Forthcoming chapter, **Handbook on Electricity Regulation.**

Time Varying Rates (TVRs) are moving from the periphery to the mainstream of electricity pricing for residential customers in the United States

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"There's never been any lack of interest in the subject of electricity tariffs. Like all charges upon the consumer, they are an unfailing source of annoyance to those who pay, and an argument among those who levy them… There is general agreement that appropriate tariffs are essential to any rapid development of electricity supply and there is complete disagreement as to what constitutes an appropriate tariff."

D. J. Bolton[2]

Electric tariffs for residential customers[3] through the 1960's were almost entirely volumetric rate designs expressed in cents per kWh. Often, the energy charge dropped with usage, making it a declining block rate.

In those days, the provision of electricity followed a declining cost curve and rates reflected that phenomenon. In the early 1950's, Lewis Strauss, chair of the US Atomic Energy Commission, had famously said the day would come when electricity would be too cheap to meter.[4]

That day never came. Instead, rate shock arrived when OPEC imposed an oil embargo which followed the Yom Kippur War of 1973. It was further amplified when the Iranian Revolution occurred in 1979. In November 1978, the Public Utilities Regulatory Policies Act (PURPA) was passed.[5] It made energy conservation a priority. Load management of electric loads was expanded to include time-of-use (TOU) pricing. A few states in the Mid-Atlantic region decided to make these rates mandatory for very large customers. One state provided incentives for customers to install thermal energy storage equipment and to pair it with a TOU rate.[6] In addition, 16 pilots with TOU rates were launched by the Federal Energy Administration (FEA). They were dispersed throughout the US and included the territory of Puerto Rico.

These pilots received widespread attention. Their results were evaluated by the Research Triangle Institute in North Carolina. At the behest of the National Association of Regulatory Utility Commissioners (NARUC), the Electric Power Research Institute (EPRI) launched the Electric Utility Rate Design Study (EURDS) in 1976. Among other

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[2] Bolton (1938).
[3] Unless otherwise qualified, in the rest of this chapter the term "customer" refers to residential customers.
[4] https://www.nrc.gov/reading-rm/basic-ref/students/history-101/too-cheap-to-meter.html.
[5] 16 USC Ch. 46: PUBLIC UTILITY REGULATORY POLICIES (house.gov)
[6] "How to level the load," *The Energy Daily*, December 5, 1985.

topics, it reviewed and summarized the results of the FEA pilots.[7] Later, EPRI combined the data from the five best pilots and published a meta-analysis.[8]

Lack of interval metering posed a major barrier to TOU pricing. So did the consistent opposition of consumer advocates. They favored flat volumetric rates. As an in-between measure, inclining block rates were introduced.

In the 1980's, Demand-Side Management (DSM) was spread throughout the US.[9] DSM included utility energy efficiency programs and government codes and standards to promote energy efficiency and load management. Tariff reform took a back seat.[10]

To offset rising bills, retail choice became a priority in the 1990s. It succeeded with large commercial and industrial customers but made little headway with households.

TOU rates languished in the US until California's energy crisis of 2000-01. Soon thereafter, TVR including TOU rates and newly introduced dynamic pricing garnered interest. Dynamic pricing included critical-peak pricing (CPP) and real-time pricing (RTP). In this chapter, TOU rates and dynamic pricing rates are called time-varying rates (TVR).

A second generation of TOU pilots was carried out, initially in California[11], and later in Connecticut, Florida, Illinois Maryland and Michigan.[12] Simultaneously, smart meters began to be rolled out.

Today, 97.7 million smart meters are deployed to households in the US, representing 69% of all residential meters. TVR are finally getting significant attention. In 2021, 8.7% of households were on TOU rates, more than double the percentage in 2018, which had not changed much since 2013. If the trend continues, some 25-35% of households may be on TOU rates by the time this decade ends.

This chapter discusses why that is the case. It's organized as follows:

Section 1: Evolution of TVR

Section 2: Lessons Learned from Four Decades of Deploying TVR

Section 3: Strategies for Rate Modernization

Section 4: What's Likely to Happen in the Future?

Section 5: Conclusions

[7] For the early history of the EURDS, see Robert G. Uhler (1976). He was the first Executive Director and was succeeded by Rene Males.
[8] Douglas W. Caves, Laurits R. Christensen, and Joseph A. Herriges (1984).
[9] Clark W. Gellings and John H. Chamberlin (1993).
[10] Academics and researchers continued to publish articles, such as Chao (1983).
[11] Ahmad Faruqui and Stephen S. George (2005).

[12] Ahmad Faruqui and Sanem Sergici (2011); Ahmad Faruqui, Sanem Sergici and Lamine Akaba (2013); Ahmad Faruqui, Sanem Sergici and Lamine Akaba (2014); and Ahmad Faruqui, Neil Lessem, and Sanem Sergici (2017).

Section 1: The Evolution of TVR

With rare exceptions, electric rates for households in the US did not feature time variation until the 1960's.[13] The preferred medium for managing peak loads was direct load control of water heaters and central air conditioners.

Since the conclusion of the landmark Madison Gas and Electric Company case of August 1974, commissions, utilities, and intervenors began studying the desirability and feasibility of implementing TOU rates. In 1978, PURPA required commissions to consider and make a determination regarding the cost-effectiveness of TOU rates, which were accorded the status of a federal rate-making standard.

To address these issues, the FEA, a precursor to the Department of Energy, worked with several states and Puerto Rico to conduct pilots with TOU rates. The pilots represented the first of many waves that would follow and their designs were of uneven quality.[14] Even then, they showed that customers lowered their on-peak usage by curtailing it and/or shifting it to off-peak periods, thereby improving load factor and lowering costs.

Between the late seventies and the mid-eighties, EURDS went through four phases and published nearly a hundred reports. In its second phase, EURDS was directed by a Project Committee comprised of commissioners and utility vice presidents. At one point, it was headed by Professor Alfred Kahn, who chaired the New York Public Service Commission while on leave from Cornell University.[15]

In an interview with the EPRI Journal, he was quite vocal about the merits of TVR: "Never mind whether you want to go to incremental-cost pricing or stick with historical-average pricing. You should at least have time-of-consumption rates; rates that differ, reflecting the fact that, even historically, the costs of installing more capacity should not be put on people who consume off peak. They are not responsible for construction of that capacity. It is indisputable that the costs imposed on a system, if only the generating costs are different when you consume at peak on a hot summer day or you consume in the middle of the night-so that truly cost-based rates cannot avoid varying consumption, logically."[16]

J. Robert Malko, an economist from the Wisconsin Commission, managed EURDS.[17] Several advisory committees drawn from commissions and utilities guided the work of the EURDS. The utility staff were drawn from investor-owned utilities, municipal utilities and cooperatives.

