Making Resource Adequacy a Private Good: The Good, the Bad and the Ugly

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Since smart technologies have advanced to the point where real-time monitoring and direct customer load control are now feasible, making resource adequacy a private good is now becoming a viable option. This could represent a cost-effective alternative to capacity remuneration mechanisms with pre-determined adequacy targets, and promote efficient use of electricity to help accelerate the decarbonisation process. However, it also raises ethical questions related to the definition of essential demand and the fairness of how electricity system costs are allocated.

The existence within a system of sufficient generation capacity to satisfy electricity demand at all times (or within a predetermined target), referred to as "resource adequacy"[1], has been a source of great attention in the last few decades among regulators and academia, and more recently also among the public due to Texas's severe electricity shortage in 2021[2].

Resource adequacy is also known as "system adequacy" or "adequacy", which emphasises the long-term planning process of a power system's ability to meet demand and is currently ensured by schemes like capacity remuneration mechanisms in various countries. It is one component of the broader concept of "security of supply", which is a general term encompassing all measures of the ability of the system to deliver electricity to all points of utilization.[1] Indeed, security of supply also includes concepts like "operating reliability", that is, the ability of the system to withstand transient and short-term contingencies, usually supported by ancillary

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services such as voltage support (see section 1 of the supplemental information for more details on the terminology). This paper will focus only on adequacy because operating reliability is subject to system-wide stability conditions of the network infrastructure, which can only be achieved through coordinated management of the agents within the system.

Until recently, groups of consumers (e.g., those belonging to the same substation) could be disconnected in case of severe system stress, but a specific individual user could not be easily disconnected. Resource adequacy has therefore always been considered a non-excludable good[3] (i.e., everyone can benefit from it, and the exclusion of users is difficult). Along with its rivalrous property, it is usually classified as a common-pool resource.[3] The non-excludability trait is accompanied by the difficulties in securing individual payment from private provision, which is a known market failure. Thus, in many systems,[4] resource adequacy is currently administered by the government authorities and centrally managed through capacity markets or other similar scheme.

However, unlike operating reliability, the option of regarding resource adequacy as a private good is now open, thanks to the increasing availability of smart home and grid technologies, such as the Linky meter in France. Indeed, the development of these assets has largely improved real-time management and two-way communication between utilities and customers, which directly enables the provision, metering, and on-demand excludability of service at the household or business level effectively. In addition, the transition towards net-zero continues with more intermittent renewable generation and the phasing out of fossil fuel generation, which can make generation-side management more expensive and complex due to the need for additional reserves, energy storage and technical management.[5,6] This has motivated a growing trend from passive to active customer-level operations and engagement instead of solely relying on supply-side management. This incentivizes the shift towards new consumer-centric design paradigms which can differentiate the provisions of resource adequacy and levels of protections according to users' preferences.

Here, we propose that resource adequacy no longer needs to be administered by regulators. Instead, apart from ensuring resource adequacy for essential loads (such as hospitals), it could be offered to users as a customizable service based on their personal preferences (a common way to quantify them is through the value of loss load (VOLL)). This has the potential for significant impact given that most electricity demand could be considered non-essential. This change in perception can help ensure the correct procurement of capacity, reduce the cost for consumers, and promote the adoption of distributed energy resources by consumers. In addition, it would incentivise non-essential demand reduction, enhance the efficiency of energy allocation and usage, and thereby could contribute to decarbonisation under proper policies. However, this change would require a socially acceptable definition of essential demand and raise ethical and practical challenges.

Resource adequacy can be a private good now

The increasing rollout of smart meters has directly enabled real-time monitoring at the disaggregated consumer level, supporting the excludability of service. While the idea that "system operators can physically enforce contracts by turning off the lights" was viewed as impossible in 2005 around 2000, smart meters and plugs have been able to realise remote control of the service connection at household or even at appliance level, such as the recent trial POWBAL (see section 2 of the Supplemental information). In Europe, over half of the households have been deployed smart meters in 2021, with for example 100% in Italy and France rolled out Linky Meter to over 35 million households by 2022 as shown in Figure S1 in section 2 of the supplemental information. Facilitated by significant developments in the functionality of the smart meter, technologies such as remote control as well as contractual design and support, system operators in France can now ensure that the electricity usage is within an electricity supply limit that the household has subscribed to. Meanwhile, consumers could track through the monitor and adjust or switch off the electrical devices to continue with their electricity access.[7]

