DOCKET NO. E-100, SUB 179

ATTACHMENT A

Review and Comments on Duke Energy Carolinas, LLC and Duke Energy Progress, LLC's 2022 Proposed Carbon Plan

NCUC Docket NO. E-100, Sub 179

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1. Qualifications

Elena Krieger, PhD, is the director of research at PSE Healthy Energy, where she oversees the organization's scientific research efforts. Dr. Krieger joined PSE in 2013 to launch the organization's work on clean energy. Her research focuses on accelerating the transition to clean and renewable energy resources, and developing transition pathways that realize health, environmental, equity, and resilience co-benefits. Her recent work includes analyzing the integration of energy storage and other distributed energy resources to reduce greenhouse gas and criteria pollutant emissions and increase resilience and clean energy access for underserved communities. Dr. Krieger received her PhD from the Department of Mechanical & Aerospace Engineering at Princeton University, where her research focused on optimizing energy storage in renewable energy systems. She currently serves on the Disadvantaged Communities Advisory Group to the California Energy Commission and California Public Utilities Commission, on the board of the Carbon Lighthouse Association, and is a member of the 2021 cohort of New Voices of the National Academies of Sciences, Engineering, and Medicine. Dr. Krieger holds an AB in Physics and Astronomy & Astrophysics from Harvard University.

Yunus Kinkhabwala, PhD, joined PSE in 2021 as a clean energy scientist where his work focuses on the public health and economic impacts of clean energy transitions and how such impacts are distributed among populations. With PSE, Dr. Kinkhabwala developed datasets representing household spending on energy from publicly available sources and used such data to guide policies outlined in the PSE's Pathways to Energy Affordability in Colorado report in 2022. Dr. Kinkhabwala received his PhD in Applied Physics from Cornell University as a National Science Foundation (NSF) Graduate Research Fellowship Program (GRFP) fellow where he developed methods inspired by statistical physics to forecast small area demographic changes.

Patrick Murphy, PhD, is a senior scientist at PSE Healthy Energy, where he researches clean energy transitions with a focus on resilience and energy equity. Dr. Murphy has 20 years of experience as an energy and systems engineer, operations research analyst, research program manager, and military intelligence officer. He has applied his training and experience to address energy access, emissions reduction and mitigation, and security technologies. He has helped researchers pursue funding from strategic partners and public sector agencies. He researched and implemented environmentally and economically sustainable energy solutions in the United States and Africa, with a focus on resilient energy systems and the economics of reliability. He managed resilient power systems research in the Homeland Security Advanced Research Projects Agency (HSARPA) to prevent and mitigate outages caused by natural and man-made disasters. He consulted for various government and defense agencies to optimize research portfolios for future military systems. Prior to his civilian career, Dr. Murphy was an Army intelligence officer deployed in the former Yugoslavia. Dr. Murphy received his PhD in Operations Research and Master's in Science Policy from George Washington University, and Bachelor's Degrees in Electrical Engineering and Political Theory from the University of Notre Dame.

Please see accompanying CVs for additional qualifications.

2. Assignment

We have been retained by Appalachian Voices to review the plan (the "Carolinas Carbon Plan") filed by Duke Energy Carolina, LLC ("DEC") and Duke Energy Progress, LLC ("DEP") in the above referenced docket. We have been asked to analyze the risks associated with gas expansion and to discuss the potential for building out alternative resources in lieu of gas and the additional benefits resulting from a more aggressive adoption of energy efficiency resources. In this last category, we have been asked to specifically address how clean energy measures focused at low and moderate income households can improve energy affordability.

3. Introduction and Summary of Opinions

Duke Energy's proposed Carolinas Carbon Plan (hereinafter "Plan") lays out a pathway to reduce carbon emissions by 70 percent by 2030-2034 from 2005 levels and reach carbon neutrality by 2050.[1] However, the plan relies heavily on the expansion of gas generation, raising concerns about increased lifecycle greenhouse gas emissions and potential stranded assets. Duke did not consider the full potential of non-fossil resources—such as demand-side energy efficiency, near-term offshore wind growth, distributed energy resources, and energy storage—to mitigate the need for gas plant expansion. Here, we outline the potential risks associated with gas expansion, and discuss the potential for building out alternative resources in lieu of gas. We also analyze how some of these resources can provide additional co-benefits, including an assessment of energy cost burden

[1] Duke Energy, Carolinas Carbon Plan (May 16, 2022) [hereinafter Carolinas Carbon Plan].

reduction through the adoption of energy efficiency resources. Duke analyzed four possible pathways for meeting its carbon targets, but additional pathways considering a broader expansion of cleaner resources hold the potential to bring additional greenhouse gas, air pollution, affordability, and resiliency benefits.

4. Risks Associated with New Gas Plants

The Plan proposes the addition of more than 3 gigawatts (GW) of new gas plants, in part to replace retiring coal capacity. The retirement of coal plants is expected to bring significant greenhouse gas and public health benefits due to the reduction in carbon dioxide (CO_2) and health-damaging air pollutant emissions.[2] However, Duke does not account for the full lifecycle greenhouse gas impacts of switching to gas, and these lifecycle emissions undermine the climate benefits of coal-to-gas switching. Furthermore, combustion of gas and, as proposed in the future, hydrogen, continues to produce health-damaging air pollutant emissions such as nitrogen oxides (NO_x). Finally, building new gas plants exposes the utility to future costs risks associated with stranded assets and volatile natural gas prices, which risk being passed on to customers and negatively impacting affordability.

4.1. Greenhouse gas and air pollutant emissions

The Plan proposes the addition of 2.4 gigawatts (GW) of new combined cycle gas plants and 0.8-1.1 GW of new gas combustion turbines. In its accounting, largely due to the structure of the existing carbon targets, Duke only accounts for the direct stack-level emissions of CO_2. However, failing to account for lifecycle methane emissions from gas use enables Duke to rely on a fossil fuel with significant greenhouse gas impacts. Methane leaks throughout the entire cycle of production, processing, transmission, and use of gas.[3] Summary estimates of emissions across the United States suggest that this leakage is approximately 2.3 percent of gas production and 2.9 percent of gas delivered, resulting in an increase of radiative forcing, a measure of the amount of downward-directed radiant energy onto Earth's surface, of 92 percent over a 20-year time period and 31 percent over 100 years.[4] This leakage therefore nearly doubles the near-term climate impact of direct CO_2 emissions from gas generation estimated by Duke, undermining potential climate benefits of gas use. To achieve

[2] Retiring the coal plants in Duke's portfolio as early as possible will yield the greatest possible health benefits. Duke provides, for example, a range of years from 2027-2033 to retire the Marshall, Roxboro and Mayo facilities (Table 4-2). Based on estimates from Clean Air Task Force's Toll from Coal (2019) analysis, every year of avoided generation will reduce mortality impacts by 47 for Marshall, 31 from Roxboro, and 12 from Mayo. See: www.tollfromcoal.org/#/map/(title:none/NC//detail:none/NC//map:none/NC)

[3] Brandt, A. R., Heath, G. A., Kort, E. A., O'Sullivan, F., Pétron, G., Jordaan, S. M., ... & Harriss, R. (2014). *Methane leaks from North American natural gas systems*. Science, *343*(6172), 733-735.

[4] Alvarez, R. A., Zavala-Araiza, D., Lyon, D. R., Allen, D. T., Barkley, Z. R., Brandt, A. R., ... & Hamburg, S. P. (2018). *Assessment of methane emissions from the US oil and gas supply chain*. Science, *361*(6398), 186-188.

real climate benefits, Duke's low-carbon portfolio should rely on non-fossil alternatives such as renewable energy and demand-side efficiency.

In addition, the combustion of gas produces health-damaging air pollutants such as NO_x. NO_x is a criteria pollutant regulated by the U.S. Environmental Protection Agency both due to its direct health impacts—exposure can cause respiratory problems and may increase the likelihood of asthma—and due to its role as a precursor to the formation of ozone and fine particulate matter ($PM_{2.5}$).[5] Ozone and $PM_{2.5}$ are both associated with respiratory impacts including asthma, particularly for vulnerable populations such as children and the elderly. $PM_{2.5}$ in particular is associated with heart attacks and premature death.[6] The health-damaging air pollutant emissions associated with gas are significantly lower than coal, but still present: gas combustion for power generation in the U.S. in 2017 was associated with approximately 730-1,100 deaths nationwide,[7] and this toll has likely increased in parallel with the 22 percent growth in gas consumption in the power sector in the subsequent four years.[8] The Carbon Plan's P1 modeling run estimates 2,200 tons of NO_x emissions associated with gas and oil combustion for power generation in 2030.[9] Replacing methane with hydrogen, as Duke proposes to do after 2030, continues to produce NO_x emissions.[10] Technologies such as hydrogen fuel cells may be a reasonable consideration for flexible dispatchable supply without relying on combustion technology.

4.2. Financial risks

Increasing reliance on natural gas also opens a number of potential financial risks. The first is increased exposure to gas price volatility. For example, the Henry Hub Natural Gas Spot Price more than quadrupled from May 2020 to May 2022, from $1.75/MMBtu to $8.14/MMBtu.[11] The Base Henry Hub forecast used by Duke, however, does not go above $4.00/MMBtu until the 2030s, and never exceeds $7.00/MMBtu. Even the High forecast does not exceed $8.00/MMBtu until nearly 2040.[12] This fuel price volatility therefore poses an unaccounted-for risk of driving up customer bills. Duke itself

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[5] U.S. ENVIRONMENTAL PROTECTION AGENCY, Nitrogen Dioxide (NO2) Pollution (2021), www.epa.gov/no2-pollution/basic-information-about-no2

[6] U.S. ENVIRONMENTAL PROTECTION AGENCY, Particulate Matter (PM) Pollution (2021), www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm

[7] Buonocore, J. J., Salimifard, P., Michanowicz, D. R., & Allen, J. G. (2021). *A decade of the US energy mix transitioning away from coal: historical reconstruction of the reductions in the public health burden of energy*. Environmental Research Letters, *16*(5), 054030.

