Equitable retail rate design for decarbonized and resilient electricity systems

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Abstract

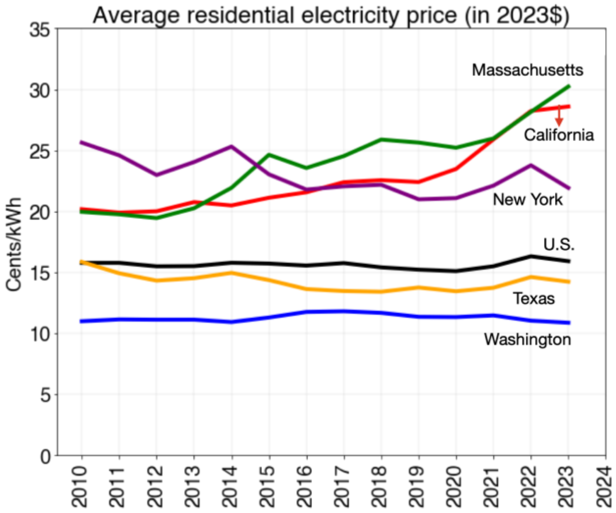
Residential consumers will participate in the energy transition by adopting new energy technologies. Distributed energy resources such as rooftop solar and batteries and flexible demand for electric vehicles and heat pumps enable residential customers to shape their energy consumption. In this context, the design of electricity rates will be crucial. Rates will influence the integration of energy technologies and ensure electricity utilities, which face growing infrastructure costs, can recover the required revenues. If electricity were treated as just another commodity, the most efficient price would equal the social marginal costs. However, electricity has immense human and social importance, which means access to it should also be guided by important equity and feasibility considerations. Electricity rates should not burden communities, should be easy to understand, and the economic benefits of their designs should not be limited only to a few customers. This perspective provides a background of different electricity rates currently in use for residential customers in the United States and their equity and efficiency implications.

Introduction

Over the last decades, the U.S. electricity industry has undergone important changes that will have non-trivial impacts on residential consumers. First, electricity generation from variable renewable energy resources such as wind, solar, and storage technologies has increased owing to declining costs [1]. Second, transmission and distribution expenses have increased due to an aging infrastructure [2]. Third, customers with distributed energy resources (DER) and flexible loads can generate electricity and actively interact with the grid enabled by the proliferation of advanced metering infrastructure (AMI) or smart meters. Fourth, electrification with low-carbon power has emerged as the predominant strategy for reducing air emissions from transportation, heating, and residential energy use [3]. Indeed, while utilities have faced low or negative growth in electricity sales in recent years, demand will likely increase due to the electrification of end uses and transportation [4], [5]. These separate but interconnected developments provide new opportunities and challenges for the electricity industry and society.

Currently, while the average U.S. residential electricity price is roughly 16 cents/kWh [6], there is a wide variation across states, as shown in Figure 1. The average residential electricity price is calculated as the total revenue from the residential customers divided by the total electricity sold. California and New England have the highest average electricity prices (22-26 cents per kWh). These states experienced a 30-40% increase since 2010 (in real terms). Meanwhile, the Southern U.S. and parts of the Midwest have seen a milder, and other states (Texas, Nevada, Maryland, and Delaware) have seen a decline in real electricity prices since 2010 [6].

A.



