AI-powered Microgrids Facilitate Energy Resilience and Equitability in Regional Communities

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This blog article is addressed to those who are developing AI technologies to support energy futures for renewable energy. The future of energy is moving towards more distributed and decentralized resource management with the goal to make our energy infrastructure more resilient and equitable. The question that is addressed here by identifying the right technology abstraction as understood through some of our key projects are: **What are the critical attributes of AI systems to support decentralized renewables energy infrastructures?**

Why decentralized Energy Infrastructures?

According to the American Council for an Energy-Efficient Economy (ACEEE), one-fourth of all U.S. households and two-thirds of low-income ones face high energy burdens—over 6% of their income on utilities. Particularly, two out of five low-income households experience severe burdens, allocating more than 10% of their income to energy costs. Racial disparities compound this issue, with Black households spending 43% more, Hispanic households 20% more, and Native American households 45% more of their income on energy compared to white households (see Drehobl et. al, 2020).

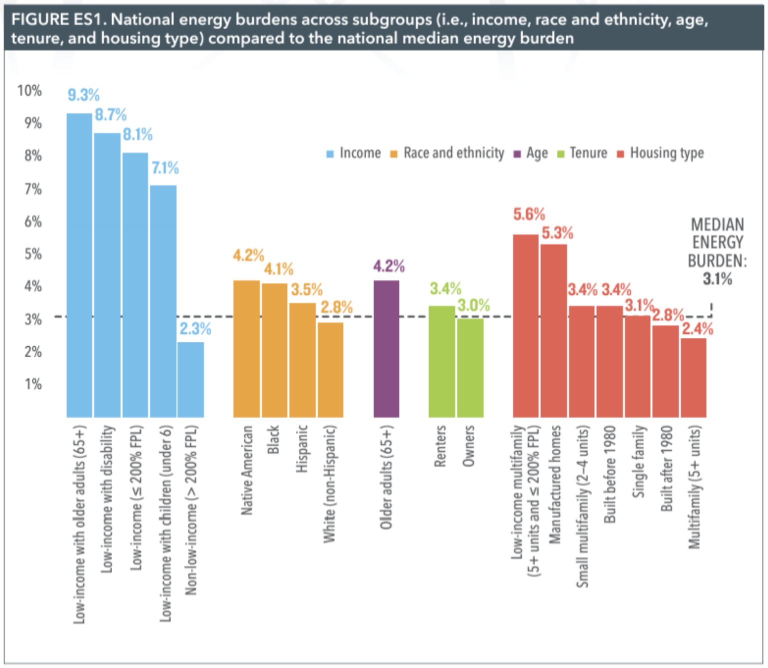


Figure 1: Energy Burden on Major Ethnic Groups in the US (Drehobl et. al, 2020)

The energy sector significantly contributes to environmental pollution, impacting air, water, and soil quality. As the largest single source of global air pollution, the sector was responsible for 89% of all carbon dioxide emissions in 2019 (International Energy Agency [IEA], 2020), driving climate change and health issues related to poor air quality. Additionally, fossil fuel extraction and processing lead to water pollution through oil spills, coal mining runoff, and power plant discharges, with the United States Environmental Protection Agency (EPA) identifying these activities as major water pollution sources (EPA, 2021). Soil contamination from the energy sector, involving heavy metals and toxic substances, affects ecosystems and agricultural productivity (Zeng, Li, & Yang, 2019). The energy sector's role in greenhouse gas emissions, significantly impacts climate change (United Nations Framework Convention on Climate Change (UNFCCC, 2020). Mitigation efforts include shifting to renewable energy, which accounted for 28% of global electricity generation in 2020 (IEA, 2021), improving energy efficiency, and enforcing stricter environmental regulations.

The rise of affordable small-scale renewable energy, particularly rooftop solar, is revolutionizing energy systems around the world. Traditional large-scale electric grids often pose inefficiency and equity issues, more acutely affecting communities with histories of marginalization. Often such communities face the brunt of "energy poverty", where a significant portion of a household's income is spent on energy needs. Large utility providers frequently have limitations to account for income disparities in their rate structures, thereby imposing flat rates that disproportionately burden lower-income households. These cost structures include operational cost which account for high energy consumptions in richer neighborhoods which is normalized across all, thus making marginalized communities having to pay for higher energy usage by wealthier neighborhoods. Frontline communities are also susceptible in case of disaster events, often being last to receive service restorations after blackouts, increasing their vulnerability. This centralized model presents challenges to the integration of diverse, local renewable energy sources and could contribute to high and unpredictable energy prices. Energy decisions are typically made by distant entities, which can result in a lack of representation for marginalized communities, neglecting their unique needs and challenges. Lastly, traditional utilities often lack the local focus required to provide job growth, community empowerment, and energy democracy.

Beyond pollution prevention and reducing energy burdens, the energy sector’s transition from fossil fuels to renewable sources offers a unique opportunity to diversify the sector's ownership, workforce, and supply chain. Historically, data shows that there is discrepancy in representation along gender and racial lines in the U.S. energy workforce and business enterprises. Without deliberate efforts, this underrepresentation is likely to persist in the renewable energy sector. According to the 2017 and 2020 U.S. Energy and Employment Reports, both wind and solar workforces have lower-than-average employment percentages along these categories. Additionally, the energy sector's median pay is growing faster than other economic areas, with clean energy job growth outpacing that of fossil fuels. This shift creates economic opportunities for historically underrepresented groups. This inequity in wealth across racial lines contributes to health disparities, high poverty rates, higher pollution exposure, and greater climate impacts. Corporate renewable energy buyers can help by introducing supplier diversity criteria and investing in incubator models that position diverse-owned businesses as key participants in the clean energy transition. Such measures counteract the forces leading to higher unemployment and lower income for these populations. As the renewable energy industry grows, a lack of diversity, especially in leadership, could perpetuate infrastructure development that sidelines under-resourced communities' needs. Diversifying the renewable energy sector is essential to addressing the unequal effects of fossil fuel pollution on Americans.