The EURDS advisers agreed that TOU rates should be cost reflective, in accordance with the widely accepted Bonbright principles.[18] However, there was little agreement on whether they should be based on marginal or embedded costs. The majority supported basing rates on embedded costs, a practice that continues to this day.[19]

In the eighties, there was universal agreement that a big barrier to implementing TOU rates was the absence of interval metering. In the years that followed, a few utilities went ahead and installed interval meters. A few,

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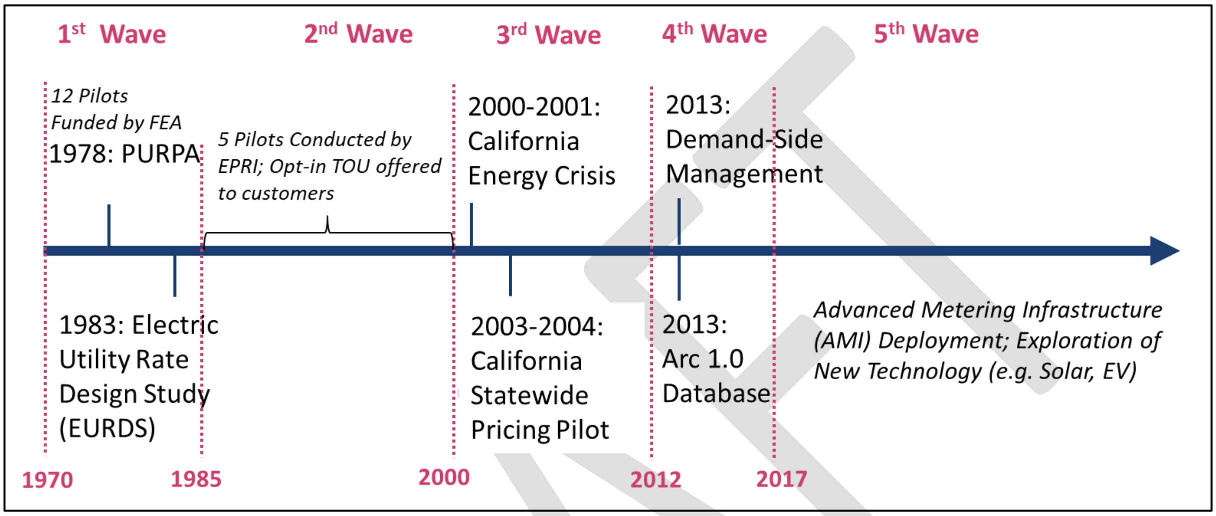
[13] European countries were ahead of the US. See, e.g., Christophe Aubin, Denis Fougère, Emmanuel Husson, and Marc Ivaldi (1995) and F. M. Westfield (1980) and Valerie Lesgards et Edouard Rossat (2022).
[14] See Aigner (1985).
[15] "Alfred E. Kahn," *Wikipedia*, last modified February 5, 2023, https://en.wikipedia.org/wiki/Alfred_E._Kahn.
[16] "Alfred Kahn breaks tradition," *EPRI Journal*, December 1976, 42-45.
[17] Faruqui worked for him in the EURDS.
[18] James C. Bonbright (1961).

[19] Hethie S. Parmesano and Catherine S. Martin (1983).

especially in California, deployed TOU rates on a mandatory basis for their large commercial and industrial customers.

Figure 1 shows the evolution of TVR and how it interacted with other driving factors.

FIGURE 1 THE EVOLUTION OF TVR



First wave

Across the 16 pilots that were implemented, the short-run effects of TOU rates on customer electricity usage were encouraging but inconsistent. In most cases, customers materially reduced peak consumption in response to the TOU rates, with very little (if any) load-shifting to shoulder or off-peak periods. The reduction in peak consumption was statistically significant in many pilots.[20] The FEA found that higher peak-to-off-peak price ratios and shorter on-peak periods generally led to stronger customer response. However, these experiments did not test customer responses in the long run.

The industry mostly put the idea of TOU implementation on hold.

Second wave

The second wave began in the mid-1980s, when EPRI examined the results from five of the best designed FEA pilots and found consistent evidence of consumer behavior.[21] Unfortunately, not much came of this discovery because of the lack of smart metering infrastructure and because of the industry's focus on retail restructuring and the expansion of wholesale electricity markets. However, a few utilities did move ahead with mandatory TOU rates for large residential customers. Virtually all utilities moved ahead with opt-in TOU rates, but few customers took those rates.

Third wave

The 2000–01 California energy crisis gave impetus to the next wave of pilots with TVR. In addition to TOU rates, they featured dynamic pricing designs.[22] Unlike TOU, where the time periods and the prices for each period are

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[20] Ahmad Faruqui and J. Robert Malko (1983).

[21] Douglas W. Caves, Laurits R. Christensen, and Joseph A. Herriges (1984).

[22] Ahmad Faruqui et al. (2001).

known in advance, dynamic prices may or may not be known in advance and the time period over which the prices are invoked may or may not be fixed in advance. In the third wave, dynamic pricing pilots included studies of TOU pricing as well as other types of dynamic pricing. Some of these pilots featured enabling technologies such as in-home displays and smart thermostats.

In California, a statewide pricing pilot involving all three investor-owned utilities was conducted in 2003–04. It showed that customers reduced peak-period energy use in response to time-varying prices.[23] This pilot was a game changer. Since 2013, many more pilots have been conducted around the globe, bringing the total worldwide experience to almost 80 pilots featuring over 400 energy-only pricing treatments.[24] Figure 2 summarizes peak reduction effects from these pilots conducted through 2021, with each data point representing a single pricing treatment.

The figure shows that as customers' peak-to-off-peak price ratio increases, customers reduce their peak consumption more, although at a declining rate. The solid curve in Figure 2 show effects in response to prices only and without enabling technologies. Enabling technologies, such as smart thermostats, were shown to enhance customer responsiveness, as demonstrated by the dotted curve.[25] These results reinforce previous findings that customers do respond to price signals and that enabling technologies significantly enhance that responsiveness.

