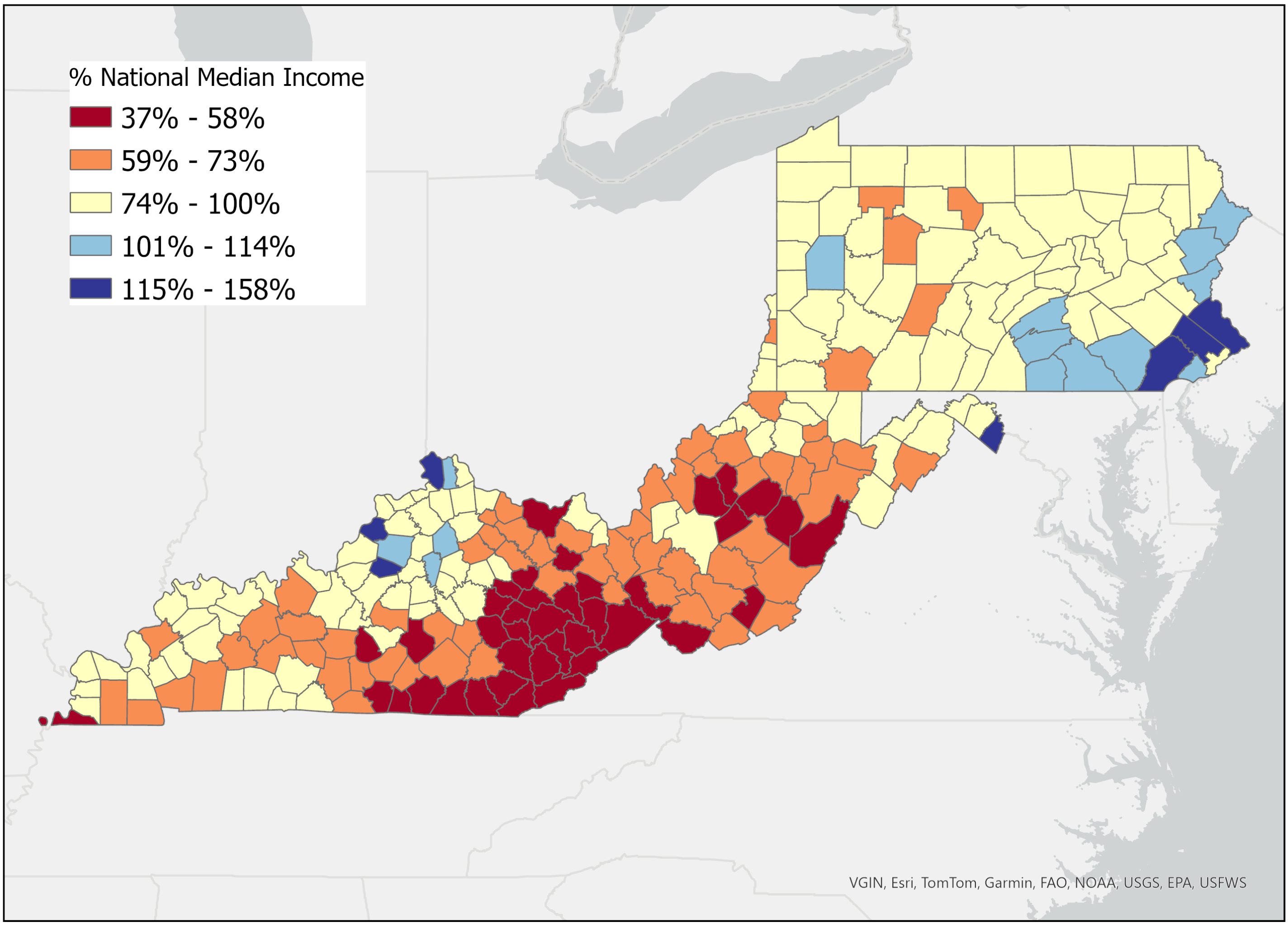


Low Income

Many coal producing sub-regions in Appalachia have a low median household income compared to the national average. The lack of economic diversity in many coal-reliant counties has limited the transition away from coal jobs towards other high-paying employment alternatives. In WV, the largest employers are now Walmart, P&G, and Toyota, but with many coal communities located in remote areas, jobs are not located where former coal mining families live. Further, coal apologists insist that "five thousand people working at Walmarts in this state don't equal 400 coal jobs." The lack of economic diversity has not only limited opportunities for those in coal-reliant communities from making a decent living, but has helped reinforce a cultural tension rooted in the idea of "the good old days" of coal mining. In 2025, for a family of four, the poverty line was set at $32,150. Three counties in Appalachian Kentucky, Pennsylvania, and West Virginia have median income levels lower than the poverty line, indicating severe socio economic distress.

