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ELECTRICITY DISTRIBUTION SYSTEMS IN EUROPE : AN OVERVIEW OF CONTEMPORARY REGULATORY CHALLENGES

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In Europe, a significant adaptation of the existing power distribution sector is necessary to support the transition toward low-carbon energy systems and facilitate the massive deployment of low-carbon distributed power technologies. This report first examines the current organization of that industry and highlights the country-specific and diverse nature of the industry structures and the institutional organizations governing the distribution sector. We then discuss the new tasks and roles assigned to Distribution System Operators (DSOs) and shed light on the emerging challenges facing these DSOs. Finally, we highlight and discuss a few emerging research topics on the sector's industrial and institutional arrangements that have important implications for assisting the rapid decarbonization and digitization of European power systems.

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MOTS-CLÉS

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1. Introduction

In the European electricity sector, the attention of policymakers and regulators has long been captured by the liberalization agenda and the complex restructuring reforms needed to establish competition in generation and retail and the completion of the internal European market for electricity based on interconnected transmission networks. As a result, for the last three decades, power distribution issues have been implicitly presented as minor matters in public policy debates.

At least three elements suggest that this traditional view no longer holds. First, **the rapid deployment and increased affordability of distributed energy technologies** (e.g., rooftop solar panels, demand response, energy storage) **radically transform the market environment of Distribution System Operators (DSOs)** – i.e., the firms responsible for the local low voltage networks. Smart energy technologies empower network users, change the nature of their interactions with the distribution grid and make them more complex. Second, **the public policy goals assigned to regulatory authorities have also shifted** over time. **The traditional objectives to promoting competition and market integration are now supplemented by the ambition to foster the rapid decarbonization of European economies**. By nature, these distributed energy technologies have a low-carbon nature and now provide credible options. Organizing their cost-efficient integration within the existing energy system is thus crucial. Lastly, **technical change also directly affects the DSOs' internal business routine**. These firms also face an enlarged set of technology options to conduct their business (e.g., batteries or dynamic asset rating can alleviate the need for network-deepening investments). These technologies can lower the total costs of the power industry while preserving the security of supply and facilitating the operation of a more unpredictable and decentralized energy mix. As the regulatory framework applied to DSOs largely predates these technological developments, it is not certain that it can provide the distribution sector with the incentives needed for an efficient integration of these technologies.

The purpose of this paper is thus to examine whether the current institutional arrangements and regulatory procedures governing the distribution sector are able to adapt to cope with these changes. To investigate that question, a necessary prerequisite is to fully understand the detailed arrangements implemented in Europe. Our analysis thus first reviews these arrangements and points out their country-specific and heterogeneous nature regarding several issues, including the level of vertical de-integration, the degree of state participation, the horizontal market structure, and the architecture and properties of the tariffs charged by DSOs. We then build on that knowledge to identify and discuss the most salient challenges confronting European DSOs. Lastly, we provide the research community with two timely – and so far, little investigated – research topics that should attract further investigations.

The paper is organized as follows: Section 2 gives a concise review of the contemporary organization of power distribution in Europe. Section 3 presents the emerging challenges faced by DSOs in Europe. In section 4, we discuss the implications regarding the adequacy of the contemporary structure and organization of that industry. Finally, the last section offers a summary and some concluding remarks.

2. Background

This section offers a concise review of the contemporary organization of the European distribution sector industry to clarify the background of our analysis.

2.1. The legacy of the restructuring reforms

After World War II, the consensus in Europe favored state participation in the power industry to rebuild and consolidate the infrastructures, achieve greater productive efficiency, reduce costs, avoid excessive profits, enable the growth of electricity consumption in industry, and favor energy accessibility to households (Besant-Jones 2006; Brown and Mobarak 2009). Electricity was then viewed as an essential public good, and its provision had to be controlled by the state, preferably in the form of an integrated state-owned utility with a mandate to act on behalf of the state. At that time, a vertically integrated monopoly covering generation, transportation, distribution, and retail activities was seen as the socially desirable organization for that industry to take advantage of the economies of scale and scope and minimize transaction costs and prices (Foster and Rana, 2020). These integrated utilities were then subjected to some form of regulation, usually using a cost-of-service framework, to prevent excessive prices.[1]

In the late 1970s and 1980s, a series of technological[2] and theoretical[3] shifts prompted a complete reconsideration of that organization (Jamasb et al. 2005; Vagliasindi and Besant-Jones 2013; Foster and Rana 2020). These new technologies and new views questioned the need for vertical integration between generation and transmission, discredited the understanding that the entire sector was a natural

[1] We refer to Ford (1997) for a concise historical review on that organization and its dynamic impacts on the construction of more efficient power stations, the retirement of less efficient ones, the resulting economies of scale, and the overall effects on electric rates and the consumption of electricity.

