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Advancing the state of energy equity metrics

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ABSTRACT

Multiple stakeholders—ranging from regulators and developers to customer and community advocates—have roles to play in the transition to an equitable energy system. Metrics are an emerging area of importance for the operationalization of energy equity as they may guide investment and policy decisions that shape the energy system along this transition. This paper aims to advance energy equity metrics for use in regulation, planning, and operations of the electricity system within the United States. Metrics were surveyed from the literature and distilled to a set that identifies which stakeholders may be associated with which metrics. Established tenets of energy justice—distributive, procedural, recognition, restorative—were also identified for each metric, providing a link between energy equity in study and in practice. This means of organization is intended to enable discussion and collaboration among stakeholders, as the objectives embodied in energy equity metrics are often beyond the control of individual stakeholders. Further stakeholder discussion is necessary to determine which metrics are practicable, who will use them, and how they will be used to support energy equity.

1. Introduction

The energy transition is an opportunity to create a system that overcomes historic, current, and expected inequities in energy services and infrastructure (National Academies, 2021). Policies and investments that consider energy equity can accelerate this transition (O'Shaughnessy et al., 2022) and will likely be necessary to assure a just transition (Raimi et al., 2021). In this paper we identify metrics and stakeholders that may guide policy and investment decisions in the path to an equitable energy transition. The goal of the paper is to assist stakeholders by advancing the operationalization of energy equity, by converting more abstract concepts into objective observations through established metrics and measurements. We acknowledge that this process requires further stakeholder consultation around the metrics identified and how to put them to use.

The metrics and measurement methods discussed in this paper focus on electricity infrastructure in the United States, both at the supply and demand side of the system. The main inequities of electricity infrastructure and the residential electricity supply process include:

- Individual energy insecurity, or the inability to pay for energy (Farley et al., 2021).
- Limited access to energy-efficient or clean energy technologies (Darghouth et al., 2022; Reames et al., 2018).
- Insufficient local infrastructure to support distributed energy resource (DER) adoption (Brockway et al., 2021).
- Economic impacts in communities due to the energy transition from fossil-fuels (Grubert, 2020).
- Exposure to externalities like pollution (Carley & Konisky, 2020).
- Vulnerabilities to utility service disconnections, e.g., due to bill nonpayment (Memmott et al., 2021).
- Longer durations of utility service interruptions than system averages, e.g., due to severe weather events (Carvallo et al., 2021).

Vulnerable and disadvantaged communities often experience a disproportionate share of these inequities. For example, in 2020, 27% of U.S. households reported facing some type of energy insecurity (of which 57% had income less than $10,000, 52% identified as being Black, 47% were Hispanic or Latino, and 41% were renters), 20% of households reduced their other basic necessities to pay their energy bills, and 10% of households received disconnection notices due to nonpayment (U.S. Energy Information Administration, 2022b). A study by Sunter et al. (2019) showed the disparity in energy access (i.e., clean and efficient energy technology access) where solar photovoltaic (PV) adoption aggregated at the census tract level for majority black census tracts was 20% behind majority white census tracts in having existing installations. The study also found that the disparity persisted even after increases in income and homeownership were considered. Similarly,

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work by Lanciani (2020) highlighted that in 2018 only 10% of utility spending on energy efficiency went to low-income communities, limiting their access to solutions that could mitigate energy burden and insecurity for households. In relation to unintentional service disruptions, Carvallo et al. (2021) analyzed the Texas freeze blackout in 2021 and found that areas with minority populations were four times more likely to suffer blackouts than white/affluent populations. A study by Tormos-Aponte et al. (2021) also showed the disproportionate power system burden distributions in Puerto Rico during the 2017 blackouts following Hurricane Maria, where the vulnerable communities had longer outages and were not prioritized for power restoration crew assignments. In addition, fossil fuel-fired power plant proximity is another stressor that exacerbates the inequities faced by disadvantaged and vulnerable communities (Thind et al., (2019)). A report from 2016 showed that 39% of people living close to coal-fired power plants are people of color, leading to a disproportionate exposure to health-impacting pollutants such as SO_2, NO_x, particulate matter, mercury, and others (NAACP, 2016).

