

Article

Who Should Own the Residual Rights over Distributed Resources?

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Abstract: Residual rights are the right to choose asset uses not specified in the contract. They are essential in situations of uncertainty. The current energy transition presents a greater variety of assets. Moreover, it is impossible to anticipate all relevant states that the assets and the environment can embody, making it impossible to optimize them contractually. Furthermore, there is consensus that the transition must occur quickly, which means high levels of investment in new specific assets. How should we distribute property rights to maximize social benefits in a context with specific and dispersed assets? Because of the complementarity between network and distributed resources, this article questions the premise that deverticalization is invariably beneficial to consumers and argues for the need to revise the concept of network and develop the regulatory implications of such a reconceptualization. We defend the need to evaluate alternative network concepts considering the technological repertoire available to operationalize them. When considering the technological repertoire available today, characterized by the competitiveness of information and communications technology (ICT) and distributed resources, we should recognize the inherently incomplete nature of the contracts signed between network operators and users.

Keywords: distributed resources; energy transition; incomplete contracts; smart grid; unbundling



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1. Introduction

According to the media, the ongoing energy transition threatens network operators [1,2]. The expression *utility death* has been in the news to denote this threat for some time. However, it is hard to reconcile this utility death image with any credible energy system scenario.

Traditionally, supply and demand are aligned by dispatchable generators according to changes in load. When demand is higher than supply, the system frequency tends to decrease. If this occurs, dispatchable generators inject more power into the grid to compensate for such a decrease and return the operating frequency at the reference frequency. If demand is lower than supply, the control acts in the opposite direction, reducing power injection into the grid. Therefore, controlled firing determines the dynamic behavior of dispatchable generators, which controls the rate at which primary energy is converted into useful work, permanently maintaining the coupling between generation and load.

However, with the increasing insertion of intermittent renewable sources and other asset classes (such as energy storage and demand control technologies), the grid must actively align between supply and demand, acting on emerging energy and para-energy technologies. For example, grid controls can trigger curtailment of non dispatchable generators (e.g., solar photovoltaics or wind power) or activate flexible loads (e.g., air conditioning) to compensate for up and down ramps from intermittent sources. In this emerging context, the economic value of the grid increases since, in addition to the passive transmission of

power flows, it should actively perform the coupling function with dispatchable generators. On the one hand, such a coupling function requires more complex network operations, but on the other hand, it allows the system to operate with lower operating costs (reduced fuel costs). But such a scenario will be possible only if investments in the grid (*The power system can be subdivided into generation, transmission, distribution, and end-users. The grid is composed of transmission and distribution assets. Our focus in this paper is distribution grids. We see the grid as a subset of the power system with specific attributes and functions.*) enable it to process generation and end-users' state information in real-time and redirect flows as necessary. In this new context, energy autonomy would happen without depending on the continuous fossil material processing to obtain energy, but it would require a massive increase in information processing. In other words, the transition from a fossil-based system to a renewable-based one corresponds to replacing matter processing with the capture of energy flows plus information processing. It is not easy to see how the social utility of the grid could diminish in such a context.

Therefore, there is no reason to assume that the potential for power system networks generating value for society will be smaller. Everything indicates that ensuring adequate investments in the network can significantly increase society's capacity to use flow energies (solar, wind, etc.) and reduce dependence on fossil fuels. Then, it is reasonable to claim that the supposed death spiral is not a result of disruptive competition from resources at the customer side of the meter but from the inherent design of rate structures [3]. This article deepens such understanding by proposing a redescription of the grid's role, considering the implication of the emergence of distributed resources (distributed generation, automatic demand control, energy efficiency, energy storage) for the grid concept. In methodological terms, our approach is a development of the premise that the effectiveness of the regulatory apparatus always has to consider the technological repertoire available to agents instead of viewing it as a black box.

A limitation of our network redescription is that, although we recognize that the energy system does not involve only the electrical networks, we will only deal with part of the electrical subsystem, which corresponds to the distribution networks. Thus, while part of our redescription applies to transmission or non-electrical networks (e.g., gas networks), this article focuses on electrical power distribution networks. Our proposal to focus on electricity distribution networks stems from our assessment of the more remarkable emergence of the problem of rethinking networks in the scope of distribution due to the increasing competitiveness of distributed resources.

Our approach emphasizes the functional role of the grid, clearly differentiating it from the generation's role, but also recognizes that part of the generator load-following function could be executed by the grid with increased economic efficiency. Although dispatchable generators have traditionally implemented the supply–demand coupling function, emerging technologies make it possible and even necessary to perform an essential part of this coupling function through the grid. However, such a transformation is impossible without a change in the grid concept, including developing the regulatory implications of this change. We propose moving away from the naive conception of the grid as a passive electricity transporter and demonstrate the need to understand the grid in more general terms, that is, as a provider of flexibility. Section 2 details our understanding of the grid as a flexibility provider that increases the socioeconomic value of energy resources. Section 3 presents a typology of possible structures to organize the grid. Section 4 uses the so-called unbundling problem to demonstrate the naive grid conception's influence on the current power sector's organization. Section 5 explains why the advent of distributed resources increases the importance of incomplete contracts [4–6]. In conclusion, we defend the need to systematically incorporate a comprehensive grid concept, capable of considering the exponential increase in the quantity and variety of the energy technologies repertoire of the 21st century, that is more compatible with the reality of prosumer capitalism.

2. The Role of Grid in Power Systems

Although the role of the energy system, in general, and the power system, in particular, in triggering and maintaining the development trajectories of contemporary civilization is increasingly recognized [7–9], the specific mechanisms by which such systems guarantee agents autonomy in their decisions are still not sufficiently clarified.