Appalachian Counties with the Lowest Median Income:

1. Wolfe, KY ($29,052)
2. McDowell, WV ($29,980)
3. Owsley, KY ($31,064)
4. Bell, KY ($32,403)
5. Magoffin, KY ($33,632)
6. Knox, WV ($33,153)
7. Lee, KY ($34,182)
8. Fulton, KY ($36,834)
9. McCreary, KY ($37,355)
10. Harlan, KY ($37,198)

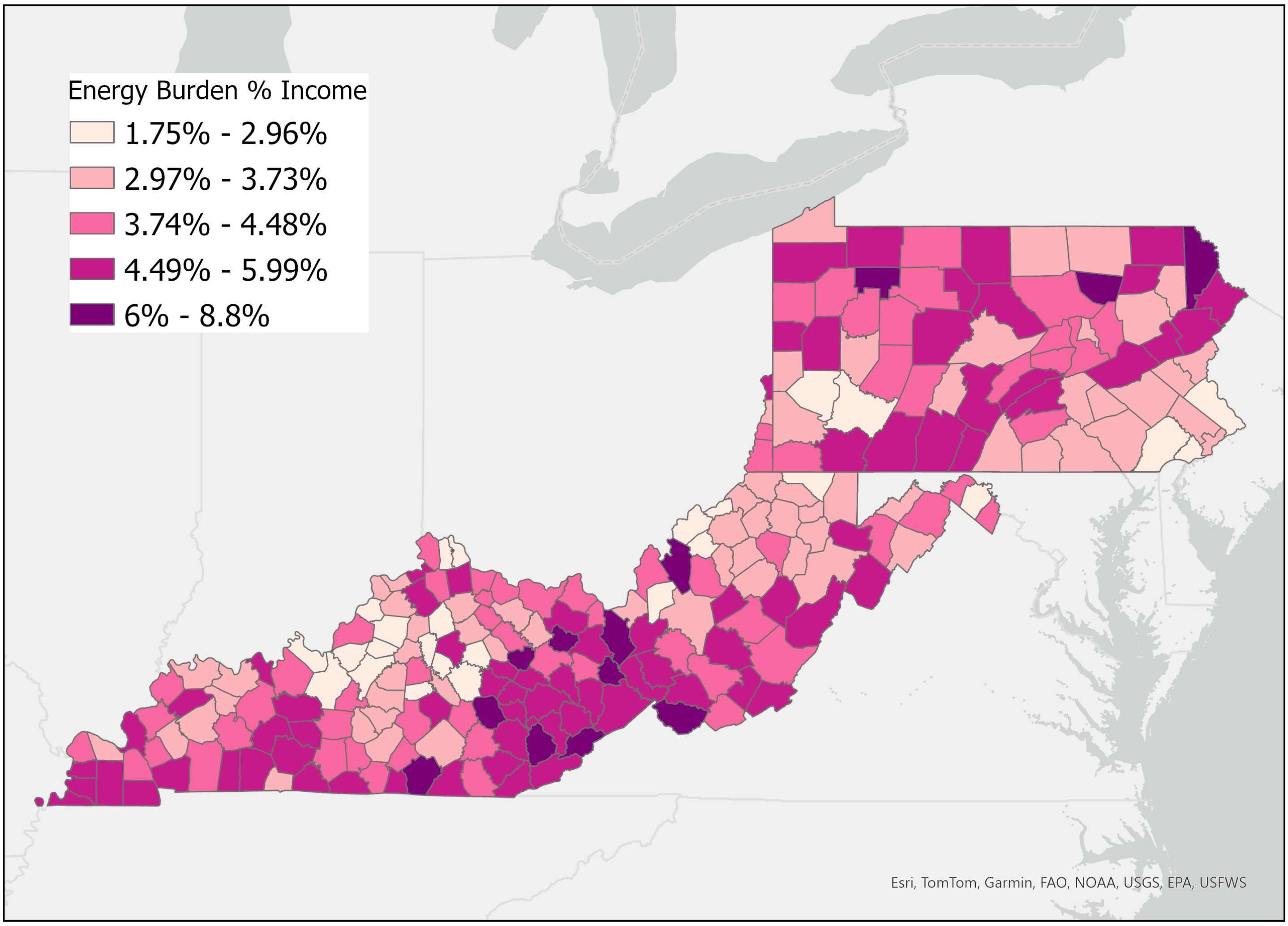


Household Energy Burden

According to the 2020 American Council for an Energy-Efficient Economy Report, "How High Are Household Energy Burdens?", households spending more than 6% of their income on energy bills have a high energy burden. Household