These inequities could have different root causes including planning and decision-making methods (e.g., least-cost energy infrastructure planning), historic discriminatory grid and housing planning practices (Irving, 2022), and broader societal inequities (Lewis et al., 2019). The stakeholders discussed in this paper can contribute to overcoming these inequities in their roles by considering energy justice and equity within their planning, regulation, and operations practices.

This work builds on and complements previous energy equity metrics efforts (Energy Equity Project, 2022; Tarekegne et al., 2021) and offers an organization of metrics by stakeholders for ease of use, relevance, and implementation. We reiterate that this paper intends to serve as a starting point for advancing discussion and that significant stakeholder consultation is necessary to build consensus. The rest of the paper is structured as follows: Section 2 offers a background of energy equity, including terms defined from the literature; Section 3 describes key stakeholders (metrics users); Section 4 offers the relevant energy equity metrics; and Section 5 offers discussion of the use of metrics as well as considerations for future work.

2. Energy equity: background

Energy equity draws from the established field of environmental justice. Whereas environmental justice encompasses broad environmental and human health effects of pollution and infrastructure development, energy equity focuses on those effects specific to the energy system. Energy equity is also connected to the field of climate justice, which recognizes the differing responsibilities—based on historic greenhouse gas emissions—and capacities of states and communities to respond to climate change (Bodansky et al., 2017). Justice principles are increasingly recognized in the transformational change necessary to mitigate and avoid the worst effects of climate change (Intergovernmental Panel on Climate Change, 2022; Males et al., 2022). Climate justice also raises inter-generational equity considerations and shares this forward-looking character with energy equity. Furthermore, energy equity considers the fair access to energy decision-making and participation in energy system governance.

Integrating equity into energy system planning and regulation requires an augmentation of traditional objectives and how they are measured. Electricity infrastructure providers have long been accountable for safety, efficiency, affordability, and reliability of their services. These objectives have established metrics and are integrated into planning and regulatory processes to allow for implementation and evaluation. Adding energy equity to these traditional objectives requires examining the objectives (and other emerging objectives such as resilience and decarbonization) in relation to the different types of customers and their interactions with the system. For example, energy equity would require addressing disparities in electricity reliability at the individual customer or community scale that may be obscured by coarser, average-customer or system-level measurements. Novel and traditional metrics may support the integration of energy equity into electricity system planning and regulation.

2.1. Definitions

Definitions of key concepts in the energy justice and equity space are still emerging. The current lack of consensus around energy equity metrics may stem in part from the lack of consensus around definitions. Some of the well-used definitions are captured below to offer a foundation for what we mean by energy equity and how it fits the discussion in this paper. These definitions of energy equity draw from four established justice tenets: distributive, procedural, recognition, and restorative. A description of the tenets is captured in Table 1.

Foundationally, the term *energy equity* stems from or is equivalent to the concept of *energy justice* (Baker et al., 2019) and may be defined as:

> Energy equity is the fair distribution of benefits and burdens of energy production, distribution, and consumption, and fair engagement in this system's decision-making processes (Farley et al., 2021; Sovacool & Dworkin, 2014; Tarekegne et al., 2021).

> Energy equity recognizes that disadvantaged communities have been historically marginalized and overburdened by pollution, underinvestment in energy infrastructure, and lack of access to energy-efficient housing and transportation. An equitable energy system is one where the economic, health, and social benefits of participation extend to all levels of society, regardless of ability, race, or socioeconomic status. Achieving energy equity requires intentionally designing systems, technology, procedures, and policies that lead to the fair and just distribution of benefits in the energy system (Pacific Northwest National Laboratory).[1]

2.2. Metrics

We use the following definitions and distinctions of *metric*, building on the work by Tarekegne et al. (2021) and other sources (Littell et al., 2017; Pato et al., 2019; Whited et al., 2015).