Thanks to smart meters and smart devices, the public perception of electricity demand has also evolved over time. Though most users are still paying a fixed tariff for electricity, an increasing number of countries, including the US, India, the UK, and most of Europe are implementing time-of-use tariff schemes. Approximately 25% – 50% of households in Estonia and Spain have adopted dynamic real-time pricing (see section 2 of the supplemental information). This indicates that two long-held beliefs (i.e., "every kWh is the same" and "consumers are homogeneous"[5]) are progressively being dispelled. Meanwhile, the political and public unacceptability of scheduled power outages has been gradually mitigated when more consumers are actively involved with a better understanding and communication of their preferences based on different conditions and consumers. Choice experiments, such as the one by Broberg, Daniel and Persson[8], have shown that consumers' value lost due to load shedding can depend on the duration, quantity and consumer types. For example, a power outage for an entire day is worse than losing one hour twenty-four times over a month. Furthermore, consumers tend to favour a partial cut-off from a more demanding activity rather than a total disconnection from a less demanding one.[4] For instance, reducing 2 kW from an activity with an anticipated load of 3 kW is preferable to reducing 2 kW from an activity with an expected load of 2 kW. The adoption of supply contracts with a greater risk of load shedding can also be influenced by the consumer's income and environmental consciousness (e.g., Broberg, Daniel and Persson[8]).

Apart from the changing public perceptions, four additional main forces are identified in the literature which drive the changing role of demand. Firstly, in the past, generation side management was the system operator's primary instrument for power balancing because it was more flexible, predictable, and cost-effective. However, as more renewable generation is deployed in the system in response to more significant decarbonization objectives, generation side management becomes more expensive.[5,6] Secondly, the electrification of transportation and heating will bring a significant amount of potential flexible demand and storage resources (e.g., electricity vehicles), which enables more active demand-side management. Thirdly, lower transaction costs supported by digitalisation, greater automation and advanced technology[6] have made demand-side monitoring, controlling and preference differentiation less complex and costly. Lastly, along with changing public perceptions, more active contract designs and a better understanding of heterogeneous consumer preferences have lowered information barriers needed to unlock demand side flexibility. As the number of participants grows and the preferences become more diverse, more demand will be become adjustable.[9] Considering system adequacy as a private good differs to normal demand response programmes (see section 3 of the supplemental information for more discussions).

Facilitated by shifting public perception and feasible service excludability through advanced technology, considering resource adequacy as a private good of the resource adequacy becomes a possible solution to help decrease costs and improve allocation efficiency.

Considering resource adequacy as a private good can improve cost and allocation efficiency

The primary issues with adequacy being administered by regulators with a pre-determined aggregate target are allocation inefficiency and the over-procurement of capacity. The cost of over-procurement and inefficiency will ultimately be passed on to consumers via higher retail electricity prices (or to citizens through higher tax). Several factors contribute to this over-procurement. Firstly, as argued in Newbery[10], "the minister wishes to avoid newspaper headlines predicting blackouts resulting from his decision". The historical adverse political impacts of power outages incentivise the regulators to overstate the value of lost load due to the unacceptability of the power interruption. Following the increasing trend of renewable deployment and the extreme climate event, the cost of securing a continuous and firm power supply will rise even further. Secondly, more behind-the-meter technologies are deployed such as rooftop solar and home batteries[5]. This information asymmetry between the regulator and consumers directly leads to an overestimated adequacy target. There might be an increasing marginal cost in reaching a higher and overestimated adequacy target as an increasing amount of more flexible and expensive reserves would be needed.

Allocation inefficiency is caused by the fact that the heterogeneity of consumer needs and preferences for adequacy are not integrated into the current market constructs and the aggregate adequacy target.[4] Due to a lack of consumer involvement and information for differentiated preferences, this will also result in capacity over-procurement as risk-averse regulators will tend to guarantee the electricity supply for everyone to avoid the negative political impacts discussed above.

Besides the over-procurement caused by the administered aggregate target, allowing consumers to specify their preference on the level of adequacy could also be helpful in the case of under-procurement to incentivize the correct amount of capacity investment. In the case of Texas's severe electricity shortage in 2021[2] with unprecedented weather and demand peak, making system adequacy as a private good can allow the system operator to pinpoint and select disconnections of specific consumers based on their subscriptions. Meanwhile, it ensures that the operator prioritises a firm supply of the essential demand, which will be introduced in the next section.

As treating resource adequacy like a private good is now an option, cost-effectiveness and allocation efficiency can be improved by allowing consumers to choose their desired level of adequacy. A key consequence of this is that the information asymmetry is reduced as consumers would explicitly reveal their own preferences. Studies such as Ovaere et al.[11] have shown that this can help lower long-term capital costs and provide short-term operational cost savings. In particular, they found that operational costs can be reduced by 2%–18% if consumers are given the option to choose their level of adequacy instead of adopting an aggregated and constant VOLL.