[2] A non-exhaustive list of these changes affecting the technology includes: the plateauing of the economies of scales attained at conventional thermal power plants (Ford 1997), the emergence of more efficient and modular generation technologies (e.g., combined-cycle gas turbines) that reduced the importance of economies of scale (Jamasb et al. 2005), or the shift observed in demand trends marked by modest growth rates.

[3] These new views resulted from: (i) the theoretical works on the identification of contestable markets (Baumol et al. 1982), (ii) the works on the regulation of natural monopoly and the perceived lack of transparency and information asymmetry between utilities and regulators (Laffont and Tirole 1993; Sappington and Stiglitz 1987), and (iii) the possibility to design markets in power systems by following the lines discussed in neo-institutional economics (Joskow and Schmalensee 1983).

monopoly, and provided the motivation for an ambitious restructuring agenda aimed at favoring private participation and competition in generation and retail activities.

In Europe, these liberalization reforms addressed the four distinct actions pointed out in Foster et al. (2017). First, the utilities were subjected to vertical unbundling to separate potentially competitive segments (generation and retail) from natural monopolistic segments (transmission and distribution), to prevent discrimination in the operations of the networks, and avoid the unnecessary extension of monopoly between different horizontal levels (Joskow 1998). Second, the reforms established an independent regulatory agency to give utilities accountability for their financial and operational performance and limit political interference.[4] Third, the reforms favored private sector participation to improve operational efficiency, increase labor productivity, and favor profitable investment. Lastly, the reform introduced competition in generation and retail activities as the induced rivalry represents a powerful driver for lower prices, greater efficiency, and innovation.

That said, the EU does not have exclusive competence on local distribution power networks, which leaves room for country-specific adaptations of the common European framework. As a result, many national factors shape the sector's domestic organization, including institutional and industrial persistence, socio-economic and geographical conditions. That diversity has significant consequences on the DSOs' conduct and the sector's performance. So, the following subsections review the most salient differences and successively discuss the degree of vertical unbundling, the prevailing horizontal market structure, the degree of private participation, the pricing schemes implemented by DSOs, and the sector's regulatory mechanisms.

2.2. A heterogeneous degree of vertical unbundling

Vertical unbundling is recurrently stated as a cornerstone of the European reform (e.g., see preamble 67 of Directive 2019/944). However, the unbundling of distribution from the vertically integrated undertaking can take various forms, such as Ownership, Legal, Functional, and Accounting (Küfeoğlu et al. 2018).[5] In this regard, the European legislation does not require the ownership separation of assets of the DSO from the vertically integrated undertaking,[6] but reinforces the need for Legal and Functional Unbundling, being spared DSOs "*serving less than 100,000 connected customers, or serving small isolated systems*" (E.C., Directive 2009/72, Article 26(4)).[7] While only 7

[4] An autonomous regulator is expected to foster private participation by creating a more even playing field (World Bank 2005), favor the adoption of fair pricing methodologies, and incentivize innovation.

[5] We refer to the EC Evaluation Report (2016) and Florence School of Regulation (2020b) for the definitions of the different types of unbundling.

[6] The Netherlands is the only European country where ownership unbundling is required by law (CEER2016).

[7] In Austria, Finland, Czech Republic and Slovenia, the threshold is lower. Malta is exempt from the E.C. unbundling rules (Küfeoğlu et al. 2018).

percent of the European DSOs serve more than 100,000 customers (Eurelectric 2020), 13 percent of the European DSOs are subject to unbundling (Prettico et al. 2020).

Another important aspect concerns the delineation between transport and distribution as the voltage threshold used has a country-specific nature. From a technical perspective, substantial differences exist in the voltage levels of distribution networks among the member states, which indicates that all European DSOs do not operate the same assets (Glachant et al. 2017). As a result, some DSOs operate assets that, in other countries, would be operated by a Transmission Systems Operator (TSO) and vice versa.