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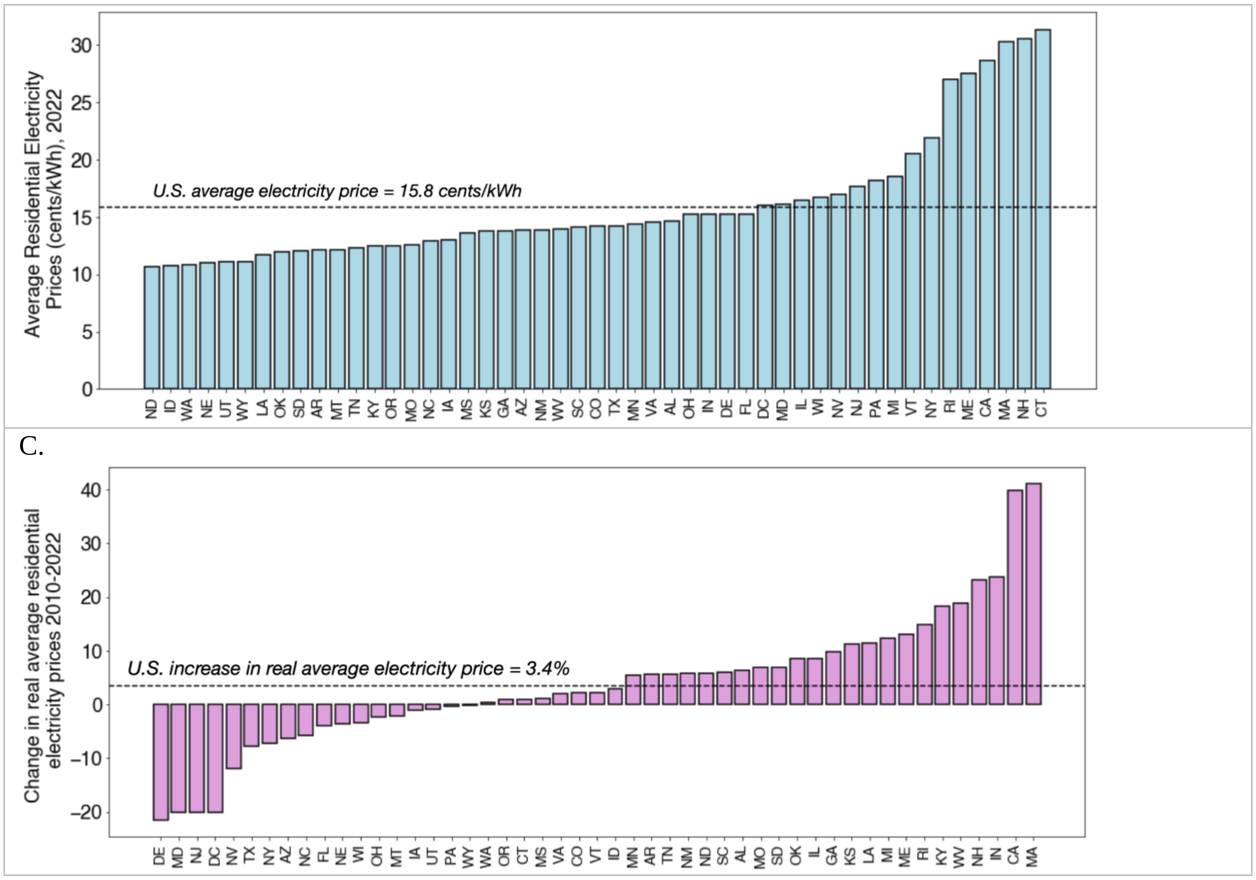

Figure 1: A) Average residential electricity price in the U.S. and selected states from 2010-2023, in real 2023 dollars. B) Average residential electricity prices in 2022. C) Change in real average residential prices since 2010. The average residential electricity price is calculated as the total revenue from the residential customers divided by the total electricity sold to them. Source: EIA-861 [6].

Electricity rates are designed for utilities to recover their costs, including a guaranteed return rate for investor-owned utilities. Historically, in most U.S. regions, electricity bills were computed using a flat volumetric rate (price per kilowatt hour) multiplied by the amount of electricity consumed within a billing cycle. Even now, most states continue to have flat rates for residential customers. In some regions, the volumetric rate varies by a pre-determined time of the day (time-of-use rates), or households face additional charges based on the highest amount of power drawn in a month (demand charges) [7]. Nearly 9.4% of residential households face time-varying rates, while others continue to have flat rates. California, Arizona, Maryland, and Delaware have a substantial proportion of households with time-varying volumetric rates (greater than 35%) (Figure 2).

