# Assessing the Potential for Renewable Energy Development in Appalachia

Charlotte H. Browder, Abby H. Dawley, Luke K. Mathe, Conor W. Murphy, Frederick S. Van Winkle, and Julianne D. Quinn (jdq6nn@virginia.edu)

*Abstract* – **This paper explores the feasibility of renewable energy development in the Appalachian region of Virginia, an area historically dependent on the declining coal industry. Applications for cleaner energy sources present themselves in Appalachia, taking advantage of the reclamation of mined lands as an opportunity to reinvigorate the energy industry and address climate change. Starting with a literature review and data collection, we explored the potential development of solar, wind, and hydroelectric energy systems in the region. When assessing the potential for these energy sources, we used a weighting scheme to combine a comprehensive set of metrics according to the preferences of a defined group of stakeholders. Our metrics included both technical constraints and the priorities of stakeholders with respect to solar energy, wind energy, and hydroelectric energy. We also considered county policies encouraging the development of renewable energy projects and how developing renewable energy in areas currently struggling socio-economically would impact the economy. We used ArcGIS Pro to determine available land for development and to analyze metrics over this land. Our findings uncovered that Carroll and Floyd counties were the strongest candidates. After narrowing our scope down to these two counties, we found specific sites that satisfied all our development criteria. This analysis contributes to our ultimate goal of helping the population of these counties develop renewable energy resources to stimulate the surrounding economy and address environmental concerns.**

## I. INTRODUCTION

The Appalachian region of Virginia has seen its economy grow and decline with the boom and bust of the coal industry. At its height, the region was producing over 46.5 million tons of coal on a yearly basis, and was actively mining over 800 sites [1]. The economic impact of coal mining went beyond just energy production as experts estimate that for every mining job created, three other non-mining jobs were created to support these communities. The rise of coal helped the region experience economic prosperity for many years, but that growth has recently been curbed. From 2005 to 2020, employment in the coal industry has fallen by 54% and it is estimated that the industry will continue to see steady layoffs of 5% every year [2].

The decline of the coal industry, impacting regional economies and jobs, is due to two primary factors. First, advancements in mining technology and the rising costs of Appalachian coal, coupled with dwindling reserves, have made many coal jobs obsolete [3]. Second, the global push towards renewable energy, highlighted by the International Energy Authority's goal of achieving Net Zero Emissions by 2050, necessitates a significant increase in renewable investment. The Biden Administration supports this shift with targets of 80% renewable energy by 2030 and 100% carbon-free energy by 2035, backed by the Inflation Reduction Act's $370 billion funding for renewable technologies [4][5]. These measures aim to replace coal with sustainable energy sources, offering new economic prospects for affected communities.

Although western Virginia has fallen on socioeconomic hardship, transitioning to renewables could have a positive impact. From stimulating economies to building reliable energy infrastructure, the investment in renewables offers hope to a community like western Virginia. A report done by the Political Economy Research Institute claims that in West Virginia alone, more than 25,000 jobs could be created annually due to investment in renewable energy [6]. This shift promises significant job growth, offering a revitalizing boost to regions impacted by the declining coal industry. Our project focuses on assessing renewable energy's potential in the region, seeking dual benefits of cleaner energy and new job opportunities for local communities.

## II. LITERATURE REVIEW

### A. Economics

To assess the potential for renewable energy to boost the economy in Appalachia, we first reviewed the literature on economic impacts of renewable energy development and their associated costs. According to the Appalachian Regional Commission (ARC), private sector employment in Appalachia has failed to match the pace of trends in the rest of the U.S. [6]. This has left 182 counties across Appalachia categorized as economically "distressed" or "at-risk." [6] In a 2011 project analyzing renewable energy options in Appalachia, authors found that multiple sources of renewable energy should be used in order to meet energy needs and keep costs low [7]. In 2022, President Biden signed the Inflation Reduction Act, which includes tax credits for developments in clean energy [8]. Tax credits are also available in certain economic "opportunity zones," also defined by ARC [6]. Subsidies from the government paired with localized funding, like the Appalachian Solar Finance Fund, can make renewable energy development in Appalachia feasible [9].