For example, it is customary to emphasize the role of dispatchable generation in balancing supply and demand at any given moment. This role is proper and essential, but such a role would be impossible without the permanent connection between energy resource users and resource sources guaranteed by the grid. An essential feature of this coupling between sources and users guaranteed by the joint action of generators and grid operators is that all users are served simultaneously, without queues—all the users are attended at the same time, no matter their location or the moment of the demand. This arrangement ensures that the power system constantly adapts to users' needs, thus giving them ample flexibility to organize their activities. In practice, this process replaces the serial service characteristic of queues with the parallel service characteristic of operation at a reference frequency (50 Hz or 60 Hz, depending on the country). When demand is higher than supply, the frequency tends to decrease. If this occurs, more power is injected into the grid to compensate for such a decrease and return the operating frequency at the reference frequency. If demand is lower than supply, the control acts in the opposite direction, reducing power injection into the grid. It is worth emphasizing that this dynamic process is only possible because everyone is permanently connected to the electric field produced by the set of generators, which must operate synchronized at the reference frequency. The grid physically guarantees this total connection of all agents to the same electric field—without it, the flexibility in using energy resources would be impossible despite the enormous amount of primary sources available. Thus, the grid is essential to the coupling between sources and users.

At the same time, the generation transforms primary resources into electricity and makes temporal allocation of aggregate power; *the grid translates this aggregate capacity into temporal and spatial electrical power for each user*. As a result, the combined action of generation and grid transforms energy into a social object that can be activated whenever the users consider it convenient. That is, generation and grid perform equally necessary but distinct functions.

Another way of describing the process that guarantees energy autonomy to the socio-economic system is by observing that every user of the power system inevitably depends on two elementary contracts: an energy purchase contract with generation and an options contract with the grid. The generation contract guarantees total work capacity, while the grid contract makes it possible for users to decide when to use the work capacity produced by generation. For most of the power system history, these two elementary contracts with generation and grid appeared together, and there was no need to distinguish them for users.

Nevertheless, the current energy transition context has become increasingly important to understand that generation and grid are distinct functional components of the power system. It is crucial to understand that the service value provided by the grid is derived from the energy value but does not correspond to energy sales. The grid service is a peculiar form of derivative. The first mention we have identified of the grid-users relationship as an options contract comes from the context of a legal dispute:

“Capacity is not actual electricity. It is a commitment to produce electricity or forgo the consumption of electricity when required. Generation resource owners sell capacity to utilities, which need sufficient capacity to provide electricity to their customers reliably. This creates a kind of options contract. When a utility experiences a high demand for electricity, it can call on the capacity resource to produce that electricity”. ([10], p. 3)

This options terminology comes from the derivatives market. In derivatives markets, a long position implies purchasing a right, which corresponds to a short position referring

to the sale of such a right. In this context, rights and obligations refer to the exercise of a purchase (long call, short call) or a sale (long put, short put) [11]. The grid user pays both for the right to dispose freely of amounts of power and for the total integrated power in a certain period (total consumed energy).

When signing a contract with distribution, the consumer pays for the right to use work capacity at any time, assuming a peculiar long call position. The distribution, in turn, receives for assuming the obligation to guarantee this right, thus placing itself in a short call position. The short call position assumed by distribution allows users to use variable capacity quantities and decide the best time to use any fraction of the total work capacity produced by generation.

Historically, the power system started as a means to obtain a specific energy service (lighting). Nevertheless, it evolved towards becoming a real-time general energy service provider. More and more agents began to select electricity as the most suitable means to obtain energy services in various forms. This trend involved employing electric motors; communication in telegraphs, radios, and televisions; information processing in micro-processors, etc. This evolution often involved replacing other energy technologies with electrical ones, with the electric motor being a particularly illustrative example ([12], p. 513): *“Shortly after steam power began to yield to electricity, installation of electric motors called attention to the obvious restraints placed upon efficiency by the steam engine. Its systems, practices, and factory organization became almost visibly redundant. Thus, as “unit drive” electric power grew in plant after plant, thorough reorganization of factory layout and design took place. Machines and tools could now be put anywhere efficiency dictated, not where belts and shafts could most easily reach them. To these advantages were simultaneously added to revamped industrial processes, leading to mass-production and batch-processing technique.”*. The use of electric motors to provide mechanical power went from 5% of total mechanical horsepower in 1899 to 90% in 1939 [13]. With the advent of electricity, the degree of energy customization to users’ needs has staggeringly increased:

“Electricity’s rapid rise to dominance as a source of industrial power, then, was based on a number of compelling advantages. Electricity could be “packaged” in almost any size, whereas steam engines became highly inefficient below a certain size. Thus, “fractionalized” electric power sources of precisely the right capacity for each industrial application meant large energy and capital savings. Recourse to large steam engines that generated large amounts of power in situations that required only small or intermittent doses, could now be avoided. Electricity offered opportunities for “fine tuning” the supply of power to specific needs. Furthermore, the electric motor reduced the requirements for floor space and offered much greater freedom in the organization and layout of the workplace. Electric motors meant that the flow of work in factories did not have to accommodate a clumsy system of overhead belting and shafting in order to transmit power, very wastefully, from a central power source to a large number of machines”. ([13], p. 15)

In other words, the advent of electricity represented a more flexible energy source for economic agents. The benefit of the power system is that it delivers the most flexible work capacity in real-time. By combining generation and grid functionalities, it is possible to guarantee real-time work capacity tailored to the needs of any user. The power system guarantees access to flexible capacity work, preserving socioeconomic agents’ autonomy and the pricing system’s effectiveness by combining generation and grid functions in complementary ways. The century-old history of the power system does not indicate the possibility of reducing one function to another.

