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REVIEW

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Promoting real-time electricity tariffs for more demand response from German households: a review of four policy options

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Abstract

Background Demand response is an important option for accommodating growing shares of renewable electricity, and therefore, crucial for the success of the energy transition in Germany and elsewhere. In conjunction with smart meters, real-time (or 'dynamic') electricity tariffs can facilitate the flexibilization of power consumption and reduce energy bills. Whilst such tariffs are already quite common in several EU member states, Germany lags behind in this respect. The country makes for an interesting case study because of the sheer volume of additional flexibility that its energy transition necessitates.

Main text This paper discusses how German policymakers can make real-time tariffs more attractive for households and thus entice them to better adapt their consumption to current market conditions. Following an analysis of the current impediments to the adoption of such tariffs, we discuss four policy options: (1) a more ambitious legal definition of real-time tariffs that can promote market transparency and leverage potential savings for consumers, (2) a shift in energy taxation that encourages the uptake of renewable power and increases price spreads, (3) a new model of dynamic network charges which combines grid-serving and market-serving incentives, and (4) a subsidy for users of real-time tariffs that helps internalise the benefits they provide to all electricity consumers. Given the similar regulatory framework, our suggestions should generally also apply to other countries in Europe and beyond.

Conclusions Overall, we argue that there is considerable scope for policymakers to better exploit market forces to ensure security of electricity supply at lower social cost. Our call for stricter regulation in order to allow the markets to better guide consumer behaviour may seem like a paradox—but it is one well worth embracing.

Keywords Real-time electricity pricing, Demand response, Energy transition, Flexibility, Network charges, Electricity tax

Background

Growing shares of intermittent, and therefore, inflexible renewable electricity sources necessitate new solutions to continuously balance power consumption and generation.[1] Other components of the energy supply system

[1] Some of the points made in this article have already appeared in a German-language article by the same authors [1].

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must step in to provide the required flexibility by adapting to current market and/or grid conditions [2]. Yet it is often not clear why the relevant actors would want to do so, as an effective framework of incentives for flexibility is generally lacking in the European Union [3] and especially in Germany [4]. This is an urgent matter, as the need for flexible capacities is expected to almost double by 2030 to keep up with the projected renewables growth and fossil phase-out (ibid.).

Several potential sources of flexibility offer themselves to accommodate the renewables: gas-fired power plants that will increasingly run on hydrogen, different storage technologies, increased sector coupling and, enabling all of them, grid expansion. Yet a growing role will also accrue to demand-side flexibility.[2] Compared to fossil peak-load generation, demand response reduces emissions[3] and a region's dependence on fuel imports—two primary objectives of EU energy policy [6]. It is also considered to be cheaper than, for example, utility-scale storage [ibid.] and to reduce the need for grid expansion [7] and the required subsidies for renewables [3]. These benefits help bring down the overall social cost of electricity provision [8], as reflected in power prices, network charges,[4] subsidies and other indirect costs. Accordingly, demand response has been on the EU policy agenda at least since the Energy Efficiency Directive 2012/27/EU; it constitutes a pillar of the EU's 'Energy Efficiency First' principle (cf. e.g. the revised Energy Efficiency Directive EU/2023/1791) and is the subject of much ongoing legislation [6].[5]

Amongst the various types of load shifting [10], this article focuses on price-based demand response (henceforth: 'PBDR') by households.[6] Households contribute two-thirds to Germany's theoretical potential for demand-side flexibility [11] and a sizable share to the country's emissions [12]. However, unless households are given better reasons to adapt their electricity consumption to current conditions, the required flexibility must come from more expensive sources, and these additional costs must be borne by electricity consumers and/or taxpayers, which might jeopardise public support for the energy transition. What policymakers can do to incentivise more PBDR from households is, therefore, the guiding question of this paper.

Electricity price fluctuations are the natural source of flexibility incentives but households generally (see below) do not receive those signals and are thus mostly oblivious to current market conditions [2]. The main reason for this lies in an important distinction. On the *wholesale* spot market, electricity prices change by the hour (day-ahead) and even quarter-hour (intraday), reflecting the current scarcity of electricity [13] and potentially providing strong incentives for demand response [14]. On the *retail* market however, fixed or static tariffs, where consumers pay the same amount per kWh all year, continue to be the standard choice, as they have been for over a century. To some extent, these extremely 'sticky' retail electricity prices reflect the preferences of risk-averse consumers. Mostly, however, they are mere relics of a time when demand was thought to be utterly unresponsive to power price changes. This decoupling of consumer prices from current production costs through static tariffs prevents electricity users from making—at least roughly—socially optimal consumption decisions.

Within the small market segment of non-static electricity tariffs, by far the most common design are 'time-of-use' (TOU) tariffs, where the unit charge differs between peak and off-peak periods. Introduced in the 1960s [15], TOU tariffs were primarily targeted at specific appliances such as storage heaters to create additional night-time demand for the output of must-run power plants, especially nuclear power stations. However, with their fixed schedules of usually only two price levels, such tariffs are of little value for demand response to today's volatile renewable power generation [16]. Another non-static tariff alternative is 'critical peak pricing' (CPP), where rates are mostly flat but may rise sharply during 'critical' hours of scarcity, of which users are informed in advance so they can adjust their consumption [17]. CPP can provide more efficient flexibility incentives than TOU pricing [14] but is virtually unknown in Germany.