*B. Solar*

Our literature review of solar energy assessed the solar energy resources in the Appalachian region of Virginia, the stakeholders involved in the area, and the potential for growth of the technology in the region. According to a report done by The Grid Lab and UC Berkeley, Appalachia stands to gain more than $28 billion from now until 2030 if they commit to investing in solar energy [10]. These funds come from a combination of Operating and Management Wages, Construction Wages, Land Lease Agreements and Local Tax Revenues.

Out of all states in the Mid-Atlantic region, Virginia ranks third out of eight states that are producing solar energy. The state currently produces 631 MW per year of solar energy, but according to the Solar Energy Industries Association (SEIA), the state could provide 50% of energy demand by investing heavily in the technology [11]. Goals like this are achievable as the cost of producing solar power has continued to decrease over the last decade. Solar power only costs ~$0.10 / KWh while fossil fuels tend to cost ~ $0.15 - $0.20 / KWh [12].

*C. Wind*

Best characteristics for siting and sizing wind farms were determined based on current wind energy technology. Good locations for wind turbines include tops of smooth rounded hills, open plains and water, and mountain gaps that funnel and intensify wind. They are best in unpopulated areas that have frequent sustained winds and inexpensive access to the power grid. Developed areas are less favorable due to infrastructure blocking wind and higher population density [13]. Also, wind turbines will have greater health and climate benefits in places where coal plants are the predominant energy production method [14]. The Appalachian region fits these criteria. Wind turbines can be placed in multi-use landscapes, fitting into different areas without greatly disrupting current land use. Annual average wind speed should be at least 9 mph for small wind turbines and 13 mph for utility-scale turbines. Currently, 57% of U.S. wind production is in 5 states in the middle of the country (TX, IA, OK, KS, IL), and there are very few wind farms on the East Coast [15]. This research shows a clear lack of wind turbines in Virginia and suggests potential in Appalachia.

*D. Hydropower*

Our literature review of hydropower and relevant technologies explored the potential application of expanding existing hydropower technologies in Appalachia, as well as developing more. In 2021, hydropower represented 6.6% of all electricity generated in the US and 38% of electricity from renewable energy generated in the US. Pumped Storage Hydropower (PSH) represented 93% of grid storage in the US in 2021, and it is the current least cost technology option for 4-16 hour storage duration [14]. In Bath County VA, one of the counties considered in the area of study for this project, a PSH facility began commercial operation in 1985 and has a net generating capacity of 3,003 MW, or enough to power approximately 750,000 homes [16].

Pumped Storage Hydropower (PSH) is an energy storage technology that uses two reservoirs at different elevations as a battery. When excess energy is on the grid, water is pumped to the higher reservoir. During high-demand times, gravity pulls water down a penstock connecting the two reservoirs and energy is generated. Coupled with wind or solar, PSH can be a powerful tool to help solve grid intermittency issues. Being completely mechanical, PSH is advantageous over competing chemical battery solutions that have a shorter lifespan, are hard to recycle, and rely on rare earth metals [17]. We explored the potential to utilize existing dams and abandoned coal mines as reservoirs for PSH in Appalachia, as well as the potential for new reservoir locations based on the slope of the land, since high slopes have high power potential.

## III. METHODS

Our analysis of renewable energy potential focused on the 25 counties in Virginia that are in the Appalachian Regional Commission. To determine what land would be feasible options for renewable energy development, current land use was taken into account. Conservation and easement land was excluded, as was category 4 and 5 forest and agricultural land [18]. These land types were identified using data from the Virginia Department of Conservation and Recreation [19][20]. After filtering, we had an ArcGIS layer of all land in the Appalachian region in Virginia available for renewable energy development, shown in Fig. 1.