3. Types of Power Flexibility

So far, we have argued that the grid does not sell electricity but flexibility to use electrical work capacity. However, how does the grid operationalize this energy option? Today, it is possible to point out the following possibilities:

- (i) **Grid Physical Capacity.** In this case, work capacity produced in a different location from the user, usually through centralized generation, is directed to satisfy the user's needs. The grid must be able to carry centralized generation for any user physically. It corresponds to the traditional way power systems provide flexibility.
- (ii) **Behind-the-Meter.** In this case, flexibility is offered by producing energy at the consumption point. Therefore, the required energy does not need to circulate through the grid. This strategy includes both distributed generation and energy storage. In this arrangement, providing flexibility to use energy is not separate from generation. The effectiveness of this arrangement depends on a high degree of control over the local generation profile or the possibility of exploring correlations between the generation and the demand profiles (e.g., photovoltaic generation versus air conditioning demand). Power system users have increasingly evaluated the opportunity costs involved in this option as lower than in the flexibility provision solution traditionally adopted in the electricity sector. However, this increase in the viability of the behind-the-meter solution results from the possibility of grid users selling the energy they produce to the power system, which indicates that this strategy does not decrease the grid value. On the contrary, the behind-the-meter solution partially explores a new grid valorization frontier.
- (iii) **Demand-Side Management.** Usually, more power generation is injected into the grid whenever there is an increase in demand. Alternatively, it is possible to satisfy the increase in user A's demand by reducing user B's demand, provided that this reduction somehow increases the utility of user B. This alternative satisfies user needs without additional generation resources or inflows through the grid. In this case, flexibility does not rely on additional power injections but on the temporal reallocation of demands actively triggered by the power system. In economic terms, demand-side management proposes to weigh, for the same moment, the power injection marginal cost vis-à-vis the user idleness marginal cost. Therefore, it departs from the traditional power systems postulate that the user idleness cost is always untenable.

Even today, grid physical capacity is often considered the only way to provide flexibility. The exclusive focus on this approach forces grid operators to design the grid in such a way as to support the maximum expected value of users' aggregate demand at all grid points. In this approach, the grid operator investments must always guarantee that the demand for the entire electrical work capacity can circulate inside the network. Therefore, any expansion of services by grid operators invariably involves increasing the physical capacity to support inflows through the grid. Since the physical volume of resources demanded determines the planning and operation of the grid in technical and economic terms, we can call them volumetric grids. In volumetric grids, acquiring equipment such as transformers, cables, feeders, etc. is paramount to ensure safe transit of any level of demandable capacity. That is, the standard solutions of the volumetric grids are wired solutions in opposition to so-called non-wired solutions [14–16], a way of expression that suggests the dependence on physical investments in the grid's transport capacity. Indeed, volumetric grids have been the paradigm for planning and operating electrical networks. The paradigm provides the mental models and the toolbox regulators and engineers use to build solutions for power system problems.

While still the industry standard, the grid physical capacity option has drawbacks. Designing the network so that every observed increase in demand circulates within it produces substantial economic inefficiency in the invested capital. No matter how small the time interval, the network operator observes a demand value—he must invest so that this demand can circulate through the network, which impacts the level of asset utilization.

A graphical representation of the asset utilization rate helps make the impact of organizing the grid parameterized exclusively according to maximum demand more straightforward. In this sense, a representation widely used in energy planning is the load duration curve (LDC). The individual daily peak loads can be arranged in descending order to form a cumulative load model, composing the LDC ([17], pp. 37–40). Figure 1

shows 1993 LDCs at the system generation level and for a typical distribution substation of the Pacific Gas and Electric Company (PGeE) [18]. The figure shows that there are only a few hours in the year when the rated capacity of these assets is fully utilized [18]. Also, the distribution system is not as well utilized as the generation assets [18], indicating that the problem of economic efficiency of investments is even more pronounced in distribution than in generation.

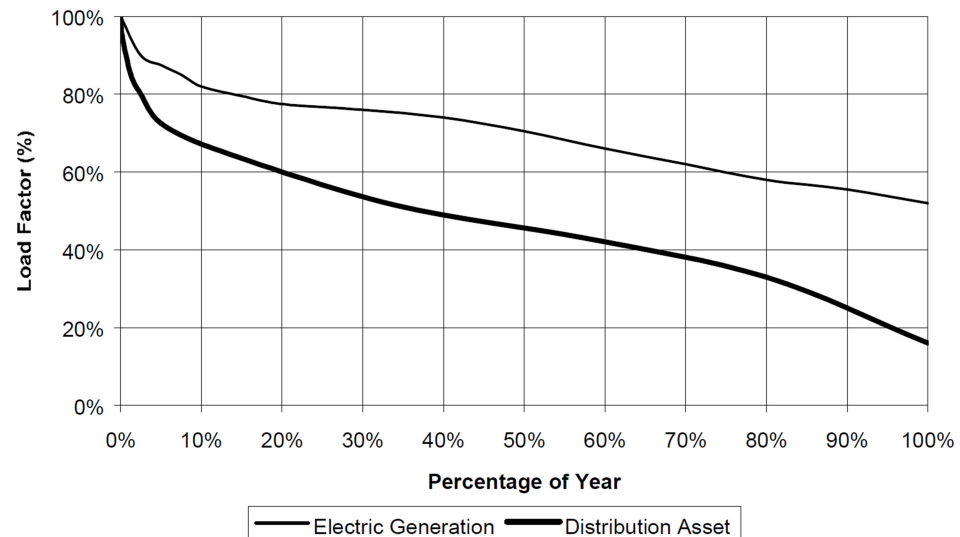


Figure 1. PG&E load duration curves for 1993 illustrate decreased utilization of assets closer to the customer ([18] apud [19]).

We have used measured data to build an LDC for a distribution asset located on the University of São Paulo campus as indicated by Figure 2 below.