[8] U.S. Energy Information Administration. "Natural Gas." Accessed: July 12, 2022. www.eia.gov/dnav/ng/hist/n3045us2a.htm

[9] Appalachian Voices DR 1-28. PC Results - HB951 - A1 (Cap Plan 2030-No CO2 Tax-Forced Retire-1800 Solar-CT Bat Replace-Nuke Add-Nuke Cycle-49 Purc) - 5-1-22.xlsx

[10] Lewis, A. C. (2021). Optimizing air quality co-benefits in a hydrogen economy: a case for hydrogen-specific standards for NO x emissions. *Environmental Science: Atmospheres*, *1*(5), 201-207.

[11] U.S. Energy Information Administration. (2022). "Natural gas." www.eia.gov/dnav/ng/hist/rngwhhdm.htm

[12] Duke Energy. (2022). "Carolinas Carbon Plan." Appendix E: Quantitative Analysis.

has estimated that without building new gas pipeline infrastructure, gas prices in North Carolina risk increasing 33 percent by 2030 compared to the projected baseline.[13] Increasing gas prices — due to lack of pipeline infrastructure or other causes — contribute to a risk that new gas infrastructure will be increasingly expensive and non-competitive with renewable energy resources such as wind and solar, whose costs have declined by 40 percent[14] and 82 percent[15] in the last ten years for utility-scale wind and solar, respectively. Combined with future potential climate regulation (both at the federal level and in individual states) — including scenarios such as a price on direct CO_2 emissions as well as upstream methane emissions or otherwise growing costs due to increased climate regulation — new gas infrastructure runs the risk of becoming a stranded asset. All of these considerations pose a financial risk to Duke and, in turn, to the affordability of electricity for Duke's customers.

5. Alternatives to New Gas Plants

Duke Energy did not fully assess the potential for alternative resources to gas to meet its demand. The alternatives we consider here, including offshore wind, distributed energy resources, demand-side efficiency, and utility-scale energy storage, cannot directly replace a gas plant one-to-one. However, portfolios of these resources can meet the same energy and capacity requirements that Duke proposes to meet with gas. We have neither the capacity nor sufficient data to perform a full EnCompass modeling to identify specific portfolios that could meet future demand. Instead, we evaluate Duke's assumptions regarding potential capacity and growth rates for these alternative resources, and suggest Duke run additional scenarios to incorporate these higher growth rates.

5.1. Demand-Side Energy Efficiency

The Plan states an annual demand-side efficiency savings target of 1 percent of the previous year's sales, but Duke's approach does not realize many of the potential benefits of efficiency due to a variety of factors. In the first part, the target of 1 percent per year only applies to "eligible resources," which we calculate to yield actual demand-side savings of 0.9 percent per year in 2023 declining steadily to 0.68 percent per year in 2044.[16] Duke considers approximately ⅔ of its total load eligible for efficiency programs.

As a second concern, the Plan's annual savings also rely very heavily on *behavioral* demand impacts: for example, 72 to 82 percent of annual incremental residential demand-side savings in DEC territory from 2023-2030 are associated with behavioral changes in consumption, and a greater percentage

[13] Duke Energy. (2022). "Carolinas Carbon Plan." Appendix N: Fuel Supply. P. 9.
[14] Wiser, R., M. Bolinger, B. Hoen, D. Millstein, J. Rand, G. Barbose, N. Darghouth, W.l Gorman, S. Jeong, A.Mills, and B. Paulos. (2021). "Land-Based Wind Market Report: 2021 Edition." *Lawrence Berkeley National Laboratory.*
[15] Feldman, D., V. Ramasamy, R. Fu, A. Ramdas, J. Desai, and R. Margolis. (2021). "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2020." Golden, CO: *National Renewable Energy Laboratory*. NREL/TP-6A20-77324.
[16] DE's Confidential Response to Public Staff Data Request 15-2.

thereafter.[17] While behavioral interventions are important, they are limited: for example, a study of OPOWER's Home Energy Report letters found they produced a reduction in consumption of 2 percent.[18] Duke estimates the lifespan of these behavioral interventions to be a single year,[19] suggesting that the majority of its annual 1 percent savings do not have a lasting impact. For sustained savings, behavioral measures should be coupled with non-behavioral interventions. The short lifespan of the majority of its annual efficiency savings appears to be reflected in Duke's modeling: approximately 70 percent of *cumulative* residential DEC savings reported by Duke in 2030 and 2035 come from non-behavioral measures.[20]

In total, the Carbon Plan's demand-side efficiency savings sum to 5,478 gigawatt-hours (GWh) in 2030 and 6,772 GWh in 2035,[21] equivalent to only 4.3 percent and 5.1 percent of the total sales, respectively. Significantly higher savings are possible. The National Renewable Energy Laboratory (NREL) estimates energy efficiency potential for residential single family buildings is 24 percent of 2012 energy consumption.[22] While Duke's plan incorporates less than 1 percent demand-side savings per year when accounting for total sales, states like Massachusetts and Rhode Island had annual savings over 2 percent in 2021.[23] We calculate that if Duke saved 1 percent of *all* retail sales, as opposed to solely "eligible resources," it would save an *additional* 4,700 GWh in 2030 and 10,300 GWh in 2035 (total savings of 10,200 GWh and 17,100 GWh respectively); if Duke saved two percent per year, it would save an *additional* 14,300 GWh in 2030 and 25,400 GWh in 2035 (total of 19,700 GWh and 32,200 GWh respectively). In its own calculations, Duke reports that one percent savings on all annual load (not just "eligible" resources) would save 6,500 GWh in 2030 and 9,300 GWh in 2030 and 2035, respectively.[24] We suspect these lower values are due to Duke's over-reliance on behavioral measures with a one-year intervention lifetime. The measured lifetimes reported by Duke for non-behavioral interventions largely range from 9-20 years, with only a few exceptions. This analysis suggests that a conservative estimate for one percent efficiency savings is roughly twice the value reported by Duke and a feasible estimate of two percent potential savings is even three times higher. Moreover, Duke's modeled annual efficiency savings actually *decrease* over time, rather than increasing with program development and infrastructure.

In addition to saving energy, expanded demand-side efficiency can reduce capacity needs. Duke Energy's models suggest approximately 6,100 megawatt-hours (MWh) of energy savings corresponds

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17 Calculated from DE's Response to Appalachian Voices Data Request 1-3.
18 Allcott, H. (2011). Social norms and energy conservation. *Journal of Public Economics*, *95*(9-10), 1082-1095.
19 DE's Response to Appalachian Voices Data Request 1-3.
20 Calculated from DE's Response to Appalachian Voices Data Request 1-3.
21 DE's Response to Appalachian Voices Data Request 1-12.
22 Wilson, E. J., Christensen, C. B., Horowitz, S. G., Robertson, J. J., & Maguire, J. B. (2017). "Energy Efficiency Potential in the U.S. Single-Family Housing Stock." Technical Report NREL/TP-5500-68670. *National Renewable Energy Laboratory.*
23 Berg, W., E. Cooper, and M. DiMascio. (2022). "State Energy Efficiency Scorecard: 2021 Progress Report." Washington, DC: *ACEEE*.
24 DE's Response to NCSEA-SACE Data Request 3-23.

to 1 megawatt (MW) of winter peak demand reductions, and around 5,700 MWh of energy savings corresponds to 1 MW of summer peak demand reduction.[25] These are in a similar range as reported by ISO New England, which projects summer peak capacity savings of approximately 1 MW per 5,140 MWh of energy savings.[26] Using Duke's estimate of capacity benefits, a one percent annual efficiency saving rate would lead to an *additional* summer capacity benefit of approximately 800 MW in 2030 and 1,800 MW in 2035, above and beyond the benefit of currently projected efficiency. At two percent annual savings, the additional benefit would be 2,500 MW in 2030 and 4,500 MW in 2035.

Currently, Duke proposes to build 2,400 MW of gas combined cycle plants by 2030. In scenario P1, DEC and DEP report combined cycle capacity factors of 74 percent and 65 percent, respectively.[27] (For comparison, the combustion turbines are given capacity factors under 1 percent.) Assuming, therefore, a capacity factor of 70 percent, that would lead to annual generation of approximately 14,700 GWh. This calculation suggests that incremental investments in demand-side energy efficiency to achieve 2 percent savings per year (non-behavioral) might exceed the capacity value and nearly meet the energy value of the proposed gas combined cycle plants by 2030.

In addition to potentially obviating the need for new gas combined cycle generation, the expansion of demand-side efficiency may provide bill benefits for customers. Efficiency resources are typically cheaper, per MWh saved, than supply-side generation.[28] Customers adopting energy efficiency measures lower their use and, subsequently, their bills. These bill savings may be particularly valuable for low-income households facing high energy cost burdens, as discussed in Section 6 below. However, Duke's historic reported efficiency savings for low-income customers have been negligible.[29] In their projected efficiency savings for DEC territory, roughly 5 percent of annual residential non-behavioral savings come from low-income programs, although they make up nearly 30 percent of all households.[30,31] No low-income-specific measures are reported for DEP territory whatsoever. A worksheet in Appalachian Voices DR 1-17 shows that only 4.2 percent of Duke's combined low-income North Carolina customers participated in any non-behavioral efficiency and demand response programs.[32] Expanding low-income efficiency efforts holds the potential to provide energy and capacity savings, reducing the need for investment in new infrastructure such as gas plants, while improving affordability for the customers who most need it.