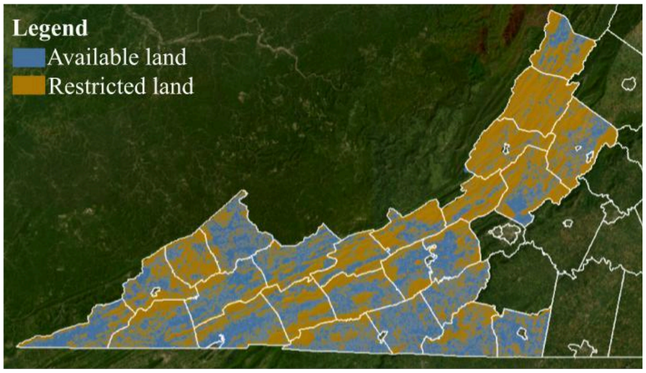


Figure 1. Available (blue) and restricted (orange) land for renewable energy development in Appalachian Virginia.

To evaluate the potential of various counties in the region to develop renewable energy sources, we used a weighting scheme to prioritize technical and social factors according to the priorities of hypothetical stakeholders favoring a particular balance across metrics. We explored three cases: a Solar Use Case, a Wind Use Case, and a Mixed Use Case, in which solar power, wind power, or a mix of renewables were favored by stakeholders. We used a total of 11 metrics to rank our 25 counties; the spreadsheet we created can be found in the GitHub repository abbydawley/AppEnergy. For each metric, the data were normalized based on the range of observed values to ensure uniformity in the way data was analyzed. We then decided on a "base metric" to establish how much of each other metric stakeholders would be willing to give up for one unit of the established base metric. Using an example from the current weighting sheet, we chose PV Output/Year to be the base metric for the Solar use case. From this base metric, assumed stakeholders would be willing to trade-off 0.4 Wind AEP for 1 unit of PV output/year. This renders wind AEP less important in the weighting scheme. The goal of this method for weighting our metrics was to avoid assigning arbitrary weights and to have a formulaic method we could stand behind. For this paper, we show the results from the hypothetical weights used in the Mixed Use case, but the method could easily be adapted to alternative sets of weights. From this, one could evaluate tradeoffs in which counties are most favorable according to different stakeholders priorities. The weighted scores for the Appalachian counties of Virginia under the Mixed Use case are visually represented in Fig. 2.

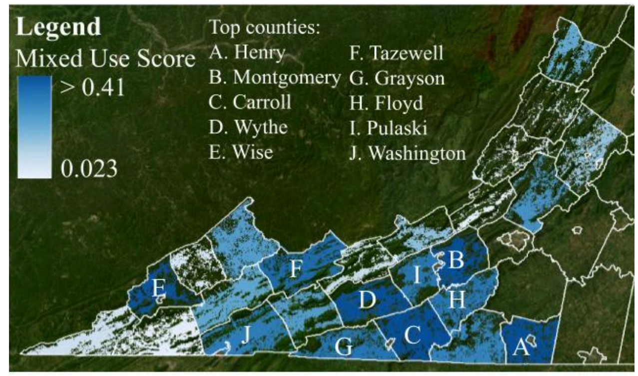


Figure 2. Average scores over available land in each county for Mixed Use Case (darker blue is higher score and more favorable).

Once the counties were assigned scores, two of the top-scoring counties, Carroll and Floyd were selected for further investigation, with others being dropped from consideration due to unfavorable ordinances around renewable energy development. Neither Carroll nor Floyd had favorable locations for expanding hydropower, so we focused on flat land that is preferred for solar and wind development first by filtering to only include land with a slope less than 7 degrees. The slope layer was accessed through ArcGIS Online. Then, we calculated the levelized cost of energy (LCOE) from wind and solar farms on this land, which helps to predict the cost of energy projects.