FIGURE 2 THE ARC OF PRICE RESPONSIVENESS BY TECHNOLOGY

In the third wave of pilots, observers also discovered that low income customers can be price-responsive, although not to the same degree as the average residential customer. A 2012 study summarized the insights gained from these pilots.[26]

[23] "Impact Evaluation of the California Statewide Pricing Pilot," Charles River Associates, March 16, 2005, accessed at http://www.calmac.org/publications/2005-03-24_SPP_FINAL_REP.pdf.
[24] Ahmad Faruqui, Sanem Sergici and Cody Warner (2017); Ahmad Faruqui, Sanem Sergici and Ziyi Tang, "Do Customers Respond to TVR: A Preview of Arcturus 3.0" (2023).
[25] The difference between the curves is statistically significant and each of the curves by itself is also statistically significant.
[26] Ahmad Faruqui, Ryan Hledik, and Jennifer Palmer (2012).

Overall, the third wave of pilots yielded rich information on customer responsiveness to time-varying pricing. Pilots in the third wave provided the impetus and scientific evidence for widespread investment in advanced metering infrastructure.

Fourth wave

The fourth wave involved the large-scale rollout of TVR. Some featured two pricing periods and others featured three pricing periods. Today, the ratio of peak to off-peak prices in 85% of the two-period TOU rates is at least 2:1 while the mean price ratio is 3:1. TOU rates with three periods have a similar price ratio as those with two periods.[27]

FIGURE 3 PRICE RATIO IN TWO-PERIOD TIME-OF-USE RATES

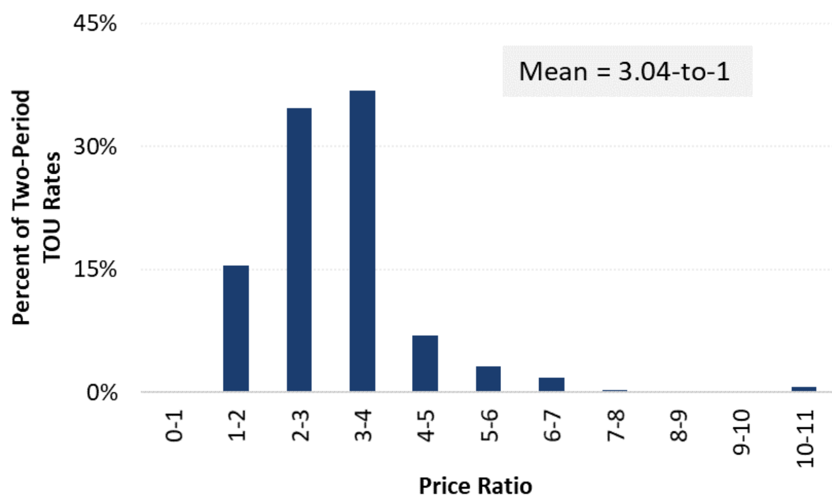
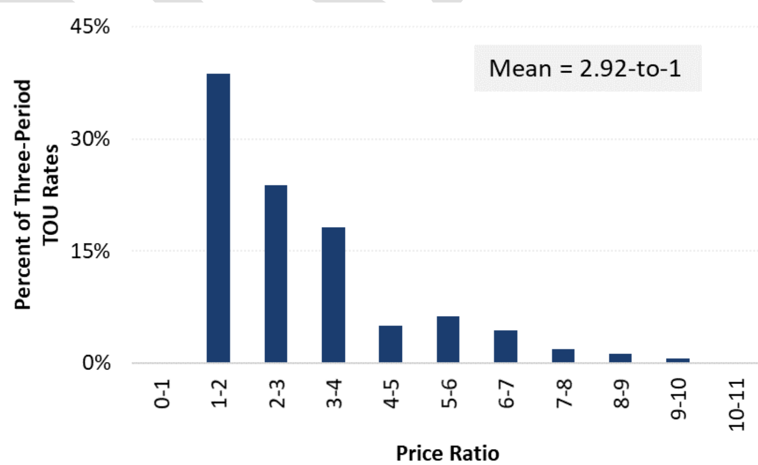


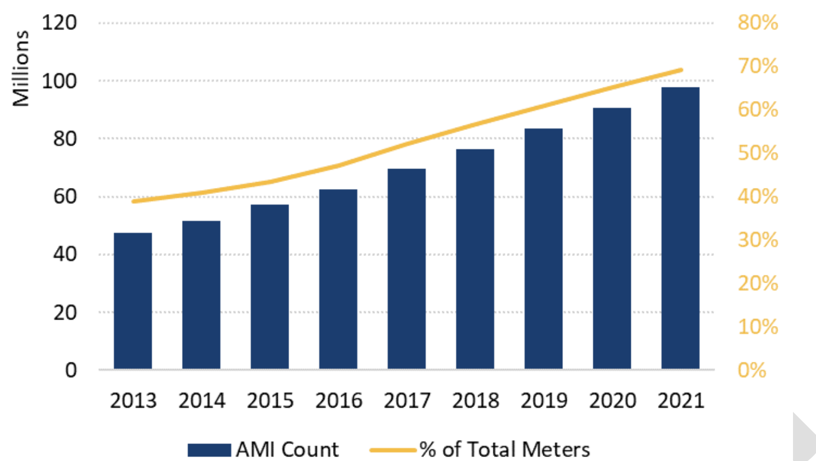
FIGURE 4 PRICE RATIO IN THREE-PERIOD TIME-OF-USE RATES



[27] US Department of Energy, Utility Rate Database, OpenEI, last modified February 2023, accessed at https://openei.org/wiki/Utility_Rate_Database.

In the fourth wave, the implementation of TVR did not keep pace with the installation of advanced metering infrastructure. According to EIA-861 Survey, 97.7 million households have advanced metering infrastructure, which is about 69% of total residential electric meters in 2021.[28]

FIGURE 5 SMART METER INSTALLATION (2013-2021)



But only 12.3 million households are enrolled on a TVR, which is about 9% of total number of residential customers. The barriers to large-scale implementation of TVR include:

- Insufficient evidence of benefits: Stakeholders are still not convinced benefits would be realized through full-scale deployment. Unless evidence of benefits is compelling, regulators, utilities, and customers will fear that a broader group of customers will be harmed by the new rates and that they will fail to promote economic efficiency or equity.
- Customer dissatisfaction and backlash: The move from flat rates to TVR will more efficiently and fairly allocate costs among individual customers but it will definitely raise bills for customers whose load factors are lower than the average load factor for the residential class. It may take time for those customers experiencing bill increases to understand how to manage their electricity consumption relative to the new rate structure. Additional investment in customer education and outreach will be needed to help customers fully understand the new rates, how to choose among their rate options, and how to adjust their usage patterns to lower their bills. It would be useful to give customers a choice of several rates, including flat rates, TOU rates with different price differentials across periods, and dynamic pricing rates.
- Effects on sensitive or disadvantaged customers: Special attention has to be paid to the needs of customers with medical disabilities, customers who are unemployed and low income customers in general.