The most market-friendly incentives for PBDR arise from real-time (or 'dynamic') tariffs, also referred to as

[2] In the words of Yule-Bennett and Sunderland [3]: "We used to schedule supply to meet load. Now we need to schedule load to meet supply." (p. 9)

[3] While most of the literature assumes emission benefits of demand response, the actual impact depends on the structure of the merit order [5]: If peak loads are shifted from natural gas to lignite, for example, emissions will rise. The more likely case in the progressing energy transition, however, is a shift from fossil to renewable power, with clear emission savings.

[4] In Germany, the network charges absorb various costs of maintaining security of supply, such as payments to reserve power plants and compensation for renewable energy redispatch due to grid constraints [9].

[5] Yet any near-zero emissions scenario of electricity supply must rely on a mix of flexibility sources – ideally employing the cheapest one first – as no single technology can provide the necessary capacity. Furthermore, complementary effects among the sources suggest that a mix of flexibility options will be cheaper than any individual technology on its own.

[6] Commercial and industrial electricity users are subject to different regulation, e.g. regarding the electricity tax, the structure of the network charges, etc., and therefore require separate analysis.

spot pricing [18],[7] which are slowly gaining ground in some EU member states, as intended by the European[8] legislator. Instead of a constant unit charge, suppliers of such tariffs typically demand the day-ahead spot price, which is determined by auction around noon for each hour of the following day, or, less frequently, the intraday price. To this, suppliers add all applicable taxes, surcharges and levies (which we shall summarily refer to as the 'statutory price components'), plus their markup. The users of real-time tariffs who shift part of their consumption from high-price to low-price periods can reduce their electricity bills whilst providing an external benefit to society at large.

To examine more closely the adoption of real-time tariffs for households and what policymakers can do to promote PBDR, we take a detailed look at the legislative framework in Germany. Most policy recommendations derived for Germany should principally also apply at least to other EU countries, given their regulatory homogeneity, common policies, etc. For example, virtually all of them feature a unit-based electricity tax [19], share similar experiences of energy market liberalisation and have broadly comparable climate protection goals. Then again, Germany is an extreme case. The country's size and ambitious goals for the energy transition[9] mean that amongst the EU member states, Germany must probably procure the largest amount of flexibility to ensure security of supply. This challenge has loomed for a long time [21] and the lack of an effective framework for flexibility incentives [22] poses a major obstacle on the country's further decarbonisation path.

Germany has the largest demand response potential in Europe [11], which will grow further with the electrification of the heating and mobility sectors [13]. As on the EU level, greater flexibility from demand response in general [23] and PBDR from households in particular ranks high on the German policy agenda.[10] Unlike simple TOU tariffs, real-time household tariffs were absent from the German market until recently, not least due to the country's protracted smart meter rollout [24]. The next section discusses in more depth the impediments to the widespread adoption of real-time electricity tariffs in Germany. We then review four select policy proposals that can contribute to unlocking the flexibility potential of households. They pertain to the definition and financial support of real-time tariffs, energy taxation, and a new model of dynamic network charges. Whilst several other measures have been proposed in the literature and in policy circles, the ones we advocate promise tangible effects at comparatively low costs of implementation. Potentially adverse effects of these measures on individual groups of consumers are discussed briefly in the Conclusion.

Obstacles to the adoption of real-time tariffs

Tariff availability

The most basic precondition for households to adopt real-time tariffs and subsequently engage in PRDR is that such offers are available on the market. In Germany, the first real-time tariffs for non-commercial users likely emerged in 2020.[11] In 2023, the Federal Network Agency (*Bundesnetzagentur*, *BNetzA*) found that only 52 of the over 1000 electricity suppliers in Germany offered real-time tariffs—compared to 563 suppliers of TOU tariffs [25]. The new tariffs may threaten established business models [9], and demand for real-time pricing was expected to grow slowly until recently, so especially for smaller suppliers [26], establishing new offers was barely worth the fixed cost of product and process design, marketing and advertising, etc. Accordingly, some of the first movers on the German market were foreign companies that had developed such tariffs in their more advanced home countries, like Tibber in Norway, where over 90% of households use a dynamic electricity tariff [4].[12] In 2021, transposing Art. 11(1) of the EU Electricity Directive 2019, the German legislator in Art. 41a of the Energy Industry Act (*Energiewirtschaftsgesetz,* EnWG) required all electricity suppliers with more than 200,000 customers to offer a real-time tariff to any consumer with a smart meter.[13] In 2022, that threshold was reduced, and from 2025, all suppliers must offer real-time tariffs. However, the value of mandating such offers is questionable. The suppliers cannot be compelled to make the offers attractive and to advertise them. Indeed, some companies

[7] According to Schittekatte et al. [18], well-designed variable tariffs that combine elements of TOU and CPP can yield up to 60 to 70% of the flexibility incentive effect of spot pricing.