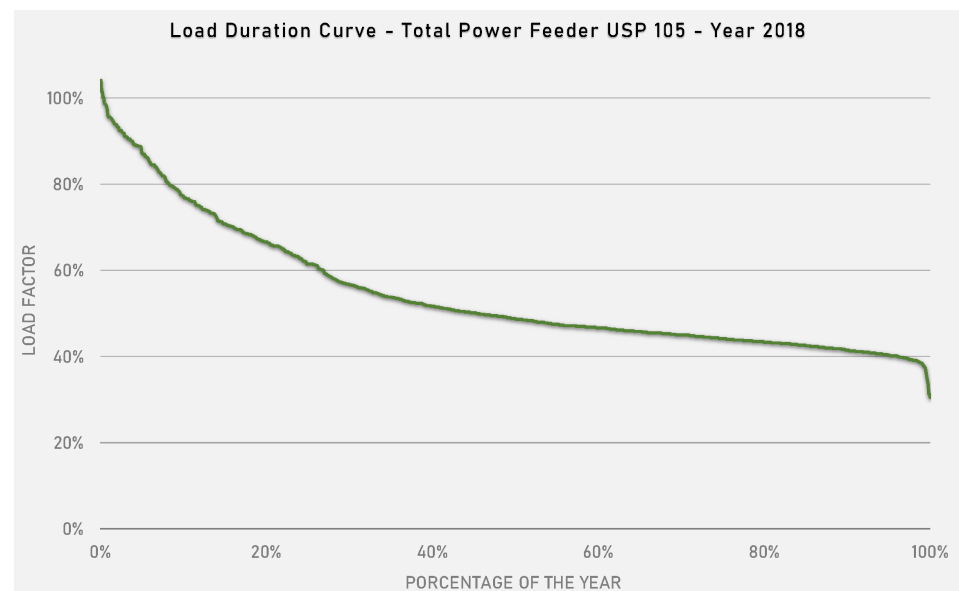


Figure 2. Load duration curve of network distribution asset in the year 2018. Source: Own elaboration by the authors using data from feeder at University of São Paulo.

The ordinate indicates the percentage of the total apparent power used by the asset (feeder), while the abscissa indicates the percentage of the year such use occurs. Only 5% of the time is more than 88% of the feeder capacity used. Therefore, 95% of the time, at least 12% is idle. Moreover, only 20% of the time, more than 65% of the total capacity is used.

This situation indicates idleness in this asset, which causes economic inefficiency and poor resource allocation.

Although the above figures are not encouraging from the point of view of economic efficiency, they are a normal condition in traditional planning. Indeed, high levels of idleness combined with short periods of demand peaks are not unique to the electricity sector; this is a common feature in infrastructure assets. What is new is the possibility that we can start operating with higher asset utilization rates, *if we can find a way to use distributed resources in a coordinated manner*. The emergence of distributed resources in the electricity sector makes it increasingly possible to customize energy services and reduce asset idleness. The potential massive penetration of distributed resources makes relying exclusively on grid physical capacity solutions unnecessary and even counterproductive. The more distributed resources' financial costs decrease, the more opportunity costs associated with grid physical capacity solutions increase. This situation makes it advisable to determine the regulatory implications of the emerging competitiveness of distributed resources (*In 2022, the world installed 45% more solar power capacity than the year before [20]. The data also indicate that compound annual growth of more than 15% is typical among the top 20 markets [20]. If not all, a significant part of this trend comes from the growing technological competitiveness of renewable sources; the average levelized cost of electricity (LCOE) for stand-alone and island 100% renewable energy systems has decreased by 9% annually between 2016 and 2021 from \$₂₀₂₁0.54/(kWh) to \$₂₀₂₁0.29/(kWh) [21].*). Outside the solar PV market, there are also reasons for optimism. For example, it is estimated that in Europe, distributed energy resources can offer 100 GW of demand response potential [22]. The subsequent sections of this article provide contributions in this regard.

4. Naive Grid Concept and Unbundling Corollary

We defend the need to explicitly develop the regulatory implications of considering the grid as a flexibility provider, not merely an electrical capacity transporter. We must recognize that the grid organization can be structured in multiple ways to see how emerging energy technologies can develop and mature. Here, we use the terms organization and structure in a sense presented by Maturana and Varela:

“Organization denotes those relations that must exist among the components of a system for it to be a member of a specific class. Structure denotes the components and relations that actually constitute a particular unity and make its organization real. Thus, for instance, in a toilet, the organization of the water-level regulation system consists of the relations between an apparatus capable of detecting the water level and another apparatus capable of stopping the inflow of water. The toilet unit embodies a mixed system of plastic and metal comprising a float and a bypass valve. This specific structure, however, could be modified by replacing the plastic with wood, without changing the fact that there would still be a toilet organization”. ([23], p. 47)

The distinction between organization and structure is pertinent when there are different ways to operationalize a given organization and irrelevant when there is a single way to instantiate it. During most of the history of the power sector, structuring the network using grid physical capacity was the only option available to agents. This situation has created difficulty for agents in realizing that the grid function is not to transport capacity but to provide flexibility. Because of this, there is a tendency, which sometimes appears implicitly in the analytical models used, to consider the grid as physical capacity as the only structure available to provide flexibility. After the often implicit consideration of the grid as a capacity transporter, it usually follows the observation that the production function available to operationalize such a function has costs that decrease with increases in the production scale, characteristic of a so-called natural monopoly. Undoubtedly, such an approach was very successful throughout the 20th century. Nevertheless, it becomes problematic as one moves from a factory energy model to a service energy model. In the former, the revenue is tied to the physical volume of sales, focused mainly on economies of scale; in the latter, it is

necessary to exploit flow energies systematically, which requires a strong focus on using the information to explore scope economies. This transition requires assessing a much higher number of possibilities to provide energy. Investments are necessary to capture energy flows as much as massive information processing. The differences between the traditional context, which prevailed in most power sector history, and the emerging context justify a more precise characterization.

The traditional context presents ubiquitous dispatchable centralized generation, relatively high information processing costs, and generally high distributed resource costs. In comparison, the emerging context combines dispatchable and intermittent sources, minor information processing costs, and high competitiveness of distributed resources.