Metric — A measurement that can help represent the state of a phenomenon.

Example: *System average interruption duration index (SAIDI).*

- Tracking metric — Reports on the state of a phenomenon
  Example: SAIDI, or SAIDI examined against a demographic overlay
- Performance metric — Quantitatively informs progress toward a target

Example: *SAIDI with a utility target value of X in year Y.*

Target— A goal or policy for attaining a specific value of a performance metric.

A distinction is already being made in practice between tracking metrics and performance metrics.[2] A performance metric is one that a stakeholder can be held accountable for. Performance metrics are therefore ideally quantitative, objective, and within the control of the stakeholder. However, not all metrics are performance metrics and there is a significant need for energy equity tracking metrics. The role of

[1] Pacific Northwest National Laboratory uses this definition in its thematic work on energy equity. (https://www.pnnl.gov/projects/energy-equity)

[2] See, for example, stakeholder sessions with the Illinois Commerce Commission (https://www.icc.illinois.gov/informal-processes/Electric-Utility-Performance-and-Tracking-Metrics) and Minnesota Public Utilities Commission Docket E-002/CI-17–401, wherein several "information-only" metrics were discussed. (https://efiling.web.commerce.state.mn.us/edockets/searchDocuments.do?method=showPoup&documentId=%7B0082456D-0000-CA1F-9241–23A4FFF7C2FB%7D&documentTitle=20199–155917–01)

Table 1
Energy justice and equity tenets.

Justice tenet	Scope	Example in energy system
1. Distributive	How are benefits and burdens distributed?	Spatial and sociodemographic variations in electricity quality, exposure to pollution, and customer ability to pay
2. Procedural	How is the distribution of benefits and burdens governed?	Inclusiveness, transparency, and representativeness of planning and regulatory processes
3. Recognition	Who partakes in the benefits, burdens, and governance process?	Specific recognition of the needs and capacities of disadvantaged communities
4. Restorative	What damages have occurred in the past, and how can they be restored or prevented in the future?	Impact assessments that inform the planning process to avoid potential damages to people and the environment

tracking metrics is to inform on the state of a phenomenon without necessarily having an associated target or assigned stakeholder responsibility. As energy equity is an emerging system objective, we expect that equity metrics may initially be tracking metrics, not performance metrics. Tracking metrics may eventually become performance metrics. For the purposes of advancing discussion, in this paper we also interpret *metric* to include concepts that may not (yet) be quantitative measures.

Several states and utilities have identified energy equity metrics in legislation, regulatory dockets, or plans. Washington's Clean Energy Transformation Act requires collection and reporting of energy burden and energy assistance need for all utilities.[3] Oregon's HB 2021 also identifies energy burden and disconnections data to be addressed in utility clean energy plans.[4] Beyond these two states, though, there seems to be little consistency in the metrics identified. Metrics under discussion in Illinois go beyond energy burden to additionally consider addressing procedural equity.[5] Connecticut intends to measure participation in energy efficiency programs,[6] and Eversource Energy in Massachusetts intends to develop an equity index that measures investments in environmental justice communities.[7] The array of approaches under consideration indicates that this is still an emerging area.

2.3. Disadvantaged communities

Many equity metrics acquire meaning only when placed against the backdrop of customer sociodemographic (for example, SAIDI examined against a demographic overlay). At a minimum, an equitable energy system would aim to improve performance in a way that minimizes disparities among customers or communities on the system. Clarification is therefore needed around these demographic descriptions. Tarekegne et al. (2021) identified the need for a consistent definition of *disadvantaged communities (DACs)* in the energy system context. This is currently emerging through a set of burden indicators developed as guidance for implementation of the Justice40 Initiative by the U.S. Department of Energy. A disadvantaged community is defined as:

> A census tract ranked in or above the 80th percentile of the cumulative sum of the 36 burden indicators [fossil dependence (2), energy burden (5), environmental and climate hazards (10), socio-economic vulnerabilities (19)] for its state and with at least 30% of households classified as low-income.[8]