2.3. Different degrees of state participation

The discussion on the ownership of distribution assets and operators is still ongoing in Europe. The diversity of ownership arrangements certainly reflects the historical organization of the countries as well as differences in the role of local/national governments (Eurelectric 2020). The majority of DSOs own their networks and are granted a license to operate them by local or national governments. In certain countries (e.g., France and Germany), DSOs are given public concession contracts to operate the network for a set period of time while the local governments remain the long-term owners. In the later cases, DSOs are responsible for both operation and maintenance as well as capital investment.

Table 1 presents the data related to DSO diversity in the European Union countries (Küfeoğlu et al. 2018). One can observe that the majority of European DSOs have mixed ownership and are legally and functionally unbundled from generation, transmission, and retail, in accordance with the E.C. legislation. Some countries like Croatia, Cyprus, Estonia, Greece, Malta, and Slovakia, however, still have a vertically integrated structure.

Küfeoğlu et al. (2018) raise comparative questions, hitherto unanswered, regarding differences in service quality, prices, and capacity for innovation between private, mixed, and public DSOs, prompting future research on the identification of a more efficient model.

Table 1. Electric Power Distribution Data in EU Countries

(Source: Küfeoğlu et al. 2018, Table 2)

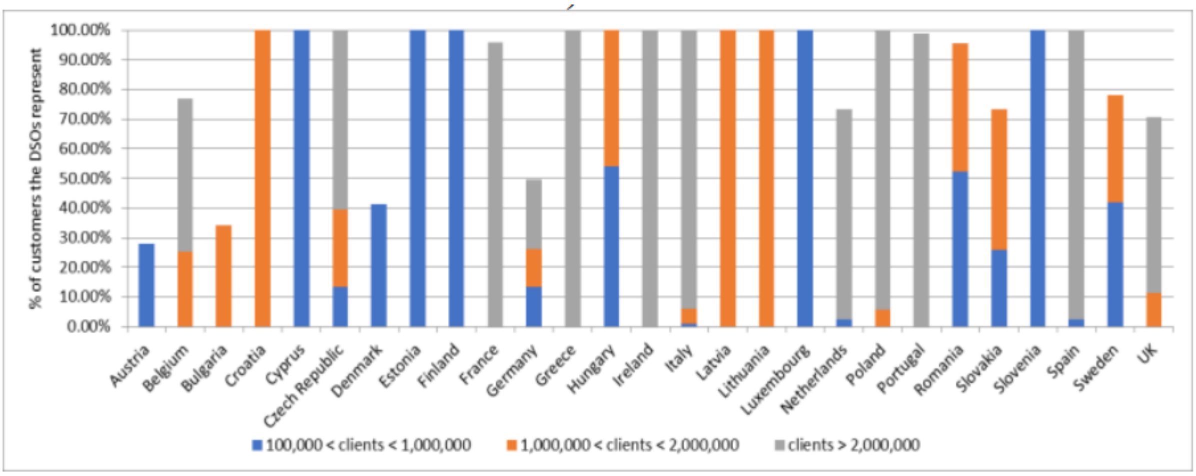
E.U. Country	Nb of DSOs	Legal Structure	Ownership	Population (thousand)	Connected populaton per DSO (thousand)
Austria	138	D	mixed	8.747,36	63,39
Belgium	8	D	private	11.348,16	1.418,52
Bulgaria	7	D	private	7.127,82	1.018,26
Croatia	1	G,T,D,R	public	4.170,60	4.170,60
Cyprus	1	G,T,D,R	public	1.170,13	1.170,13
Czech Republic	290	D	mixed	10.561,63	36,42
Denmark	49	D	mixed	5.731,12	116,96
Estonia	37	G,T,D,R	mixed	1.316,48	35,58
Finland	80	D	mixed	5.495,10	68,69
France	148	D	mixed	66.896,11	452,00
Germany	875	D	mixed	82.667,68	94,48
Greece	2	G,T,D,R	public	10.746,74	5.373,37
Hungary	6	D,R	private	9.817,96	1.636,33
Ireland	1	D	public	4.773,10	4.773,10
Italy	135	D	mixed	60.600,59	448,89
Latvia	11	D	mixed	1.960,42	178,22
Lithuania	7	D	mixed	2.872,30	410,33
Luxembourg	6	T,D	mixed	582,97	97,16
Malta	1	G,T,D,R	mixed	436,95	436,95
Netherlands	7	D	mixed	17.018,41	2.431,20
Poland	169	G,D,R	mixed	37.948,02	224,54
Portugal	13	D	mixed	10.324,61	794,20
Romania	48	G,D,R	mixed	19.705,30	410,53
Slovakia	3	G,T,D,R	mixed	5.428,70	1.809,57
Slovenia	1	D	public	2.064,84	2.064,84
Spain	340	D	mixed	46.443,96	136,60
Sweden	170	D	mixed	9.903,12	58,25