It is possible to assess the effect of the change in context on industrial organization by evaluating the impact of information technologies outside the electricity sector. The drastic reduction in computing costs has given rise to business models guided by logic and dynamics that radically differ from those observed in industrial capitalism, which experts have called prosumer capitalism [24–26]. In prosumer capitalism, companies exploit acts of production and consumption in the most synergistic way possible [24–26]. This new form of exploitation raises questions about the power of monopolies, not only in the economy but also in the cultural sphere, while at the same time presenting real opportunities for productivity increases. When consumers use the services of companies such as Amazon, Facebook, or Uber, they provide information that allows these companies to adjust in an increasingly profitable way both the set of assets they own and the provision of the services they contract. One of the ways such a strategy can increase productivity is by mining information regarding the states of assets, including assets of third parties. For example, Uber's service connects idle cars with potential users. Ultimately, it increases the use of car assets through available information and proportionally low investment in physical assets from the company. In practice, these companies use information technologies to systematically coordinate specific acts of production with specific acts of consumption, thus operationalizing synergies and increasing productivity.

Despite the possibilities for reorganizing the transformation of primary sources into electricity, the prevalence of the naïve network concept in the power sector has prevented the development of business models that explore prosumer capitalism's full potential in the energy transition context. Despite the extensive regulatory changes triggered by the liberalization process after 1990 and the growing competitiveness of distributed resources, we continue to organize the network under the logic of the naïve grid concept. The technological repertoire of information technologies and distributed resources has had little impact on conceiving the grid.

With the liberalization of energy markets, an issue that began to worry analysts and agents was the role of network operators in commercial activities. After all, the operator could use its privileged access to grid assets to discriminate against third parties competing with its commercial sector ventures. The most accepted solution for this problem is the vertical separation of power sector activities, also known as unbundling. Network unbundling comes in two forms: ownership and legal unbundling. In its most rigorous form, ownership unbundling prescribes mandatory split ownership of the monopoly network business from the commercial businesses, removing the incentives to discriminate against third parties [27]. The other possibility is legal unbundling, where cross-ownership of the network and commercial businesses are allowed [27]. However, extensive administrative rules try to isolate the network from the commercial business [27].

All unbundling forms assume that the inefficiencies produced by deverticalization are smaller than those produced by verticalization. Nevertheless, evidence is generally not presented to corroborate such claims. In a study assessing the impact of deregulation, Mackay and Mercadal [28] note that the literature on the consequences of deregulation is surprisingly scarce. The authors [28,29] investigated the evolution of electricity prices in the United States (1994–2016) by comparing price evolution in states that remained regulated with states that deregulated, controlling for the influence of relevant variables such as

size and energy mix (Ref. ([28], p. 17): “By individually matching utilities based on their size and generation mix prior to the onset of deregulation, we are able to nonparametrically control for changes in macroeconomic factors—such as fuel costs and demand for electricity—when measuring a number of outcome variables.”). Figure 3 below is a graphical summary of their results:

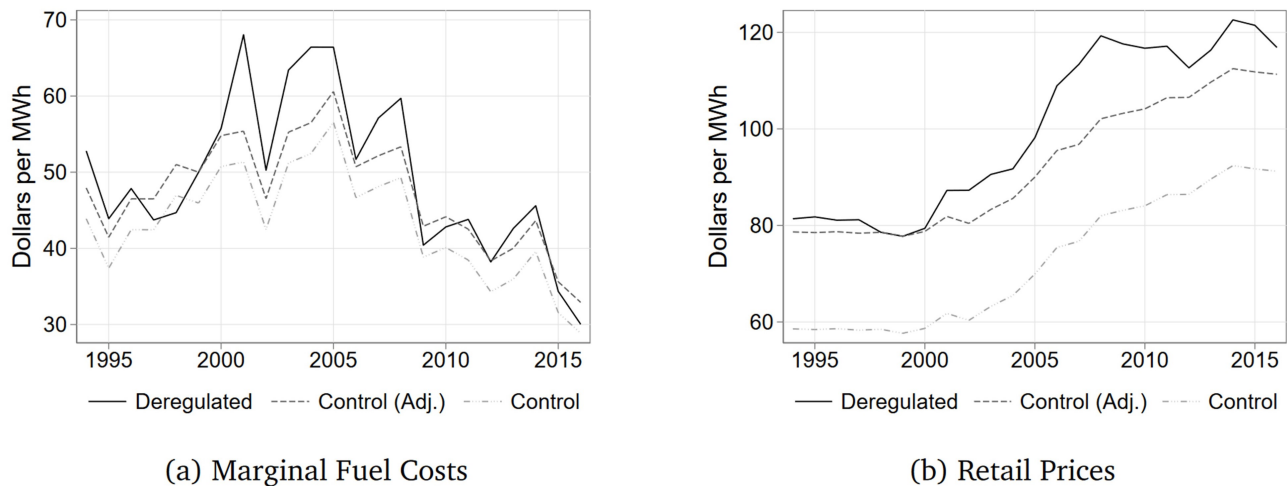


Figure 3. Source: [28]. Panel (a) plots the average marginal fuel costs of generation for all generating facilities that in 1994 belonged to utilities in deregulated states (solid black line) and control states (dotted line). Panel (b) plots the quantity-weighted retail price for investor-owned utilities in deregulated states and in control states. The dashed line in both panels plots retail prices and fuel costs for control states after adjusting for level differences in 1999.

Panel (a) in Figure 3 indicates that marginal fuel costs have recently fallen in regulated and deregulated markets. However, panel (b) indicates retail prices have risen in both markets. In deregulated markets, the increase has been substantially more significant. Thus, the empirical results do not indicate gains for consumers.

The above results corroborate some experts’ criticism that unbundling can negatively affect coordinating activities that produce energy services [30,31]. Yet in 1990, Nobel Prize economists Hart and Tirole considered that the debate about the conditions under which vertical mergers are anticompetitive still needed to be settled [32].