Community-centered Renewable Microgrids

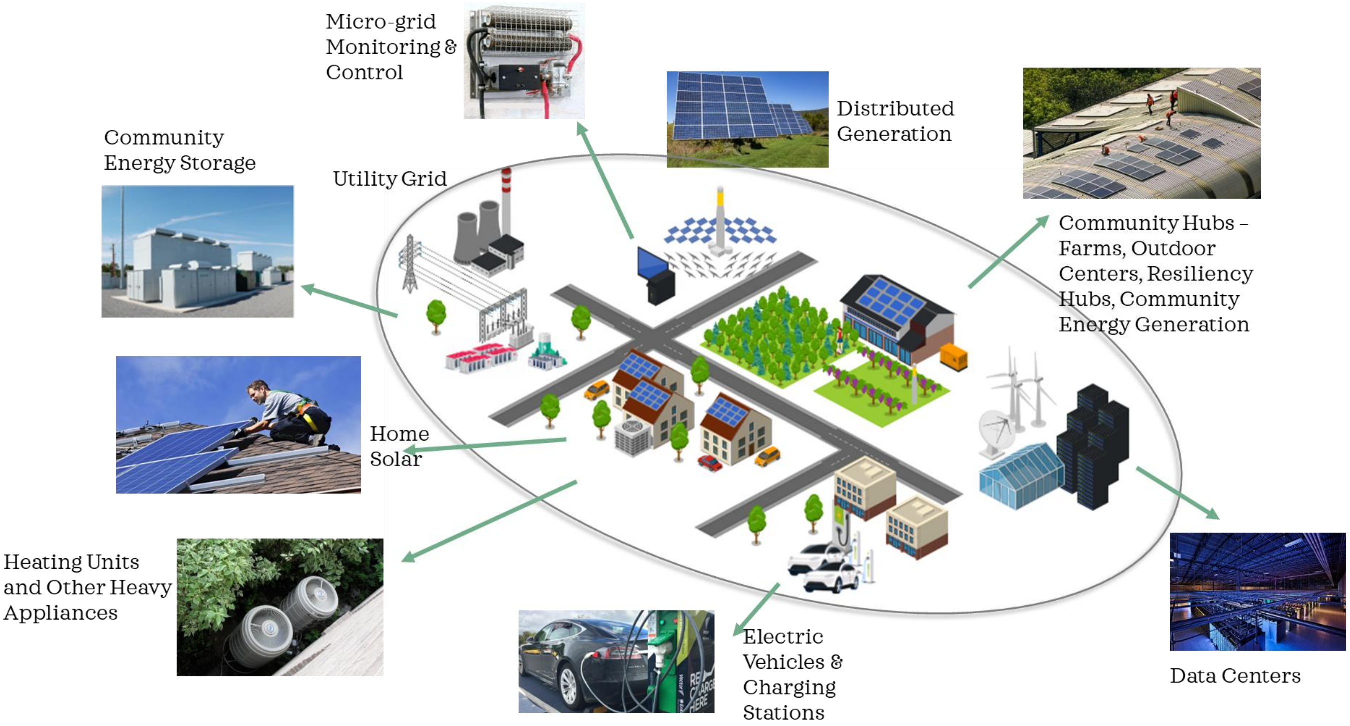


Figure 2 Microgrid Illustration

Microgrids offer a way to address these issues. As the name implies, community microgrids are small-scale versions of the grid, which are a collection of Distributed Energy Resources (DERs) such as energy producers, consumers, storage, etc, often with a defined electrical boundary acting as a single controllable unit. This enables microgrids to be smarter and put more focus on individuals as active participants instead of as passive consumers. Community-centered microgrids can contribute to energy resilience, especially in the face of frequent natural disasters and aging infrastructure that may leave communities without power (Department of Energy, 2020). They empower local regions by reducing reliance on distant power plants and increasing energy efficiency, as energy does not have to travel long distances (Lund et al., 2015). Furthermore, microgrids are highly scalable and can integrate with renewable energy sources, making them a sustainable choice for communities (Hirsch et al., 2018). By establishing localized control over energy, communities can also ensure more equitable distribution and pricing, thereby reducing energy poverty.

Woods Mackenzie projects 387 GW of installed energy capacity will be distributed by 2025, which is over 30% of capacity in 2021. By 2035, microgrids are envisioned to be essential building blocks of the future electricity delivery system to support resilience, decarbonization, and affordability. Microgrids will be increasingly important for integration and aggregation of high penetration distributed energy resources. Microgrids will accelerate the transformation toward a more distributed and flexible architecture in a socially equitable and secure manner (Bent, et.al 2022).

AI-powered microgrids offer innovative solutions to address the complexities of energy transition, making them a reliable option for sustainable communities. These microgrids can manage the complexity of scientific and economic models by employing scientific generative AI, which simulates various scenarios and provides insights for more accurate predictions and efficient economic planning (Feng et al., 2021). AI enhances grid design, improves preparedness and prevention measures, facilitates decarbonization efforts, and reduces uncertainty through advanced predictive analytics (Li et al., 2020). Automation powered by AI is crucial for handling the complexities of grid and market operations, particularly with high volatility and the integration of numerous distributed energy resources (DERs) (Department of Energy, 2020).

AI also supports regulatory and policy frameworks by enhancing explainability and providing robust policy support, ensuring compliance, and facilitating informed decision-making (Jones & Stein, 2019). Multi-modal and multi-fidelity AI addresses data disparity, socio-economic inequity, and transmission challenges by integrating diverse data sources and improving the overall reliability and equity of the energy system. Additionally, AI-driven multi-sector decarbonization strategies can effectively tackle energy burdens, promoting equity and sustainability across different sectors (Hirsch et al., 2018).

As the planning, siting, and permitting of variable generation increases, operators will need more accurate weather and climate forecasts to balance supply and demand reliably. The declining proportion of dispatchable resources reduces both controllability and inertia, necessitating improved load estimation approaches and the deployment of smart grid technologies such as storage. Operators cannot address the complexities and accuracy margins of forecasting, planning, and operating reliably under such uncertainty without AI technology. AI can revolutionize the planning paradigm for the future power grid by providing fast and efficient surrogates, high-fidelity scenarios, and stochastic optimization schemes for large-scale integrated energy systems. AI-based, multi-fidelity surrogate models for dynamic components must be designed, built, and integrated to create a large-scale dynamic emulator with uncertainty quantification for power grid planning. This AI-based or hybrid grid emulator can replace existing numerical simulation tools, allowing for both online and offline steady-state and dynamic contingency analysis of utility-scale systems. Improved long-term planning can be achieved using AI to develop more realistic scenarios that account for technological evolution and climate changes, quantifying the associated uncertainties (DoE Report, 2024).

Microsoft’s Commitment to Energy Transition

Additionally, Microsoft as a company has taken significant steps to address greenhouse gas emissions, announcing in January 2020 a corporate-wide commitment to be carbon negative for scope 1, 2, and 3 emissions by 2030 (including scope 3 emissions from suppliers). Furthermore, in 2021 the company announced that by 2030 Microsoft will have 100 percent of our electricity consumption, matched by zero carbon energy purchases 100 percent of the time, with co-benefits for under-resourced communities. Developers commonly fund community initiatives near project site locations, but those projects are not always connected to community resiliency, decarbonization, or energy asset ownership. As an example, based on efforts to engage Microsoft’s renewable energy supply chain to reimagine community benefits towards driving positive environmental justice outcomes, Microsoft is striving to direct 5 to 10 percent of that revenue toward community investments. These investments further drive carbon reductions while empowering the populations on the front lines of industrial pollution and climate change. This blog article presents some of the efforts within our ecosystem to enable energy transition through the development of community solar. As part of this, we also present the various community and academic collaborations that are pioneering this effort on energy transition.

Preparing for Future Grids – Microgrid for Equitability

Setting up a microgrid requires a thorough and multifaceted research approach, encompassing goal setting, performance metrics, economic analysis, baseline grid analysis, renewable siting surveys, DER optimization, and deployment planning. Establishing clear goals is paramount; this involves engaging in organizational and community design sessions, interviewing key stakeholders, local businesses, and residents to identify their needs and expectations. These sessions help in defining resiliency and economic development goals, such as integrating renewable energy sources, enhancing grid reliability, providing power backup, and reducing peak demand (Hirsch et al., 2018). Goals should reflect the community's vision for sustainability and economic prosperity, ensuring that the microgrid not only supports current energy needs but also future-proofs the community against potential disruptions.

To measure the success of a microgrid, performance metrics must be established across various dimensions. Economically, it is crucial to measure the reduction in energy costs, the increase in renewable energy usage, and the level of community financial participation. Environmentally, the focus should be on quantifying the reduction in environmental incidents and the uptime of critical facilities during power outages due to the microgrid's presence. Social and equity metrics should track the availability of critical community services during outages and assess the impact of financial policies on low-income ratepayers (Jones & Stein, 2019). Administratively, the effectiveness of stakeholder coordination and the efficiency of funding utilization need to be evaluated, while legally, changes in regulatory environments that facilitate microgrid deployment and benchmarks for measuring resilience value must be monitored.