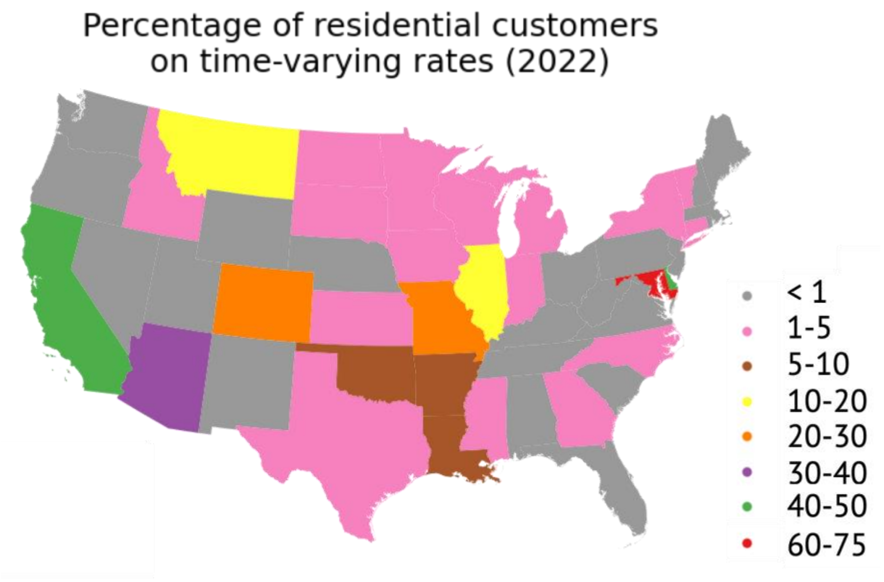

Figure 2: Percentage of residential customers on time-varying rates in 2022. Source: EIA 861[6]

Simple volumetric rates have the benefits of being easy to communicate and use, but they do not reflect the underlying time and space-varying costs of producing and delivering electricity. They also lump residual costs unrelated to electricity production and delivery, such as costs related to long-term infrastructure, public purpose programs, energy policy, wildfire mitigation, etc., onto prices [8], [9].

Recent technological changes in the residential sector – smart meters, DER, flexible electricity demand, and automation -- have sparked new interest within utilities and commissions to redesign electricity rates to reflect the short-term production and delivery costs. If customers respond to such prices, it can lead to efficient energy use, lower peak demand, and fewer unnecessary infrastructure upgrades. Further, residual costs of the grid can be decoupled from energy costs and recouped through fixed charges, as explored in California and Hawaii [10], [11]. On the other hand, such dynamic price signals require consumers to react rapidly to prices. This is a big departure from the traditional way electricity is used and may entail additional burdens for consumers.

Given the nature of electricity, electricity rate design requires equity and economic efficiency considerations. Bonbright laid out principles for equitable and efficient rate-making in the context of public utility rates [12] and stressed the balance between the high capital needs of vertically integrated utilities[1] and the public interests of ratepayers. Electricity rates should be “simple, understandable, acceptable, free from controversy in interpretation, stable, and non-discriminatory” [12], [14].

While these tenets still apply, important changes in the utility structure and technologies have led to considering alternative electricity rate designs. In this piece, we discuss the efficiency and equity implications of different rates and highlight the need to enhance consumers' understanding of rates moving forward. While our focus is primarily on residential customers in the United States, the recommendations and background are also valid for commercial and industrial ratemaking and other countries.

Common types of rate designs

Historically, most residential customers have faced a flat volumetric rate and a small monthly charge. These rates bundle the revenues a utility aims to recover – including a guaranteed rate of return on its capital [15] -- from customers onto the total electricity sold. The traditional flat volumetric rates are giving way to rates that reflect the costs of electricity production and delivery. A primer from the Environmental Defense Fund (EDF) [16] describes different types of rates, including a figure that illustrates such differences. Below, we include an adaption of EDF’s figure, where we add additional rate types and summarize the rate design definitions (Figure 3). The rates could be designed as (i) simple volumetric rates, where consumer pay a fixed price per kWh for their electricity consumption; (ii) increasing or decreasing block rates (also called tiered rates), where rates move to higher or lower tiers for larger levels of consumption; (iii) seasonal rates that address variations in load and costs across seasons; (iv) time-of-use pricing (TOU), in which rate are higher in some pre-determined time periods. TOU has become quite popular, with nearly half of the electricity rates introduced in 2023 having time-varying components (Figure 4) [17]; (v) critical peak pricing (CPP), where rates are increased for a fixed number times when system-wide peak demand events occur (these instances of price hike are not pre-determined); (vi) real-time pricing (RTP), where hourly electricity rates paid by consumers reflect or are equal to the wholesale market energy prices. In all the above rates, the bill can be further decoupled into energy-related volumetric rates and non-energy-related fixed charges, which don’t depend on consumption.