However, despite the theoretical doubts and the few empirical results, the economic regulation of power systems carried out since the 1990s keeps assuming that vertical integration is always harmful to grid users. Why does unbundling enjoy such an acceptance? One reason is that in the traditional context of the 20th century, the grid had no active function, and the power system used almost entirely dispatchable centralized generation, with tiny use of distributed resources (*examples of distributed resources used in the 20th century include diesel generators working as backup and cogeneration plants.*). Because of the high costs of information processing and distributed resources, the technological repertoire is such that there is one single production function to provide flexibility, operated in the following terms:

- (i) The grid has a passive function, not actively interfering in the optimal allocation of energy resources. Only central generators should play an active role in meeting end-users’ demands, ideally without operator interference. In this context, a characteristic property distinguishes the relationships between the power system and the users: the demand to be met by the network operators is defined in a way that is entirely exogenous to the investment decisions of the network operators. Such a context justifies accepting the naive grid concept and related implications, including the regulatory ones.
- (ii) Another crucial characteristic is that the production function available to operate the grid constitutes a so-called natural monopoly. More specifically, the available technology repertoire is exclusively made up of wired solutions with scale-decreasing

costs. As it operates in a natural monopoly, the grid can inflict considerable losses on other agents despite its passive operational nature if the regulators do not adequately supervise it.

The risks of granting greater autonomy to grid operators in the above context seem high without clear benefits. However, when we stop seeing the grid as a mere carrier of capacity and start understanding it as a provider of flexibility, the limits of the grid's physical capacity typology and the possibilities opened up by distributed generation and demand control become clearer. In the electrical system, flexibility is the right to have power available where and when we want it. As explained in Section 2, this right is different from accessing quantities of energy. In economic terms, it corresponds to the possibility of modulating one's load curve according to autonomously defined criteria, which, in turn, means starting and stopping transformations in the production and consumption processes in a completely autonomous manner, without having to refer to external processes (for example, decisions by an external entity or the fact that it is day or night). Such flexibility has costs, which depend on the structures used to operationalize it. In practice, ensuring flexibility in the use of energy resources amid high load variability by operating under grid physical capacity forces us to accept operating assets with high levels of idleness and, therefore, with low economic efficiency; for a significant part of the time, nobody will use the investment in physical capacity.

One way to get around the grid physical capacity inefficiencies on the distribution grid is to use distributed resources. However, doing so requires incorporating emerging distributed generation and demand control technologies dispersed in a given region to the preexisting grid, which suggests the relevance of increasing verticalization, at least in the distribution grid. However, the emergence of these technologies has not changed the verticalization debate, which remains stuck in the dominant discussions (and technological repertoire) available in the context of the 1990s, when the deregulation processes effectively unfolded. The regulatory process has kept unbundling as a corollary of the naive grid concept notwithstanding the technological changes since then.

Despite the importance of the accumulated debate on the effects of deverticalization, we must maintain sight of the specificity of the current context. Even if one ignores the theoretical and empirical arguments against deverticalization or considers that deverticalization has been successful, it needs to be evaluated if the justifications for deverticalization in the traditional context are transferable to the emerging moment. The fact that segregating centralized generation from the grid is rational does not mean that segregating distributed resources from the grid should also be an optimal solution. It is at least plausible to speculate that the complementarity of distributed resources is greater than that of centralized generation with the grid. In short, upstream unbundling (separation between centralized generation and grid assets) should not be taken as proof that downstream unbundling (separation between distributed resources and the distribution grid) is rational. However, without a more comprehensive grid concept, conducting systematic simulations and empirical studies that would allow us to evaluate such speculation becomes impossible. A naive grid concept has epistemologically blocked [33] the emergence of new studies and business models.

In the emerging context, the repertoire of energy technologies increases and differentiates, imposing new requirements on the operation of the grid. Although it is easy to use terms such as smart grid to denote the new requirements that agents demand, it is not evident that such requirements are consistent with the naive grid concept. It seems unreasonable to expect that an element that should only provide physical capacity to connect different points comes to have decision-making functions, something implicit in the smart grid concept. The naive grid approach has been an obstacle because it does not adequately represent the economic value of information or distributed resources. In the next section, we depart from such guidance and use incomplete contract theory to explain why the growing competitiveness of distributed resources challenges the assumption adopted since the 1990s that grid deverticalization always benefits its users.

5. The Increasing Importance of Incomplete Contracts

Since the development of the theory of incomplete contracts, the weight of arguments in favor of verticalizing production chains has increased considerably [4,5,34]. However, the theory of incomplete contracts does not defend that the system must invariably be verticalized. Its contribution goes in another direction: it forces us to explicitly represent different ways of organizing the industry instead of tacitly sticking to a form of organization taken as evidently correct and not subject to scrutiny. Today, the regulatory discussion has been conducted as if increased competition, merely understood as a higher number of companies, invariably benefits consumers as long as it does not occur in transmission and distribution. There is a very restricted view of the possible organizational models without reevaluating such models with the emergence of new technologies. To overcome this overly simplistic scenario, it seems appropriate to view the firm as a set of assets whose mobilization depends on property rights that some agent eventually must activate in unanticipated ways, particularly in the context of the energy transition, which requires investments in specific assets whose technical and commercial models are not yet fully known.

The emerging context combines dispatchable and intermittent sources, which tends to increase the complexity of the grid. On the other hand, the drastic reduction in information processing costs and the increase in the competitiveness of zero marginal costs resources make the new context not merely a cost that society will have to bear but also a real opportunity to obtain productivity gains. However, taking advantage of possible benefits requires the development of an institutional apparatus that adequately aligns incentives. Investments with the potential to increase productivity (e.g., by reducing fuel costs) and reduce dependence on fossil fuels (e.g., by increasing solar photovoltaics) will only increase quickly enough if they are associated with high rates of return. No matter how worthy Environmental, Social, and Governance (ESG) practices ([35]: *“The most surprising finding is how thoroughly the “Big 3” investors—BlackRock, Vanguard and State Street—turned against environmental and social shareholder proposals in the past year. In the U.S., BlackRock’s support for E&S proposals dropped from 41.3% in the 2020–2021 season, to 23.7% in 2021–2022, to a mere 8.7% in 2022–2023. Vanguard’s drop was equally precipitous, from 29.6% to 12% to a tiny 3% in the past year. And State Street went from 43.7% to 28.6% to 21.2%. Clear signs of the backlash.”*) are, the change in productive structures under capitalism can only occur if it is possible to organize interests and assets towards the goals valued by society.