Some questions remain about how customers will react with full-scale deployment, even though study after study has shown that such rates will yield real and quantifiable efficiency benefits to customers. Despite this evidence, there are persistent fears about a customer backlash or a failure to realize expected benefits. There are ways to overcome these fears, including:

[28] Annual Electric Power Industry Report, From EIA-861, U.S Energy Information Administration, Oct 6, 2022, accessed at https://www.eia.gov/electricity/data/eia861/.

- Customer bill effect studies: Utilities and regulators can conduct studies to understand how customer bills will be affected.
- Customer behavior studies: There are models available today for carrying out simulations to determine the likely customer response. These models draw from findings in prior pilot studies.
- Customer outreach and education: Utilities can engage in customer outreach programs to explain why tariffs are being changed and how the new tariffs will work. It will be important to ensure the new rates use clear and understandable language. Utilities can enlist neutral parties to endorse the change and they can use modern social media to spread the word.

Tapping into the newer generations of technology-savvy customers will be crucial. Utilities can develop new and more efficient ways to communicate with their customers, help to develop apps and smart energy tools, and otherwise explore methods to enhance the customer experience with technology. Here are some options for easing the transition:

- Transition rates: Utilities and regulators can design transition schemes that change the rates gradually over three to five years.
- Bill protection: Alternatively, bill protections can be provided to customers, ensuring that customer bills will not go up but they will be able to keep the savings, with those protections being phased out gradually over time.
- Add protections for sensitive customers: For the first five years, rates could be optional for sensitive or disadvantaged customers, such as low-income customers, small users, and disabled customers. Or these customers could be provided financial assistance for a limited period of time.
- Provide additional information and options to customers: There may be ways to provide additional options for customer participation. For example, consider a subscription concept in which customers "buy" their historical usage at the historical price, and buy or sell deviations from that usage at the new tariffs. This option would also help to transition into the fifth wave of tariff reform involving transactive energy.

Fifth Wave

We have now entered the fifth wave. Enabling residential customer responsiveness under TVR should be a priority. Once cost-reflective tariffs are in place, technological barriers will have to be overcome to achieve customer engagement. Better tools will have to be provided to customers to help them lower their bills.

New technology is already beginning to reveal to customers the extent to which electricity cost can vary depending on usage patterns over time. Public policies and initiatives are opening the door for households to have more control over the source of their electricity—beyond retail choice—through distributed generation. Smart appliances, thermostats, and apps are giving residential customers more tools to control and customize usage patterns. Customers will still have the right to access reliable power supply, but these changes will continue to give households more power to optimize their individual electricity use, their cost of electricity, and their environmental footprint.

We also expect continued improvements in data exchanges from and to smart houses to give residential customers opportunities to capture value directly from wholesale electricity markets. This means that customers will not only react to wholesale market and system conditions, but they will actively participate in wholesale markets through agents or technologies that allow customers to communicate and coordinate directly with market administrators and system operators. Not all customers will have the appetite for engaging in power supply decisions to this degree, but the newer generations of customers who are used to social media, fast-paced and complex communications, and a suite of apps to manage their lives will not find this foreign. Some customers will install solar panels, battery storage, and load flexible HVAC systems and appliances to lower their bills and take advantage of TVR.

In one vision of how this could evolve, customers would subscribe to a “baseline” load shape based on their typical usage patterns. They could buy or sell deviations from the baseline on the wholesale market through sophisticated energy management systems or agents. This was originally called “demand subscription,” but the idea has morphed into “transactive energy”.[29] This vision has gained some traction with millennials through Wi-Fi thermostats, digital appliances, and first-generation home energy management systems. Regardless of the specific method, we believe that in the future the gaps among customers, retail markets, and wholesale markets will be significantly reduced.

But this future cannot be realized if customers do not have even the basic information on how their usage patterns relate to the real cost structure of electricity. Customers cannot react to the high production and investment costs of electricity during peak demand periods if they are shielded from observing these costs at the point of consumption. Customers who are charged the traditional and mostly flat volumetric rate for electricity will be immobilized in the transactive energy future. They will not have the incentives or information necessary to lower their bills in an efficient manner, participate in valuable demand-side services in wholesale markets, or actively contribute to more efficient electricity production and investments in the future.

Household electricity historically has been mostly a uniform commodity for consumers, indistinguishable by source or time of use. For the most part, utilities could price electricity as if it were a uniform commodity without harming their bottom line. But in recent years a number of industry shocks and changes have made it clear that this pricing scheme is not always best for customers or utilities. The first four waves of tariff reform have gauged consumer response and enabled utilities to price electricity more efficiently as the diverse product it is. At the same time, customers are awakening to the diversity of electricity supply depending on location, time of day, and environmental attributes.

Driven by the need to reduce carbon emissions and to promote load flexibility, the California Public Utilities Commission (CPUC) is evaluating a rate design concept called CalFUSE in to enable widespread adoption of demand flexibility solutions.[30] The opt-in CalFUSE frameworks include a broad spectrum of six elements to: develop standardized, universal access to current electricity price, introduce dynamic prices based on real-time, wholesale energy cost, incorporate dynamic capacity charges based on real-time grid utilization, transition to bidirectional prices, offer subscription option, and introduce transactive features. The tariff separates the collection of energy and distribution costs and introduces the notion of scarcity pricing to allocate capacity charges to time periods.

Section 2: Lessons Learned from Deploying TVR

Several lessons can be gleaned from the past four decades which would help in designing better rates in the future.

[29] Stephen Barrager and Edward Cazalet (2014).
[30] California Public Utilities Commission (2022).

1. Don’t oversell the benefits of TVR

In the early 2000s, Puget Sound Energy in the Pacific Northwest rolled out what its CEO termed a “dynamic pricing” rate. But the new rate was simply a TOU rate with three pricing period. Notably, the price differential between the peak and off-peak periods was only 30%. Customers were informed they would save money on the rate. Some customers shifted nearly half their loads from peak to off-peak periods only to discover a year later that they had only saved 50 cents to a dollar per month. Customers felt cheated. Ten percent dropped out. Local and national media outlets reported on the story. The backlash was severe. The utility ended the program, giving TOU rates a bad rap.