Calculating LCOE requires the following parameters: wind turbine rating (MW), capital expenditures ($/kW), fixed charge rate (%), operational expenditures ($/kW/yr), and net annual energy production (MWh/MW/yr) [21]. Using ArcGIS, we found that the top annual wind energy production (AEP) values were about 20,000 MWh. We also found that a wind turbine rating of 5.3 MW was most appropriate for this project [22]. This allowed us to calculate net annual energy production per turbine of 3,773.58 MWh/MW/yr. To obtain the remaining parameters, we referenced the National Renewable Energy Laboratory's 2022 Cost of Wind Energy Review [21]. We scaled their values for capital expenditures and operational expenditures to align with our wind turbine rating and energy production, allowing us to ultimately calculate an LCOE of $37.38/MWh. This is slightly more expensive than the national average LCOE of land-based wind projects of $32/MWh, as existing U.S. projects are in the most productive areas for wind generation. [23].

To calculate LCOE for solar energy, we used data obtained from the International Energy Agency and solar direct normal irradiance (DNI) numbers in MWh. According to the map in Fig. 3, the average solar DNI in the areas of greatest intensity is about 5 kWh/m$^2$. This translates to an LCOE of $3.20/MWh/m$^2$. The average LCOE for utility scale solar projects varies widely, but $3.20 is considered low for this scenario [24]. In comparison to solar and wind, the average LCOE for coal is $108/MWh and for natural gas it is $60/MWh [25].

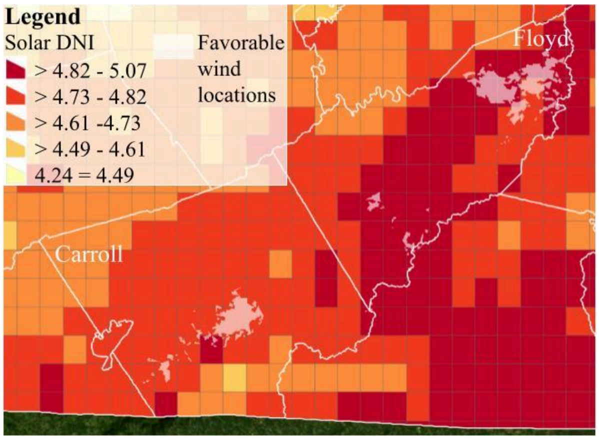


Figure 3. Solar DNI over Caroll and Floyd (darker red is higher and more favorable), with best wind location areas shaded white.

After LCOE was found, we filtered to include land with an LCOE less than 45. Lastly, we took the National Land Cover Database (NLCD) land use data to filter for only hay/pasture land. These are areas where “pasture/hay vegetation accounts for greater than 20% of total vegetation” [26]. This was chosen to avoid land that has already been developed. This left us with the areas of land that fit all of our requirements: slope under 7, LCOE under 45, and hay/pasture land.

The primary goal of the site selection was to find a place to implement a “Hybrid Renewable Site”, which would be optimal for both solar and wind development. Because the criteria for developing wind turbines is more complex, we decided that the wind criteria would take the lead on site selection, and from there solar selection would be used to find the optimal site within the best sites for wind. Solar sites were determined by evaluating PV/Output based on sunlight over the year. This metric was used to determine how much energy could be produced from a solar panel at the optimal angle. The threshold that was used for this was PV/Output > 1500 kilowatt-hour per kilowatt-peak (kWh/kWp).

## IV. RESULTS

The location of the ideal combination of development factors for wind and solar in Floyd and Carroll counties can be seen in Fig. 3. We found that the north-eastern region of Floyd County, and western-central region of Carroll County are the two best locations in these counties for wind energy development. Likewise, we found that these areas of Floyd and Carroll counties are among the most promising areas for solar energy development in Appalachian Virginia, following our ArcGIS analysis of Solar DNI in the region. The overlap in these areas allows for the possibility of mixed solar and wind energy development.