An economic analysis is also essential, beginning with a feasibility analysis to evaluate the cost benefits and net value of the microgrid. This includes analyzing cost reductions in transmission and distribution (T&D), other ratepayer benefits, and local job creation (Department of Energy, 2020). It is also important to consider federal aids, institutional power purchase agreements, and incentives from initiatives like the Inflation Reduction Act (IRA), as well as federal loans that can support the project's financial viability. A baseline grid analysis should be conducted to inventory existing grid assets, including load profiles, grid operations, and existing generation capabilities, identifying critical and prioritized loads (Lund et al., 2015). A renewable siting survey is necessary to assess all viable energy potentials within the grid area, informing other requirements such as energy storage capacity and control system functionality. DER (Distributed Energy Resources) optimization involves designing an optimal DER portfolio that includes load management, integrating insights from the baseline grid analysis and the renewable siting survey. This phase includes simulating various economic pathways to determine the most efficient grid design. Finally, a comprehensive deployment plan should be developed, encompassing the final system design, a robust financial model, and an operational plan, which includes operational design and vendor analysis (Feng et al., 2021). This structured approach ensures that the microgrid is well-planned, economically viable, environmentally sustainable, and socially equitable.

Various AI Technologies supporting Microgrid Projects

To showcase a collective effort to address these challenges, this blog article presents the following collaborative projects:

- An AI based microgrid control system for a sample configuration demonstrated through a tabletop simulation. This project demonstrates how AI powered micro-grids can reduce community & organization energy burden and potentially become an economic & resiliency resource
- A collaboration with University of Washington Urban Infrastructure Lab which investigates how AI-enhanced community microgrids can bolster grid and community resiliency and provide measurable societal benefits through public investment in disadvantaged communities, while exploring governance, market structures, and innovative business models in renewable energy development.
- A grassroots effort within West Atlanta for upgrading resilient infrastructures and mobilizing economic development in a way that promotes community ownership & community development. This work is based on a multi-stakeholder collaboration to set up micro-grid in key energy burdened neighborhoods in West Atlanta, USA. To do so, the project is to design and construct innovative urban energy resiliency hubs integrating microgrid technology, IoT sensor for measurements, solar generation, and energy storage. The goal of this work is to design an energy resiliency center tailored to local needs ensuring access to critical services during power outages & building community endowment fund.
- A collaboration with BRAID UK fellow at University College London on Human-Centered AI for the Equitable Smart Energy Grid to make energy more accessible for low-income neighborhoods. The research collaborates with London communities and schools to implement electricity sensor prototypes and a web app, enabling solar panel and battery sharing among neighbors while monitoring dynamic pricing. Through workshops and co-design activities, participants' experiences will refine the interface, and marginalized voices will shape equitable smart-grid development and youth education on these technologies.
- A collaboration with University of Washington Global Innovation Exchange project where a group of inter-disciplinary master students built a dashboard to enable detailed financial projections for microgrid investments. This work provides decision support tool for understanding the techno-economic trade-offs for setting up micro-grids.

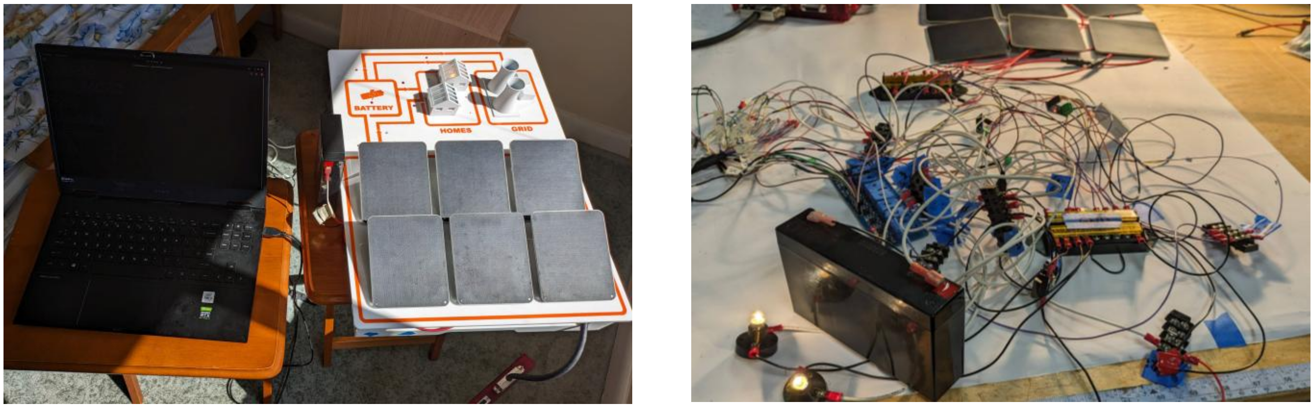


Figure 3: Tabletop Simulator Prototype for a Microgrid

Figure 4 (Video) Table Top Simulation of Microgrids

Tabletop Simulation for Microgrid Optimization and Time-shifting

The decarbonization of the bulk electric power system, whose generation mix still mainly consists of gas and coal-fired thermal generation, is mainly being driven by the rapidly falling costs of utility-scale wind and solar. These variable generation sources, such as wind and solar, produce energy without emissions, unlike conventional thermal power plants. However, they cannot be controlled or adjusted on demand, which means their output depends on natural conditions like sunlight and wind. In essence, nature dictates their energy supply over time. At low penetrations (e.g., 5-20%), variable renewable energy (VRE) can be accommodated by the existing grid. However, at the high penetrations needed for a low-carbon grid, the variability and unpredictability of solar and wind pose major challenges to a reliable power supply that is able to instantaneously meet electrical demand. Even momentary supply-demand imbalances in electrical grids can cause cascading blackouts and thus reliability is a major challenge for a future grid powered mainly by renewables. Energy storage in the form of batteries or pumped hydro has been widely studied as a well to smooth out the fluctuations in VRE production. Co-locating energy storage with renewable generation is a way for renewable generation to make firm commitments in energy markets. This is important as it reduces the amount of uncertainty and variability that the renewable generator introduces into the balance of the power grid. The operators of combined renewable plus storage plants seek to optimize the revenue they obtain from energy markets. This will often include long-term contracts with penalties for non-delivery (like PPAs), day-ahead and real-time markets, as well as fast-timescale markets for frequency regulation. In this work we study the combination of long-term and real-time markets, although the modeling and optimization framework can be extended to include additional or faster-timescale markets.

The work generates a stochastic optimization framework for performing multi-market energy optimization. This is the task of computing optimal energy dispatches in several, coupled energy markets under uncertainty. Examples of such markets are long-term forward contracts like power purchase agreements (PPAs) and capacity markets, as well as more real-time scheduling markets like the day-ahead, real-time, and frequency regulation markets. Each of these markets has distinct transaction timescales, which range from decades to seconds. The uncertainty arises from the stochasticity of energy production by renewables (ultimately caused by weather) and the unpredictability of short-timescale market prices.