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[25] Calculated from data provided in DE's Response to NCSEA-SACE Data Request 3-23.
[26] ISO New England. (2020). Energy-Efficiency Forecast. www.iso-ne.com/system-planning/system-forecasting/energy-efficiency-forecast/
[27] Appalachian Voices DR 1-28. PC Results - HB951 - A1 (Cap Plan 2030-No CO2 Tax-Forced Retire-1800 Solar-CT Bat Replace-Nuke Add-Nuke Cycle-49 Purc) - 5-1-22.xlsx
[28] ACEEE. (2021). "The Cost of Saving Electricity for the Largest U.S. Utilities: Ratepayer-Funded Efficiency Programs in 2018." www.aceee.org/sites/default/files/pdfs/cost_of_saving_electricity_final_6-22-21.pdf
[29] Southern Alliance for Clean Energy. (2021). "Energy Efficiency in the Southeast Third Annual Report." See P. 9.
[30] Calculated from DE's Response to Appalachian Voices Data Request 1-3
[31] Energy demand is likely somewhat lower in these households, but not enough to warrant the significantly lower investment.
[32] DE's Response to Appalachian Voices Data Request 1-17

It therefore behooves Duke to model a Plan scenario with high energy efficiency (e.g. 2 percent annual savings through 2030), including specific low-income efficiency targets, to determine the impacts on overall system design and need to build new gas capacity. Findings should also be reported in terms of average bill impacts. Currently, Duke reports bill impact *per 1,000 kWh* of use (e.g. see Chapter 3, p. 20). However, with higher efficiency savings, average kWh of use is likely to decrease, and it would be more beneficial to compare scenarios based on average bills, reflecting this lower total use. Thus, this scenario could demonstrate both total costs, capacity and energy benefits, and affordability impacts.

5.2. Utility-Scale Energy Storage

The Plan currently proposes to add 1.7-2.1 GW of battery storage by 2030-2034 and 2.0-4.2 GW by 2035, alongside an additional 1.7 GW of new pumped storage. These are key deployments, but could be expanded further. In particular, energy storage is an increasingly competitive option compared to gas combustion turbines. Duke currently proposes an additional 0.8-1.1 GW of gas combustion turbine capacity, but this could likely be replaced with energy storage, or a portfolio of resources.

Across the country, energy storage is being built in lieu of combustion turbines used for peaker power plants. For example, in summer 2021, a 100 MW/400 MWh battery came online in Oxnard, California, instead of a previously proposed gas plant.[33] A few months later, Florida Power and Light brought the 409 MW/900 MWh Manatee Solar Energy Center online.[34] In spring 2022, the New York Power Authority issued a request for proposals for utility-scale storage to replace its peaker power plants.[35] This trend seems likely to continue. Lithium-ion battery pack prices plummeted 90 percent between 2010 and 2021[36] and are likely to continue to drop in the coming decade. Numerous states have adopted energy storage targets for the coming decade. For example, New York, which has similar total electricity consumption to North Carolina,[37] recently doubled its 2030 storage target from 3 GW to 6 GW and already has 12 GW of storage in its interconnection queue.[38] If Duke were to pursue a similar storage

[33] Spector, Julian.(2021). "Oxnard won independence from an unwanted gas plant, and you could too." *Canary Media.*
[34] Florida Power and Light. "Battery Storage." Accessed: July 12, 2022. www.fpl.com/energy-my-way/battery-storage.html
[35] New York Power Authority. (2022). "New York Power Authority Issues Solicitation for Battery Storage Proposals to Use Its Small Clean Power Plant Sites and Electrical Infrastructure." www.nypa.gov/news/press-releases/2022/20220421-battery
[36] Bloomberg New Energy Finance. (2021). "Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite." about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite
[37] U.S. Energy Information Administration. "Electricity Data Browser." Accessed: Jul 12, 2022. www.eia.gov/electricity/data/browser
[38] New York Department of Public Service. (2022). "Third Annual State of Storage Report." Available at: https://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterSeq=55960

target for 2030 (approximately 1 GW for every 23,500 GWh of current annual demand), that would lead to a target of GW of storage by 2030.

The Plan would benefit from conducting additional modeling runs to determine if additional energy storage — both standalone and as part of clean energy portfolios — might successfully replace new combustion turbine capacity. As an example of a clean energy portfolio option, Rocky Mountain Institute modeled clean energy alternatives to a combustion turbine in the Mid-Atlantic region and found that a portfolio of demand response, energy efficiency, and energy storage would be cheaper than a combustion turbine by 17-60 percent (net present value without and with accounting for the value of excess energy generated).[39] Scaling the RMI model for a 475 MW peaker to the 1,100 MW used in Plan scenarios P1-P3 suggests that the proposed combustion turbine could be replaced with 512 MW of energy storage, 1,820 MW of energy efficiency, and 2,411 MW of demand response — and would produce additional value from these resources, such as energy efficiency savings at non-peak times. However, the Plan does not consider significant levels of demand response and energy efficiency, nor how distributed resources combined with energy storage can meet peak demand needs.

In addition to modeling the performance of a similar clean energy portfolio in lieu of a combustion turbine, Duke should consider a scenario with advanced energy storage technologies. The Plan currently includes small modular nuclear reactors in its scenarios, but emerging energy storage technologies, such as flow batteries, seasonal thermal energy storage, metal-air batteries, advanced compressed air energy storage, and others are all significantly more technologically mature than small modular nuclear reactors. It would behoove Duke to include a scenario that considers a low-cost long duration storage technology. In both scenarios, the storage could be charged by renewable energy resources — such as the expansion of offshore wind and distributed solar — and indeed might help improve the integration of these resources onto the grid. In addition, distributed energy storage (see section on DERs below) has the potential to provide resilience and bill benefits to Duke customers.

5.3. Offshore Wind

The Plan includes three possible offshore wind deployment scenarios, ranging from zero offshore wind (P3) to 800 MW between 2030 (P1) and 2032 (P4), and 1,600 MW installed in 2029 and 2031 in P2. Duke constrained the modeling so that offshore wind could only be added in two blocks (800 MW by 2030 and 800 MW by 2032). However, these constraints greatly limit offshore wind's potential and even undercut North Carolina's own goals. Appendix J refers to offshore wind as "mature" and "scalable," and yet handicaps the resource by not enabling it to be built in the near term, citing challenges with transmission siting, and capping the total capacity that can be added before 2040.

[39] Rocky Mountain Institute. (2018). "The Economics of Clean Energy Portfolios". https://rmi.org/wp-content/uploads/2018/05/RMI_Economics_Of_Clean_Energy_Portfolios_2018.pdf

The stated goals are also significantly less than those laid out in Governor Roy Cooper's Executive Order 218, which aims for 2.8 GW of offshore wind by 2030.

North Carolina and South Carolina have significant wind energy potential, including nearly 300 GW in North Carolina (200 GW at wind speeds over 8.5 m/s at 90m) and 130 GW in South Carolina (30 GW at wind speeds over 8.5 m/s at 90m).[40] The Biden Administration recently auctioned off Bureau of Ocean Energy Management (BOEM) leases off the coast of the Carolina for an area including 1.3 GW of offshore wind potential, one of which was won by Duke.[41] Offshore wind is a particularly valuable grid resource due, in part, to its high capacity factor compared to other renewable energy resources (40-45 percent off the coast of North Carolina) and excellent winter peak performance.[42] If Duke integrated 2.8 GW of offshore wind energy by 2030 — in line with the Governor's executive order but likely an underestimate of potential expansion when accounting for additional offshore wind in South Carolina — it would generate 10,300 GWh of electricity, assuming a 42 percent capacity factor.[43] Its winter effective load carrying capacity, estimated at 39 percent,[44] would reach about 1.1 GW.

5.4. Distributed Energy Resources

Distributed energy resources (DERs), located on the customer side of the meter, include rooftop solar photovoltaic units, small wind generating units, fossil fuel generators, battery storage, electric vehicles, and some smart appliances. Renewable DERs and storage can lower energy costs and reduce emissions for households and businesses, as the cost of and emissions from onsite generation can often be lower than grid electricity. In addition, DERs can provide some resilience during power outages and allow utilities to defer and delay investment in—or accelerate the retirement of—fossil fuel power plants.

Barriers to adoption of DERs persist. Few utilities consider the value of DER in planning future generation, transmission, and distribution investments. In part this is due to utilities lacking experience in using DERs to defer or avoid grid investments and monetizing costs and benefits of DERs.[45] In addition, DERs have largely been available only for the small fraction of the population that

[40] Schwartz, M., D. Heimiller, S. Haymes, and W. Musial. (2010). "Assessment of Offshore Wind Energy Resources for the United States." Technical Report NREL/TP-500-45889. *National Renewable Energy Laboratory.*
[41] U.S. Department of the Interior. (2022). "Biden-Harris Administration Announces Winners of Carolina Long Bay Offshore Wind Energy Auction." www.doi.gov/pressreleases/biden-harris-administration-announces-winners-carolina-long-bay-offshore-wind-energy
[42] Dvorak, M. J., Corcoran, B. A., Ten Hoeve, J. E., McIntyre, N. G., & Jacobson, M. Z. (2013). US East Coast offshore wind energy resources and their relationship to peak-time electricity demand. *Wind Energy*, *16*(7), 977-997.
[43] Duke Energy. (2022). "Carolinas Carbon Plan." Appendix E: Quantitative Analysis.
[44] Wintermantel, N. and C. Benson. (2022). "Duke Energy Carolinas and Duke Energy Progress Effective Load Carrying Capability (ELCC) Study." Table 13. *Prepared for Duke Energy by Astrapé Consulting.*
[45] Frick, N. M., Price, S., Schwartz, L. C., Hanus, N. L., and Shapiro, B. (2021). "Locational Value of Distributed Energy Resources." *Lawrence Berkeley National Laboratory.*

have the means and property to invest in and benefit from them. Low-income households and populations of color have lower adoption rates for DERs.[46] Barriers to adoption include lack of access to capital and financing, lower rates of home ownership, and aging rooftops incompatible with rooftop solar.

Notably, the Plan fails to address or promote DERs as part of its carbon mitigation strategy and fails to take into account the benefits of DER for energy affordability for disadvantaged and low-income households. As a result, the plan underestimates the potential for DERs, and makes no considerations for equity and affordability in adopting efficiency measures and DERs.