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[1] A vertically integrated electricity utility is one where a single entity owns and operates generation, transmission, and distribution. Historically, the electricity industry operated in a vertically integrated way, since it was cheaper for one firm to provide this service than multiple firms, i.e., electricity could be viewed as a natural monopoly [13].

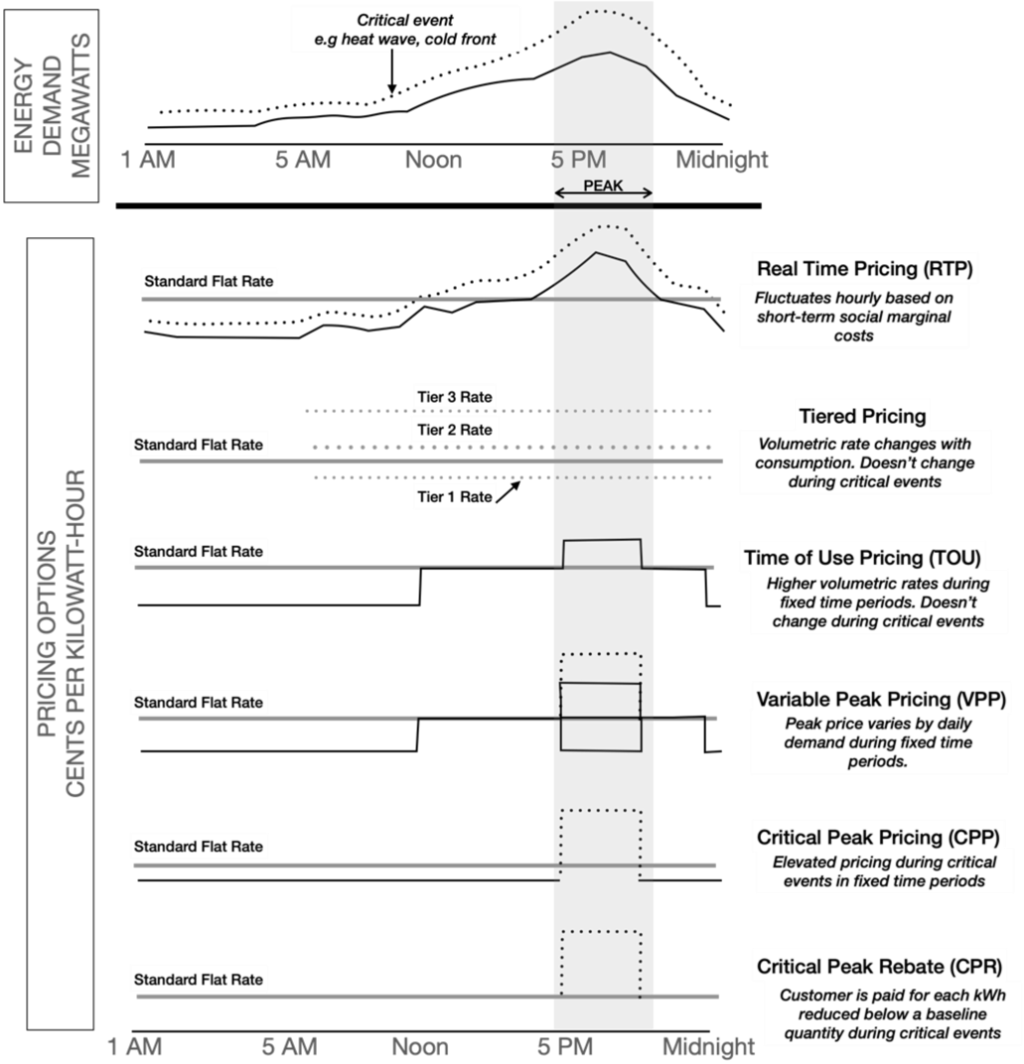


Figure 3: Schematic showing different types of rate designs. This figure is adapted from an EDF report [16] (Copyright © 2024 Environmental Defense Fund. Used by permission. The original material is available at https://www.edf.org/sites/default/files/a_primer_on_time-variant_pricing.pdf). We added tiered pricing in this figure, which was not in EDF's original figure.