[8] See Recitals 10 and 37 of the EU Electricity Directive 2019. Yet under the impression of the 2022 electricity price spike, the European Commission [6] has on the contrary argued that consumers should be *isolated* from short-term price signals: "the proposal includes a set of measures aimed to create a buffer between short-term markets and electricity bills paid by consumers". (p. 3)

[9] Germany shut down its last nuclear power plant and reached a renewable power share of more than 50% in 2023 [20] and plans to phase out electricity generation from coal by 2038.

[10] See for example the justification of the Bill on the Restart of the Digitisation of the Energy Transition (*Gesetz zum Neustart der Digitalisierung der Energiewende*), Bundestagsdrucksache 20/5549, p. 70.

[11] Self-declared pioneer supplier Tibber began offering a real-time tariff that year.

[12] The prevalence of real-time pricing in Norway is attributable to several factors: Thanks to historically cheap electricity from hydropower, space heating has long been largely electrified. Furthermore, today the country features the highest penetration of electric vehicles in the world, so flexible loads abound [27]. Finally, Norway's smart meter rollout was completed in 2023.

[13] Prior versions of the law, which reach back to 2008, only required suppliers to offer TOU tariffs [28].

have been actively hiding the mandatory dynamic tariffs on their websites, whilst others publish the tariff details only upon request.

Smart meter availability

Broadly speaking, using hourly real-time electricity tariffs requires a smart meter.[14] Whilst roughly half of the EU member countries have equipped at least 90% of their consumers with smart meters [29], Germany lags far behind. The EU had urged the member states already in 2009 to install smart meters if a national cost–benefit analysis yielded a positive result. For Germany, Ernst & Young [30] returned a negative assessment in 2014. In 2016, the new Metering Point Operation Act (*Messstellenbetriebsgesetz,* MsbG) envisaged a smart meter rollout for selected groups as soon as at least three models were certified for the German market. This was achieved in 2020, but the next year, the certification was invalidated by a court decision. During the ensuing legal back-and-forth, very few smart meters were installed [31]. Consequently, by the end of 2022, only around 272,000 of over 52 million consumption points in Germany were equipped with a smart meter [25]. This figure effectively places an upper limit [2] on the otherwise unknown number of real-time tariff users [15].[15] In 2023, the MsbG was amended to accelerate the smart meter rollout. For consumption points that use more than 6 MWh per year, which covers many homes with a heat pump and/or an electric vehicle, the installation of a smart meter became mandatory, with the rollout to be completed by 2030 for at least 95% of these consumers. For smaller consumers, meter operators may decide whether to install a smart meter or merely a digital meter. From 2025, consumers can demand to have a smart meter installed within four months. The amendments also lowered the bar for the certification of new devices, reduced bureaucracy, and capped the annual cost of smart metering for households at €20, the same as for a digital meter. If these measures have the intended effect, smart meter availability will soon cease to be an obstacle.

Flexible loads

Thirdly, PBDR presupposes that part of the households' electricity consumption can be postponed at least for several hours without too much effort. Such postponement can be achieved in two ways. First, households can reschedule the activities that ultimately consume the energy. For example, latest-generation dish washers, washing machines and tumble dryers are often 'smart' in that they can be remotely controlled, making them convenient to run when electricity is cheap. Second, storing energy within their homes allows consumers to decouple the final use of the energy from the moment when the electricity is withdrawn from the grid. The greatest flexibility potential in this regard lies in stationary batteries, which increasingly complement rooftop PV systems, in cooling and heating applications with thermal energy storage, as featured by some heat pumps, and in electric vehicle charging through a power outlet controlled by the consumer (e.g. a wallbox), as charging can be postponed for up to several days [13].

Whilst still only few German households have an electric vehicle and/or heat pump – and many of them have at best limited access to these technologies[16]—public funding in recent years has produced strong growth in both fields. The number of fully electric vehicles on German roads has grown exponentially since 2011, doubling every 15 months on average [32]. By 2030, the government aims for 15 million vehicles [33]; however, sales stalled when the subsidies ran out at the end of 2023, calling the ambitious targets into question [34]. Furthermore, half a million heat pumps are to be installed each year [35]. Overall, flexible capacities controlled by households are expected to grow by more than ten times in the next seven years [13].

Psychological obstacles

Once the above preconditions are met, consumers face what may be the biggest obstacle yet: the inertia of habits [36]. For generations, fixed electricity prices have been the norm; there is no culture of scheduling one's daily activities based on the price of power [10]. Even if a household has all the required hardware and even though various smart technologies such as home energy management systems or electricity suppliers' apps aim to minimise the inconvenience [3], the effort of learning the new ways of demand response remains a psychological burden. Moreover, German consumers are reluctant to switch electricity tariffs.[17] Such an adaptation takes time and a sufficient stimulus [14].

The behavioural and psychological costs remain once the transition to flexible consumption has been made. Even technology-assisted PBDR causes a degree of

[14] A digital electricity meter suffices if supplemented with a device that transmits the consumption data to the supplier.

[15] It also refutes the results of a 2022 survey which found that 2% of the respondents used such tariffs [26]. The survey questions did not properly distinguish between time-of-use and real-time tariffs.

[16] Urban renters – i.e. roughly half of all German households – rarely have control over how their homes are heated, and if they have an electric vehicle, they must often rely on public charging infrastructure, which limits the scope for PBDR.