The Plan projects the adoption of 537 MW of distributed solar by 2030 and 882 MW by 2035, generating 700 GWh and 1,150 GWh respectively.[47] This represents only 0.5 percent and 0.9 percent of retail sales in 2030 and 2035, greatly underestimating potential adoption.[48] In contrast, NREL estimates that maximum solar penetration potential is at least 30 percent of peak load.[49]

The Carbon Plan indicates that solar production will grow by 16 percent compound annual growth rate (CAGR). In Table 2-1 and 2-2, this is shown as about 80-100 GWh per year between 2023 and 2037, allowing for no improvements in methods, growth in industry capabilities, or expansion of potential participants. In year one, growth from 150 GWh to 229 GWh is an impressive 42 percent, but the planned rate of growth rapidly shrinks to less than eight percent per year by 2037. In contrast, according to the Energy Information Agency (EIA), between 2014 and 2021 North Carolina has actually experienced exponential growth in small scale solar adoption at a rate of 30 percent per year.[50] South Carolina's growth rate has been even higher. Considering an exponential growth rate of 30 percent per year, starting from 150 GWh in 2023, this plan could reasonably be expected to achieve 3,500 GWh by 2035—more than double the Plan's estimates. Even this value, at 2.4 percent of retail sales, is likely too low. For example, distributed solar in New Jersey, which has significantly lower solar irradiance,[51] generated 3.7 percent of retail sales in 2021[52] and will continue to grow if current trends continue. Still further north, distributed solar in Massachusetts reached 5 percent of retail sales in 2021. Aiming for 5 percent distributed solar across Duke territory North and South Carolina by 2030 would generate more than 6,350 GWh from approximately 4.8 GW.

[46] Sunter, D.A., Castellanos, S., and Kammen, D.M. (2019). "Disparities in Rooftop Photovoltaics Deployment in the United States by Race and Ethnicity." *Nature Sustainability.* 2.1, 71-76.
[47] DE's Response to Appalachian Voices Data Request 1-12.
[48] Calculated from DE's Response to Appalachian Voices Data Request 1-12.
[49] Hoke, A., Butler, R., Hambrick, J., & Kroposki, B. (2012). "Maximum Photovoltaic Penetration Levels on Typical Distribution Feeders: Preprint." Technical Report NREL/JA-5500-55094. *National Renewable Energy Laboratory*.
[50] U.S. Energy Information Administration. "Electricity Data Browser." Accessed: Jul 12, 2022.
[51] Roberts, B. (2018). "Global Horizontal Solar Irradiance." *National Renewable Energy Laboratory.* www.nrel.gov/gis/assets/images/solar-annual-ghi-2018-usa-scale-01.jpg
[52] U.S. Energy Information Administration. "Electricity Data Browser." Accessed: Jul 12, 2022.

Solar and DER adoption in North Carolina has been overwhelmingly associated with wealth. Almost half (more than 47 percent) of rooftop solar installations were on homes whose residents are in the top 20 percent income bracket. Three quarters of rooftop solar installations have been on homes with incomes in the top 40 percent of income, and only 4 percent of solar installations were for the lowest 20 percent income bracket.[53] This clearly indicates that programs to increase adoption and reduce barriers for low-income and disadvantaged households would unlock huge potential gains in solar DER deployment and CO_2 reduction, and energy affordability, potentially even beyond current trends of 30 percent growth per year. Methods and programs should include low-interest or no-interest financing, community outreach and training, net metering pricing incentives for low- and moderate-income households, and community solar that allows renters and households without suitable rooftops to access affordable, clean, distributed energy.[54]

Solar DER, especially when paired with battery storage, has the potential to reduce peak demand, as maximum solar energy often coincides with maximum demand, often driven by cooling needs. Batteries enable intermittent solar to continue to provide peak cooling energy even when clouds interrupt production, or when cooling demand continues after peak sunlight hours. Adding energy storage to distributed solar installations can further enable these systems to help meet peak demand needs. Duke estimates that utility-scale solar+storage has a capacity value of 32 percent.[55]

Local storage also enables resilience to normal (3-5 hour) outage events. The batteries that enable the use of sunlight after the sun has gone down, and to avoid expensive peak rate hours from grid electricity, can also support some consumption during short duration outages. Bigger batteries could also support longer outages, but may drive up costs significantly unless allowed to provide aggregated grid services to Duke.

Duke currently has 690 MW of demand response in its portfolio,[56] equivalent to approximately 1 percent of the winter peak. Only 32 MW of this demand response is residential. As mentioned above, expanded demand response may be able to play a significant role in reducing the need for gas combustion turbines. Furthermore, residential demand response can help improve affordability for low-income residential customers, as described further in Section 6. However, demand response does not play any significant role in the Carolinas Carbon Plan and does not appear to be selectable at higher rates in the model used by Duke. About ⅓ of residential demand response customers are below 200 percent of the Federal Poverty Line.[57] Expanding demand response and maintaining this share for low-income customers could provide some affordability benefits.

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[53] Lawrence Berkeley National Laboratory. “Solar Demographics Tool.” emp.lbl.gov/solar-demographics-tool
[54] Lukanov, B., A. Makhijani, K. Shetty, Y. Kinkhabwala, A. Smith, and E.M. Krieger. (2022). “Pathways to Energy Affordability in Colorado”. *Physicians, Scientists, and Engineers for Healthy Energy and the Institute for Energy and Environmental Research for the Colorado Energy Office.*
[55] Duke Energy. (2022). “Carolinas Carbon Plan.” Appendix E: Quantitative Analysis.
[56] Duke Energy. (2022). “Carolinas Carbon Plan.” Appendix G: Grid Edge and Customer Programs. Table G-12.
[57] Duke Energy. (2022). “Carolinas Carbon Plan.” Appendix G: Grid Edge and Customer Programs.

5.5. Meeting Energy and Capacity Needs

The Carolinas Carbon Plan relies on the expansion of 2.4 GW of natural gas combined cycle plants and 0.8-1.1 GW of gas combustion turbine facilities to meet 2030 demand. These would supply 14,700 GWh and 70 GWh of energy, respectively, assuming a 0.7 percent capacity factor for the combustion turbine based on the P1 modeling runs.[58] Together, this totals approximately 3.2-3.5 GW of capacity and 14,800 GWh of energy. However, the previous sections describe how the Plan places unnecessary constraints on the expansion of offshore wind, energy storage, distributed energy resources, and energy efficiency. Removing these barriers would enable the supply of significantly more energy and capacity than provided by the gas plants, and without the associated risks of gas price volatility, lifecycle greenhouse gas emissions, and stranded asset concerns. Additional EnCompass runs could incorporate higher levels of these resources to determine an optimal cost mix, and a report of average bills per household (rather than average bill per 1,000 kWh) would enable a comparison of affordability for each scenario.

Based on the above analysis, the following resources should be considered:

- **Energy efficiency:** Annual demand-side efficiency savings of 1 percent per year (based on non-behavioral interventions with multi-year measure lifespans) would realize 4,700 GWh of energy savings and provide 800 MW of demand reduction by 2030 beyond Duke's current efficiency plans. Achieving 2 percent demand-side savings per year would provide 14,300 GWh of energy savings and 2,500 MW of demand reduction beyond Duke's current plans, roughly on par with the proposed gas combined cycle facilities. Duke could also enable demand-side efficiency to be selected as a resource in its optimization model, and in all scenarios should report the results in terms of average bill benefits to customers. Targeting programs towards low-income households would provide affordability benefits and open up opportunities to achieve historically underutilized savings potential.
- **Offshore wind:** Adopting 2.8 GW of offshore wind by 2030, in line with the Governor's executive order, would provide 10,300 GWh of electricity and meet 1.1 GW of peak demand.
- **Energy storage:** Building 0.8-1.1 GW of battery storage to replace the proposed combustion turbines would likely be cost-competitive given similar examples across the country. The combustion turbines could likely also be replaced with a portfolio of storage, efficiency, and demand response. Modeling an "advanced storage technology" scenario would also enable Duke to plan around a potential future where prices drop for emerging technologies such as flow batteries and metal air batteries; these technologies are already further along in development than the small modular nuclear reactors used in the Plan.

[58] Appalachian Voices DR 1-28. PC Results - HB951 - A1 (Cap Plan 2030-No CO2 Tax-Forced Retire-1800 Solar-CT Bat Replace-Nuke Add-Nuke Cycle-49 Purc) - 5-1-22.xlsx

- **Distributed solar:** Expanding distributed solar to provide 5 percent of demand, similar to levels currently achieved in Massachusetts, would generate nearly 6,400 GWh of electricity. Coupling these resources with distributed storage would provide additional capacity and resilience benefits, and may be particularly valuable if programs are expanded to ensure equitable access for low-income and historically underserved populations.
- **Demand response:** Demand response resources, which currently meet 1 percent of peak demand, should be allowed to be selected as a model resource and may be particularly valuable for combustion turbine replacement.

Combined portfolios of efficiency, energy storage, offshore wind, demand response, and distributed solar and storage have the potential to provide significantly more energy and capacity resources by 2030 than the proposed gas plants in the Plan, but the full use of these resources have been excluded from consideration. Ensuring access to these resources for low-income households may be particularly valuable for affordability, as discussed in the following section, and expanded low-income programs would provide combined energy, capacity, and affordability benefits. We recommend the inclusion of portfolios which increase use of these resources, both through 2030 and to achieve a 100 percent renewable target by 2050.

6. Energy Cost Burden Benefits of Energy Efficiency

6.1. Energy Cost Burden Estimates in Duke Territory

Energy bills strain low-income household budgets across the US. A recent survey[59] found that high energy bills lead to various negative outcomes.[60] For example, almost one-fourth of respondents experienced housing problems and had to move in with friends or family or to a shelter or were homeless; three-fourths of respondents forwent household necessities to pay energy bills; and one-fourth kept their home at unsafe or unhealthy temperatures due to not having enough money. Furthermore, these financial burdens lead to longer periods of poverty and increased incidences of death[61]. However, Duke has historically performed a negligible amount of outreach for low-income households[62] despite the fact that approximately a third of their customers have incomes less than twice the federal poverty limit.[63]

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[59] The National Energy Assistance Directors' Association. (2018). "2018 National Energy Assistance Survey Final Report." www.appriseinc.org/wp-content/uploads/2019/02/NEADA-2018-LIHEAP-Survey.pdf

[60] Bednar, D. J., & Reames, T. G. (2020). Recognition of and response to energy poverty in the United States. *Nature Energy*, *5*(6), 432-439.