This definition advances the operationalization of energy equity by providing a consistent and measurable sociodemographic overlay for evaluating disparities in energy system performance. At the same time, it is worth noting some limitations of this definition:

- Census tract data may not completely reflect customer-level inequities.
- Communities are not necessarily spatially contiguous, as *community* can also refer to dispersed groups of people that experience similar conditions.[9]

[3] SB 5116 (https://lawfilesext.leg.wa.gov/biennium/2019–20/Pdf/Bills/Session%20Laws/Senate/5116-S2. SL.pdf?q=20210822161309)

[4] https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB2021/Enrolled

[5] https://www.icc.illinois.gov/informal-processes/Electric-Utility-Performance-and-Tracking-Metrics

[6] Final Determination Equitable Energy Efficiency (https://portal.ct.gov/-/media/DEEP/energy/ConserLoadMgmt/Final-E3-Phase-I-Determination.pdf)

[7] Docket 22–22 (https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14405624)

[8] https://www.energy.gov/diversity/justice40-initiative

[9] As acknowledged in interim guidance on the Justice40 Initiative: https://www.whitehouse.gov/wp-content/uploads/2021/07/M-21–28.pdf

- Not all communities that bear burdens of the energy system are *DACs*, and vice versa.[10]

These can be considered areas for further refinement in defining the target population or sociodemographic overlay for examining energy system inequities.

3. Stakeholders

Equity metrics are produced and utilized by a number of different stakeholders, each with their own level of influence and authority. Their ability to exert that influence varies greatly; the stakeholders included here were selected from the literature based on their responsibility for the creation, enforcement, and/or implementation of metrics in existing and future programming. They include federal and state governments, regulators of the energy system, power utility companies, planners and zoning officials, and developers who build energy generation and infrastructure. They have in common the ability to exercise power within the energy system — the public, community advocates, and other system participants can contribute to the development of metrics, but are limited in the decision-making and implementation process and primarily subject to the authority of the identified stakeholders.

Categorizing equity metrics by stakeholder serves several purposes. It takes into consideration the particular constraints on stakeholder authority, as is the case for energy regulators who have strict limits on information they can include for decision-making. Classifying metrics by stakeholder allows individual system participants to identify who else has common interest or can fill gaps in their skills or authority, which can enable better collaboration among stakeholders to achieve specific equity goals or implement policies and programs.

This classification of metrics is also intended to create a transparent matrix of those entities who are responsible for creating, enforcing, or implementing a metric, so that the public — in particular, community and energy equity participants and advocates — can see who might be involved with the establishment and measurements of particular system concerns. The diversity of participants means that entities can hold multiple roles in relation to equity metrics depending on their placement in the larger structure of the energy system. The descriptions in this section are intended to provide an overview of the responsibilities, constraints, and authority of each stakeholder and how their power may interact with others in order to establish a clear landscape of those who create, enforce, and are required to implement equity metrics in the United States energy system. Understanding how these entities interact is vital for pulling the right lever that can initiate an action or create equitable outcomes.

3.1. Federal government

The federal government of the United States passes legislation and establishes policies and provides funding for their implementation on the state and local level. The Tenth Amendment of the Constitution delineates the relationship between the federal government and state governments, namely that powers not expressly granted to the federal government are reserved for the states. The powers of the federal government to engage in regulatory action are drawn from legal interpretations of this concept of federalism and how it applies to the clauses of the Constitution.

National standards govern large-scale problems, including air and water quality, as well as energy generation and transmission that expands beyond the land area of a single state (Todd, 2020). Congress passes laws that delegate authority to federal agencies to examine regulatory issues and set specific standards under the process established by the Administrative Procedure Act (1946). The authority to regulate commerce between the states, other countries, and Native American tribes granted in the Commerce Clause, in particular, has been the primary justification for the major environmental laws since 1970 (Klein, 2003). The Environmental Protection Agency, for example, was required by the Clean Air Act (CAA) of 1970 to establish national ambient air quality standards for criteria pollutants that states must adopt plans to meet (U.S. Environmental Protection Agency, 2022a). This administrative tiering is replicated at the state level, as state agencies are delegated by state legislatures, and allows for expert determination of specific standards that Congress cannot delineate due to their granularity and the shifting nature of scientific advancement.