We found that the average energy consumption in all of Virginia is around 14.96 MWh per capita [27][28]. Applying this to Floyd County, with a population of 15,566 their annual energy demand would be 232,482 MWh [27]. Floyd produces no electricity of their own within the county. Utilizing this same consumption standard, we estimated the demand in Carroll County to be 435,799 MWh annually for their population of 29,048 residents [28]. However, Carroll does produce its own electricity, with 89,465 MWh produced annually, all from hydro-electric power plants [28]. Thus, the remaining annual demand for energy that could be met by solar and wind installations is 346,334 MWh.

We next estimated the amount of land necessary to meet this demand from a solar or wind farm alone, as well as the cost to build such a farm. One MW of installed solar capacity produces 2,146 MWh annually, and requires around 7 acres of land, at an average installation cost of $990,000 [29]. One land based 5.3 MW rated turbine produces 20,000 MWh of electricity annually [30]. Each turbine requires up to 278 acres of space to operate at maximum capacity, although in actuality many are given just fractions of this number. Installation of a single turbine costs around $10,012,500, given the cost of the turbine itself, permits, foundation design, transformers, and the actual erection of the turbine [31]. When we applied these costs and land use estimates to the demand for both Floyd and Carroll counties, we found the total area and cost of installing both solar and wind projects that could cover 100% of the demand for each county. These estimates can be seen in Table I below. Carroll only has 5,383 acres of suitable land, which is not enough area for a wind installation of large enough size to meet the energy demand of the county.

TABLE I. 100% of energy demand met by solar and wind in Floyd and Carroll counties.

| Location | Type of energy | Required land | Cost |
|---|---|---|---|
| Floyd | Solar | 758 acres | $107,256,600 |
| | Wind | 3,200 acres | $110,062,500 |
| Carroll | Wind | 6,400 acres | $220,117,500 |
| | Solar | 1,130 acres | $159,776,100 |

TABLE II. Demand split 50-50 between wind and solar in Floyd and Carroll counties.

| Location | Required land | Cost |
|---|---|---|
| Floyd | 1,992.5 acres | $103,660,800 |
| Carroll | 3,375 acres | $189,950,550 |

A potential solution to the problem of acreage could be splitting the demand 50-50, with each county having solar and wind farms helping produce electricity. The installation costs for these mixed energy installations can be seen in Table II. This significantly decreases acreage needed for Carroll, but does cost $30 million more than strictly solar based energy production. Thus, Carroll County seems to be a better location for heavy solar development, whereas Floyd could be an ideal scenario for mixed energy projects.

## V. DISCUSSION

While this analysis revealed great potential for renewable energy development in Floyd and Carroll counties of Appalachian Virginia, there is still much work to be conducted moving forward. Certain locations have been identified as the most feasible for both wind and solar developments; however, research on the most optimal energy portfolios for these locations would better inform any future development. Considering technologies such as biomass could also help optimize an energy portfolio and warrants further research. Additional work could explore how available clean tax credits and subsidies in the region could incentivize businesses and residences to transition to renewable energy, drawing on work done in this project. A number of federal and state solar, wind, hydro, clean vehicle, and carbon tax credits exist, but how a renewable energy developer leverages these credits to optimize renewable energy installations is unexplored. Future work could also include speaking to residents of the identified areas in Floyd and Carroll counties. Input from residents is extremely valuable in creating buy-in so that development is socially and politically feasible.

We also identified limitations to our assessment, including land ownership and data availability. In conducting a literature review of the topic, we found many examples of renewable development projects that were proposed and abandoned due to land-owners pushing back on the project. Land ownership seems to be one of the largest hurdles to renewable energy development, but working with landowners was outside the scope of this project. Also, available data for current energy usage by county and municipality was limited, so energy needs were calculated through average per capita usage in the entire state. A closer look at more accurate energy usage data would increase the accuracy of our energy demand and cost predictions.