[61] Memmott, T., Carley, S., Graff, M., & Konisky, D. M. (2021). Sociodemographic disparities in energy insecurity among low-income households before and during the COVID-19 pandemic. *Nature Energy*, 6(2), 186-193.

[62] Southern Alliance for Clean Energy. (2021). "Energy Efficiency in the Southeast Third Annual Report." See P. 9.

[63] NC Low-Income Collaborative Analytics. Filed in Docket E-7 Sub 1214. Joint NC LIAC Quarterly Progress Rpt. April 25, 2022.

To quantify the impacts of energy bills on household budgets, researchers often employ the energy cost burden metric—the percentage of a household's pre-tax income spent on energy. Energy cost burdens over six percent are considered to be "high".[64] Here we estimate household energy bills within the Duke service areas to examine trends in the energy cost burdens. Utility bills, most commonly for electricity and natural gas, are dominated by the end uses of space heating/cooling, water heating, and appliances. Using models based on prior methods[65,66] we simulate a portfolio of household energy spending broken down by fuel type and end use.[67] These models rely on data from the American Community Survey,[68] EIA Residential Energy Consumption Survey,[69] the American Housing Survey,[70] and climate data. Merging these energy use values with local energy rates provides simulated household energy bills across the Duke service area in North Carolina (including both Duke Energy Progress and Duke Energy Carolinas). In Figure 1, we show the breakdown of energy cost burdens amongst low- and moderate-income (LMI) households.

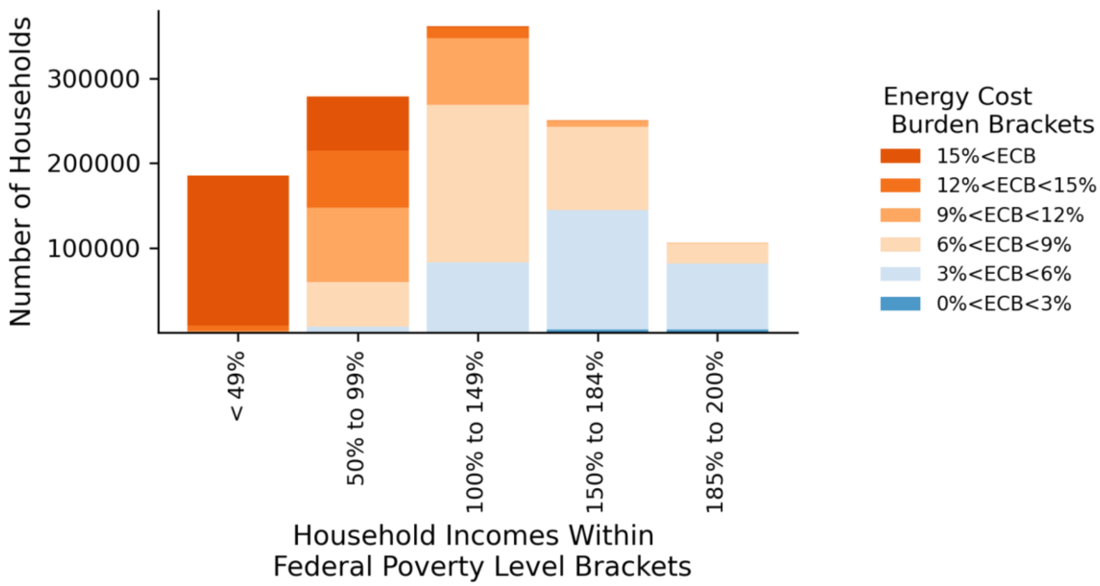

Figure 1. Energy cost burden distributions within LMI income brackets.

[64] Roger D. Colton. "Home Energy Affordability Gap." www.homeenergyaffordabilitygap.com/
[65] Min, J., Hausfather, Z., and Lin, Q. F. (2010). A High-Resolution Statistical Model of Residential Energy End Use Characteristics for the United States. *Journal of Industrial Ecology*, 14(5), 791-807.
[66] Jones, C., and Kammen, D. M. (2014). Spatial Distribution of US Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density. *Environmental Science & Technology*, 48(2), 895-902.
[67] For details see Lukanov, B., A. Makhijani, K. Shetty, Y. Kinkhabwala, A. Smith, and E.M. Krieger. (2022). "Pathways to Energy Affordability in Colorado." *Physicians, Scientists, and Engineers for Healthy Energy and the Institute for Energy and Environmental Research for the Colorado Energy Office.*
[68] U.S. Census Bureau. "TIGER/Line FTP Archive: 2019 ACS." Accessed: October 2021.
[69] U.S. Energy Information Administration. "Residential Energy Consumption Survey 2015." Available at: www.eia.gov/consumption/residential/data/2015/
[70] U.S. Census Bureau. www.census.gov/programs-surveys/ahs.html

There are approximately 1.15 million households here, including 500,000 households less than the Federal Poverty Level (FPL) and 650,000 households between one and two times the FPL. Approximately 850,000 of these LMI households have energy cost burdens greater than six percent. As expected, the lowest incomes experience the highest levels of energy cost burden with a decreasing proportion as incomes increase. While this analysis limits itself to LMI households less than twice the FPL, above that income bracket there remain an additional 35,000 households with energy cost burdens greater than the six percent threshold. This number of LMI households is approximately 17 percent higher than reported by Duke.[71] The discrepancy in total LMI households arises from using publicly available data in the absence of private data available to the utility.

A related metric of cumulative financial energy burden is the energy affordability gap, the total amount of money needed in the form of financial assistance to bring energy bills below the six percent threshold. Figure 2 presents the energy affordability gap within income brackets. The total energy affordability gap for LMI households adds up to roughly $630 million dollars annually with the most significant amount needed for the very lowest income brackets. This value is a conservative estimate, and has separately been estimated to be as high as $1.4 billion for the entirety of North Carolina by the research firm Fisher, Sheehan & Colton.[72]

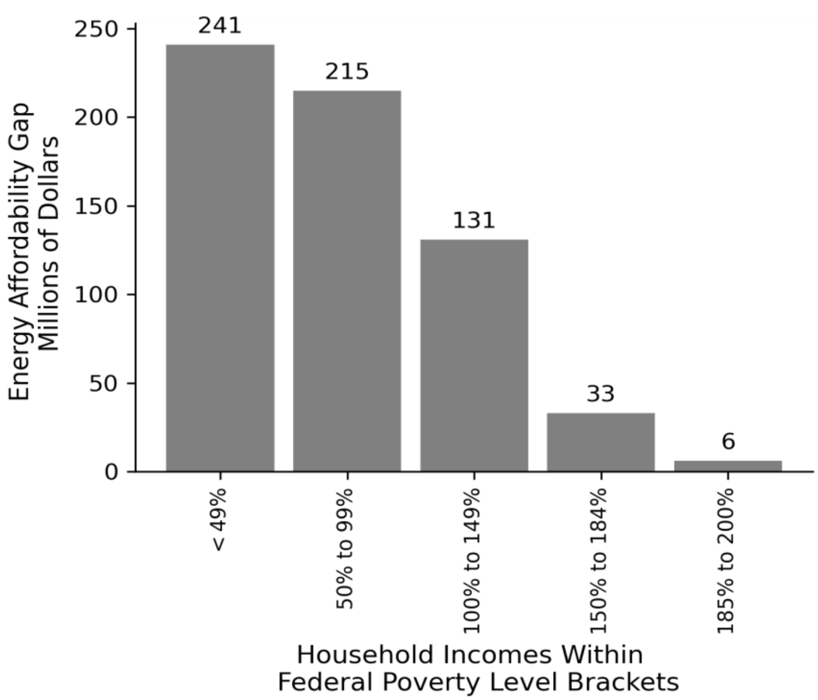

Figure 2. Energy affordability gap for North Carolina households in Duke territory within FPL income brackets.

[71] DE's response to Appalachian Voices Data Request 1-17.

[72] Roger D. Colton. "Home Energy Affordability Gap." www.homeenergyaffordabilitygap.com/

6.2. Impact of Energy Efficiency Investments

Investments in energy efficiency, community solar, and demand response can significantly decrease energy bills of LMI households. To demonstrate the cumulative impact of such investments, we simulate a scenario in which all households with incomes under twice the FPL sequentially receive these interventions. We visualize these changes in energy cost burdens in Figure 3. First, energy efficiency improvements have the potential to significantly reduce household energy cost burdens. In this scenario, households with energy cost burdens greater than ten percent receive weatherization and efficiency investments in the form of grants, while households with energy cost burdens between six and ten percent receive a mixture of grants and loans with three percent interest rates over a 15-year loan period that are paid using on-bill payments.[73] We assume $100 annual bill savings for every $1,000 of investment and target the level of investment to meet the six percent energy affordability level.[74] Second, we assume a 20 percent discount in electricity bills from the use of community solar. Community solar is more accessible to LMI households of whom around half are renters. Programs such as the Illinois Community Renewable Generation Program have provided similar levels of savings.[75] Third, we assume bill savings using demand response at a rate of $2/kWh for a total of 100 kWh in an annual bill cycle. Below, we visualize the energy cost burden distributions before (2019) and after each of these investments.