Lesson: Don’t oversell the savings from TVR.

2. Pilots are not Always Needed

After witnessing the California energy crisis, the Ontario Energy Board decided to move all customers in the province to TOU rates once smart meters had been deployed. No pilot preceded the TOU deployment. The TOU program succeeded because the Premier was a visionary.

Lesson: A pilot is not always necessary.

3. Embrace Gradualism

One of the most successful TOU programs in the U.S. was launched by SMUD in California. It conducted pilots with CPP and TOU rates. Results were positive and the utility decided to introduce them to its customers. The success of the roll-out campaign can be attributed to a smooth transition plan which spanned three years.

Another example is provided by the Australia Energy Market Commission. To accelerate the deployment of TOU rates, it suggested that they be made mandatory for the largest customers, opt-in for vulnerable customers and be the default for everyone else. However, advocates of the vulnerable customer group thought the design was “a trap” and vehemently opposed it. In the end, the plan did not win the government’s approval and was scuttled.

Lesson: Coordinate the design and rollout of TVRs with all stakeholder.

4. Think Outside the (Service Territory) Box

Until 1990, RTP was an academic concept in the US[31] until Georgia Power introduced it to its large commercial and industrial customers. The utility hired a pricing manager from ESKOM in South Africa who had implemented a successful RTP program for large mining customers. Because mining uses electricity heavily and because mining operations can be disrupted, RTP was the perfect rate option for this sector. The pricing manager brought the practice with him to the U.S.

The RTP rate had a two-stage structure. In the first stage, customers paid what they had paid historically by holding their load profile constant. In the second stage, they paid for changes in the load profile on an hourly basis. The

[31] It had been discussed elsewhere. See, e.g., Littlechild (2003).

first stage bill included a fixed charge, a demand charge and a flat energy charge. In the second stage, the hourly prices were based on marginal energy costs. Customers were notified of the prices on an hour-ahead basis.

The utility recruited customers from inside and outside of the U.S. to relocate to the utility's service territory and participate in the RTP program. The program was designed for customers with maximum demands higher than 1 MW. Load dropped 17 percent on average whenever wholesale price exceeded $1/kWh. Initially offered to industrial customers, the program was later extended to commercial customers. Years later, a day-ahead version was made available to C&I customers with less than 1 MW demand.

Lesson learned: Persistence and perseverance pay off.

5. Key Decision Makers Need to be On Board

TVA, a federal agency, serves power to more than 150 publicly owned utilities in the southeastern US and also designs their rates. TVA wished to modernize its rate designs. However, smart metering was not available. To brainstorm solutions, the agency organized a workshop with its distribution utilities. After considering all the options, seasonal rates were proposed and everyone was on board with them. However, TVA's board rejected the idea. The board members were concerned that customers with central air conditioning systems would see higher bills.

Lesson: Anticipate adverse reaction from those who are going to see higher bills.

6. Mind the Transition Costs

In Oklahoma, OGE's CEO asked his leadership team to explore demand-side solutions instead of building a 600-MW power plant. After doing comprehensive market research, the utility reached the conclusion that there was enough appetite for the utility to pilot a sophisticated variable-peak pricing (VPP) rate with four levels of critical-peak pricing. It also installed smart thermostats on customer premises. Instead of the utility controlling the thermostat, customers had their own control and could pre-set it to their comfort level in advance.

The pilot was successful and the utility offered VPP to all its customers on an opt-in basis. In five years, the participation rate reached nearly 15 percent. On average, the program reduced the peak demand of participating customers by 40 percent, lowering customer bills by 20 percent. The program's success was attributed to word-of-mouth marketing. The VPP prices were sent directly to the thermostat, where the customer had programmed the temperature settings by price.

Lesson: Customer centricity is vital to the success of innovative rates.

7. When There's a Will, there's a Way.

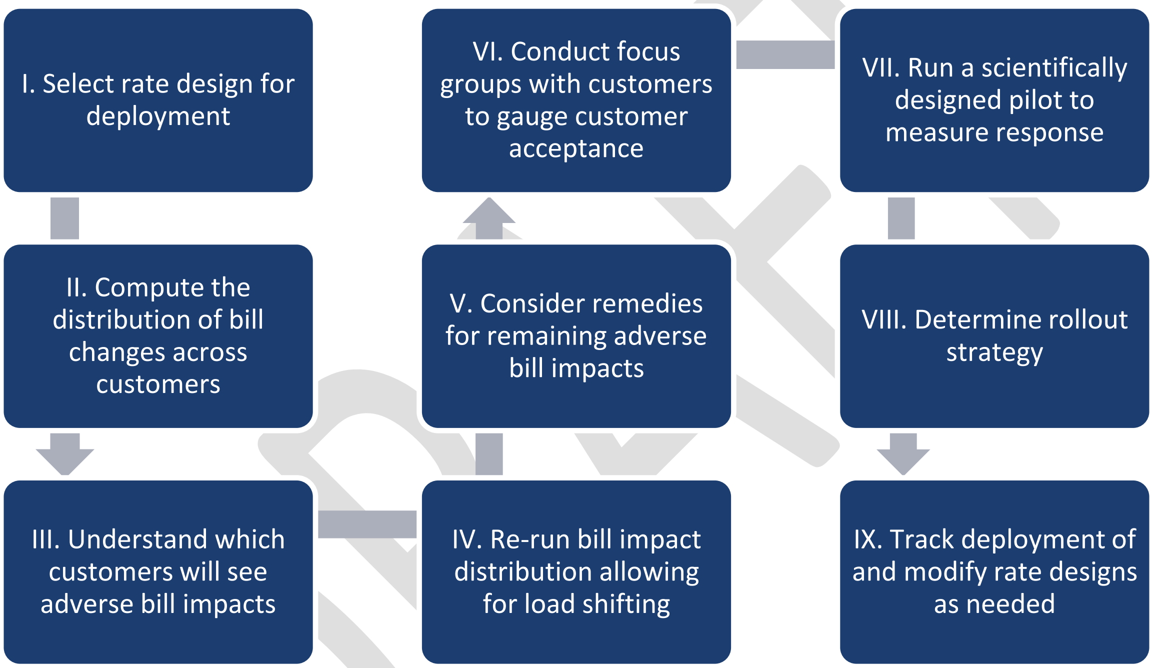
In the course of exploring rate design reforms in the late 2000s, BGE in Maryland became interested in applying the lessons learned from California's pricing pilots involving TOU rates and CPP rates which involved all three investor-owned utilities and ran for two years. The utility decided to launch a CPP pilot of its own and also pair it with a peak-time rebate (PTR) pilot. The pilot ran for four years. The results showed that the peak reduction from CPP and PTR were about the same. The utility decided to proceed with PTR since it believed that there were no losers under this design. PTR was offered to all customers as a default option. Analysis showed that some 88% of customers participated in it and peak demand during critical hours dropped by 15-20%.