## VI. CONCLUSION

Appalachia was once a cornerstone of America's energy production industry. With the growth of wind and solar energy technologies, and the diminishing demand for coal, Appalachia stands in a position to benefit from a transition to renewable energy. The natural resources, as well as available land and economic status of both Floyd and Carroll counties, set them apart as two potential sites for renewable energy development to take place. Through the implementation of utility scale solar and wind farms, these counties could meet their entire electricity demand through renewable sources, and potentially scale from there to export electricity to neighboring counties that lack the resources to produce electricity for themselves.

## REFERENCES


[1] "Virginia Coal," *vept.energy.vt.edu*. https://vept.energy.vt.edu/coal.html (Accessed Apr. 8).

[2] R. Pollin, J. Wicks-Lim, S. Chakraborty, and G. Semieniuk, "IMPACTS OF THE REIMAGINE APPALACHIA & CLEAN ENERGY TRANSITION PROGRAMS FOR WEST VIRGINIA Job Creation, Economic Recovery, and Long-Term Sustainability," 2021. Accessed: Apr. 11, 2024. [Online]. Available: https://peri.joomladesignstudios.co/images/WV-CleanEnergy-2-22-21.pdf

[3] "Here's why Central Appalachia's coal industry is dying," *Washington Post*, Nov. 25, 2021. Available: https://www.washingtonpost.com/news/wonk/wp/2013/11/04/heres-why-central-appalachias-coal-industry-is-dying/ (Accessed Apr. 8).

[4] International Energy Agency, "Net Zero by 2050 – Analysis," *IEA*, May 2021. https://www.iea.org/reports/net-zero-by-2050, (Accessed Apr. 1).

[5] H. J. Mai, "Energy experts share how the U.S. can reach Biden's renewable energy goals," *NPR*, Feb. 02, 2023.https://www.npr.org/2023/02/02/1148370220/biden-renewable-energy-goals, (Accessed Apr. 1).

[6] E. Bowen, Christiadi, J. Deskins, and B. Lego, "An overview of coal and the economy in Appalachia: Fourth Quarter 2020 update.," Appalachian Regional Commission, https://eric.ed.gov/?id=ED613678 (accessed Apr. 8, 2024).

[7] M. Vlachopoulou et al., "Spatial analysis of renewable energy potential in the greater southern Appalachian Mountains," Renewable Energy, https://www.sciencedirect.com/science/article/abs/pii/S0