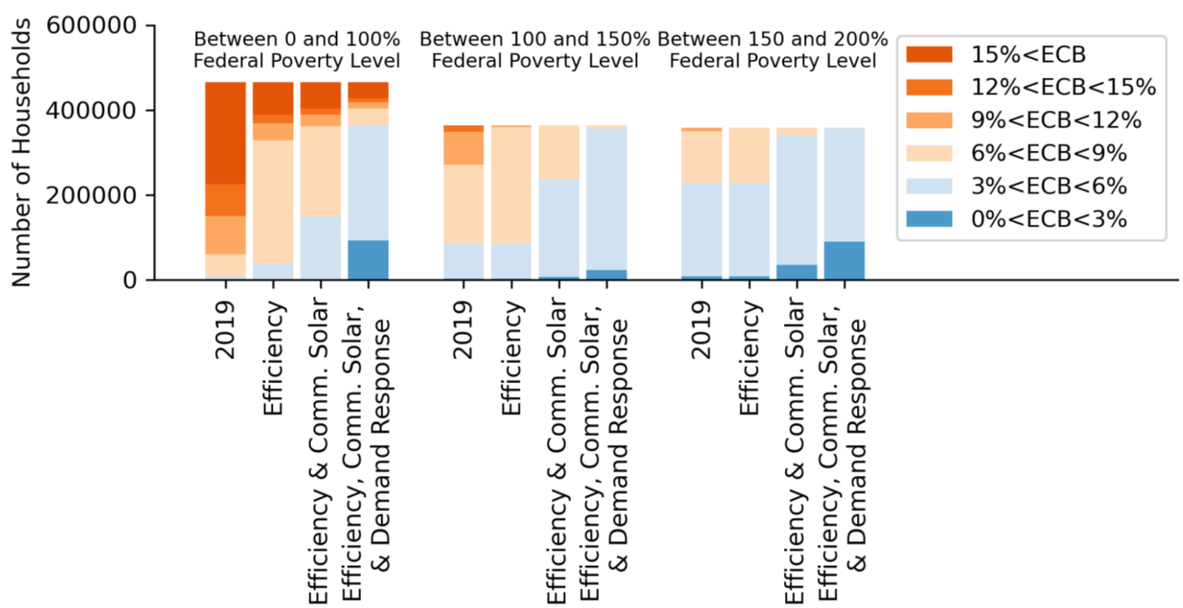

Figure 3. Energy cost burden distributions after sequential household interventions.

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[73] This follows an approach developed by Arjun Makhijani in Lukanov et al. (2022).

[74] Blasnik, M. et al. (2014). National Weatherization Assistance Program Impact Evaluation: Energy Impacts for Small Multifamily Buildings. *USDOE Office of Energy Efficiency and Renewable Energy (EERE).* www.osti.gov/biblio/1223639

[75] The Power Bureau. (2021). "Cost Analysis of Renewable Energy Deployment in Illinois." www.pathto100.net/_files/ugd/61ae1d_ec2b2988b40343a68266c8a11ef1221a.pdf

After these investments in efficiency, the vast majority of households with energy cost burdens greater than nine percent will have seen their burden reduced to less than nine percent, and nearly all households between one and two times the FPL will have energy cost burdens less than the six percent threshold. The lowest income brackets experience the greatest improvement in their energy cost burdens since their assistance is in the form of grants, but even households that pay for these improvements in the form of loans still see a reduction in the energy cost burdens. Notably, the total energy affordability gap is reduced from $630 million to $237 million after the investment in efficiency, then to $70 million after community solar is introduced, and finally down to $30 million after demand response is implemented.[76]

Importantly, while these interventions eliminate the energy affordability gap for the vast majority of households, each of these investments also provides co-benefits in terms of carbon reduction and demand reduction. For example, the efficiency investments in LMI households alone could reduce annual energy demand by roughly 2,800 GWh.

In Figure 4, we simulate the economic scenario in which, over a 15- year period, all households with incomes under twice the FPL receive all of the above interventions. Approximately eight thousand households per year receive treatment implemented, with the lowest-income households prioritized first. We plot the total amount needed in the form of grants and loans and compare that with a business-as-usual scenario in which the annual energy affordability gap of $630 million in present day dollars remains constant. While initial investment starts high, we see that after roughly four years, the combined level of annual energy assistance and grants needed for efficiency (black line) are equal to the annual amount needed in a bill assistance-only approach (dotted line). After approximately ten years in the year 2033, the cumulative amount of grants and bill assistance (area under black line) given the proposed scenario becomes equal to the cumulative amount of bill assistance under the business-as-usual approach (area under dashed line). After 2033, there are increasing amounts of savings for this proposed scenario. At the end of the 15-year period we estimate a cumulative sum of grants and bill assistance of $7.7 billion under the proposed scenario compared with $9.45 billion of bill assistance given no investments. This difference results in a net savings of $1.75 billion over this time period alone. Moreover, these savings will continue to accrue after the proposed timeline since the majority of these investments have lifetimes that extend well past the year 2037.

[76] If we assume low estimated savings values of $70 per $1000 investment in efficiency, 10 percent discount from community solar, and 50 kWh energy offset of demand response for each year, we find the energy affordability gap still reduces from $630 million to $380 million, $265 million, and $190 million respectively.

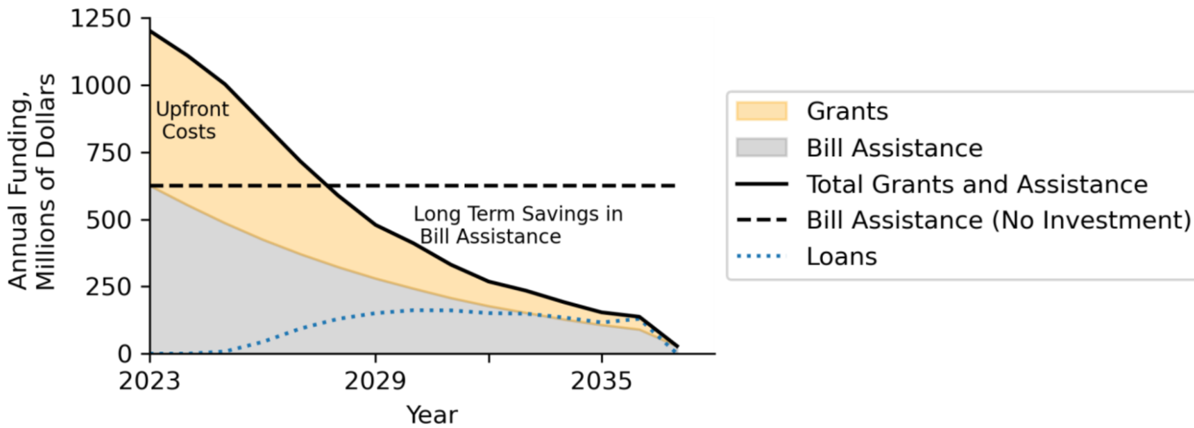

Figure 4. Annual funding and savings from proposed household investments.

Summary

A great opportunity exists to decrease energy cost burdens for low-income households while simultaneously reducing carbon emissions. Under the proposed scenario above, with a large up-front investment and associated outreach to low-income households, we demonstrate the potential to address the majority of households experiencing high energy cost burdens and reduce the total energy affordability gap by 95 percent. While we demonstrated this approach for North Carolina, a similar strategy could be applied for South Carolina customers as well. By expanding efficiency, demand response, and distributed solar targets within the Plan and ensuring that these resources reach LMI households, Duke can help improve affordability for its customers while simultaneously utilizing an underappreciated set of resources to achieve its carbon goals.

7. Conclusion

We have found that the Carolinas Carbon Plan developed by Duke unnecessarily limits the utilization of numerous cost-competitive clean energy resources, including offshore wind, demand response, energy storage, distributed solar, and demand-side efficiency. The Plan proposes to build new natural gas plants to meet 2030 demand needs. However, the potential expansion of clean energy resources instead would likely provide not only sufficient energy and capacity to preclude the need to build new gas resources, but likely could far surpass this demand and simultaneously provide co-benefits such as reducing greenhouse gas and health-damaging air pollutant emissions, improving affordability for low-income customers, and increasing resilience. Building new gas has outsized climate impacts due to lifecycle methane leakage, will continue to produce health-damaging air pollutants, and exposes Duke and its customers to financial risk due to gas price volatility and stranded asset risks. We recommend Duke model pathways to achieve its carbon and energy target that rely more heavily on these clean energy resources, including a broad expansion of programs targeted at LMI customers.

VERIFICATION

Pursuant to the Commission's ***Order Establishing Additional Procedures and Requiring Issues Report*** **entered on April 1, 2022 in the above-referenced docket, I, Elena Krieger, hereby verify that the contents of the foregoing Report are true to the best of my knowledge and belief, except as to those matters stated on information and belief, and as to those matters, I believe them to be true.**

This the 15 day of July, 2022.

Elena Krieger

Sworn to and subscribed before me this the 15 day of July, 2022.

Notary Public Cristian DelToro-Delgado

My commission expires: 08/13/2022

A notary public or other officer completing this Certificate Verifies only the identity of the individual who signed the document to which this certificate is attached, and not the truthfulness, accuracy, or validity of that document.

State Of California County Of Alameda
Subscribed & Sworn to (or affirmed) before me
On this 15 day of July 2022
by Elena Krieger
Proved to me on the basis of satisfactory evidence to be the person(~~s~~) who appeared before me .

CRISTIAN DEL TORO-DELGADO
COMM. # 2253958
NOTARY PUBLIC - CALIFORNIA
ALAMEDA COUNTY
My Commission Expires
AUGUST 13, 2022
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Education

2007 – 2019 **PhD, Princeton University - Mechanical and Aerospace Engineering**.
- Dissertation title: *Effects of variability and rate on battery charge storage and lifespan*
- National Science Foundation Graduate Research Fellowship, 2008 – 2011
- Fellow, Princeton Energy and Climate Scholars, 2008 – 2010
- Cummins Merit Fellowship, 2007 – 2008

2002 – 2007 **AB, Harvard University - Physics and Astronomy & Astrophysics**, *Cum Laude*.
- Harvard College Research Program Fellowship recipient, 2006
- Weissman International Internship Fellowship recipient, 2005
- Robert C. Byrd Scholarship, all academic years

Research and Professional Experience

2019 – Present **Director of Research**, *PSE Healthy Energy*, Oakland, CA.
- Managed research efforts across institute's energy, health, environment, and equity practice areas.
- Led research efforts on nationwide opportunities for energy storage adoption, prioritizing health, equity and resilience; worked with state regulators, policymakers and NGOs to integrate findings.
- Developed novel framework for integrating health, environment, and equity into deep decarbonization strategies across Colorado, Nevada, and New Mexico.