energy costs can include electricity, gas (utility or bottled), and other fuels including fuel oil and wood. A high energy burden can be caused by physical, economic, social, and behavioral factors, and can impact physical and mental health, education, nutrition, job performance, and community development. 10 counties in Appalachian Kentucky, Pennsylvania, and West Virginia are designated areas with a high energy burden, with households paying 6% or more of their income on energy bills.

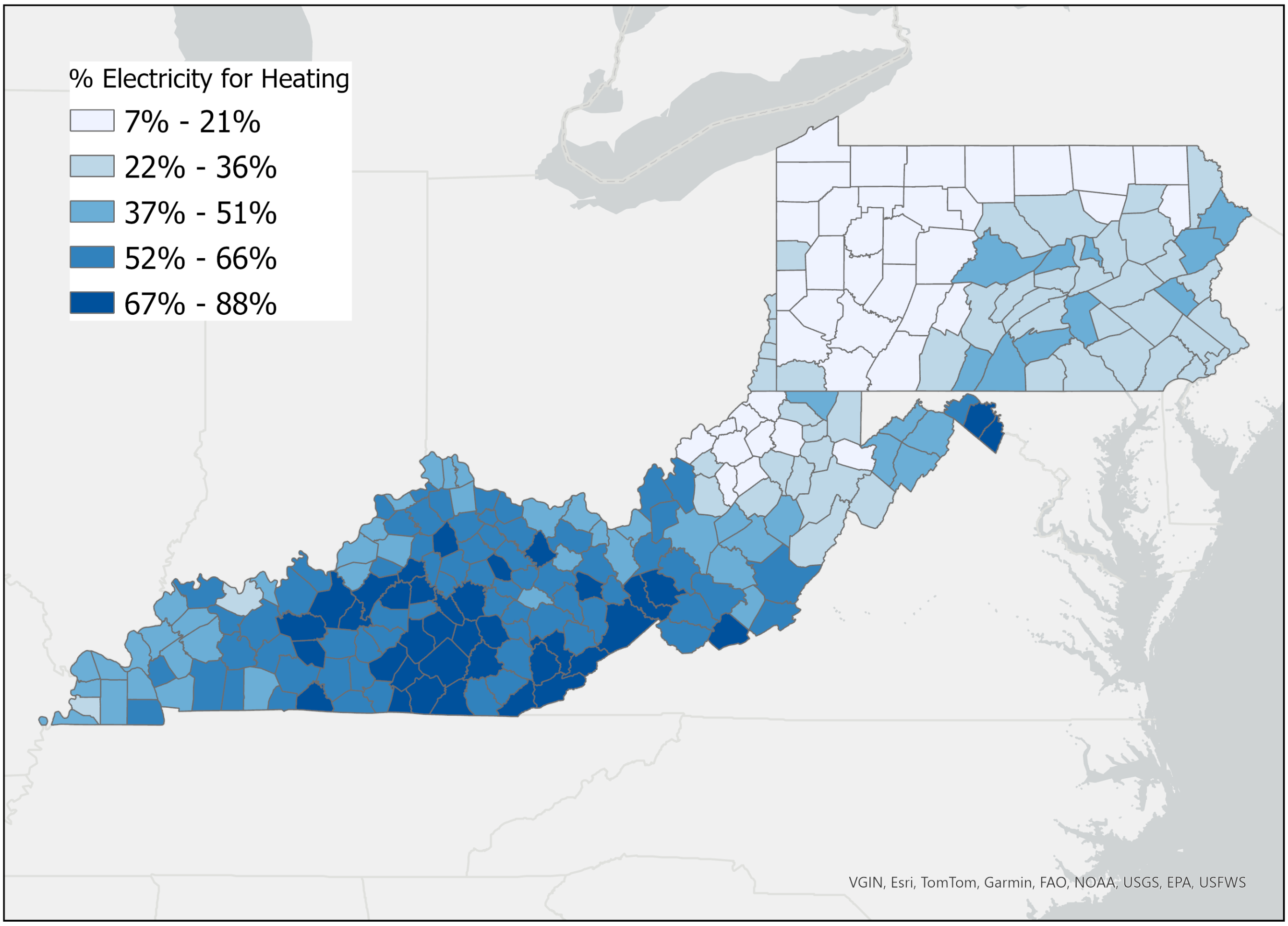
Most Energy Burdned Counties in Appalachia:

1. Forest, PA (8.8%)
2. McDowell, WV (7.75%)
3. Leslie, KY (6.95%)
4. Sullivan, PA (6.82%)
5. Wayne, PA (6.5%)
6. Menifee, KY (6.47%)
7. Martin, KY (6.42%)
8. Jackson, KY (6.21%)
9. Letcher, KY (6.08%)
10. Elliot, KY (6.00%)



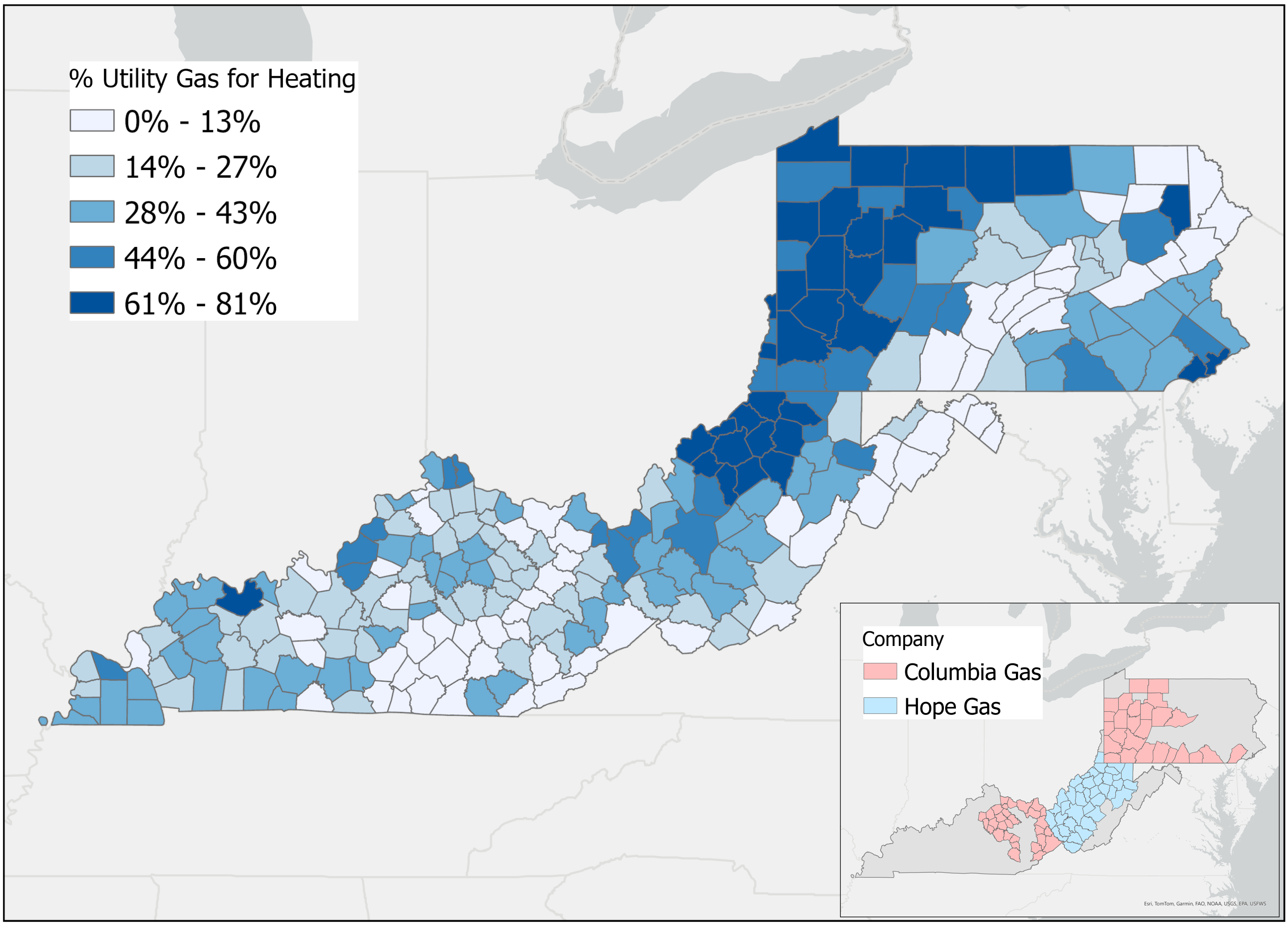
High Costs of Electric Heating

Between 2008 and 2020, electricity prices in WV increased faster than any other state in the country with an average annual rate of 3.77% compared to the national average of just 0.70%. A continued reliance on electricity generation from aging coal power plants is driving up the cost of electricity in both WV and KY. Despite a decrease in coal-fired electricity generation across the country, the percentage of coal in WV's electricity mix increased from 88% in 2020 to 91% in 2021. Kent Chandler, the former chair of the KY Public Service Commission explained, "For decades, Kentucky had an economic advantage of building coal power plants and burning that coal and producing cheap electricity here. That economic advantage has been eroded." The reliance on coal has impacted the ability of WV and KY to attract economic development in addition to burdening ratepayers with higher utility bills. Data provided by Kentucky Power, the utility in Eastern Kentucky, indicated that the poorest ratepayers, on average, had the highest electricity usage compared to the utility's average residential customer, leading to the highest bills. Many low-income households in Kentucky qualify for federal assistance through the Low Income Home Energy Program (LIHEAP), which helps disadvantaged ratepayers pay utility bills. When electricity consumption peaks for Kentucky Power in the winter months, LIHEAP ratepayers use on average more than 2,500 KWh per month, which is amounts to electricity costs over $400. In the past three winters, 20% of Kentucky Power LIHEAP ratepayers used over 4,000 KWh of electricity, with some using as much as 6,000 KWh. This high electricity usage has been attributed to homes with poor insulation and inefficient heating sources, necessitating the need for home retrofits and efficient heating systems. It is estimated that heat pumps using mine water could reduce heating costs by 67% annual and cooling by 50% compared to other conventional methods, cutting the electricity bills of energy burdened households while improving overall comfort levels year-round.