960148111001960.
[8] "Fact sheet: How the inflation reduction act's tax incentives are ensuring all Americans benefit from the growth of the Clean Energy Economy," U.S. Department of the Treasury, https://home.treasury.gov/news/press-releases/jy1830#:~:text=The%20Inflation%20Reduction%20Act%20modifies,proportion%20of%20qualified%20apprentices%20from (accessed Apr. 8, 2024).
[9] A. Long, A. Wells, A. Crosson, H. Vargason, and M. Palmer, "About," Solar Finance Fund, https://www.solarfinancefund.org/about/ (accessed Apr. 8, 2024).
[10] D. Slanger, "Reality Check: Appalachia Poised to Become Clean Energy Country," *RMI*, Sep. 21, 2021. https://rmi.org/rmi-reality-check-appalachia-poised-to-become-clean-energy-country/#:~:text=the%20next%20decade.- (accessed Apr. 11, 2024).
[11] "The Nature Conservancy in West Virginia," *The Nature Conservancy*. https://www.nature.org/en-us/about-us/where-we-work/united-states/west-virginia/?vu=r.v_westvirginia.local.na.wv (accessed Apr. 11, 2024).
[12] Inspire Clean Energy, "Is Renewable Energy Cheaper? Least and Most Expensive Energy Sources," *Inspire Clean Energy*, Jan. 04, 2021. https://www.inspirecleanenergy.com/blog/clean-energy-101/is-renewable-energy-cheaper (accessed Apr. 11, 2024).
[13] Terry, "The Top 4 Characteristics Of An Ideal Onshore Wind Farm Site," AIS Wind Energy, https://aiswindenergy.co.uk/the-top-4-characteristics-of-an-ideal-onshore-wind-farm-site/. (accessed Apr. 8, 2024).
[14] K. Siler-Evans, I. L. Azevedo, M. G. Morgan, and J. Apt, "Regional variations in the health, environmental, and climate benefits of wind and solar generation," *Proceedings of the National Academy of Sciences*, vol. 110, no. 29, pp. 11768–11773, May 2013. doi:10.1073/pnas.1221978110
[15] "Wind explained: Where wind power is harnessed," U.S. Energy Information Administration (EIA), https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php (accessed Apr. 8, 2024).
[16] S. Fridley, "Inside Bath County Power Station," YouTube, https://www.youtube.com/watch?v=_DiC-NQBpFE&t=1s (accessed Apr. 8, 2024).
[17] S. Desai, "Pumped Storage Hydropower: A grid intermittency solution," Earth ArXiv, https://eartharxiv.org/repository/view/3547/ (accessed Apr. 8, 2024).
[18] "Department of Conservation and Recreation's Virginia Conservation Lands Database," Conservation Lands Database, https://www.dcr.virginia.gov/natural-heritage/clinfo (accessed Apr. 8, 2024).
[19] "Forest Conservation Value," Virginia Conservation Vision Forest Conservation Values Model, https://www.dcr.virginia.gov/natural-heritage/vaconvisforest (accessed Apr. 8, 2024).
[20] "Agricultural Model," Virginia Conservation Vision Agricultural Model, https://www.dcr.virginia.gov/natural-heritage/vaconvisagric (accessed Apr. 8, 2024).
[21] T. Stehly, P. Duffy, and D. M. Hernando, 2022 Cost of Wind Energy Review, https://www.nrel.gov/docs/fy24osti/88335.pdf (accessed Apr. 8, 2024).
[22] K. Fletcher, personal communication, February 2024.
[23] R. Wiser and M. Bolinger, Land-Based Wind Market Report: 2022 Edition, https://www.energy.gov/sites/default/files/2022-08/land_based_wind_market_report_2202.pdf (accessed Apr. 8, 2024).
[24] International Energy Agency, "Renewable Energy Market Update," *IEA*, June 2023. https://www.iea.org/reports/renewable-energy-market-update-june-2023 (Accessed Apr. 11, 2024).
[25] "Average levelized cost of energy (LCOE) by energy source worldwide in 2021," Statista, https://statista.com/statistics/1312123/global-lcoe-by-energy-source/. (accessed Apr. 8, 2024).
[26] "National Land Cover Database Class Legend and description," National Land Cover Database Class Legend and Description, https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description (accessed Apr. 8, 2024).
[27] A. Zdanov. "Floyd County, Virginia Electricity Overview." findenergy.com. https://findenergy.com/va/floyd-county-electricity/ (accessed Apr. 1, 2024).
[28] M. Hope. "Carroll County, Virginia Electricity Overview." findenergy.com. https://findenergy.com/va/carroll-county-electricity/ (Accessed Apr. 1, 2024).
[29] B. Lambert. "The Ultimate Guide to 1 MW Solar Power Plant Cost and Profit." Medium.com. https://medium.com/@grazelog/the-ultimate-guide-to-1-mw-solar-power-plant-cost-and-profit-6efcad725f99 (accessed Apr. 1, 2024).
[30] S. Duchamp and T. Brown. "GE renewable energy launches Cypress onshore wind platform, designed to grow, adapt, thrive and lower the cost of electricity for customers." GE.com. https://www.ge.com/news/press-releases/ge-renewable-energy-launches-cypress-onshore-wind-platform-designed-to-grow-adapt (accessed Apr. 1, 2024).
[31] L. Daniels. "Chapter 8: Wind Costs." windustry.org. https://www.windustry.org/community_wind_toolbox_8_costs (accessed Mar. 8, 2024).