2013 – 2019 **Director, Clean Energy Program**, *PSE Healthy Energy*, Oakland, CA.
- Launched new program area and directed team research focused on accelerating clean energy transitions.
- Directed and executed research on health, environment, equity and resilience facets of carbon mitigation and clean energy growth, focusing on California, Pennsylvania, Ohio, New York and New Jersey.
- Worked with state-level policymakers and regulators to integrate science into energy policy.
- Synthesized and translated energy science for diverse stakeholders via lectures, media publications, interviews, *pro bono* consulting projects, meetings, workshops and interactive data tools.

2007 – 2013 **Graduate Research Assistant**, *Princeton University*, Princeton, NJ.
- Modeling and experimental work optimized energy storage efficiency and lifespan in renewable energy systems; assessed impact of charging variability on battery performance and degradation.
- Laser processed materials to improve surface morphology for ultracapacitor electrodes and solar cells.
- Designed disaster relief energy generation and storage technology; assessed deployment sites in Haiti.
- Provided recommendations on enterprise development to Clinton-Bush Haiti Fund with policy team.

2009 – 2011 **Assistant in Instruction**, *Princeton University*, Princeton, NJ.
- *Energy for a Greenhouse-Constrained World*, Spring 2010, Spring 2011.
- *Innovation in Technology and Foreign Policy*, Fall 2009.

2007 **Intern**, *Appropriate Infrastructure Development Group*, Quetzaltenango, Guatemala.
- Disseminated clean energy and water technology via business incubation.
- Developed improved cookstove prototypes; stoves became a top seller at incubated business.

2006 **Research Assistant**, *Harvard University Department of Physics*, Cambridge, MA.
- Performed femtosecond laser ablation of black silicon for solar cell applications.

2005 **Intern**, *Ecofogão*, Belo Horizonte, Brazil.
- Engineered improved wood and ethanol stoves to increase efficiency and reduce harmful emissions.

2004, 2005 **Intern**, *Lawrence Berkeley National Laboratory*, Berkeley, CA and Eritrea.
- Evaluated effectiveness of cookstove implementation approaches for Eritrean Department of Energy.
- Measured indoor air quality and correlated features of stove construction with measured emissions.
- Developed financing models for dissemination of clean energy and water technology.

2004 – 2005 **Research Assistant**, *Harvard-Smithsonian Center for Astrophysics*, Cambridge, MA.
- Analyzed X-ray data from Chandra to search for pulsations from cataclysmic variables.

Board Positions, Advisory Roles, and Memberships

2021 – Present **New Voices in Sciences, Engineering and Medicine Cohort Member**, *The National Academies of Sciences, Engineering and Medicine*, Washington, D.C.

2021 – Present **Disadvantaged Communities Advisory Group Member**, *California Public Utilities Commission and California Energy Commission.*
- Provide monthly input on key energy, climate, pollution, and population concerns to state agency commissioners and staff.

2015 – Present **Science Advisor**, *American Resilience Project.*
- Provide data and technical review for films addressing energy, climate, security, and resilience.

2011 – Present **Member, Board of Directors**, *Carbon Lighthouse Association*, San Francisco, CA.
- Provided guidance to start-up non-profit to provide verifiable carbon reductions.
- Chairman of the Board, 2012-15.

2015 – 2017 **Member, Advisory Board**, *U.S. Climate Plan*, Washington, D.C.
- Advisor on energy science for non-profit advancing clean climate policy across U.S.

2016 **Member, Steering Committee**, *Battery Research Workshop: Carbon Neutrality Initiative*, Berkeley, CA.
- Co-organized battery storage workshop with University of California, Lawrence Berkeley National Laboratory, and industry on energy storage research and deployment priorities.

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[1] Boris R Lukanov and **E.M. Krieger**. Distributed solar and environmental justice: Exploring the demographic and socio-economic trends of residential PV adoption in California. *Energy Policy*, 134:110935, 2019.

[2] Shonkoff, S.B.C., J. Hays, L.A. Hill, **E.M. Krieger**, D. Hughes, N. Hosang, and A. Law. Trump: renewables for self-sufficiency. *Nature*, 540(7633):341–341, 2016.

[3] **Krieger, E.M.**, J.A. Casey, and S.B.C. Shonkoff. A framework for siting and dispatch of emerging energy resources to realize environmental and health benefits: Case study on peaker power plant displacement. *Energy Policy*, 96:302–313, 2016.

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[2] Michanowicz, D., Lebel, E., Domen, J.K., Hill, L.A., Jaeger, J., Schiff, J., **Krieger, E. M.**, Zoya, Goldman, J.S.W., Nordgaard, C., B., Shonkoff, S.B.C. Methane and Health-Damaging Air Pollutants From the Oil and Gas Sector: Bridging 10 Years of Scientific Understanding. *PSE Healthy Energy,* 2021.

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[1] **Krieger, E.M.** and A. Makhijani. California's wildfire response should include small-scale solar power. *The Sacramento Bee*, Dec. 10, 2018.

[2] **Krieger, E.M.** Rolling back climate regulations will hurt low income and disadvantaged communities. *The Hill*, Mar. 29, 2017.

[3] **Krieger, E.M.** and Z. Hausfather. Methane leaks threaten to undermine Clean Power Plan targets. *The Hill*, Feb. 15, 2016.

[4] **Krieger, E.M.** and S.B.C. Shonkoff. Strong EPA methane rule required to fully realize Clean Power Plan benefits. *The Hill*, Aug. 26, 2015.

[5] **Krieger, E.M.** Low fossil fuel prices embody their inherently risky volatility. *The Hill*, Feb. 18, 2015.

[6] **Krieger, E.M.**, M. Shank, J.T. Peek. Don't Let China Dominate: When it comes to renewable energy, China is trumping the U.S. *U.S. News & World Report*, Sep. 18, 2014.

[7] **Krieger, E.M.** and J.T. Peek. We need an alternative energy grid. *The Hill*, Sep. 4, 2014.

[8] **Krieger, E.M.** Quake shows need for a resilient energy infrastructure. *Capitol Weekly*, Aug. 29, 2014.

Selected Talks, Invited Lectures, and Testimony

[1] **Krieger, E.M.** Incorporating health and equity into New Mexico's deep decarbonization efforts. *New Mexico Climate Summit Keynote.* Santa Fe, NM. 2021.

[2] **Krieger, E.M.** *et al.* Tackling peak pollution: achieving environmental justice for frontline communities. *Hybrid Roundtable for the U.S. House of Representative Committee on Oversight and Reform.* Queens, NY. 2021.

[3] **Krieger, E.M.** *et al.* Addressing emissions in California's transportation corridor communities. *California Energy Commission EPIC Forum.* 2021.

[4] **Krieger, E.M.** Energy storage as an equity asset. *Energy Storage for Social Equity Roundtable, Pacific Northwest National Laboratory and the U.S. Department of Energy.* 2021.

[5] **Krieger, E.M.** Battery storage 101. *Webinar for community organization partners.* 2021.

[6] **Krieger, E.M.** Rethinking infrastructure in smart cities: energy, transport, and resilience. *Moderator at Sustainable Future Forum–Maifest, Bavarian U.S. Offices for Economic Development.* 2021.

[7] **Krieger, E.M.** *et al.* Panel: Catalyzing sustainability through material design. *Materials for today and tomorrow: a Princeton University materials science symposium.* Princeton, NJ. 2021.

[8] **Krieger, E.M.** Realizing the non-energy benefits of distributed energy resources: emissions, equity, and resilience. *UC Davis.* 2021.

[9] **Krieger, E.M.** and A. Smith. Equity-focused climate strategies for Nevada: socioeconomic and environmental health dimensions of decarbonization. *Nevada Black Legislative Caucus Briefing.* 2021.

[10] **Krieger, E.M.** and A. Smith. Equity-focused climate strategies for Nevada: socioeconomic and environmental health dimensions of decarbonization. *Nevada Hispanic Legislative Caucus Briefing.* 2021.

[11] **Krieger, E.M.** and A. McPhail. Equity-focused climate strategies for Colorado: socioeconomic and environmental health dimensions of decarbonization. *Colorado Climate Action Network.* 2021.

[12] **Krieger, E.M.** The viability of a 100 percent renewable New York. *Panel discussion for Beyond Indian Point.* NY. 2020.

[13] **Krieger, E.M.** *et al.* SB 100 Panel: equity, workforce, and additional considerations. *California Energy Commission.* CA. 2020.

[14] **Krieger, E.M.** Opportunities to replace New York peaker power plants with energy storage. *NY-BEST's 10th Annual Capture the Energy Conference.* NY. 2020.

[15] **Krieger, E.M.** *et al.* The impact of COVID-19 on the environment. *Rattlestick Virtual Salon.* 2020.

[16] **Krieger, E.M.** Valuing environment, equity, and health in distributed energy resource planning. *Sacramento Municipal Utility District.* Sacramento, CA. 2019.

[17] **Krieger, E.M.** Energy storage and the grid of the future. *Cornell University.* Ithaca, NY. 2019.

[18] **Krieger, E.M.** and E. Tome. Energy data resources. *The Network for Energy, Water, and Health in Affordable Buildings Annual Convening*, Los Angeles, CA. 2019.

[19] **Krieger, E.M.** Peaker analysis: Environment and equity screen. *Replacing Peaker Plants with Batteries and Renewables Workshop*, Cavallo Point, CA, 2019.

[20] **Krieger, E.M.** Bringing science, health, and equity to energy policy. *UC Santa Barbara.* Santa Barbara, CA. 2019.

[21] **Krieger, E.M.** Clean energy strategy. *Full Circle Fund.* San Francisco, CA. 2019.