Applying reinforcement learning (RL) to solve stochastic energy optimization problems is an area of growing interest within the research community. However, several challenges remain, particularly in learning safe policies that respect physical and hard constraints and managing variability in exogenous information during policy learning. To develop practical control algorithms using an RL approach, these issues must be addressed effectively. This challenge motivates the following research agenda:

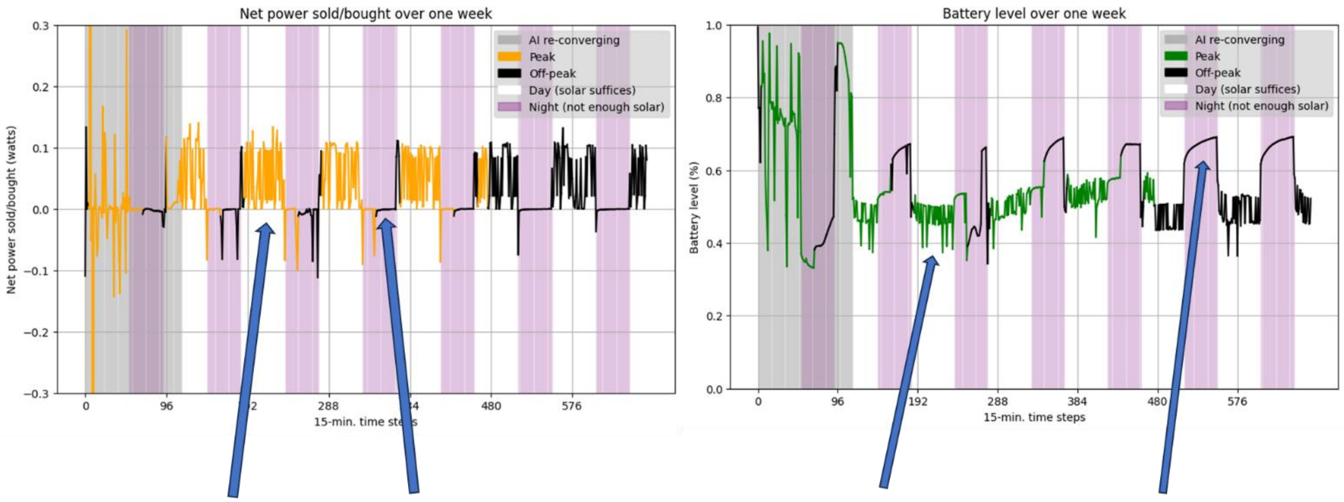
- Formulating a multi-objective stochastic optimization framework for modeling multi-market energy scheduling problems.
- Guaranteeing the satisfaction of hard constraints for power systems.
- Handling variability in exogenous data for prices and renewable generation.

This work is released as a pre-print at Werner & Kumar (2023).

The tabletop simulation prototype demonstrates an optimization strategy for market profit while ensuring local power availability by strategically buying and selling power at optimal times. The optimization models are designed to be user-friendly and accessible to non-technical users, making advanced energy management approachable for all community members. This prototype adds to a proof of concept (POC) demonstrating the control mechanism's ability to manage hardware and handle complex, stochastic fluctuations in inputs, showcasing its robustness and reliability in realistic scenarios.

This research tackles the multi-market energy optimization problem by formulating it as a stochastic optimization challenge, utilizing Markov decision processes (MDP) to handle the uncertainty in exogenous prices and variable renewable energy (VRE) production. Instead of seeking an optimal sequence of decisions, which is common in deterministic optimization, we focus on finding an optimal policy that takes into account the system's state and information. This approach is particularly relevant given the complex and stochastic nature of energy markets. The energy system is modeled as a microgrid connected to the bulk power grid, incorporating renewable generation, energy storage, and controllable loads. The model operates over a finite time horizon, with states and actions adjusted based on data granularity, such as nodal price data or exchange market data. The system's state includes variables like battery state-of-charge (SOC) and renewable energy injections, while actions encompass storage charge and discharge activities. The transition function, which governs how the system evolves, depends on these states, actions, and exogenous factors like real-time prices and renewable energy availability.

This framework places significant emphasis on state and action constraints to ensure physical feasibility and compliance with power system regulations. For instance, energy storage devices have upper and lower bounds on their SOC, and charge/discharge actions are similarly constrained. Renewable generation is capped by nameplate capacity and can be curtailed but not exceeded. The system must adhere to power flow laws at the point of common coupling (PCC) with the grid. To address the inherent uncertainty, the model considers fluctuations in renewable generation and real-time market prices, which are influenced by factors such as weather conditions and market dynamics. This uncertainty is managed through a reinforcement learning (RL) approach, specifically using Proximal Policy Optimization (PPO), which ensures stable and efficient learning by limiting drastic policy changes during updates. This method balances exploration and exploitation, making it well-suited for the dynamic and complex environment of energy systems. Through this approach, we aim to develop a robust control mechanism that can optimize market profits while ensuring reliable local power availability, ultimately contributing to the advancement of smart, resilient, and sustainable microgrids.



Sells more power than bought when solar is available

Relies on battery to power load at night, makes fewer transactions

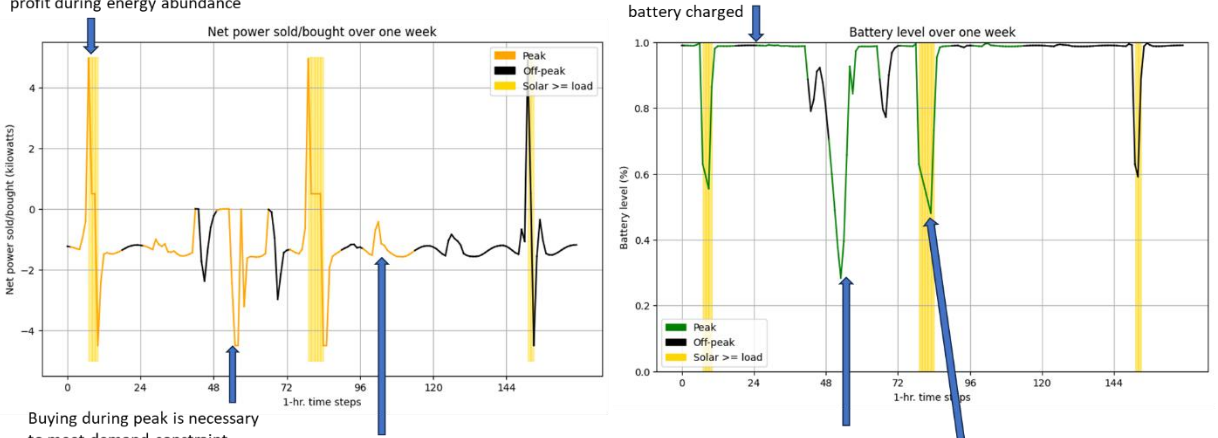
Battery reserves are sold during the day as solar can power load

Conserves power at night to avoid buying and maximize selling during the day

Figure 5: Simulation of the Table top Microgrid Model

Looks for opportunities to maximize profit during energy abundance

Operating in an energy deficit, keeps battery charged



Buying during peak is necessary to meet demand constraint

Minimizes cost by using solar to charge battery

Responds to battery drain during high demand

Can sell reserves during solar surplus

Figure 6: Selling and Buying decisions on Simulated Microgrid Model using CAISO data

AI & Institutional frameworks for Microgrids

Microsoft Research is partnering with the Urban Infrastructure Lab (UIL) at the University of Washington to explore community microgrids, a novel form of collective energy generation and management. This collaboration is part of Microsoft Research's new AI & Society program to ignite interdisciplinary collaboration. Together, computer scientists and urban planners are bringing unique experiences and perspectives into the discussion and practice of community microgrids. We all recognize the urgent global need for climate mitigation and clean energy transition and the limitations of traditional renewable energy facilities like solar farms and off-grid solar panels. Community microgrids introduce an additional layer to our existing electricity grids, offering an opportunity to mitigate these limitations while providing extra benefits. Urban planning serves as a governmental instrument in addressing market failures, offering a set of practical toolkits to tackle externalities such as climate change and renewable energy development. With a new institutional economic perspective, the collaboration seeks to understand the market and critical community needs, identify transaction costs and barriers associated with developing community microgrids, plan ahead, and propose organizational and social innovation approaches to recycle the downstream costs. Driven by our focus on prioritizing public interest and promoting social good, we strongly emphasize energy and climate risk inequality across communities and how to better serve the interests of disadvantaged, tribal, and underrepresented communities. We see the revolutionizing potential of AI in social infrastructures and see significant human-AI collaboration gaps in community settings and energy sectors. To better share the story with communities and decision-makers, this research quantitatively and qualitatively measures the environmental, economic, and societal benefits of microgrids and examine their potential to support sustainability and social goals. Through integration into an AI-powered interactive decision-support platform for stakeholders with consideration of responsible AI practice in community settings, this research seeks to facilitate information sharing, decision-making, stakeholder coordination, and community engagement, which will support collective action in developing community microgrid systems in the real world.