Note: Regarding the legal structure, D indicates that distribution is legally and functionally unbundled from generation (G), transmission (T), and retail (R). A label of D,R implies the distribution activity is in a legal structure which combines D and R. A label of G,T,D,R indicates that the same legal body can directly or indirectly have control over these operations. See: Küfeoğlu et al. (2018).

2.4. A diversity of horizontal market structures at the national level

Distribution is considered to be a natural monopoly on a given territory but at the national level, there are important differences in the industry structure prevailing in that sector. To illustrate the difference in the sizes of the individual DSOs, Andreadou et al. (2019) propose a typology based on the number of connected consumers, namely the tiny (less than 100,000 connected consumers), the small (between 100,000 and 1,000,000), medium (between 1,000,000 and 2,000,000) and large DSOs (more than 2,000,000). The relative importance of each category is then assessed using the share of consumers supplied by each category (see Figure 1). Their data indicate that countries like Austria, Bulgaria, Denmark, and Germany are highly dependent on very small DSOs – serving less than 100,000 consumers – as they cover more than 50 percent of the national population.

Figure 1. Percentage of total consumers each DSO category represents (source: Andreadou et al. 2019)



Furthermore, Table 2 presents the number of DSOs in each country and that information suggests that three markedly different market structures prevail in Europe, namely the concentrated, mildly concentrated, and fragmented ones.

A mildly concentrated model can be observed in countries like Bulgaria, Hungary, The Netherlands (or in the UK outside the EU). In these countries, the distribution sector gathers a limited number of independent distribution firms, each operating as a monopoly in a given region. From a regulatory perspective, that industry structure allows a direct comparison of the performances and the accounting data reported by each firm and thus helps mitigate the information asymmetry between the regulated distribution companies and the regulatory agency. An important consequence is that it naturally supports the implementation of yardstick competition à la Shleifer (1985) whereby the allowed revenue obtained by the regulated firm depends on the costs and performance of the other regulated firms.

A fragmented industry structure prevails in countries like Germany. From a regulatory standpoint, the market structures have merits and limitation. On a positive side, a large sample of DSOs provides regulators with many observations that make it possible to conduct empirical studies on the drivers of costs, investment, and operational performance. However, a significant limitation is that dealing with each of these firms is a burdensome task that precludes the application of individual regulatory measures (e.g., firm-specific rate making or control of the inputs used to prevent overcapitalization). From a financial perspective, an important issue is whether the size of these individual firms is sufficient to generate the ample enough revenue needed to support investment in costly new distribution technologies and network development.[8]

Table 2 - Number of DSOs in the European Union Countries

(Sources: Eurelectric 2020; Prettico et al. 2020)

E.U. Country	Number of DSOs	Number of legally unbundled DSOs (> 100.000 customers)
Austria	126	11
Belgium	16	12
Bulgaria	4	4
Croatia	1	1
Cyprus	1	1
Czech Republic	290	3
Denmark	40	10
Estonia	34	1
Finland	77	9
France	144	6
Germany	883	80
Greece	1	1
Hungary	6	6
Ireland	1	1
Italy	128	8
Latvia	11	1
Lithuania	6	1
Luxembourg	4	1
Malta	1	0
Netherlands	6	6
Poland	184	5
Portugal	13	1
Romania	51	8
Slovakia	3	3
Slovenia	1	1
Spain	354	5
Sweden	170	6
TOTAL	**2556**	**192**

[8] On the latter point, an open question is whether small DSOs attain the critical size needed to get the most of the modern network planning tools that are based on an intensive use of geographical information systems. Indeed, these tools require detailed geographical data sets that convey a comprehensive representation of the grid and thus *de facto* have a proprietary nature. The management and updating of these data sets represent a fixed cost that can hardly be avoided. Furthermore, one can also wonder whether small DSOs can attract and keep the skilled specialists needed to use them efficiently.