[17] Only about 9% of German households switch electricity suppliers each year [25, 37], compared to an EU average of 12% [4]. This rate refers to switching from one fixed-price tariff to another. Even if the same rate applied to the – much more daunting – switch to a real-time tariff, it would take 25 years for 90% of consumers to embrace dynamic pricing.

inconvenience from behaving differently than one otherwise would, whilst manual demand response tends to be limited in scope. Freier and von Loessl [14] cite a range of evidence to this effect. Amongst other findings, demand response is twice as great when automated. Ideally, users merely need to set some parameters whilst the technology assumes the task of daily optimisation. However, besides its substantial financial cost, automated demand response also involves a trade-off: Though intended to facilitate the response, automation may require substantial initial learning effort and energy literacy [38], as well as some loss of comfort [39].

A psychological cost that smart technology can at best reduce, but never eradicate, is risk aversion [14]. Real-time tariffs place short-term price risks on consumers, although some tariffs limit the risk through price caps. Whilst the price movements enable potential savings for flexible users, the risk per se is unwelcome, and the fear of sudden price spikes may partly explain consumers' hesitation to embrace real-time tariffs [18]. Concordantly, the willingness of German consumers to consider real-time tariffs dropped from 2021 to 2022, against the general trend. This is likely due to the 2022/2023 electricity price surge [26], which, although it also affected users of traditional tariffs, made the inherent price risk of dynamic tariffs loom even larger. Evidence also indicates that consumers prefer real-time tariffs with price caps and with less frequent price changes [40].

Profitability

The above-mentioned obstacles to PBDR are not insurmountable. Some of them require the contribution of the households, which will be prepared to expend the required efforts if they can expect adequate rewards. Given the prospect of sufficiently large savings, the demand for flexible appliances will quickly rise, bringing down prices, consumers will actively ask to have smart meters installed in their homes, and habits will prove to be more flexible than is often assumed.

In discussing the potential gains from PBDR, we consider only the financial dimension, i.e. the savings on electricity bills. We thus ignore other motives, e.g. idealistic ones, such as promoting the energy transition, the joys of using modern technology, of 'beating the market', etc. Whilst such motives played an important role for early adopters of real-time tariffs, they cannot support large-scale PBDR.

A household's financial savings potential depends, on the one hand, on its responsiveness: the size of the loads to be shifted, by how long they can be shifted, and the consumer's (or her automated systems') proficiency at scheduling consumption based on the price profile. On the other hand, the savings increase with the spreads of the real-time tariff.[18] Evidence from several countries suggests that only large price spreads will convince households to engage in PBDR [10, 14, 40]. In our own simulations using German market data, we optimistically assumed that an electric vehicle could be charged over optimised cycles of multiple days. In various scenarios, the resulting average savings from being flexible and switching to a real-time tariff never exceed 4 ct/kWh. If the vehicle consumes 2.5 MWh[19] per year, this only sums to annual savings of about €100, or some three to five percent of the household's total electricity bill (for 6 MWh).[20] This amount is unlikely to prompt major investments or behavioural changes. Without a stationary battery, an electric vehicle or a heat pump—i.e. the situation which most households still find themselves in – the gains are much smaller. Surveys have found that German consumers require between €100 and €200 in annual savings before considering a real-time tariff [15, 26]. Importantly, survey respondents need not put their money where their mouth is, so if anything, these estimates are likely to be low compared to real-life consumer decisions.

One reason for the insufficiency of the savings potential is that only a part of the electricity price in a real-time tariff is indeed dynamic, namely the procurement cost of energy and the value-added tax on it. In early 2024, this potentially flexibility-inducing part amounted to roughly half of the German household electricity price [42], which is the third-lowest share in the EU [4]. The other half is levied on a fixed per-unit basis: electricity tax, four different surcharges,[21] network charges, and value-added tax on these items. These statutory price components dampen the relative price spreads of real-time tariffs [15] and thus obstruct the "undistorted market signals to provide for increased flexibility" that the European Commission [6] calls for. On a societal level, this leads to unnecessarily high costs of electricity supply; on an individual level, it makes demand response less profitable than it could be if the statutory price components were designed differently [14].

If policymakers really want more flexibility from households, they must make PBDR more profitable. To do so,

[18] There are two additional but much smaller potential sources of savings. First, the shifting of price risk from suppliers to consumers ought to mean that real-time prices are lower than fixed prices on average as suppliers save hedging costs [24]. Second, adopting a real-time tariff may reduce electricity consumption due to an awareness effect [14].

[19] While Consentec [22] and Ziemsky et al. [15] assume 3MWh, other sources place the average annual energy consumption of electric vehicles closer to 2 MWh.

[20] Note, however, that results on average savings mask the fact that the switch to a non-static electricity tariff will also make some consumers worse off [41].