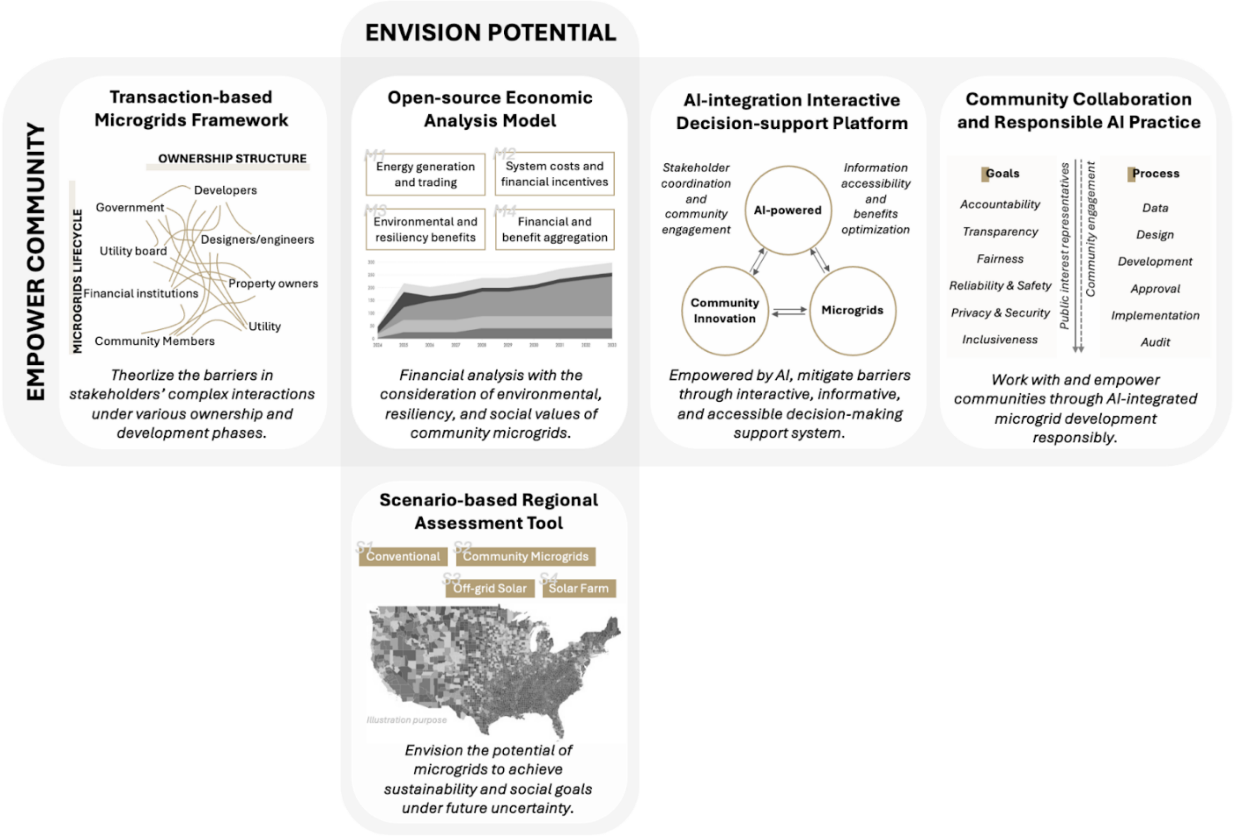


Figure 7: Institutional Framework Design and Planning for Community Microgrid

Grassroot Community Smart Electrification and Solar Microgrid

West Atlanta is changing and gentrifying, as are many neighborhoods in Atlanta. Currently, residents of West Atlanta experience among the highest energy burdens in the state of Georgia (Brown, 2019). With land and housing prices skyrocketing while income stagnated, many residents have been pushed out of their neighborhoods while development overlooked the needs of West Atlanta residents for emergency services. While the City of Atlanta established several "cooling centers" across the city to serve residents' emergency needs on high-heat days, no such facilities are located in West Atlanta. This is due to the historical legacy of redlining. Redlining has resulted in the concentration of heat-absorbing infrastructure and a paucity of green spaces, creating a pronounced urban heat island effect. Consequently, temperatures in these areas are significantly higher compared to more affluent neighborhoods, exposing residents to severe health risks. This disparity is a stark example of environmental racism, where low-income and minority communities bear the brunt of climate-related stressors without the necessary resources to mitigate them, such as access to air conditioning and energy-efficient housing (Sutter, 2021). Moreover, the increasing frequency and intensity of heatwaves due to climate change strain the already fragile energy infrastructure in West Atlanta, underscoring the critical need for resilient and sustainable energy solutions (Smithsonian Magazine, 2020).

Microgrids present a viable and technical solution to these energy and environmental challenges. Microgrids can lower energy costs for residents, generate local employment opportunities in the renewable energy sector, and improve public health outcomes by reducing heat-related illnesses and enhancing overall living conditions (Sutter, 2021; Smithsonian Magazine, 2020). Implementing microgrids in West Atlanta is helping to foster an equitable, sustainable, and economically empowered community, capable of withstanding the escalating impacts of climate change. The Vicars Community Center (VCC) Resilience Hub, a community center and organization, serves over 18,000 residents, advancing environmental justice in the community.

The VCC resilience hub is tackling these issues by helping to establish a solar microgrid for the West Atlanta Watershed Alliance (WAWA) community farm and surrounding neighborhoods. Microsoft researchers and collaborators are integrating AI into the microgrid to achieve energy savings, improve resilience, and create local job opportunities. Figure 8 shows the VCC resilience hub and Figure 9 shows the WAWA community farm powered by the microgrid, highlighting key infrastructure for installing distributed energy resources (DERs). This initiative not only ensures sustainable energy but also generates revenue from market participation, funding VCC projects and community-building activities. Here, the economic case for microgrid projects is based on benefits beyond resiliency it delivers in normal (grid connected) mode. Multiple value streams are being associated with energy savings for customers and grid services, such as increasing grid resiliency, building community endowment, peak demand charge reduction and increased capacity value. However, the ability for certain locations to access such markets requires significant grid upgrades.