From an industrial perspective, one can also wonder whether each individual firm (especially the smaller ones) attains an efficient scale. A related issue concerns the procurement of the new distribution technologies and the limited bargaining power of small individual DSOs when these technologies are supplied by a small oligopoly of large multinational firms. At the industry level, a fragmented horizontal structure can be prone to substantial coordination costs whenever the firms need to agree on the definition of a common technical standard (e.g., for communication protocols). These coordination issues can conceivably delay or adversely affect the adoption of new technologies.

Lastly, some member states exhibit a concentrated structure as a single DSO serves the largest part of the population (e.g., France, Ireland, Greece, Portugal). That operator certainly has the size and the ample revenues needed to support both the redistributive policies imposed by the regulator (e.g., the spatial cross-subsidization between urban areas and low-densely populated regions implemented in France) and ambitious investment plans in new technologies. Regarding procurement, these large DSOs can conceivably exert some form of 'countervailing power' à la Galbraith (1952) and use their bargaining power to lower costs and facilitate the implementation of new technologies.[9] From an operational perspective, a single and efficient DSO can also leverage its ability to conduct local experiments to identify and rapidly disseminate the best working practices on a national scale. However, from a regulatory perspective, that industry structure *de facto* precludes the application of yardstick competition and is also suspected to be prone to regulatory capture.

2.5. Tariff Design issues

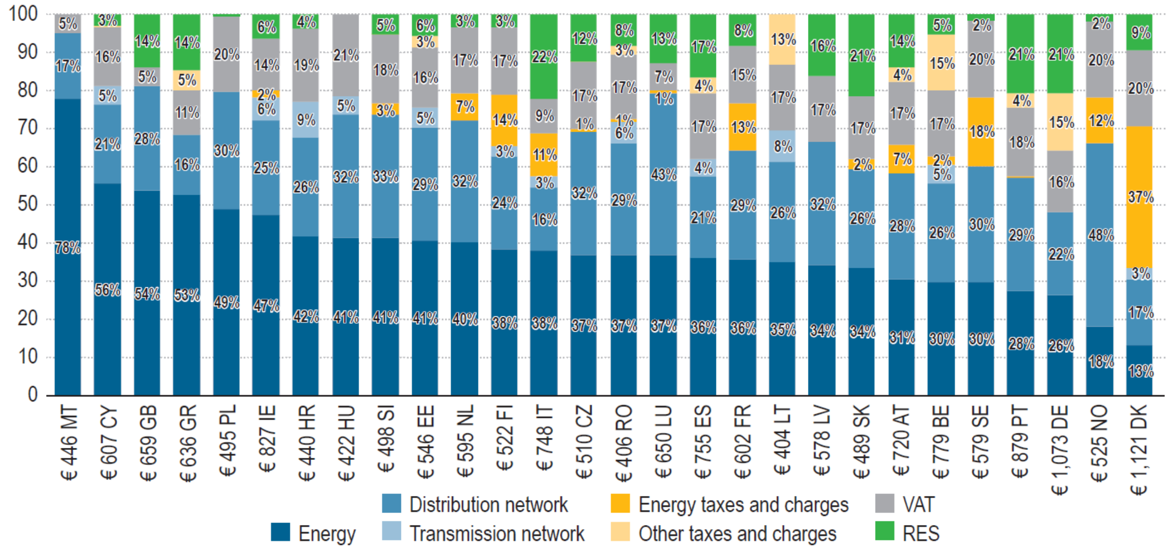
In Europe, the distribution network tariffs are either fixed or approved by national regulators (EU Directive 2019/944, Article 59) and vary widely throughout the member states. Below, we highlight the main issues pertaining to these tariffs.

a – Cost recovery

Distribution network costs (i.e., the cost related to distribution losses, return on capital invested, depreciation charges, operational expenditures, metering, maintenance) represent a significant portion of the total power system cost, varying between 16 and 48 percent of the final electricity bill of European countries in 2016 (See Figure 2 from ACER 2017).

[9] Further research is certainly needed on that specific point as, to the best of our knowledge, the literature on applied economics has so far never examined the conditions for an effective exertion of such a 'countervailing power' by large DSOs. Hence, the existence and the magnitude of the price concessions extracted by large DSOs from technology suppliers still have to be assessed. In that vein, a related future research effort could also explore: (i) whether the regulatory mechanisms governing DSOs provide them with an incentive to effectively exert that 'countervailing power,' and (ii) whether the associated gains result or not in lower bills for network users.