Two recent pieces of legislation passed by Congress will supply significant funding for power system and infrastructure improvements and capacity expansion in coming years: the Infrastructure Investment and Jobs Act and the Inflation Reduction Act of 2022, which funds energy efficiency, distributed generation, and electric vehicle incentives, as well as tax credits to encourage production of clean energy, technology manufacturing, environmental justice and equity ("Inflation Reduction Act of, 2022," 2022; "Infrastructure Investment and Jobs Act," 2021).

Additionally, the federal government has the resources and scale of authority to collect national-level data and provide it freely for public use. This data is used widely by entities across the country, including in federal initiatives, to understand the demographics and conditions of people at varying levels of detail to maintain individual privacy and to enact policies that require the equal or equitable treatment of population groups.

3.2. State government

State governments provide the bulk of funding for water, power, and transportation infrastructure improvements (Municipal Securities Rulemaking Board, 2021; National Association of State Budget Officers, 2021). They fund programs through budgetary line items, ratemaking, and taxes, and can issue bonds for specific improvements. Municipal securities in particular are a significant mechanism for infrastructure funding for state and local governments (Municipal Securities Rulemaking Board, 2021). While states and their agencies administer and are required to follow federal policies and regulations, they often set their own state-level programming and priorities for energy infrastructure and resilience actions. In some cases, states set standards that exceed those of the federal government. California had motor vehicle emissions standards before federal ones were enacted under the CAA, and the legislation thus allows California to set its own emissions limits by applying for a waiver of preemption (U.S. Environmental Protection Agency, 2022c). Other states are then able to adopt the standards set by California, but not to set their own, which is explicitly disallowed by the CAA (California Air Resources Board, 2022).

State legislation has also been used to establish green banks that fund clean energy, energy efficiency programs, and environmental infrastructure improvements (Connecticut Green Bank, 2021). Other state-level regulation of the energy system includes legislation that requires investor-owned utilities (IOUs) to engage in specific planning actions, as seen in Florida when Governor Ron DeSantis signed SB 796 requiring IOUs in the state to file storm protection plans every three years (DeSantis, 2019). While these plans project 10 years out and are consistently updated, the legislation also makes it easier for utilities to recover costs associated with these improvements by increasing customer rates (Florida Public Service Commission, 2022). This rate increase can exacerbate households struggling with high energy burdens, particularly in a state with a significant elderly population, which raises equity concerns.

[10] These challenges and potential inconsistencies are exemplified in recent press coverage of New York's implementation of disadvantaged community definitions. (https://www.eenews.net/articles/wealthy-n-y-areas-called-disadvantaged-for-climate-aid/)

3.3. Regulators

Federal regulation of the energy system is administered by the Federal Energy Regulatory Commission (FERC), which covers wholesale energy generation transactions and the interstate transmission system. FERC has jurisdiction over traditional investor-owned utilities, regional transmission organizations (RTOs) and independent system operators (ISOs). Because they have authority over energy sale and transmission through interstate commerce, isolated intrastate systems (as is the case in Alaska, Hawaii, and the Electric Reliability Council of Texas) are outside their statutory authority (Greenfield, 2018). FERC standards include a number of actions across multiple categories, including tracking performance metrics and transmission line maintenance, as well as coordination between system actors (Federal Energy Regulatory Commission, 2021).

In states with a vertically integrated electric sector, public utility commissions (PUCs) regulate generation, transmission, and distribution (U.S. Environmental Protection Agency, 2010). In states with a restructured system, PUCs regulate distribution, whereas generation markets are administered by an ISO or RTO that operates the transmission system to assure full access to market participants (ISO/RTO Council, 2022).