Figure 8: VCC Resilience Hub and Community Microgrid Infrastructure

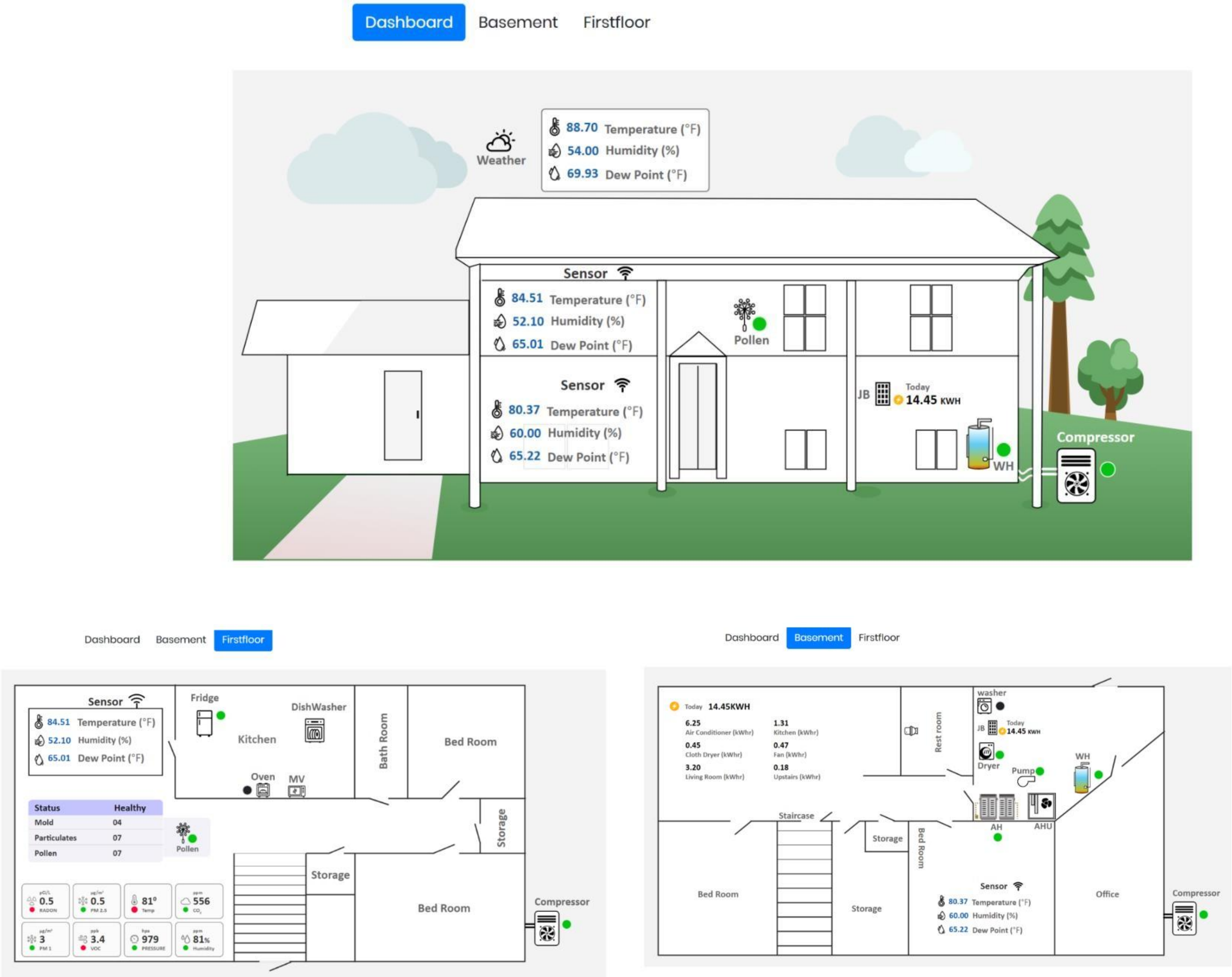
Figure 9: Community Garden collocated with Community Micro-grid

As Dr. Erica L. Holloman-Hill, a West Atlanta legacy home resident and owner of Ayika Solutions Inc (ASI) talks shares, “This house, where I grew up, where my three youngest children were born, and where my grandmother passed away, is now the Living Energy Burden Lab for Ayika Solutions Inc (ASI), my environmental consulting and research company. Why? Because I am part of the same low-to-moderate-income households living in energy-inefficient single-family homes. This legacy home has a HERS rating of 179. At a score of 150, it is strongly suggested that I purchase a newer, more energy-efficient home. But if I can't afford to move (affordable housing in Metro Atlanta is a joke) or don't want to move (the home my mother and grandmother purchased holds deep meaning for me), what are my options? Deep electrification and retrofits beyond mere weatherization.”

In the summer of 2023, in partnership with ReMiX – The soul of Innovation and Maverick IQ (organizations supporting communities in West Atlanta), Ayika Solutions Inc set out to quantify and describe the experience of a legacy household with a HERS rating of 179. Various sensors were placed on major appliances and throughout the home to assess energy loads and other environmental factors (temperature, humidity, mold/pollen). The findings were not surprising; the lived experience of the family in the home (e.g., high energy bills, uncomfortable heating and cooling, high humidity in the basement) was now captured in data (Figure 10). Partnering with students from Clark Atlanta University, the community organizations designed a digital twin of the home and an interactive digital platform (Figure 11).

As Dr. Holloman-Hill talks about the opportunities of partnership with organizations such as Microsoft, “This allowed me to better understand the interconnectedness between our household choices (intentional or unintentional) and quality of life. A quality of life that could be greatly improved by the electrification of homes like mine, yet access to the upfront cost capital remains the greatest barrier, not the innovation, as we demonstrated over the summer of 2023. The capacity to control the electricity generated, used, and shared is not far-fetched and is only strengthened through public-private partnerships. Partnerships such as this one help share my story and highlight the possibilities of building AI-supported social technologies (e.g., PV, BESS, microgrids) for households like mine. As my grandmother says, “It begins at home,” and to build equitable and resilient communities, homes are where we must begin.

Figure 10. Estimated cost of electricity per day based on household kWh usage between Jul. 29, 2024 – Aug 13, 2023. Courtesy of Dr. Erica L Holloman-Hill, resident and owner of Ayika Solutions Inc.



88.70 Temperature (°F)
54.00 Humidity (%)
69.93 Dew Point (°F)

84.51 Temperature (°F)
52.10 Humidity (%)
65.01 Dew Point (°F)

80.37 Temperature (°F)
60.00 Humidity (%)
65.22 Dew Point (°F)

Today 14.45 KWH

Status	Healthy
Mold	04
Particulates	07
Pollen	07

pCi/L 0.5 RADON
µg/m³ 0.5 PM 2.5
81° Temp
ppm 556 CO₂
µg/m³ 3 PM 1
ppb 3.4 VOC
hpa 979 PRESSURE
ppm 81% Humidity

Today 14.45KWH

6.25 Air Conditioner (kWhr)
1.31 Kitchen (kWhr)
0.45 Cloth Dryer (kWhr)
0.47 Fan (kWhr)
3.20 Living Room (kWhr)
0.18 Upstairs (kWhr)

Figure 11. Smart Electrification: Snapshot of digital twin created for Dr. Erica Holloman Hill’s home. Courtesy of Dr. Erica L Holloman-Hill, resident and owner of Ayika Solutions Inc.

Human-Centered AI for the Equitable Smart Energy Grid

BRAID is a six-year (2022-2028), UK-wide programme dedicated to integrating Arts and Humanities research more fully into the responsible AI ecosystem, as well as bridging the divides between academic, industry, policy and regulatory work on responsible AI. As we transition to renewable energy, diverse households could share locally generated energy from sources like solar. AI systems could help manage some of the uncertainties in such micro-grids, as well as giving individuals and communities access to rich data about their energy. University College London researcher Dr Kyrill Potapov is collaborating with MSR to understand the responses of lower socio-economic status (SES) groups to such sociotechnical arrangements, and the role of AI within them. This eighteen-month fellowship draws on Human-Computer Interaction and Philosophy to explore how technology can support agency; for example, by developing understanding of AI-managed micro-grids, and giving users greater control over how and when they use energy.

The research will involve working with communities and schools around London. We will use electricity sensor based prototypes in participants' homes to simulate sharing solar panels and battery with a small group of neighbours. Over the course of a month, participants will use a web app to see how the AI is charging and discharging their battery and the dynamic pricing of carrying out activities at certain times. The app should help them plan and reflect on their practices. We will bring participants together for workshops to gather their experiences and co-design ways to improve the user interface, or the wider sociotechnical arrangements. Figure 12 shows design sessions organized by the researchers promoting low income energy equity. This will be complimented by co-design workshops in secondary schools, exploring how to introduce young people to these complex concepts, as well as harnessing their creativity and knowledge as stakeholders in their local areas. Throughout this work we seek to bring marginalised voices into design and analysis to develop our understanding of the risks, challenges and opportunities of building equitable smart-grids.