Lesson: A PTR may be more palatable than a CPP rate.

Section 3: Strategies for Rate Modernization

Each utility follows its own pathway, depending on its particular circumstances. In general, most utilities follow this pathway.

Figure 6 A Nine-step Pathway for Transitioning to Modern Rate Design



I. Select Rate Design for Deployment

Select the specific rate design for deployment. In some case, more than one rate design may be picked for deployment. Utilities should evaluate each of these options and offer choices to customers along an efficient pricing frontier. Some of the choices being considered or offered by utilities to their customers are listed in the Table 1.[32] When these rate design options are offered to customers, they will be able to pick the one that represents the best combination of risk and reward.

FIGURE 7 THE EFFICIENT PRICING FRONTIER

[32] Ahmad Faruqui and Cecile Bourbonnais (2020).

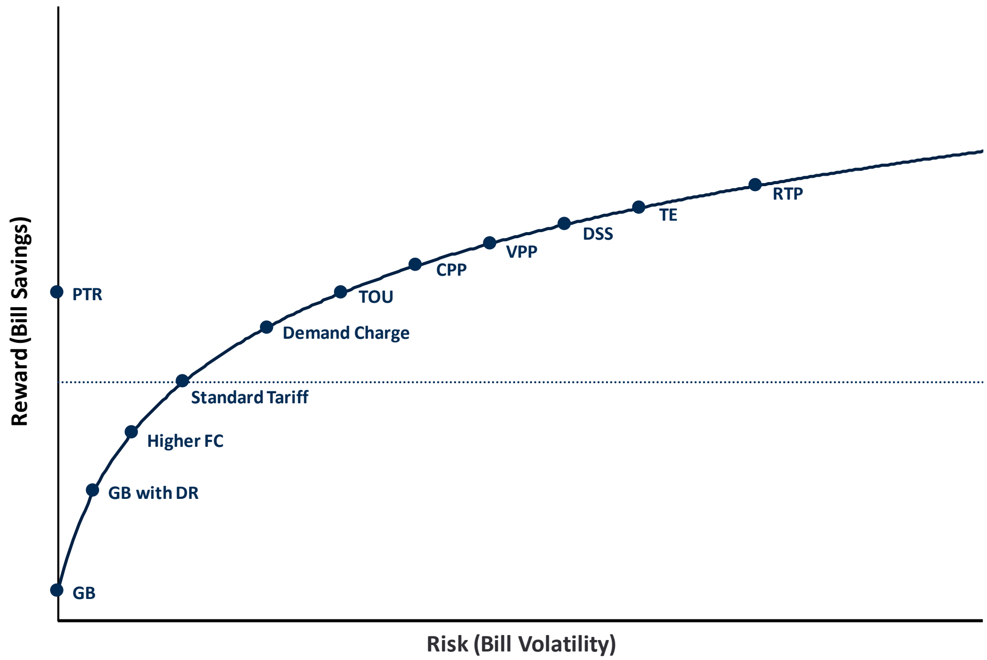


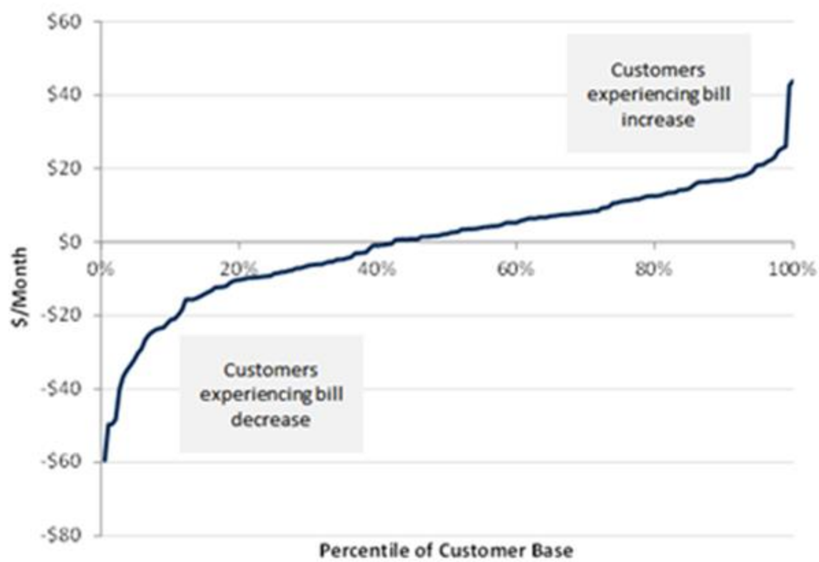
TABLE 1 RATE DESIGN OPTIONS

Rate Design	Definition
Guaranteed Bill (GB)	Customers pay the same bill every month, regardless of usage.
Flat Rate	A uniform $/kWh rate is applied to all usage.
Demand Charge	Customers are charged based on peak electricity consumption, typically over a span of 15, 30, or 60 minutes.
Time-of-Use (TOU)	The day is divided into time periods which define peak and off-peak hours. Prices are higher during the peak period hours to reflect the higher cost of supplying energy during that period.
Critical Peak Pricing (CPP)	Customers pay higher prices during critical events when system costs are highest or when the power grid is severely stressed.
Inclining Block Rates (IBR)	Customers are charged a higher rate for each incremental block of consumption.
Peak Time Rebates (PTR)	Customers are paid for load reductions on critical days, estimated relative to a forecast of what the customer would have otherwise consumed (their "baseline").
Variable Peak Pricing (VPP)	During pre-defined peak periods, customers pay a rate that varies by utility to reflect the actual cost of electricity.
Demand Subscription Service (DSS)	Customers subscribe to a kW demand level based on the size of their connected load. If they exceed their subscribed level, they must reduce their demand to restore electrical service.
Transactive Energy (TE)	Customers subscribe to a "baseline" load shape based on their typical usage patterns, and then buy or sell deviations from their baseline.
Real-Time Pricing (RTP)	Customers pay prices that vary by the hour to reflect the actual cost of electricity.