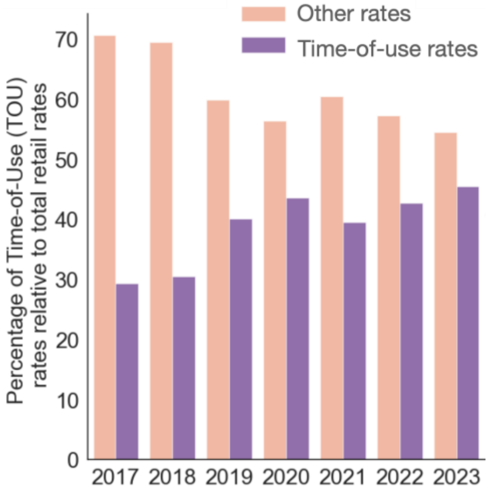


Figure 4: Proportion of time-varying rates since 2017. Source: The Utility Rate Database [17]

Efficiency of different rate designs

Electricity costs can be categorized into generation, transmission, distribution, and other purposes and sorted by demand (kW), energy (kWh), or customer-related incremental costs [18]. Costs are estimated in cost-of-service studies for calculating a utility’s revenue requirements and often do not include negative externalities associated with electricity production, such as air emissions that cause climate change and air pollution. According to microeconomic theory, an efficient electricity price would correspond to the equilibrium between the short-run social marginal cost of producing and the marginal utility of consuming electricity. Marginal costs include marginal generation costs, marginal transmission, and distribution capacity costs. Other system-related costs, such as costs related to ancillary services, losses, congestion, and negative externalities, need to be included to reflect social marginal costs. These costs vary with time and space [19]. However, determining short-run social marginal costs also raises questions about what is incremental, over what time frame, and whether costs are forward-looking projections or backward-looking incurred costs [20]. Demarcating social marginal and residual costs for redesigning the economically efficient rate is thus laden with subjectivity and uncertainties.

Efficient prices based on short-run marginal costs often do not recover all utility costs, as they ignore long-lasting infrastructure and regulatory costs. In recent decades, these "residual costs” – “the difference between incurred utility costs and the revenue collected through the marginal cost framework” [18], [21] – have become an increasing portion of utility costs. Examples of residual costs include residual network costs (transmission and distribution), costs related to coping with renewable variability and promoting renewable adoption, subsidies for vulnerable populations, institutional and regulatory costs, and costs related to wildfire mitigation and grid hardening [8]. In the U.S., the share of non-generation costs (which form the bulk of residual costs) has increased from 31% in 2010 to 50% in 2021 [2].

Equity implications of alternative rate designs

Equity challenges in rate design include 1) ensuring affordability for vulnerable and low-income ratepayers and 2) improving accessibility to flexible energy technologies. Regarding affordability, electricity bills continue to be a source of economic stress for many U.S. households [22]. Twenty million households are behind on their utility bills and owe $16 billion to their utilities (electricity being one of the utilities considered) [23]. This amounts to $800 per family, double that of $400 per family before the Covid-19 pandemic [23].

The current electric utility pricing system is regressive (i.e., low-income households spend a much higher proportion of their income on electricity than middle and high-income households), particularly in the Eastern U.S. Sixty percent of low-income families (15.4 million) undergo severe energy burdens, with energy bills constituting more than 10% of their income [24]. Affordable electricity is required to foster economic development and enable climate mitigation and adaptation in low-income communities. Expensive electricity will discourage electrification and prompt consumers to forgo essential heating and cooling to reduce their bills [9], [25]. State governments and utilities have implemented initiatives to improve electricity affordability through rate subsidies and assistance programs, such as the federal Low-Income Home Energy Assistance Program (LIHEAP), which earmarked $4 billion in 2022 to help low-income consumers with bills [26]. Utilities and public commissions complement LIHEAP through alternative rates and payment programs to improve bill assistance, debt forgiveness, and arrearage management [27]. California's CARE program extends a 30-35% discount on electricity bills to low-income ratepayers [28].