[22] **Krieger, E.M.**, S. Mullendore, J. Pino and Gary Connett. Storage as a solution to what? *State Policy Development for Equitable Storage Deployment.* Chicago, IL, 2018.

[23] **Krieger, E.M.** Climate change, energy, health, and social justice in California. *Arizona State University.* 2018.

[24] **Krieger, E.M.**, S. Mullendore and M. Jacobs. Energy storage integration using an equity, health, and environmental framework. *Energy Storage Association Webinar.* 2018.

[25] **Krieger, E.M.**, S. Mullendore and L. Zucker. Using health, environment and equity metrics to target peaker replacement. *Clean Energy Group Webinar.* 2018.

[26] **Krieger, E.M.**, D. King, and M. Santiago. Energy storage: applications, health and equity. *National Environmental Justice Conference.* Washington DC, 2018.

[27] **Krieger, E.M.** and A. Makhijani. A clean energy pathway for New Jersey. *The Watershed Center.* Pennington, NJ, 2017.

[28] **Krieger, E.M.** Opportunities for health, environment and equity benefits from energy storage. *Resilient Power Project Meeting.* Sausalito, CA, 2016.

[29] **Krieger, E.M.** and S.B.C Shonkoff. Improving air quality with energy storage: A new deployment strategy for public health and environmental equity. *Clean Energy Group Webinar*, 2016.

[30] **Krieger, E.M.** Are we there yet? Progress towards climate change mitigation. *Marin Environmental Forum*, CA, 2016.

[31] **Krieger, E.M.** Towards a renewable energy future: Integration strategies and technical hurdles. *Speaker Series on Energy and the Environment*, Youngstown University, OH, 2015.

[32] **Krieger, E.M.** Is 100 percent renewable energy possible? *Marin Environmental Forum*, CA, 2015.

[33] **Krieger, E.M.**, J. Casey and S.B.C. Shonkoff. A framework for optimizing the health and environmental benefits of grid energy storage: A case study on peaker power plants. *UC Berkeley*, CA, 2014.

[34] **Krieger, E.M.**, J. Bowie and A. Bartley. New York State's response to climate change: A panel discussion about the Public Service Commission's Reforming the Energy Vision (REV) Initiative. *Fordham University School of Law*, NY, 2014.

[35] **Krieger, E.M.**, J. Cannarella, and C.B. Arnold. A model for energy storage in the frequency domain. *The Electrochemical Society Fall Meeting*, Honolulu, HI, 2012.

[36] **Krieger, E.M.** and C.B. Arnold. Modeling the rate dependence of charge efficiency in batteries. *The Electrochemical Society Spring Meeting*, Seattle, WA, 2012.

YUNUS A. KINKHABWALA, PhD

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EDUCATION

Cornell University *September 2015 – October 2021 – Ithaca, NY*
MS, PhD, Applied Physics

Region XIII Teacher Certification *April 2009 – May 2010 – Austin, TX*
Math/Physics Teacher Certification

University of Illinois at Urbana-Champaign *September 2003 – May 2006 – Urbana, IL*
BS, Physics

WORK AND RESEARCH EXPERIENCE

Clean Energy Scientist, PSE Healthy Energy *October 2021 – Present*
Oakland, CA

Math/Science Teacher, International School of Dakar *September 2011 – June 2015*
Dakar, Senegal

Math/Physics Teacher, Eastside Memorial High School *September 2009 – June 2011*
Austin, TX

Schools/Community Resource Volunteer, US Peace Corps *September 2006 – November 2008*
Magogeni, Mpumalanga Province, South Africa

SELECTED PUBLICATIONS AND REPORTS

1. Boris Lukanov, PhD,Arjun Makhijani, PhD, Karan Shetty, M.ESM, Yunus Kinkhabwala, PhD, Audrey Smith, MPH, Elena Krieger, PhD. Pathways to Energy Affordability in Colorado. ***PSE Health Energy***. 2022.
2. **Yunus A. Kinkhabwala**, Boris Barron, Matthew Hall, Tomas A. Arias, Itai Cohen. 2021. Forecasting racial dynamics at the neighborhood scale using Density-functional Fluctuation Theory, arXiv:2108.04084 (under review).
3. Yuchao Chen, **Yunus A. Kinkhabwala**, Boris Barron, Matthew Hall, Tomas A. Arias, Itai Cohen. 2020. "Forecasting the dynamics of segregated population distributions at the neighborhood scale using Density-Functional Fluctuation Theory", arXiv:2008.09663 (under review).
4. J. Felipe Méndez-Valderrama, **Yunus A. Kinkhabwala**, Jeffrey Silver, Itai Cohen & T. A. Arias. 2018. Density-functional fluctuation theory of crowds. Nat Commun 9, 3538 (2018).

PATRICK M. MURPHY, PhD

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EDUCATION

George Washington University *September 2009 – January 2016 – Washington, DC*
PhD, Engineering Management, Operations Research

George Washington University *June 1998 – August 2000 – Washington, DC*
MA, Science, Technology, and International Affairs

University of Notre Dame *August 1987-May 1992 – South Bend, IN*
BS Electrical Engineering BA, Government,

WORK AND RESEARCH EXPERIENCE

Senior Scientist, PSE Healthy Energy *Nov 2020 – Present Oakland, CA*

Lead Engineer, Carbon Lighthouse *Jan 2020 – Sep 2020 – San Francisco, CA*

Senior Engineer, Carbon Lighthouse *Oct 2017 – Jan 2020 – San Francisco, CA*

Director Public Sector Engagement, parc *Aug 2015 – Jul 2017 – Palo Alto, CA*

Program Director, Global Development, Notre Dame *Aug 2015 – Jul 2017 South Bend, IN*

Managing Director, Energy Center, Notre Dame *Apr 2009 – Jun 2012 South Bend, IN*

Program Director, Global Development, Notre Dame *Aug 2015 – Jul 2017 South Bend, IN*

Program Manager, Department of Homeland Security Advanced Research Projects Agency
Mar 2007 – Mar 2009 Washington, DC

Associate, Booz Allen Hamilton *Oct 1998 – Feb 2007 Washington, DC*

Intelligence Officer, United States Army *Feb 1993 – Feb 1997 Germany, Bosnia, Croatia*

SELECTED PEER-REVIEWED PUBLICATIONS AND REPORTS

1. Twaha, S., Ramli, M.A.M., **Murphy, P.M.**, Mukhtiar, M.U. (2016). Renewable Based Distributed Generation in Uganda: Resource Potential and Status of Exploitation. Renewable & Sustainable Energy Reviews, Renewable & Sustainable Energy Reviews (pp. 786-798).
2. **Murphy, P.M.**, Twaha, S., Murphy, I.S. (2014). Analysis of the Cost of Reliable Electricity: A New Method for Analyzing Grid Connected Solar, Diesel, and Hybrid Distributed Electricity Systems Considering an Unreliable Electric Grid, with Examples in Uganda. Energy, Volume 66, 1 March 2014, Pages 523-534.
3. **Murphy, P.M**. (2013). Electricity and Development: a Risk-Based Analysis of Grid Extension and Distributed Energy Resources. Society for Risk Analysis, 2013 Annual Meeting, Risk Analysis for Better Policies, 8-11 December, Baltimore, MD.
4. "2005 Urban, Asymmetric and Expeditionary Warfare Science and Technology Investment Strategy and Research Prioritization," Office of Naval Research

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5. "Communications Dependency on Electric Power Working Group Report, Long-Term Outage Study," for National Communications System Committee of Principals, co-author responsible for Chapter 9: Risk Management Assessments
6. Vonortas, X N., **Murphy, P.M.**, (2002), "Strategic Innovation Alliances," Knowledgebase for Sustainable Development an Insight into the Encyclopedia of Life Support Systems" UNESCO

SYNERGISTIC ACTIVITIES

1. **Participation on Panels and Working Groups to Inform Resilience and Security Policy**
   Invited Participant, NIST Transactive Energy Challenge Workshop, 2015
   Member, Notre Dame Global Adaptation and Index Advisory Committee, 2013-2014
   Invited Speaker, "CE3: Connectivity, Electricity, and Education for Entrepreneurship," 2014 Catholic Relief Services: ICT4D: Building Resilience Through Innovation Conference, Nairobi, Kenya, 2014
   Invited Speaker, "Electricity for ICT4D: Estimating the cost of reliable electricity from grid extension and distributed energy resources," Catholic Relief Services ICT4D: Building Resilience Through Innovation Conference in Nairobi, Kenya, 2014
   Invited Speaker, "Connectivity, Electricity, and Education for Entrepreneurship (CE3) on Energy for Intelligent Communities, 2013 Intelligent Communities Forum (ICF) Institute Global Symposium, Canton. OH, 2013
   Invited Speaker "Employing Energy Efficiency Advances as a Catalyst for Post-Conflict Nation Building," 7th Annual Military Energy Alternatives, Falls Church, VA, 2012
   Invited Chair "Reviewing Backup Power Needs for Military Bases to Achieve Independence," for 6th annual "Military Energy Alternatives" conference, Washington, D.C., 2011
   "Resilient Electric Grid" speaker at Australia-US Bilateral Science and Technology Agreement Discussions, Canberra, Australia, 2007
   "Resilient Electric Grid" speaker at the International Electrical Infrastructure Assurance Forum, 2nd Annual meeting, Edinburgh, Scotland, May 2008
   Representative to DOE SmartGrid Task Force, Department of Homeland Security Science and Technology (DHS S&T), 2007-2009
   Representative to the Interagency Working Group on Hydrogen and Fuel Cells (IWG) / Manufacturing for Hydrogen Energy Technologies Interagency Community of Interest (COI), Department of Homeland Security Science and Technology (DHS S&T), 2007-2009
   Representative to the Department of Defense Director Defense Research and Engineering (DDR&E) Energy Security Task Force, Department of Homeland Security Science and Technology (DHS S&T), 2007-2009
   Representative to the Department of Commerce Communications Dependency on Electric Power Working Group, Department of Homeland Security Science and Technology (DHS S&T), 2007-2009