On the implementation side, general ideas of reliability differentiation schemes that support the supply of adequacy as a private good have been proposed in the literature. For example, the idea of demand subscription services[12] can accommodate consumers' diverse reliability preferences by allowing them to subscribe to different firm power service levels, and loads above this can be curtailed under a set of pre-set conditions. More broadly, reliability insurance[13] has been proposed which offer consumers compensation for power outages in return for an upfront premium, where consumers could also adjust their subscription plan over time according to their preferences. The insurance counterparty is motivated to diversify their investments and contract with generators to reduce outage risks. By charging different prices for firm power service levels or affordable insurance premia, these schemes can effectively internalise the consumer reliability externalities (i.e., the extra social cost associated with the fact that for each extra unit of electricity consumption, there will be an increasing inadequacy risk and loss supply for other consumers, as defined by Meade[3]).

Apart from improving efficiency and reducing costs, these schemes could also encourage consumers to adopt distributed assets, such as solar panels and batteries[13], to enhance the reliability of their electricity access as well as the grid flexibility and security of supply. Furthermore, Riesz, Gilmore and MacGill[14] proposes that differentiated value of loss load and demand flexibility could counteract the market price volatility associated with renewables.

Considering resource adequacy as a private good and energy access equity

While it is true that treating resource adequacy as a private good can enhance efficiency and lower costs for consumers, and can be implemented by schemes in various forms, it reduces energy access equity but may increase the fairness in the adequacy cost allocation.

Energy access equity refers to the fact that everyone has equal access to electricity, which is the case when the adequacy is provided as a public service administered by regulators. When treating system adequacy as a private good, the equity of energy access could decrease because consumers will subscribe to different levels of adequacy depending on both their preferences and financial budget. This can lead to the possibility of completely losing rights to access electricity, which will result in serious fairness, ethical and political concerns for vulnerable consumer groups[4] including low-income households and people with disabilities. Of particular concern are individuals relying on electricity-dependent life support systems. This indicates the importance of ensuring consumers have a guaranteed access to electricity for life-essential needs or “essential demand”, which will be defined and discussed in detail in the next section.

Moreover, even though consumers are guaranteed essential electricity access, the unequal access to electricity, which could be correlated with the socio-economic status of the customers, may negatively influence the decisions of vulnerable consumers and businesses to conduct additional economic activities such as extra education and production expansions, which may exacerbate resource and income inequality.

Though shifting resource adequacy from a public service to a private good can result in decreased equity of energy access, it could be considered to increase fairness in the allocation of adequacy costs to consumers, since consumers bear the cost of the services they use, rather than subsidising the access to firm capacity of others. Additionally, it could increase the compensation for demand flexibility and energy efficiency improvements.

Considering resource adequacy as a private good requires a socially acceptable definition of essential demand

As discussed in the previous section, ensuring access to an acceptable level of essential demand is important for finding a middle ground between economic efficiency and energy access equity. If the level of essential demand is not properly defined in reliability differentiation schemes, or if consumers are not guaranteed access to electricity for life-essential needs, significant ethical and political concerns will arise. However, reaching consensus on the precise standard of a socially and ethically acceptable level of essential demand may be challenging.

The definition and threshold of the essential demand remain controversial. The closest definition of essential demand in this context can be the minimal basic electricity access or services needed to achieve day-to-day living requirements (e.g., must-run services like hospitals’ intensive care units or energy required to maintain the temperature). The access to essential demand must be guaranteed because otherwise, it could be unethical to consider adequacy as a private good. There are a range of different options for implementing essential demand, which could be a fixed power amount, or could also have an energy component, so that a minimum amount of power and a certain amount of energy for heating etc. must always be available each day. The amount could vary over time based on the local temperature and culture differences etc. According to the International Energy Agency[15,16], the minimum requirement for having electricity access is set at 50 kWh per person annually in rural households or 100 kWh per person in urban households. The other modern minimum energy thresholds, such as Moss et al.[16], also consider economic growth and greater prosperity. These thresholds also concern energy access for commercial activities, which the market ought to allocate effectively rather than ensuring access to. Therefore, we use IEA's thresholds for the following back-of-envelope analysis.

Using Great Britain (GB) as an example, according to BEIS[17], the total electricity consumption in 2020 was 259,510 GWh. The total population in GB in 2020 was 65,186,000.[18] If we allow 100 kWh per year for essential demand per person, the total essential demand would be around 6,545 GWh per year (including 26 GWh from hospitals' intensive care units; see section 5 of the supplemental information for more details). This accounts for only approximately 2.5% of the total electricity consumption, which can be easily and firmly supplied by the current generation mix in GB, since around 15% of the generation came from nuclear in 2022.[19] Meanwhile, around 97.5% of the load could be provided with customised adequacy levels, and secured access to this consumption could be efficiently allocated by treating resource adequacy as a private good.