[21] One of them, the concession fee, can assume different values, but only in conjunction with a TOU electricity tariff (Art. 2(2) *Konzessionsabgabenverordnung*).

they may follow the advice of the EU Electricity Directive 2019: "to maximise the benefits and effectiveness of dynamic electricity pricing, Member States should assess the potential for making more dynamic or reducing the share of fixed components in electricity bills, and … take appropriate action." (Recital 38). The German government [23] promised a fundamental reform of the statutory electricity price components and has made some progress, though not necessarily with incentives for flexibility in mind. 2022 saw the abolition of the renewables surcharge (*EEG-Umlage*), which for over 20 years had distributed the cost of renewables subsidies amongst electricity users and which at its peak in 2017 accounted for almost a quarter of the electricity price [42]. The subsidies are now financed partly from taxes and partly from the sale of emission rights, not least to fossil power plants. The latter raises the price spreads between renewable and non-renewable power and thus indirectly improves the savings potential of PBDR. A much smaller surcharge, the levy for interruptible loads (*Umlage für abschaltbare Lasten*), expired in 2023, though without tangible effects on flexibility incentives. Two of the proposals in the next section concern further changes to the statutory price components with the aim of making PBDR more profitable.

Policy proposals

Defining real-time electricity tariffs

The effectiveness of the legal requirement to offer real-time electricity tariffs pursuant to Art. 41a EnWG depends on a clear and meaningful definition as a precondition for monitoring compliance [42]. Art. 3 (31d) EnWG defines real-time ("dynamic") tariffs in an almost literal translation of Art. 2 (15) of Directive (EU) 2019/944 as: "an electricity supply contract … that reflects the price variation in the spot markets". This leaves suppliers ample leeway in tariff design. Accordingly, amongst ten arbitrarily sampled real-time tariffs, we found five distinct pricing models, which differ along several dimensions: To the spot price, the suppliers either add no surcharge, a per-kWh surcharge, or a percentage surcharge. Some tariffs feature upward and/or downward limits on the spot price, whilst most have no limits. Another tariff was almost impossible to categorise. Finally, nine tariffs are based on the day-ahead price, but one refers to the intraday price.

With this variety of tariff structures, consumers will rarely be able to compare any two tariffs and to tell which one is cheaper, given their level of consumption. This reduces their price sensitivity, with adverse consequences for competition. The intransparency also imposes large search costs on consumers and may thus discourage them from considering real-time tariffs altogether [26]. The excessive variety is primarily[22] attributable to the weak definition of real-time tariffs, especially the vagueness of the term "reflects" ("*widergespiegelt*" in the EnWG). Depending on the specific design, the prices of the tariffs we examined vary more, less, or just as much as the wholesale prices. Do they all *reflect* the price variation in the spot market? In other words, does *reflect* imply a one-for-one co-movement of the tariff and the spot price? If so, in absolute or in relative terms? The law supplies no definitive answers to these questions [43].

One possible course of action for the German legislator would be to tighten the existing definition of dynamic tariffs in the EnWG. However, the resulting deviation from EU law may be problematic as member states only have limited discretion in implementing EU Directives. The alternative, which we advocate, is to *supplement*—rather than replace—the definition with what might be referred to as a "highly dynamic tariff": one whose unit rate can only be stated as a multiple (e.g. 120%)[23] of the day-ahead spot price,[24] plus the statutory price components. By this standard, which suppliers and consumers may but need not embrace as a point of reference, few of the existing real-time tariffs would qualify as "highly dynamic", but some would require only minor adjustments.

Highly dynamic tariffs would be easily comparable with each other because—as with fixed tariffs—there are only two price dimensions: the multiple and the standing charge. All other price components are the same across suppliers. This comparability should promote competition and consumer acceptance, not least because it would allow such tariffs to be listed on price comparison websites, which are currently struggling with the diverse range of pricing models. For suppliers, the definition means that they must cover their profit margin and all costs other than energy procurement from the percentage surcharge on the spot price and from the standing charge—rather than from any fixed surcharges, minimum prices, etc. The percentage surcharge amplifies the price fluctuations borne by households and thereby their potential savings.

Electricity tax

Germany introduced an electricity tax in 1999 to make electricity more expensive and thus improve the

[22] Some of the investigated tariffs are by suppliers that are not yet obliged to offer a dynamic tariff and are therefore not subject to the legal definition. This changes in 2025, when all suppliers must offer an EnWG-compliant real-time tariff.

[23] According to ACER [37], electricity suppliers' profit plus other costs amount to roughly 20% of the cost of procuring electricity on average.

[24] Intraday prices seem less suitable because, being subject to change until just before delivery, they provide a less stable basis for consumption planning. Yet real-time tariffs based on intraday prices are likely to have somewhat higher spreads [44], enabling greater savings.

incentives for energy efficiency. Since 2004, the tax rate for households has been 2.05 ct/kWh, whereas the European Directive 2003/96/EC only requires a minimum of 0.1 ct/kWh for non-business use. Improving energy efficiency remains an urgent objective, but the timing of electricity use has become even more important: Shifting consumption from times of fossil generation to times of renewable generation has greater emissions benefits than reducing consumption by the same amount when emissions are already low thanks to ample renewable power. Furthermore, whilst its specific emissions have fallen significantly since 1999, electricity carries a higher tax burden than natural gas, its main competitor in heating applications (Art. 2, German Energy Tax Act). This puts the increasingly climate-friendly electricity at a disadvantage, causing unnecessarily high emissions. Finally, as argued above, the per-unit electricity tax stands in the way of stronger incentives for PBDR.

Two potential remedies come to mind. The first one is to make the electricity tax dynamic, for example by stating it in value-added rather than in volumetric terms, at least for real-time tariffs, where it would amplify the price spreads experienced by consumers. A value-added electricity tax is discussed by Gerhards et al. [24], who also acknowledge that it will be difficult to implement, not least because in its pure form it fails to meet the EU's minimum tax rate.