II. Estimate the distribution of bill changes across customers

For the chosen rate design(s), compute the impact of the rate design on a representative sample of customers. Plot the results in the form of a "propeller" chart, such as Figure 8, identifying those who are going to see higher bills and those who will see lower bills under the assumption that customers will not change their load shape.

FIGURE 8 DISTRIBUTION OF BILL IMPACTS



III. Understand which customers will see adverse bill impacts

Try to understand the sociodemographic and regional characteristics of those customers who are going to experience significantly higher bills. Identify policies that can be used to mitigate the adverse impacts. Examples include the offering the rebates to low-income customers and carrying out energy efficiency improvements in their facilities. If the rates would be offered to them on an opt-in basis, they could be given bill protection for the first year or two as they try them out. If the rates would be offered to them on an opt-out basis, such customers could be excluded from the default provisions altogether.

IV. Re-run bill impact distribution allowing for load shifting

Re-run the bill impact analysis by allowing for changes in load shapes that would occur as customers respond to the price signals. For example, lower off-peak rates would encourage them to raise off-peak usage and higher on-peak rates would encourage them to lower peak usage. Databases and models exist to simulate changes in customer load shapes. Changes in load shapes will mitigate the adverse bill impacts.

V. Consider remedies for remaining adverse bill impacts

If the adverse bill impacts are still significant for certain groups of customers, consider instituting one of these remedies shown in

Table 2.

TABLE 2 REMEDIES FOR ADVERSE BILL IMPACT

Remedy	Implementation
Gradualism	Roll out the new rates gradually for each rate design element. For example, to introduce a TOU rate, if the peak price will be 25 ¢/kWh and the current tariff is 15 ¢/kWh, implement a peak price of 17 ¢/kWh in the first year and increase it annually by 2 ¢/kWh until it reaches 25 ¢/kWh.
Bill Protection	Provide customers with bill protection for a limited period so that they pay the lower of their old and new bill.
Optional Rates	Make the new rate design optional for vulnerable customers, mandatory for the largest customers, and the default for all other customers.
Financial Assistance	Provide customers with adverse bill impacts financial assistance for a limited period.
Enabling Technologies	Install enabling technologies such as smart thermostats on customer premises.
Two-staged Rollout	Structure the rate into two stages, where the first stage charges customers the current rate if their usage resembles a historical reference period, and the second stage exposes them to the new rate.

VI. Conduct focus groups with customers to gauge customer acceptance

These will help determine how best to communicate the rationale behind the selected rates and to see if they would be comfortable with the modern rate designs. Make appropriate modifications in language to make the modern rate designs understandable to customers.

VII. Run a scientifically-designed pilot to measure response

The pilot should be designed on scientific principles that would preserve the internal and external validity of the results, allowing them to be extrapolated to the population of customers. There are three ways of ensuring that pilots will yield results that are statistically valid and generalizable to the population at large. These include randomized control trials, randomized encouragement designs, and matching controls. Analysis of before-and-after data on the “treatment” customers who are on modern rates, and side-by-side data on treatment group and control group customers can then be carried out using econometric methods to yield a difference-in-differences estimate of the impact of the new rates on customer load shapes. Price elasticities can also be derived, allowing results to be predicted for a wide range of rates, not just those that are included in the pilot.

VIII. Determine rollout strategy

Decide on the rollout strategy. It could be opt-in, opt-out or mandatory. Examples of each are presented below.

- In Arizona, a variety of TOU rates are offered on an opt-in basis by two utilities, Arizona Public Service (APS) and the Salt River Project (SRP). About 61 percent of APS’ customers and 35 percent of SRP’s residential customers take service on a TOU rate. Analyses from a sample of customer numbers show that TOU rates with a shorter peak period yields an average reduction of 17% of on-peak kWh and TOU rates with a longer peak period have an average of 8% reduction.
- In Colorado, Fort Collins, a small utility, moved all its customers from volumetric rates to TOU rates in October 2018. The deployment was mandatory and it was preceded by a one-year pilot. The residential opt-out pilot showed a 2.5% reduction in energy consumption. Xcel Energy, a much bigger utility, began rolling out a default TOU rate in 2022 to all customers with smart meters. It was preceded by a pilot.
- In Michigan, Consumers Energy rolled out TOU rates as the default tariff to all its residential customers in 2021. The deployment was preceded by a pilot program that saw a general reduction in peak energy of between 3% and 4%. DTE Energy has recently rolled out TOU rates as the default

tariff. Customers can opt-out to other rates but all of them are TOU rates. Both utilities offer choices but they are all TOU rates.

- In Illinois, Commonwealth Edison and Ameren offer RTP to their customers but only 2% have taken it.
- Georgia Power is rolling a few TOU rates to its residential customers, including a rate with a significantly lower off-peak rate designed specifically for EV owners.
- In Missouri, regulators have ordered Ameren and Evergy to roll out default TOU rates in October with peak to off-peak price ratio that range from 4:1 to 5:1. These are the highest such ratios in default TOU rates in the US.[33]

IX. Modify rate designs as needed

Finally, track the deployment of the modern rate design(s) and survey the customers for feedback. The utility can set up social media sites and monitor the conversation, and make necessary modifications in the rate design on a regular basis.

Section 4: What's Likely to Happen in the Future?

As utilities begin the transition to net zero, they will incentivize customers to install new technologies that promote electrification through rebates and low interest financing programs. Additional incentives will come from governments at the federal, state and local levels.

The most prominent technologies that are receiving incentives today are electric vehicles (EVs) and heat pumps. Also, faced with rising bills, and seeking to move toward an organic lifestyle, customers are moving forward by installing photovoltaic (PV) panels on their roofs. An increasing number of new PV installations are integrated with battery energy storage systems. They are receiving significant incentives from the federal government. Many of these customers also drive EVs.