Considering resource adequacy as a private good can facilitate the decarbonisation of the power sector

In addition to increasing efficiency, treating resource adequacy as a private good may also help with the decarbonisation of the power sector.

Due to the substantial rise in electricity demand arising from the electrification of other sectors, the power sector becomes increasingly challenging to decarbonise.

Improving energy efficiency and reducing energy demand have been considered two powerful tools to mitigate climate change, carrying significant potential but accompanied by complex challenges. These challenges can arise from the inherent need to alter human behaviours and lifestyles.

Securing reliable access to essential demand and treating the adequacy of non-essential electricity consumption as a private good can help improve allocation and usage efficiency by incentivising the reduction of non-essential demand and investments in energy efficiency. When the resource adequacy is administered by regulators, energy bills do not necessarily reflect the adequacy costs each individual's usage placed on the system. Instead, if we treat adequacy of non-essential electricity consumption as a private good, the cost of adequacy will be allocated to consumers based on their actual preferences. Therefore, consumers may gain greater savings by improving their flexibility and the efficiency of their electricity usage as the assumption that everyone needs and should pay for the same level of adequacy will be eliminated. This can incentivise the consumers to reduce non-essential consumption and stimulate the replacement of energy-inefficient appliances, and therefore, accelerate the decarbonisation process.

Summary and future challenges

Should we consider adequacy as a private good in the near future? Figure 1 provides a summary of the comparison between treating adequacy as a public or private good in the aspects of economic efficiency, decarbonisation and energy access equity.

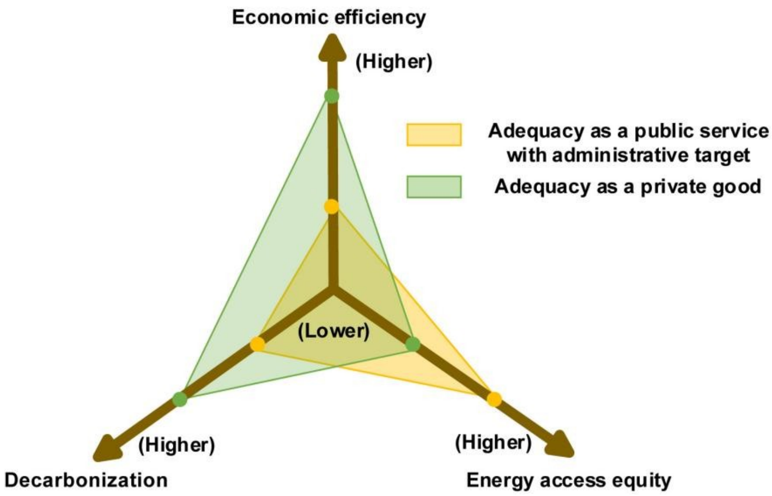

Figure 1. A radar chart comparing treating adequacy as a public service with administrative target vs. as a private good. The figure provides a qualitative overview of treating adequacy as a public service vs. private good from the perspectives of economic efficiency, decarbonisation, and energy access equity.

However, treating resource adequacy as a private good will raise several implementation challenges and concerns. The first and most vital one is the obstacle of setting a socially acceptable definition and level of essential demand. A proper setting of essential demand can reduce energy justice concerns. However, in reality, essential energy demand can vary among different regions and consumer groups and evolve with time (see section 6 of the supplemental information for more details), introducing additional complexities in terms of its estimation and ethical provision. On the other hand, shifting adequacy from a public to private good does help avoid the estimation of whole system capacity needs, and avoids estimating overall system capacity demands, which can be even more costly for consumers if the estimation is incorrect. Secondly, privacy concerns could be vital for both households and commercial consumers. More data platforms, regulations and privacy preserving mechanisms have been and will be put in place, as discussed in section 4 of the supplemental information.

Overall, supported by changing perceptions and smart grid technology advances, treating resource adequacy as a private good with reliable access to a socially acceptable level of essential demand has the potential to reduce overall energy bills for customers, improve allocation efficiency, and accelerate the decarbonisation of the energy system. While it is possible for energy access to become unequal, considering resource adequacy as a private good could enhance fairness in terms of resource adequacy cost allocation and incentivizing improvements in flexibility and energy efficiency. These potential opportunities, and the pressing importance of the net-zero transition, motivate serious consideration be given to new paradigms of resource adequacy beyond aggregate targets.

Declaration of Interests

The authors declare no competing interests.

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Supplemental information

Document S1. Supplemental information, Figures S1–S2 and supplemental references.

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