The other remedy is to redistribute the tax burden. On January 1, 2024, a change to Sec. 9b of the Electricity Tax Act (*Stromsteuergesetz*) reduced the tax rate for manufacturing and agricultural companies in 2024 and 2025 to the EU minimum. This is not what we suggest for households, as an uncompensated tax cut diminishes the efficiency incentives. Instead we propose, first, to eliminate existing tax breaks for fossil fuels in electricity production. According to Art. 37 and 53 of the Energy Tax Act (*Energiesteuergesetz*), the tax rate on fossil fuels drops to zero if these fuels are used to generate electricity. These concessions in sum amount to about €2bn per year ([45], p. 528f.). Reducing the marginal cost of fossil power generation, they in essence constitute a subsidy for emissions.[25] Second, the statutory electricity tax rate can then be reduced in a revenue-neutral fashion for the so far unprivileged users, including households. As those groups have been contributing some €4bn to €5bn annually in electricity taxes,[26] the tax rate could almost be cut in half.

Shifting the tax burden from electricity consumption to fossil generation seems natural because the latter causes most of the emissions. Making fossil power more expensive and renewable power cheaper, such a shift would promote political goals at the national[27] and the European[28] level. It could also raise the relative market value of unsubsidised renewable power. Consequently, less subsidies would be required to achieve the targeted renewables growth. For our aims, however, the main benefit would be increased electricity price spreads and thus greater profitability of PBDR.

Dynamic network charges

In 2023, network charges (transmission + distribution, including metering services) for German households averaged 9.35 ct/kWh [25], or about a quarter of the electricity price. That year, the transmission grid costs received a tax subsidy of €12.84bn (Art. 24b EnWG)—roughly half of the total grid cost [48]. In 2024, with the subsidy discontinued, the transmission grid charges more than doubled [49]. Network charges are by far the biggest item amongst the statutory price components; for households, they are now about six times as large as the electricity tax. At least on the lowest voltage level, distributing the electricity is already more expensive than generating it.

The German system of network charges, which has changed little over the past 25 years despite massive upheaval in the electricity sector [48], needs reform in many respects. The existing allocation of grid costs across time, space, and user groups was designed with a view to fairness, but not efficiency [13], and therefore fails to provide incentives for cost-reducing behaviour in several respects.[29] Again we focus on incentives for household flexibility. The high per-unit network charges obscure the price signals that real-time tariffs convey to consumers [2, 50], contrary to EU policy principles: "The network charges shall not … create disincentives for … participation in demand response" (Art. 18, Electricity Regulation 2019).

Non-static network charges can improve the incentives for PBDR and thereby reduce grid costs [52]. Akin to electricity tariffs, the simplest variable design is TOU charges, which vary by time periods usually established well in advance. In 2022, 21 of the 28 European countries

[25] The rationale for these tax breaks is probably to avoid double taxation: first of the input (the fossil fuels) and then of the output (the electricity). The result, however, is to waste a potential emission-saving effect of taxation, as fossil and renewable electricity is treated the same.

[26] The sector's annual electricity consumption of 200-250 TWh [46], multiplied by the tax rate of €20,50/MWh.

[27] Cf. SPD et al. [23]: "what is good for the climate will be cheaper, and what is bad, more expensive" (p. 49).

[28] The European Commission's [47] review of the Energy Taxation Directive of 2003 similarly aims to align the tax rates on different fuels more closely with their specific emissions.

[29] For some discussion, see [16, 49, 52]. For example, network charges for industry incentivise a flat consumption profile – which made sense in the pre-renewables era but obstructs flexibility today [13, 48]. The system also fails to reflect the growing renewable power generation by households [51].

surveyed by ACER [53] applied TOU network tariffs, as recommended by the EU at least since the Electricity Regulation of 2019. Germany is not amongst them, so far exclusively using fixed charges for households. From 2025, however, German households with smart meters may opt for a TOU network charge if they have certain types of dispatchable appliances (storage heaters, heat pumps, wallboxes, etc.) (Art. 14a EnWG). The model's main drawback is that the periods during which the different charges apply will be set annually [54, p. 17]. This means that the tariff can at best reflect average grid conditions, but not the current load situation. With the predictability of loads declining, this means that any resulting demand response will be of limited value for relieving the grid and reducing the cost of its expansion. Accordingly, both Agora and FFE [2] and Elsenbast and Winzer [50] qualify TOU network charges as an interim solution at best. The BNetzA itself [54] has advocated its model as a mere first step towards more dynamic network charges.