Another equity dimension relates to access to energy technologies, such as DER and flexible loads. Residential consumers are price-inelastic in the short term, but consumers respond to prices over a longer time frame, especially if variations are large [29]. The proliferation of DER and flexible load, along with control of resources by the utility of third-party entities, is changing the paradigm of a passive residential consumer. More residential customers can have backup power and respond to price signals for maximum bill savings. However, it also means that only households with access to flexible energy and control technologies will benefit, and those without could face bill increases under highly time-varying rates. There is strong evidence that the adoption of DERs -- rooftop solar, storage, and electric vehicles -- has been higher for medium-high and high-income households than other income segments [30], [31], [32], [33]. Heat pump adoption has been more equitable across income, but differences across race/ethnicity exist [34].

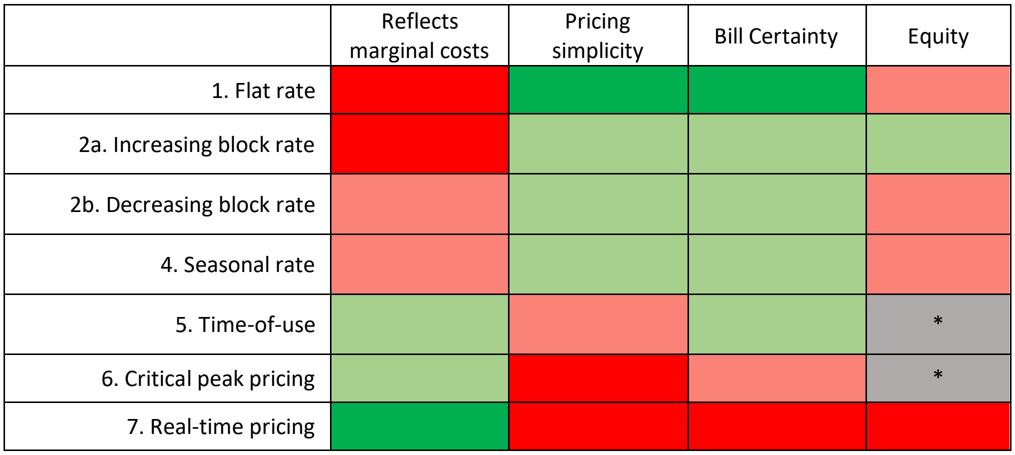
Rate design, DER adoption, and equity aspects become even more critical under net energy metering regimes where exported electricity is compensated at retail rates. Under such a scenario, DER adopters forgo their share of residual costs baked into volumetric retail rates, increasing prices for non-adopters and low-income ratepayers [35]. Reports suggest that net energy metering in California increased annual bills for low-income customers by approximately $100 in the Pacific Gas & Electric territory and nearly $130 in the San Diego Gas & Electric [36]. New pricing mechanisms may be warranted to balance the incentivization of DERs and the energy burden for low-income households. To address this issue, Duke Energy has implemented "tariffed-on-bill" financing for residential energy technologies like smart thermostats, heat pumps, and energy efficiency upgrades, which are tied to the meter, not the customer [37]. This enables utilities to finance DERs without credit or default risk [38]. California is exploring a pricing framework for demand flexibility solutions through scarcity pricing and capacity charges [39]. Other examples include Green Mountain Power, where household-level storage and solar were installed to enhance customer resilience, with the control of resources vested in the utility itself [40], [41].

Comparing rate designs across different dimensions

Electricity rates should be economically efficient, equitable, and easy to understand. Economic efficiency dictates prices vary with underlying social marginal costs, and residual costs are recovered through a combination of fixed charges. The efficiency of these rates is predicated on the expectation that customers modify their consumption in response to price signals. The equity of rates depends on affordability and, in the context of time-varying rates, whether customers have the resources, time, and technology to adapt to rapidly changing rates and how fixed charges are structured in the bill.