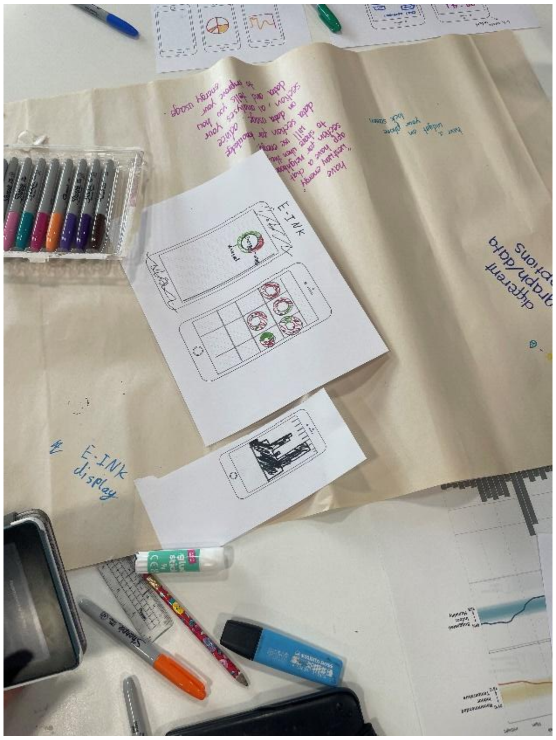
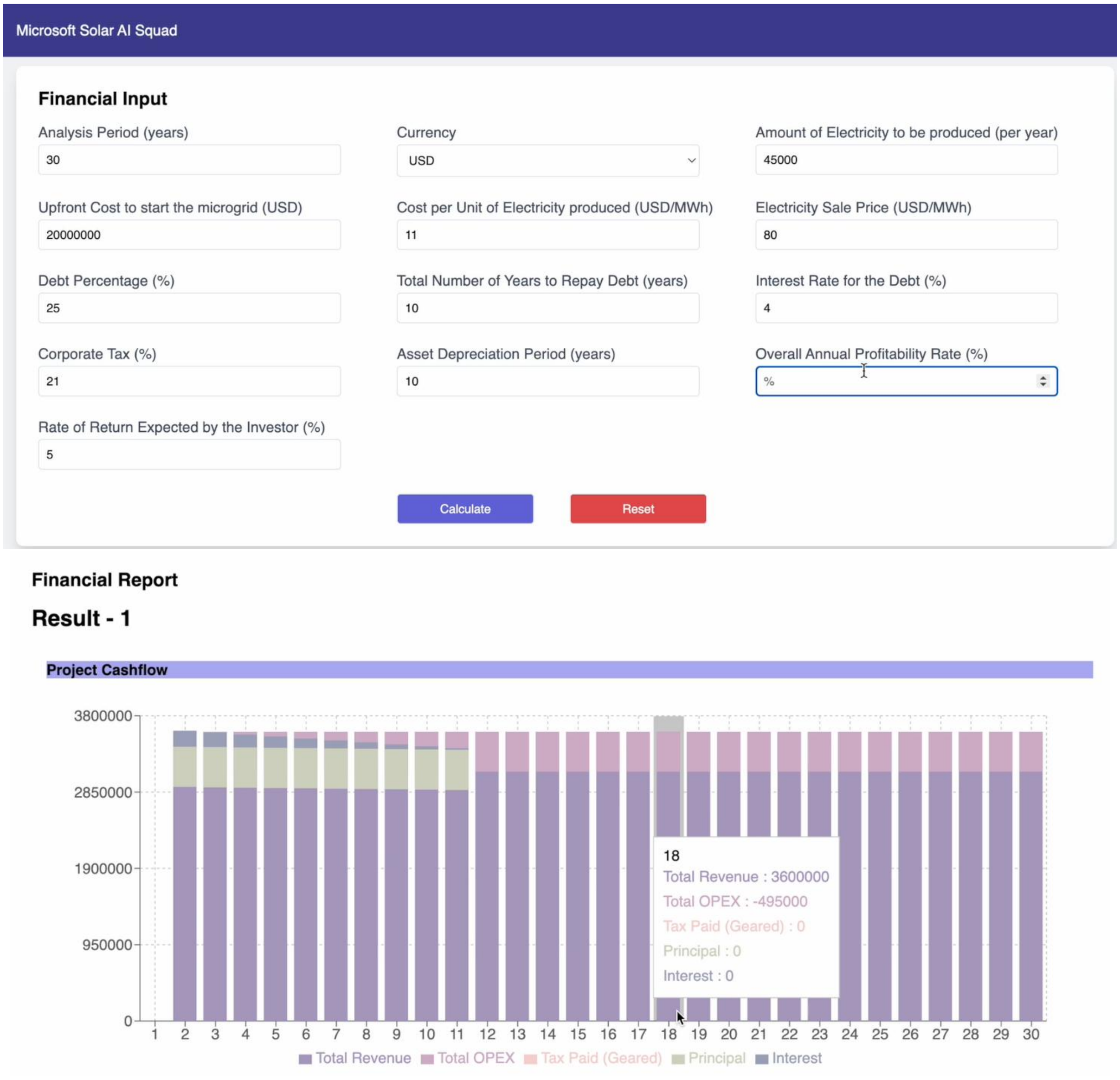


Figure 12: Design session promoting Low income Energy Equity & Education: Researchers at University College London & participants in Low income housing in London

Microgrid Economics: Dashboard for Financial Projections

The high costs and complex decisions associated with solar microgrid adoption present significant challenges. Traditional financial tools often fall short in addressing the unique aspects of microgrid projects, such as fluctuating energy outputs and varying costs. These limitations lead to uncertainty and hesitation among potential investors, impeding the transition to renewable energy. By developing specialized financial projection tools that account for these unique factors, communities can better assess the viability and long-term benefits of microgrid investments, thereby facilitating more informed and confident investment decisions. Through collaboration with University of Washington Global Innovation Exchange, a group of inter-disciplinary master students built a dashboard to simplify complex decision processes into a detailed financial projections for microgrid investments. Figure 13 shows a sample of dashboard that was built.



Microsoft Solar AI Squad

Financial Input

Analysis Period (years): 30
Currency: USD
Amount of Electricity to be produced (per year): 45000
Upfront Cost to start the microgrid (USD): 20000000
Cost per Unit of Electricity produced (USD/MWh): 11
Electricity Sale Price (USD/MWh): 80
Debt Percentage (%): 25
Total Number of Years to Repay Debt (years): 10
Interest Rate for the Debt (%): 4
Corporate Tax (%): 21
Asset Depreciation Period (years): 10
Overall Annual Profitability Rate (%): %
Rate of Return Expected by the Investor (%): 5

Financial Report

Result - 1

Project Cashflow

Figure 13: Sample Financial Projections for Microgrid setup

Putting it together – Key Attributes for AI Infrastructure to Support Energy Transition