Currently, we process material extracted from fossil stocks to generate power in central plants. Such an approach requires a not-so-complex grid but changes the planet’s heat balance [26,36], causing increasing environmental problems. Nevertheless, there are alternatives to this traditional approach. In some situations, the grid operator could process information and act on assets that capture energy or end-use equipment. In such cases, operator interference is an action to coordinate the transformation of flow energies into electricity, thus increasing the relative share of renewable energies and reducing energy service costs. Such a possibility is not empty speculation.

A feeder in an urban environment with a high air conditioner load could lighten its load if the grid operator identifies the situation and profits by selling photovoltaic solar energy. In line with the principles of the circular economy [37–39], using waste treatment to generate biogas [40] would make it possible to transform a relevant environmental problem into a dispatchable energy source. Demand control makes building load flexible, especially if it is possible to aggregate the load profile of thousands and even millions of users in real-time, facilitating the insertion of intermittent renewable sources [41]. These and other hypothetical situations are increasingly conceivable, but fitting them into a consistent regulatory model has been difficult.

Nevertheless, it is crucial to recognize that even the correct identification of the above possibilities is not automatic, requiring relevant information processing investments to continue mining data and prospect opportunities. Once a promising opportunity is identified, investments in specific assets are necessary to transform the information into economic value. The need to combine investments in information processing with specific

physical assets suggests the convenience of operationalizing business models typical of prosumer capitalism.

Moreover, the urgency of climate change imposes an additional complicating factor: the speed with which the energy transition is expected to happen [42]. Such a rapid change in energy production and use structures requires a high rate of innovation. However, innovations are hitherto unconceived relationships that an agent introduces at a given moment. It is strange to think they are compatible with full contractual relationships.

Therefore, the dependence on flow energies and the required innovation rate indicates the impossibility of fully specifying *ex ante* all the relationships relevant to the provision of energy services. It is plausible to consider that any conceivable contract specifying the terms of flexibility provision services in the emergent context must leave out a large set of relevant situations.

Having overcome the naive concept grid, recognizing the existing uncertainties and heterogeneity of assets, how should property rights be distributed in order to maximize social benefit and accelerate the energy transition? In other words, how should assets and their uses be combined?

“Grossman and Hart (1986) [4] used the theory of incomplete contracts to develop answers to the question “What is a firm, and what determines its boundaries?” in their path-breaking paper on the costs and benefits of vertical integration. Perhaps the central issue is that economic actors are only boundedly rational and cannot anticipate all possible contingencies. It might well be that certain states of nature or actions cannot be verified by third parties after they arise, like certain qualities of a good to be traded in the future, and thus cannot be written into an enforceable contract. When contracts are incomplete, and consequently not all uses of an asset can be specified in advance, any contract negotiated in advance must leave some discretion over the use of the assets; and the “owner” of the firm is the party to whom the residual rights of control have been allocated at the contracting stage. Grossman and Hart argue persuasively that the optimal allocation of property rights—or governance structure—is one that minimizes efficiency losses. Thus, in a situation where party A’s investment is more important than party B’s investment, it is optimal to allocate property rights over the assets to party A, even if this discourages investment by party B. More generally, the incomplete contracts/property rights approach produces a theory of ownership and vertical integration. It also directly addresses the question of what is a firm. Grossman and Hart argue that a firm is a collection of assets over which the owner has residual control rights”. ([43], pp. 182–183)

More specifically, if the firm is a collection of assets, how should property rights over distributed resources be allocated to minimize economic losses, given the technological portfolio available to agents today? Should the distribution operator be understood as segregated, without control over distributed resources? Or should it be seen in an integrated way, despite the risks to competition involved?

We saw in Section 4 that starting from the naive grid concept, the unbundling postulate is a natural choice, requiring strong evidence to the contrary before it can be rejected. However, when starting from a comprehensive grid conception, the following factors suggest that deverticalization can be problematic:

- (i) The high number of contingent situations and relevant states that cannot be anticipated. According to the theory of incomplete contracts [4,6,32], such situations cause underinvestment if the operations are carried out unbundled.
- (ii) No evidence exists that exploring the high number of contingent situations is possible without using the grid. On the contrary, everything we know indicates that it is essential to use the grid to combine resources in such a way as to transform uncertainties into acceptable risks. The theory of incomplete contracts indicates that when assets are strictly complementary, some form of integration is optimal (Hart).

- (iii) The high idleness level of the assets of the current distribution network indicates that the combination of decoupled tariffs with the use of distributed resources by the grid operators has a high potential to postpone investments. The growing competitiveness of distributed resources makes it possible to increase economic efficiency by reducing the idleness level of assets and postponing new investments in traditional distribution assets. Therefore, an increase in the rate of profit for the operators and a reduction in costs for the power system users seem possible (empirical studies should be executed to investigate such a hypothesis, drawing comparisons with the mainstream approach). If the distribution grid operators had the autonomy to explore such possibilities, this would open a new frontier of accumulation and increase investments toward energy transition.