More short-term, grid-serving flexibility is to be expected from critical peak network tariffs. In France, grid operators inform consumers at the medium voltage level 24 h in advance if a critical situation is expected for the next day and the network charges are raised accordingly [16, 53]. In the United Kingdom, grid charges for non-residential consumers used to depend on their electricity use during three half-hour periods (the 'Triads') in the winter season [55]. Better still from a flexibility perspective would be network charges that change on an hourly basis in line with the expected grid load. In Germany, according to the BNetzA [54], load-based dynamic network charges are not yet viable due to a lack of information about the current grid status. We contend, however, that a dynamic network tariff that generates incentives for grid-friendly demand response, as called for in the literature (e.g. [10, 13, 50]), can in principle[30] already be implemented for households with smart meters. Until the digitisation of the grids produces real-time information on the local grid situation, the day-ahead spot price of electricity can serve as a proxy as it correlates[31] with grid loads on the national level [50].[32] Simply put, with high demand for electricity, both spot prices and grid loads tend to be high. A dynamic network charge based on the wholesale electricity price, as already implemented in Sweden and Norway [53], then induces a postponement of power consumption, relieving the grid. Conversely, the dynamic charge can stimulate additional loads when low demand coincides with high renewable feed-in.

A dynamic network charge (*NC*) per kWh for distribution grid i in year t and hour h could take the following form:

$$NC_{i,h,t} = \left[DNC_{i,t} + S_{i,h}\right] + \left[a_t * f(SP_h)\right], with f' > 0, f'' < 0$$

The first expression in square brackets concerns the distribution grid charge, the second one the transmission grid charge. The latter equals a function of the hourly day-ahead spot price (*SP*) that increases at a decreasing rate, multiplied by a factor a_t. The BNetzA determines that factor each year such that, in expected terms, the transmission grid operators can earn their designated rate of return and inflexible households are no better off than under the fixed tariff.[33] The network operators' revenues will be subject to additional price risk but, like the existing quantity risk already, this can be absorbed by a dedicated set of accounts [48].

$DNC_{i,t}$ is the network charge set by distribution system operator (DSO) i in year t, much like today.[34] In order to avoid involuntary load curtailment,[35] each DSO is allowed to add a surcharge $S_{i,h}$ to the grid tariff during hours when dangerously high loads are expected. Periods of $S_{i,h} > 0$ must be announced 24 h in advance in a standardised, machine-readable format. The surcharge must be sufficiently large to offset any load-increasing effect of dynamic electricity tariffs [2] and of the transmission component of the grid fee. $S_{i,h}$ and its annual total are limited, so consumers need not fear arbitrary network charges. Actual revenue from the surcharge does not count towards the DSO's revenue cap; however, the cap (and thus $DNC_{i,t}$) is reduced by the expected revenue. Given these constraints, DSOs should require no further monitoring regarding the use of the surcharge. They will

[30] Electricity suppliers and grid operators may, however, require adequate lead times to implement new billing procedures.

[31] Using SMARD market data, we find a highly significant correlation coefficient of 0.26 between German national grid load and day-ahead wholesale prices for the first half of 2024.

[32] Besides the wholesale spot price of electricity, Freier and von Loessl [14] also propose the forecasted residual load and the share of renewable energy production as the basis of dynamic network charges and other price components.

[33] The latter condition also applies to the TOU tariff that is to be implemented in Germany [54]. Ecofys [44] employ a similar factor in a related proposal regarding the now defunct renewables surcharge.

[34] While today network charges are uniform (for a given group of users) across each distribution grid, some of which extend across entire federal states, ideally the charges will be set more locally when better data become available.

[35] Economic theory suggests that curtailment is less efficient than voluntary (price-based) load reduction, as the latter allows consumers to choose the situation in which reducing their load causes the least inconvenience [13, 22].

choose to apply it when it generates the most revenue—that is, when loads are high, just as intended. If a DSO has used up its surcharge allowance before the end of the year or if the surcharge does not have the necessary effect, load curtailment remains as the ultima ratio, as in the status quo.

Following a judgement by the European Court of Justice that required greater regulatory independence for the BNetzA [56],[36] the German regulator is currently reviewing multiple aspects of the network charges, providing a window of opportunity for reforms. Our proposal combines elements of critical peak and real-time pricing of network charges, as already successfully applied in France and Sweden/Norway, respectively. It also yields both grid-serving effects (less need for grid expansion) and system-serving effects (cheaper integration of renewables), and thus delivers the two main types of incentives that are variously being demanded of reformed network charges.[37] If implemented, the dynamic network tariff should be optional for all households with smart meters. It would complement real-time electricity tariffs, augmenting their price spreads and thus the incentives for flexibility.[38]

Financial support of real-time tariffs

So far, we have only considered indirect means of supporting consumer demand for real-time tariffs. If these measures prove insufficient, some temporary direct financial support may be required. Rationales for subsidising real-time tariffs abound. As mentioned above, users of such tariffs are likely to provide flexibility and thereby a valuable service to society—an external benefit that may not materialise unless transferred at least in part to households [10]. Other potential externalities include asset optimisation [3] and generally improved power market efficiency [44, 57]. Furthermore, consumers who shift their loads will not only save on their own electricity bills but indeed reduce average electricity prices for all [2, 58].

An external impetus can also help to resolve the first mover problem between households, producers of smart technology, and suppliers of real-time tariffs: For each party, an investment in demand response is only worthwhile if all other groups invest simultaneously [13]. In such a situation, government support can provide the necessary 'nudge', helping to coordinate joint action. To individual households, beyond improving their cost–benefit analysis, government support can serve as an endorsement, signalling that a real-time tariff is the right choice. This helps consumers overcome their inertia and embrace new mindsets and routines, reducing their psychological costs of switching. Once a critical number of households have made the transition, the trend towards real-time tariffs may become self-reinforcing as a culture of consumer flexibility evolves, reducing the psychological cost of participation, and components such as home energy management systems become cheaper on mass markets, reducing the monetary cost. This should at some point allow the subsidy to be reduced and ultimately phased out.