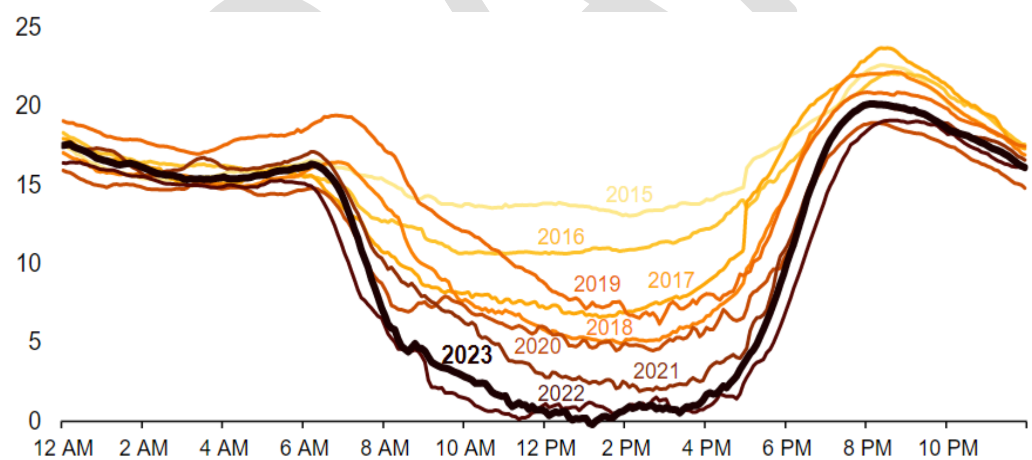
As EVs and heat pumps are widely deployed, utilities will need to find a way for managing the growth in peak loads that will follow their deployment. As the share of large scale solar grows on the supply side, utilities will see that their net peak load will shift from the early afternoon hours to the late afternoon an early evening hours. This phenomenon, knowns as the duck curve (

FIGURE 9

[33] Jeffrey Tomich, "Missouri overhauls electric rates, raising rewards – and risks – for customers", *EnergyWire*, July 12,2023, https://www.eenews.net/articles/missouri-overhauls-electric-rates-raising-rewards-and-risks-for-customers/.

Figure 9), has already begun to happen in California.[34] The peak period used to run from noon to 6 pm about two decades ago. A decade ago, it shifted to the 2 pm to 7 pm window. Now it runs from 4 pm to 9 pm.

FIGURE 9 CALIFORNIA'S DUCK CURVE (CAISO LOWEST NET LOAD DAY EACH SPRING, 2015-2023, GW)



In Hawaii, the off-peak period now lies in the afternoon hours and the same is evident in Australia, where a "sponge tariff" is offered to encourage additional energy use in the afternoon hours.

In all of these cases, a TOU tariff will prove to be an indispensable resource to encourage off-peak charging. That's already the case in California where the off-peak period now begins at midnight, to encourage the nighttime charging of EVs.

[34] "As solar capacity grows, duck curves are getting deeper in California", U.S. Energy Information Administration, June 21, 2023, accessed at https://www.eia.gov/todayinenergy/detail.php?id=56880.

More and more utilities are beginning to offer TOU rates with exceptionally low off-peak rates. These are often three-period rates where the off-peak period begins at midnight.

As for dynamic pricing, despite the substantial benefits that economists have pointed out,[35] the future remains uncertain:

- In Illinois, hourly real-time pricing is offered to the state's 4.7 million electric customers by its two investor-owned utilities. Under 2% of customers have taken it.
- In California, residential customers have been offered CPP for more than a decade. Only 2% of customers have taken it.[36]
- In Oklahoma, OG&E has had more success with a more advanced version of CPP known as variable-peak pricing (VPP). The price on critical days can rise to four different levels, depending on the severity of the demand-supply imbalance. Because of customer-friendly rate design and exceptionally good marketing, that pricing program has achieved an adoption rate of 14.7%. But it remains the exception to the rule.

New forms of pricing continue to evolve. The latest version is called Subscription Pricing. In that design, customers are offered a fixed bill based on their historical pattern of use. It's somewhat higher than their average monthly bill. It offers peace of mind to the customer and is akin to the type of pricing used by Internet providers and companies such as Netflix. A more advanced version of Subscription Pricing offers customers a chance to lower their fixed bills by reducing their usage during critical hours when the demand-supply equation appears to be going out of balance. It's called Subscription+.[37]

Utilities are beginning to realize that the best way to enhance customer satisfaction is to give them choices of rates. Some want bill stability and are willing to pay a bit more for that. That's where subscription pricing comes in. Others want flat rates. Still others are willing to move some of their consumption out of the peak period to off-peak periods and are happy to go on a TVR. Most of the last group of customers are interested in a two or three period TOU rate but some are willing to try variants of dynamic pricing. They come with added risk but also can yield the lowest bills.

Section 5: Conclusions

The evolution of TVR in the US has been very slow over the past four decades for a number of reasons. Among them, lack of metering, consumer reluctance to try something new, and a fear that these rates will raise bills. Long peak pricing periods that spanned most of the day time hours were a major barrier to customer adoption.

Consumers don't put much stock in notions such as allocative efficiency that have the status of an axiomatic truth among economists. They don't care much about rates being cost based, consistent with the principles put forward by Bonbright.

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[35] See, for example, Severin Borenstein (2005), Ahmad Faruqui (2010), William Hogan (2010), and Schittekatte et al. (2023, forthcoming).

[36] For experimental results from a small municipal utility in southern California, see Frank A. Wolak (2007).
[37] Ryan Hledik, "Direct Testimony on behalf of Evergy Missouri West," January 7, 2022. https://efis.psc.mo.gov/mpsc/commoncomponents/viewdocument.asp?DocId=939607385.

Utilities have been reluctant to offer them on an optional basis, concerned that only those who would lower their bills would sign up for time-varying tariffs, eroding revenues. They have also been skeptical that TVR would induce load shifting from peak to off-peak periods, and lower costs for all customers by reducing the need for new capacity additions.

For decades, TVR were an exotic service offering, requiring the installation of a special interval meter. Today, smart meters are deployed in nearly 70% of American households. So are programmable thermostats, many come with WIFI capability, but even today few customers bother to program them. Many appliances such as dishwashers have timers built into them but that feature is rarely used. Customer apathy is still very much a part of life.

But what has really begun to move the needle is the arrival of electric vehicles (EVs). Consumers have begun asking for TVR because they can reduce their cost of charging by more than half. Utilities are more than happy to offer TVR to EV owners since they encourage off-peak charging and avoid the need to invest in expensive peaking capacity.

An additional reason why utilities are interested in moving customers to TVR is the installation of rooftop solar panels (PVs) by customers.

The new generation of TVR are designed with customer lifestyles and convenience in mind. Peak periods are shorter than they used to be, and prices are dropped substantially in a third pricing period, which usually occurs during the night, to encourage the charging of EVs. Lessons have been learned.

As a result, TVR are being offered by more utilities, often accompanied by bill calculators on web portals to help customers pick their best rate. As a sign of the times, a few states have decided to make TVR the default option for their customers and one has made them mandatory.

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