Using Existing Natural Gas Infrastructure

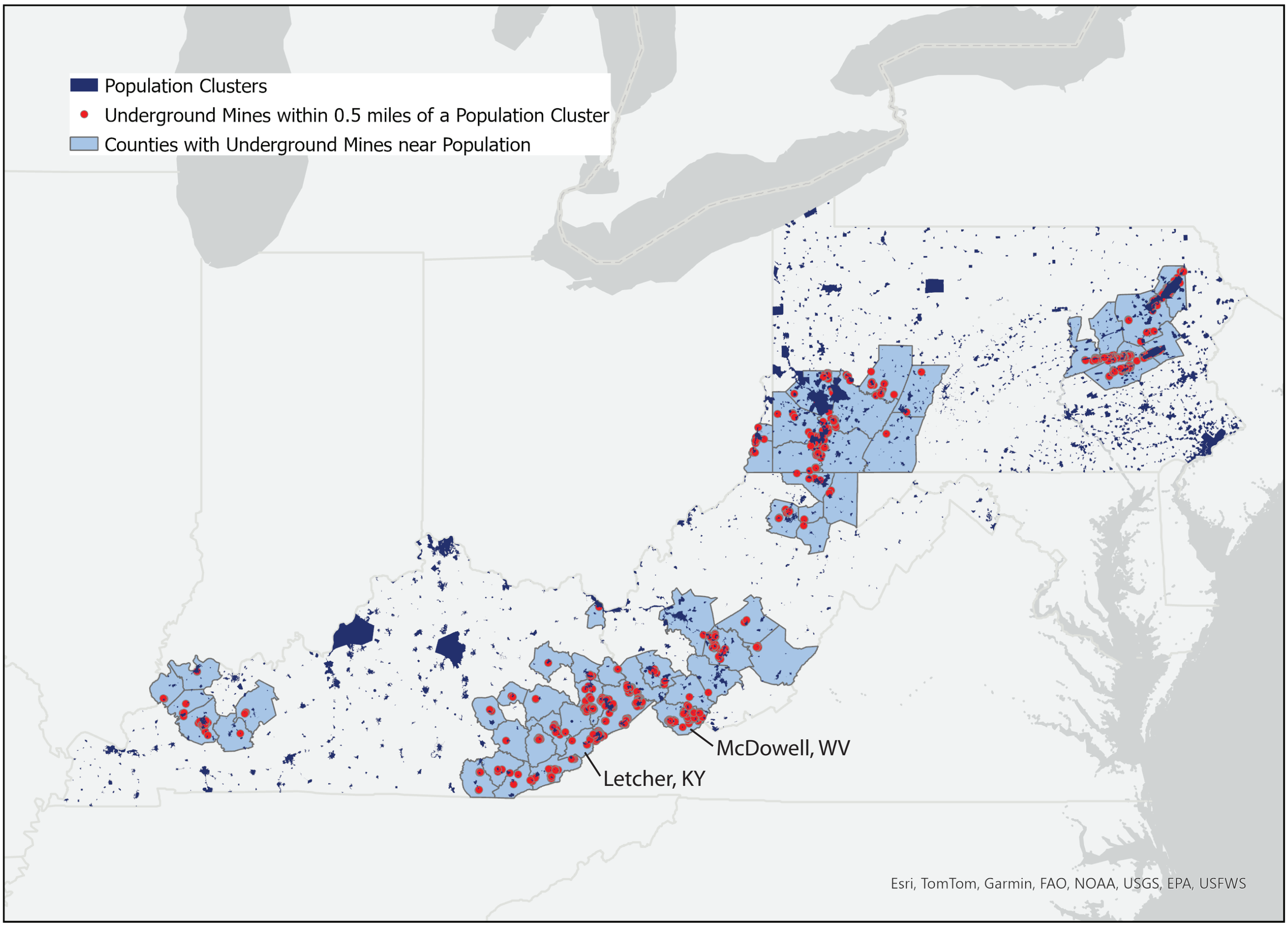
Following the framework of the Eversource pilot project in Framingham, Massachusetts, communities reliant on natural gas for heating can more easily transition to a geothermal network system. Already, 8 states have enacted laws allowing natural gas utilities to oversee geothermal networks, essentially becoming thermal utilities. Under the oversight of a utility, geothermal networks are able to leverage the utilities' ROW corridor as well as the capital financing, existing workforce, and customer base. Under one potential cost structure, the utility would pay for the upfront costs of installation and building retrofits and then spread the costs across the entire customer base over several years to make the project more accessible and affordable for all residents. By utilizing abandoned mines as a thermal asset, utility companies can reduce installation costs of which 63% goes towards borehole drilling for a low density residential area and 55% for a medium density mixed-use service area. Columbia Gas serves more than 138,000 customers in Eastern Kentucky and 446,000 customers in Pennsylvania, making the utility an ideal candidate for a transition to network geothermal. In West Virginia, Hope Gas serves around 125,000 residential, industrial, and commercial customers, presenting another opportunity for a transition to network geothermal.



4.5 Potential Sites

Viable sites for network geothermal using mine water as a thermal asset must have population centers near the abandoned mine shafts. 54 counties in Kentucky, Pennsylvania, and West Virginia have been identified as having clusters of population within 0.5 miles of an underground mine. Based on the number of underground mines, the presence of energy burdened communities, and the presence of a natural gas utility, site feasibility studies should focus on McDowell (WV) and Letcher (KY) as candidates for a network geothermal system. With a population of 17,439 and 20,423 (2023), respectively, a network geothermal project in either county could benefit many.

Further, a network geothermal project could bring interest to Appalachia, a region that has struggled to attract economic development since the decline of the coal industry. The reclamation of brownfield sites brings in federal funding which can benefit the health of the local environment and the people. For the mine owners and operators, renewable energy credits and carbon credits for geothermal development on an abandoned mine site can offer opportunities to reclaim the land in a way that generates financial benefits. As the coal industry continues to decline and abandoned mines fill up with water, there is no better time to reimagine the extraction culture of Appalachia and to "pump, baby, pump".



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