State-level regulators, including public utility or service commissions, are established by state legislatures to regulate companies providing public services that are monopolies (electricity, natural gas, water, wastewater) (Byrnett, 2019). Their purview includes reasonable, adequate, and efficient services at reasonable prices (U.S. Environmental Protection Agency, 2010). However, the authority of PUCs is limited to IOUs and does not extend to municipal or cooperative utilities.

3.4. Utilities

Utilities are the primary entity responsible for energy service delivery and reliability, in accordance with regulatory requirements (Federal Energy Regulatory Commission, 2020). In restructured wholesale markets, they own and maintain electricity distribution infrastructure, the cost of which is recovered through ratemaking actions by the state public utility or services commission. ISOs and RTOs in restructured markets are responsible for overseeing the generation and transmission of power to customers (U.S. Environmental Protection Agency, 2022b). In regulated wholesale markets, utilities are often vertically integrated monopolies responsible for the generation, transmission, and distribution of power to their service territory. Due to the economies of scale of transmission and distribution infrastructure, customers often only have one energy service provider available (Tuttle et al., 2016). In some restructured markets, customers have the option to choose alternative energy service providers who generate and/or market electricity and may not be affiliated with the distribution utility. Power purchased from alternative suppliers is delivered by the distribution utility, which charges for this service and may be part of the customer's consolidated, itemized, or separate bill (U.S. Energy Information Administration, 2022a).

Utilities engage in long-term asset planning and determine infrastructure improvement priorities, particularly as the power sector shifts from fossil fuels toward renewable energy and distributed energy resources (Ferrari, 2021).

3.5. Planners/Zoning officials

Planning and zoning officials are crucial decisionmakers who help determine the design and function of long-term built infrastructure in communities. The assets they may permit include housing and critical assets like hospitals, which contribute to the economic growth of municipalities (Faraci, 1967).

While subject to the regulations of federal, state, and local governments, they hold significant power in the day-to-day determinations of what developers are permitted to build and where. In coordination with local governments, municipal officials, and voters, they help to decide who receives development contracts. Government regulations include planning and equity considerations, such as clean energy development and identification and mitigation of climate change hazards (Shuford and Suzanne (2010)). Planning and zoning officials have ground-level authority over the siting of clean energy manufacturing and development projects, whose locations have the potential to exacerbate historic inequities or shift the burden of negative pollution and noise externalities away from already disadvantaged communities (Carley & Konisky, 2020).

3.6. Developers

Developers are responsible for the planning, design, financing, and implementation of a wide variety of energy generation and infrastructure, including renewable energy, storage, and distributed energy resources. They must coordinate with and abide by the regulations of local governments, planning and zoning requirements, and the general constraints of technology and local resource availability (including solar and wind potential and hosting capacity).

A number of states require that a portion of energy sold by utilities come from renewable generation through renewable portfolio standards or clean energy standards (Bowers, 2022; National Conference of State Legislatures, 2021). Additionally, more states have adopted policies requiring significant proportions or all of the electricity in the state be sourced from renewable or clean energy in coming decades (National Regulatory Research Institute, 2021). However, developers of clean energy technology face opposition from local governments that block or otherwise restrict these projects regardless of the potential benefits or if the area is otherwise appropriate (Aidun et al., 2022; Susskind et al., 2022). Equity issues can arise when wealthier areas are able to engage in protracted legal actions to prevent local development, but DACs without the same resources (who may already bear the brunt of manufacturing externalities) cannot do the same (Carley & Konisky, 2020).

4. Energy equity metrics

This section offers an organization of energy equity metrics by stakeholders for ease of use, relevance, and implementation. The metrics were selected through literature review of academic papers, reports, policy documents, and other relevant publications. Metrics used for equity need to assess the distribution of relevant electricity infrastructure benefits and burdens across different customer groups. This means the identified metrics in Table 2 need to be placed against an overlay of disadvantaged community indicators (for example, fossil dependence, energy burden, environmental and climate hazards, and socioeconomic vulnerabilities). In addition, stakeholders could formulate DAC definitions and indicators that are relevant to their roles and apply those to assess disparities across customer categories.