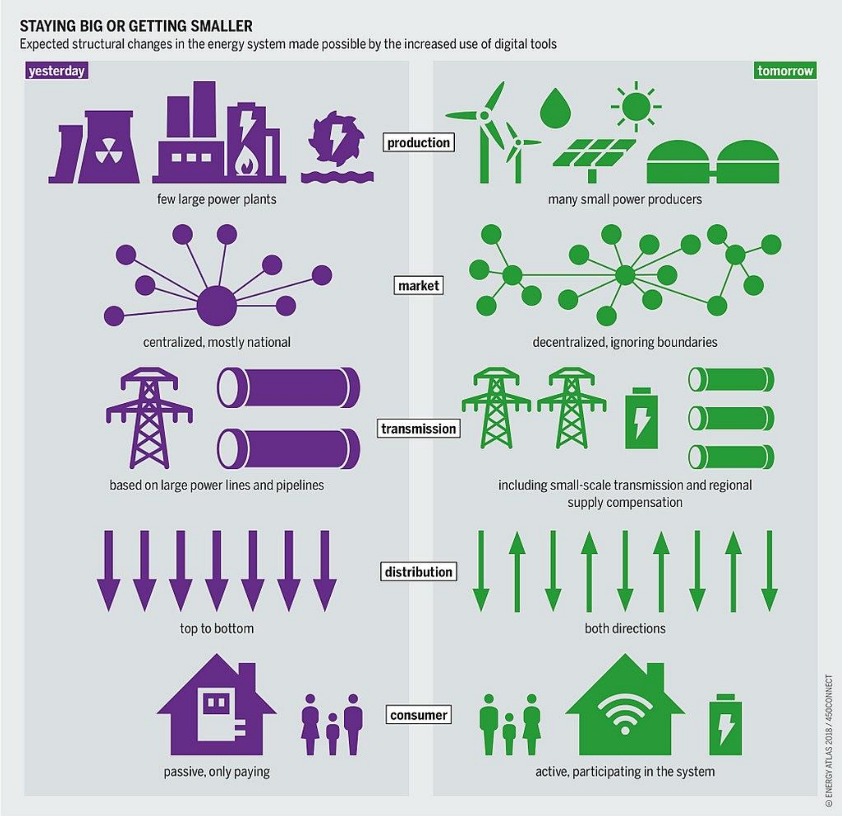


Figure 14: Energy Transition

According to the recent DoE labs report (DoE Report 2024), the benefits of transforming to a clean energy system will be accompanied by the challenges of added complexity, variability, low visibility, and decentralization of the electric power grid. Preserving affordability and improving reliability, resilience, and security in the face of these challenges will require new thinking and approaches that would not apply to the centralized system of even the recent past. Selecting the best approaches is too complex a problem to be solved by human thought alone because of the number of possible combinations and outcomes. AI tools are needed to identify and select approaches that address complexity in matching generation to the times and places of energy demand to achieve an equitable energy future. Distributed generation and the ability to manage local demand sources will require AI to generate a rich set of signals that maximize responsiveness and fidelity to utility objectives of selecting the cleanest, most affordable mix of sources, while maintaining reliable delivery. The growing body of information at the distribution scale will enable AI to optimize the deployment of energy storage to facilitate decoupling the time of generation from the time of use. At the regional scale, AI tools will help support the expansion and management of transmission infrastructure to ease bottlenecks in getting power from areas of plentiful generation to areas of high demand.

The current state of AI promises exciting opportunities to support energy transition towards more renewable and decentralized futures. Region specific organizations, communities, and neighborhoods have unprecedented opportunities to have decisive say in how they design, operate, and use energy. The advantages range from direct reduction in energy burden to developing economic empowerment. This is made possible through AI frameworks which support these socio-technical infrastructures.

The suite of projects presented above validates how AI & technology can support sustainability goals on multiple levels at specific sites– social, economic & environmental. How can current state of AI & technology help achieve the vision & goals articulated? Recent reports by another DoE lab (Bent, et.al 2022) suggests that the full value of microgrid planning and design capabilities are only realized through software interoperability and flexible software architectures that ensure such capabilities are leveraged in multiple ways and applications. Here at Microsoft, we are working towards finding the right abstractions which can allow for these solutions to be scalable, interoperable, and support multi-stakeholder collaborative decision making. Technological projects initiated by community and organizational needs on the ground help us design the right interfaces for this infrastructure. Using the requirements laid out by the DoE report on microgrid, here I articulate how these projects inform us in the design of such technology & AI infrastructure.

A) **Interoperability and Collaborative AI** is crucial for advancing microgrid technology, requiring the integration of various microgrid tools and their capabilities to address performance trade-offs, uncertainty propagation, and interdependence with other infrastructures. To achieve this, developing interoperable modeling environments that support the seamless integration of tools is essential. These environments should standardize inputs and outputs, facilitate trade-off analysis, and accommodate uncertainty propagation. Additionally, they must support interdependence with non-electrical systems like natural gas, water, and telecommunications. Recommendations include retrofitting existing tools for standardization, leveraging existing capabilities for interdependent system assessments, and encouraging open-source or easily licensable solutions to enhance collaboration and innovation in microgrid technologies. Projects such as the Smart Electrification and Micro-grid in West Atlanta informs us to the nature of complex socio-economic-technical interactions for community infrastructures and the socio-technical interfaces needed to provide interoperability & collaboration among various stakeholders, technical systems, and grid/market models.

B) **Flexible AI architectures** are essential for microgrid planning and design tools to adapt to evolving requirements. These architectures must support software modularity, allowing independent modules to model microgrids at varying levels of granularity and fidelity. This modularity facilitates flexible component modeling, enabling users to select and validate the appropriate fidelity model for their specific application. To achieve these goals, AI should incorporate flexible reliability metrics and implement multiple modeling methods for key features such as power flow and storage capabilities, ensuring existing tools can be efficiently repurposed to meet new demands. Institutional frameworks have significantly influenced energy sector investments over the past decades, including microgrid adoption (Bent et al., 2022). These frameworks encompass regulatory paradigms governing microgrid ownership, investment models, consumer protections, safety, and equity, as well as technical codes and standards for interconnection, siting, and permitting processes. An effective institutional framework requires a well-informed community of stakeholders and targeted R&D activities to evolve regulatory approaches and modernize codes and standards to accommodate novel technologies. Such a framework can enable private industry to thrive through economies of scale and increased deployments. The work by University of Washington collaborators on AI infrastructures and institutional frameworks addresses these architectural issues by addressing various economics, social and technical design questions. Additionally, the work by UCL researchers on understanding interfaces and metrics to support energy needs of low income housing communities informs architectural modular designs to include the diversity of localized metrics & objectives.

C) **Multi modal Integration**: Designing technology for community microgrids requires integrating multiple time scales, spatial scales, and infrastructure domains. Rather than creating a single all-encompassing tool, leveraging interoperable and flexible software architectures is essential. This includes integrating operational considerations into design tools, accommodating complex engineering limits, and incorporating advanced non-conventional storage modeling. High-fidelity restoration and recovery modeling, robust communication modeling, and adaptable control systems are also crucial. Furthermore, microgrids should support diverse market and grid services, including protection modeling and just in time start capabilities. Achieving these integration goals involves developing dynamic simulation libraries, aggregated DERs and microgrids, and end-to-end planning and design approaches that balance efficiency, resilience, and sustainability. The tabletop simulation model presented in Section [] shows how multiple market & grid objectives can be integrated in a specific micro-grid design. The tabletop simulation optimized operations by accommodating complex DER combinations & grid dynamics.

D) **Scalability**: Scalability is a crucial technological requirement for the future of the grid, as emphasized by Department of Energy (DoE) reports and labs. Achieving scalability involves developing standardized interfaces and communication protocols, which facilitate the integration of Distributed Energy Resources (DERs) and enhance interoperability with existing grid infrastructure. Technical advancements in scalable microgrids also require dynamic control systems capable of managing the variable outputs of renewable energy sources, such as photovoltaic (PV) systems and wind turbines, while maintaining grid reliability. Furthermore, scalable microgrids should incorporate advanced energy storage solutions to balance supply and demand effectively. With increasing diversity of DERs, addressing region specific energy needs, and adapting energy grids to local infrastructures, technology needs to address how these solutions can be scaled so that new innovation in energy models can be easily deployed across regions, and investments in R&D can be effective in addressing energy requirements. Building these prototypes across regions and with diversity of community centered needs allows us the opportunity for the right abstractions & interfaces which can scale.

Thus, by addressing these key socio-technical issues through research and prototyping at specific sites, allows us to address the over-arching potential of AI & technology to support this energy transition towards a more resilient & equitable grid design.

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