In terms of subsidy design, one of the statutory price components could be reduced for real-time tariffs relative to fixed tariffs, reflecting the fact that users of the former tend to provide external flexibility benefits. By that logic, "highly dynamic" tariffs should be subsidised more strongly than merely dynamic ones. In terms of size, being chiefly intended as a coordination and signalling device, the subsidy can be quite small. Making it too large would only attract consumers who have no intention to be flexible. Electricity cost savings from active PBDR must remain the prime motivation to select a real-time tariff.

Conclusions

The costs of generating electricity fluctuate by the minute. Yet most consumers are still isolated from short-term price changes. This discrepancy impedes demand response, causing unnecessarily high costs elsewhere in the power supply system. Real-time tariffs are a natural means of allocating electricity price risk where it can induce cost-saving changes in behaviour. They are also a low-hanging fruit in terms of eliciting demand response—the incentives are already there, provided free of charge by the spot markets.[39] Giving consumers the active role that policymakers intend for them can furthermore promote greater identification with, and support for, the energy transition.

Focussing on German households, this paper has discussed what can be done to promote the adoption of such tariffs. We have made policy suggestions regarding the definition and financial support of real-time tariffs, the electricity tax, and dynamic network charges. Due to limitations of space, our presentation of the proposals has remained superficial; future work should flesh out their details for implementation and ensure their compatibility with existing legislation. Furthermore, focussing on individual households, we have ignored aggregators,

[36] Case C-718/18, judgement of September 2, 2021.

[37] For a juxtaposition of these two objectives, see e.g. [2, 15, 16, 48].

[38] On the complementarity of dynamic electricity and network tariffs, see [2, 22, 24, 50]. Note that our scheme does not consider spatial incentive effects. Taking them into account may yield different recommendations [52].

[39] Unlike for example the flexibility incentives that are to be artificially created by auctions for potentially curtailed renewable power that are currently being prepared in accordance with Art. 13k EnWG.

whose potentially beneficial role in PBDR deserves more research.

Besides going into greater depth, future research may also consider other measures to support PBDR. If Germany adheres to its schedule for the smart meter rollout, over 5 million devices must be installed in each of the next 6 years. Every meter corresponds to a potential new user of a real-time tariff. This implies the largest shift in the German electricity market since its liberalisation in 1998 and it raises the question whether real-time tariffs should be made the default for these new potential customers [3].[40] Relevant experience already exists in Spain [58] and—with TOU tariffs— in California [10], as well as in Italy and Ontario [59].[41] Nevertheless, real-time tariffs should remain voluntary to allow consumers to self-select: Those who can offer flexibility, i.e. in particular (better-off) operators of electric vehicles, stationary batteries and heat pumps, will tend to embrace the price fluctuations and realise the associated savings. By contrast, fixed tariffs should continue to be available for those who do not have any flexibility to offer or who cannot afford the risk exposure, e.g. because the cost of electricity constitutes a major part of their budget. At least for the foreseeable future, mandatory real-time pricing could be both inefficient (because the costs of risk aversion could outweigh any benefits) and politically unwise (due to its tendency to aggravate social inequality).

For a softer intervention, future research could investigate policy options to raise consumer awareness of real-time tariffs, which in Germany is very low [26]. Evidence suggests that informing consumers about the double benefits of demand response—reducing both emissions and electricity bills—raises their willingness to consider a real-time tariff [40]. Even for households that already use dynamic tariffs, textual prompts, such as messages from the electricity supplier alerting them to upcoming savings opportunities, can significantly increase load shifting [36].

Finally, we must not to lose sight of the wider context. Demand response is but one aspect of a potential market for flexibility [3, 28, 60], which the European Commission [6] is encouraging its members to implement. Also, we do not mean to imply that the measures discussed here ought to take precedence over other reforms to improve the efficiency of electricity supply, such as the introduction of nodal pricing [9]—an ideal complement to real-time tariffs [50]—or at least breaking down the Germany/Luxembourg bidding zone into smaller areas,[42] as in Scandinavia [62].

[40] However, compatibility with Art. 11(3) of Directive (EU) 2019/944 must be ensured: "Suppliers shall obtain each final customer's consent before that customer is switched to a dynamic electricity price contract."

[41] In a meta study spanning six countries, Nicholson et al. [17] find large differences between opt-in and opt-out regimes regarding the willingness to adopt TOU tariffs.

[42] This option is discussed by acatech et al. [9], recommended by ACER [4] and currently being deliberated by the European Commission [61].

Abbreviations

BNetzA	Bundesnetzagentur (German Federal Network Agency)
CPP	Critical peak pricing
ct	(Euro) cents
DSO	Distribution system operator
EnWG	Energiewirtschaftsgesetz (German Energy Industry Act)
EU	European Union
kWh	Kilowatt-hour
MsbG	Messstellenbetriebsgesetz (German Metering Act)
MWh	Megawatt-hour
PBDR	Price-based demand response
TOU	Time-of-use

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