5. Discussion and conclusions

Organizing equity metrics by the stakeholder that creates, enforces, or implements them makes it clear that system participants have very different abilities to impact equity outcomes. Government entities, regulators, utilities, planners, developers, and members of the public may speak different languages that reflect their priorities and background experiences. By creating a matrix by participant, public processes can be improved by informing stakeholders not only what a metric for equity may be, but also by sharing knowledge and easing public participation during these discussions. With a common understanding of who is involved in particular metrics and how, all stakeholders are better positioned to advance operationalization.

Additionally, the use of metrics to pursue equity in the energy system requires engagement with stakeholders at all levels to coordinate

Table 2
Energy Equity Metrics by Stakeholder Responsible for Its Creation, Enforcement, and/or Implementation.

Equity Tenet	Metric	Measurement Examples	Federal Government	State Government	Regulators	Utilities	Planners/ Zoning Officials	Developers
Distributive	Equity program budget allocated to support DAC customers	% total budget accessed by DAC customers	●	●	●	●		
Procedural/ Distributive	Energy efficiency, renewable energy and DER program participation	% equity program participants at different income levels; Eligibility rates for energy efficiency programs by customer group	●	●	●	●	●	●
Procedural	Access to public intervenor funds	% budget to intervenor funds		●	●			
Procedural	Reporting outage and wrongful disconnection record	% utilities reporting outage and disconnection data		●	●	●		
Distributive/ Recognition	Tariff type	% customer subgroups applying and participating in rate incentives for DER adoption; Amount of fixed charges on a utility bill		●	●	●		
Procedural/ Distributive/ Recognition	Arrears forgiveness policies/plans	% utilities with arrears forgiveness programs		●	●	●		
Procedural/ Distributive/ Recognition	Participation rates in community-owned DERs	% served by microgrid; customer groups with islandable resources		●	●	●	●	●
Procedural	Equity targets, goals, and principles	% stakeholders with equity targets and goals	●	●	●	●	●	●
Procedural/ Distributive	Financing availability and access	% DAC and critical customers eligible and have access to financing options	●	●		●		
Distributive	Number of jobs created from equity policy	% jobs accessed by DACs from programs	●	●				
Distributive	Clean energy development	% electricity generation from renewables	●	●	●	●	●	●
Distributive	Clean energy access	% DACs with access to RE (e.g., access to community choice aggregator); DER hosting capacity on distribution system in relation to DACs		●	●	●		
Distributive	Reliability	% critical load by customer group; Probability, duration, frequency, restoration time of outages by customer group (SAIDI, SAIFI, CAIDI, CAIFI); Customer-level reliability metrics (CEMI, CEMSMI, CEMM, CELID)			●	●		
Distributive	Access to behind-the-meter solar services	% residentially owned solar potential achieved		●	●	●	●	
Procedural/ Recognition	Disconnection rates	# of disconnections by customer group; % energy shutoffs without reconnection for more than 30 days		●	●	●		
Distributive	Access to behind-the-meter storage services	% customers with distributed storage		●	●	●	●	
Distributive	Resilience	% customers served by critical substations and feeders with focus on DAC and critical customers% affected customers in DACs; Customer resilience (CAIDI, CAIFI, resources distributed during pre-, during, and post-resilience event days)				●		
Distributive	Energy burden	% income spent on energy; Maximum energy burden limit by customer group		●	●	●		
Distributive	Electrification rates	% households without electricity	●	●	●	●		
Procedural/ Distributive	Income-based payment plans	% stakeholders with income-based payment plans		●	●	●		

priorities, desired outcomes, and capabilities for incorporating metrics into new or existing processes. This cooperation is necessary to enact equity actions, particularly those that require the input of multiple actors to measure or change the outcomes in a community or group. The various stakeholders that create, enforce, and implement metrics may follow different avenues to these roles, based on their respective responsibilities, capacities, and institutional processes.