In the real world, the behavior of electricity consumers significantly diverges from expectations. Most consumers don’t grasp complex pricing schedules, often change behaviors in response to monthly bills rather than hourly prices, and can’t differentiate between the fixed and variable proportions of the bills [42], [43], [44]. In Table 1, we compare different electricity rate designs on whether (i) they reflect underlying marginal costs, (ii) if the pricing schedule is easy to understand, (iii) if monthly bills could have high volatility, and (iv) if they are equitable. The equity assessment for time-varying rates depends on the utility service area’s system load, household characteristics, climate, demand elasticity, and the peak-off-peak ratio in rates. Studies we surveyed have evaluated the equity impacts of TOU and CPP -- impact on bills of low-income and households with elderly occupants or kids – in various geographies and found mixed results (TOU studies: [45], [46], [47], [48], [49]; CPP studies :[46], [47], [50]). While real-time pricing improves economic efficiency, it is not equitable and would require significant changes in the design of fixed charges (RTP studies: [50], [51], [52]). Each utility region needs to identify and address potential concerns for customers who could be negatively impacted when moving to highly time-varying rates.

Table 1 – Strengths (in green) and weaknesses (red) of different electricity rate designs across different dimensions



	Reflects marginal costs	Pricing simplicity	Bill Certainty	Equity
1. Flat rate	🟥	🟩	🟩	🟥
2a. Increasing block rate	🟥	🟩	🟩	🟩
2b. Decreasing block rate	🟥	🟩	🟩	🟥
4. Seasonal rate	🟥	🟩	🟩	🟥
5. Time-of-use	🟩	🟥	🟩	*
6. Critical peak pricing	🟩	🟥	🟥	*
7. Real-time pricing	🟩	🟥	🟥	🟥

Note: * = Equity consequences depend on the utility service area's system load, household characteristics, climate, demand elasticity, and the peak-off-peak ratio of time-varying rates.

In each of the rates above, non-energy costs can be further decoupled from energy costs and recouped with fixed charges. This will lower the volumetric component. The design of fixed charge is also crucial for an equitable rate design: a uniform fixed charge across all customers is more inequitable and regressive than pure flat rates as it increases bills for low energy-consuming customers, who are, on average, also low-income. Fixed charges should be tied to other customer characteristics such as income, total consumption (kWh), peak demand (kW), or technology availability ($/kWdc of solar panels installed) to improve equity [8], [50]. Most recently, California and Hawaii have proposed introducing fixed charges that vary with household income [11][10].

Discussion and Conclusions

We conclude this perspective by highlighting three key messages: i) Near-real-time data and models allow us to approximate electricity rates to their social marginal costs; ii) Having a retail rate design that captures marginal social costs does not necessarily equate with more equitable outcomes; and iii) Increased complexity in rate design may warrant additional education and information so that consumers can make better decisions.

Near-real-time data and models allow us to approximate rates to their real social costs. The advent of smart meters, sophisticated grid modeling, and publicly available datasets on emissions and externalities enable the implementation of rate design where prices reflect the real social marginal costs of electricity.

Having a retail rate design that captures marginal social costs does not necessarily equate with more equitable rates: Rates that better capture social marginal costs will vary with time and location. Consumers who are more price-response and adaptive with energy technologies such as programmable thermostats, third-party load control, and heat pumps would benefit more than those without. Until now, generally, higher-income consumers have adopted these technologies. To improve equity of highly time-varying rates, technology accessibility and flexibility for low-income households should be prioritized in tandem.

Increased complexity in rate design may warrant additional education and information so consumers can make better decisions. Abrupt price changes can increase bill volatility and reduce customer support for more ambitious reforms needed for large-scale electrification. Highly time-varying retail rates should be introduced gradually, on an opt-in basis, and with sufficient time for consumers to adapt to changes.

As the U.S. electricity industry transitions to low-carbon electricity sources, increased DER adoption, economic efficiency, and equity aspects must be considered more systematically when assessing potential alternative rate designs. Such an approach will ensure that the transition enables a sustainable, resilient, and equitable energy future.

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