As it seems unlikely that (i), (ii), or (iii) are irrelevant considerations, it would be up to the proponents of the segregated solution to demonstrate that, despite appearances to the contrary, the economic losses of the segregated solution are minor. Because of its interpretation of what ownership of an asset is, the theory of incomplete contracts is critical in investigating scenarios in which it is important to transform uncertainty into acceptable risk; more than right over revenue streams, ownership of the asset means having control over the asset. One of the meanings of this control is the right to use the asset in unspecified ways. This ownership perspective clarifies that an opportunity *ex post* verified can be readily exploited by the asset owner but will have to be negotiated by third parties. Hart (1995) [6] expresses that by saying that the owner of the assets has residual rights over them. It is not obvious that we should always develop distributed resources through third parties who will have to pay to access the grid instead of granting grid operators full autonomy to develop business models with distributed resources ([6], pp. 5–6):

“Economists have written a great deal about why property rights are important, and in particular, why it matters whether a machine, say, is privately owned or is common property. However, they have been less successful in explaining why it matters who owns a piece of private property. To understand the difficulty, consider a situation where I want to use a machine initially owned by you. One possibility is for me to buy the machine from you; another possibility is for me to rent the machine from you. If contracting costs are zero, we can sign a rental agreement that is as effective as a change in ownership. In particular, the rental contract can specify exactly what I can do with the machine, when I can have access to it, what happens if the machine breaks down, what rights you have to use the machine, and so on. Given this, however, it is unclear why changes in asset ownership ever need to take place. In a world of contracting costs, however, renting and owning are no longer the same. If contracts are incomplete, not all the uses of the machine will be specified in all possible eventualities. The question then arises: Who chooses the unspecified uses? A reasonable view is that the owner of the machine has this right; that is, the owner has residual rights of control over the machine, or residual powers. For example, if the machine breaks down or requires modification and the contract is silent about this, the owner can decide how and when it is to be repaired or modified”.

The above considerations imply that the residual rights value increases when the economical use of the required assets involves many contingent and not previously specifiable situations, which is the case when exploring distributed resources. When one recognizes the importance of controlling specific assets for the profitability of the business models in question, the speed with which energy transition must happen, and the variety of contingent situations, it does not seem that the segregated grid can adequately answer the uncertainties involved. A final decision requires model formalization, including empirical data and forecasts of technological evolution. Nevertheless, this empirical analysis can only happen if we have an adequate grid concept and imagine alternative ways of structuring grid services.

Even if upstream unbundling were indisputably successful, this would not prove that downstream unbundling should be adopted. As an empirical test to evaluate possibilities, we should be able to compare grid distribution operator autonomy with the traditional regulation. By grid distribution operator autonomy, we mean the following:

- (i) Decoupling between distribution tariffs and volumes of energy delivered by the distribution would guarantee a specific revenue for the provision of flexibility service by the distribution grid, defined within quality criteria that encompass the entire range of consumers. Such tariff decoupling is consistent with grid operators not selling energy but offering flexibility services associated with energy use.
- (ii) Grant broad autonomy to the distribution grid operator to combine assets and build business models, including selling distributed generation at a profit. This possibility creates a strong incentive for distribution operators to develop distributed generation as an alternative to centralized generation.

The hypothesis that the autonomy of the distribution grid operator using downstream verticalization will benefit the grid's users must be subjected to rigorous scrutiny. The point here is not to demonstrate its validity but the relevance of explicitly comparing it with traditional regulation. More generally, it is essential to explicitly analyze different ways of organizing the power system, considering both the alignment of incentives and the characteristics of the repertoire of technologies existing at a given historical moment. The traditional approach has been to idealize a particular form of organization rather than comparing the advantages and disadvantages of different forms of organization.

A promising alternative to the traditional approach is to develop institutional arrangements to reconcile verticalization's positive and negative aspects. Proposals to reconcile competition and coordination should be encouraged (see, for instance, [27]). However, the institutional imagination of too many specialists has assumed, without further evidence, that the economic inefficiencies arising from unbundling are minor. Such a premise is understandable when starting from a naive grid concept. Nevertheless, this approach is unconvincing if we see the grid as a flexibility provider in a prosumer capitalist context, not a mere capacity transporter.

As the naive grid concept tends to limit the possible combination of assets, it underestimates the possibility of relying on non-dispatchable sources. On the other hand, conceiving the grid in more general terms as a provider of energy options encourages the integration between energy and information [44], facilitating the approximation between energy technologies and information technologies. Since information technologies are currently the most dynamic sector of the economy, such an approach would accelerate the energy transition. In a context where accelerated technological change is needed, a regulatory framework that opens up space to combine assets seems more promising than creating complex and artificial structures for utilities to accelerate innovation [45]. Giving up the naive grid concept to incorporate a more comprehensive concept makes it possible to integrate the power sector into the reality of prosumer capitalism. Such integration certainly brings problems and contradictions, but we must deal with them directly rather than unilaterally idealizing the energy transition under capitalism. It is only possible to make the smart grid a reality with such integration.

6. Conclusions

The article has demonstrated the need to consider the grid as an energy options provider, not a mere capacity transporter. We have also demonstrated that the unbundling postulate is a consequence of applying a naive grid concept in the power sector liberalization moment. Furthermore, understanding the grid as a flexibility provider allows us to demonstrate that the increased competitiveness of distributed resources imposes the need to recognize the inherently incomplete nature of contractual relationships between power system operators and users, particularly for distribution networks. In the current regulatory situation, simulations and empirical studies comparing different ways of organizing the grid have yet to be conducted because the naive grid concept has functioned

as an epistemological obstacle. In possession of an adequate grid concept, such studies comparing the current regulation with downstream verticalization are the next step of the research. Although the complementarity of the distribution grid and distributed resources seems strong, much empirical evaluation is required to confirm it. A first comparison is to simulate the system's evolution within current regulation with its evolution under alternative regulation, in which the distribution operator has broad autonomy to build business models, including the possibility of obtaining profit from operating in distributed generation. Despite the risks to competition, this scenario transforms the current conflict between distributed generation and distribution operator into an alliance. If the economic surplus is sufficiently high, the regulator can offset the economic losses resulting from the loss of competition via lump transfers to grid users. At the moment, a simplistic conception of the grid has prevented us from studying grid organization forms that do justice to the emerging heterogeneity of assets available in the ongoing energy transition.

Finally, although this article has focused on distribution grids for reasons of scope, a conceptual and later empirical reassessment is most likely necessary for other energy systems networks, such as electricity and natural gas transmission networks. After all, both the context in which the deverticalization of networks began to be adopted, and the technological repertoire has changed radically since the 1990s. However, reassessments should always consider the specific characteristics of such networks and the technological repertoire effectively available to network operators and society as a whole.

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