The use of energy burden as an equity metric illustrates the need for stakeholder coordination across the energy system to effectively achieve equity goals. Energy burden, determined by household expenditure on energy as a percentage of total income, is impacted by conditions influenced by a number of entities. Regulators and utilities have significant influence over the cost and distribution of energy, as well as establishing assistance programs that can help low-income customers address the affordability of electricity. However, they have limited authority to charge differential rates to their customers based on income due to legal guardrails. Local planners and zoning officials can authorize and site the development of community energy generation and DERs, which can increase the supply of and local access to electricity. Federal, state, and local governments can provide funding and incentives for energy generation and direct financial assistance for households. Additional stakeholders may have an interest in tracking and reporting energy burden as a mechanism for prioritizing action, without the ability to increase or reduce that burden. All these stakeholders have roles in the levels of energy burden and its use or measurement as a metric, but do so with very different impacts. This is the case for many energy equity metrics where stakeholders have heterogeneous effects on metric development, implementation, and change.

Advancing energy equity metrics also raises a challenge faced in other emerging fields: not all aspects of equity can be consistently quantified. For example, the restorative justice aspects of energy equity currently exist as a set of values and questions, and even proposals for metrics in this area are scarce (Energy Equity Project, 2022). Quantification of energy equity may be a beneficial step toward increased legitimacy, as has been observed in other elements of the energy transition (Sareen, 2020), and can improve equity policymaking by enabling comparison of alternatives (Sovacool, 2012). At the same time, measurement also risks manipulation and establishes a dichotomy: increased attention can be paid to what is measured, while what goes unmeasured may be obscured (Sareen et al., 2020). Because energy equity has numerous facets that cannot be easily measured, this is an especially acute risk.

Related challenges therefore also arise in fitting equity into quantitative analysis. Benefit-cost analysis is an established quantification framework in energy system planning, but it cannot capture all aspects of energy equity. This is not solely due to the nascent state of equity metrics; it also stems from methodology. Benefit-cost analysis examines impacts to society on average but does not address the distributional differences experienced by members of society at a finer scale. Emerging methodology responds to this shortcoming (National Energy Screening Project, 2022) and furthermore acknowledges that other aspects of energy equity require further, separate treatment. New methods may need to be developed to capture the holistic value of energy equity without discretizing its features.

Significant stakeholder engagement is necessary to determine what is possible with the use and measurement of equity outside of quantitative analysis. As the resident experts of what would be of greatest use in their day-to-day work, insight at all levels of the energy system and across the spectrum of quantitative and qualitative value is relevant. Regulators can provide information on what, legally, can be measured and incorporated into their process of decision-making. What do they feel they can control that will have an impact on system users under their purview? This question is relevant to federal and state government entities as well, who influence what can be implemented at scale. As these authorities work to implement energy equity considerations into existing systems, there is an important opportunity to incorporate the feedback of communities and customers on how to do so. What are their priorities, and what do they see as vital to the function of the energy system? In addition to metrics, new engagement processes may be necessary to gather input from those impacted, including through information sharing.

This paper offered an operationalization of energy equity through metrics that can be used in regulation, planning, and operation of the electricity system by relevant stakeholders. However, the work has its limitations as the currently reviewed metrics would need to be vetted by stakeholders to assure consistency, applicability, and practicality. This can be supplemented in future studies by prioritizing stakeholder engagement to inform energy equity targets and measurement needs. The metrics and stakeholder assignments provided in this paper should be utilized as a basis for designing more comprehensive and stakeholder-informed operationalization of energy equity.

CRediT authorship contribution statement

Conceptualization and research lead, Bethel Tarekegne; Jay Barlow and Rebecca Tapio wrote the paper; all authors reviewed, revised, and approved the final manuscript. Correspondence and further inquiries should be addressed to Bethel Tarekegne.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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