Figure 2. Electricity final price breakdown for households in EU capital cities (Nov–Dec 2016). (Source: ACER 2017)



Recouping the distribution cost thus represents an important issue. According to ACER (2021), only four countries (Austria, Lithuania, Slovakia, and Spain) have distribution tariffs that provide DSOs with the revenue needed to cover the total distribution costs. In the other 23 countries, distribution tariffs are not large enough, which imposes the implementation of some transfers to allow DSOs to break even. In these countries, cost-recovery is achieved through a country-specific cocktail of connection charges,[10] charges for reactive energy withdrawal/injection, co-financing instruments, and individual fees or payments by a single user for DSO services.

b – Heterogeneous pricing structures

The design of the distribution tariffs also exhibits significant differences. Table 3 indicates that there are variable proportions of volumetric (i.e., proportional to the quantity of energy withdrawn or injected), capacity-based (i.e., proportional to the peak load demanded), and lump-sum charges (i.e., fixed components).

While all European countries apply tariffs for electricity withdrawal from the distribution grid, only 10 of the 27 EU countries have published tariffs – mainly using lump-sum methods – for electricity injection in the distribution grid (ACER 2021).[11]

[10] All EU countries use shallow and/or deep connection charges in their regulatory schemes.
[11] The list of EU countries using lump-sum injection tariff methods is: France, Malta, the Netherlands, and Luxembourg.

Table 3 - Basis for withdrawal tariffs (Source: ACER 2021, pp. 39–41)

EU Country	Energy-based	Energy + Lump sum	Power + Lump sum	Energy + Power	Energy + Power + Lump sum
Austria		X		X	
Belgium (Brussels)		X		X	
Belgium (Flanders)	X			X	
Belgium (Wallonia)				X	
Bulgaria	X			X	
Croatia				X	
Cyprus	X				
Czech Republic	X			X	
Denmark		X			
Estonia	X	X		X	X
Finland		X			X
France					X
Germany		X		X	
Greece				X	
Hungary		X			X
Ireland	X	X			X
Italy	X		X		
Latvia				X	
Lithuania	X				
Luxembourg		X		X	
Malta					X
Netherlands					X
Poland					X
Portugal				X	
Romania	X				
Slovakia				X	
Slovenia				X	
Spain				X	
Sweden		X			X

In 2016, a report prepared for the European Commission pointed out that volumetric tariffs were responsible for 69 percent of the DSO revenues from household consumers, 54 percent for small industrial consumers, and 58 percent for large industrial consumers in Europe (Copenhagen Economics & VVA Europe 2016). That situation still prevails, as the data in ACER (2021) confirms that energy-based charges have a greater weight than power-based charges in most member states (see Table 4).

Table 4 - Percentage split among withdrawal charges[12] (Source: ACER 2021)

EU Country	Energy (%)	Power (%)	Lump-sum (%)	Year
Austria *				2020
Belgium (Brussels)	82	0	18	2020
Belgium (Flanders)	85 - 90	10 - 15	< 1	2020
Belgium (Wallonia)	95	0	5	2020
Bulgaria	75	25	0	2019
Croatia	84.8	15.2	0	2019
Cyprus	100	0	0	2020
Czech Republic	51	49	0	2018
Denmark	95	0	5	2019
Estonia	81	Not available	Not available	
Finland	Not available	Not available	Not available	
France	70	16	14	2019
Germany *				2020
Greece	82	18	0	2020
Hungary	77	20	3	2019
Ireland	68	9	23	(Oct 2019 - Sept 2020)
Italy	0	95	5	2020
Latvia	68	32	0	2020
Lithuania	100	0	0	2020
Luxembourg	59	16	25	2020
Malta	Not available	Not available	Not available	
Netherlands *				
Poland	71	23	6	
Portugal	49.4	50.6	0	2020
Romania	100	0	0	2020
Slovakia	35	65	0	2020
Slovenia	69.3	30.7	0	2019
Spain	25	75	0	2020
Sweden	Not available	Not available	Not available	

c – Possibly conflicting policy objectives

Cost recovery is not the unique element regulators have to consider when designing the pricing scheme for distribution activities. Indeed, one can also expect the chosen tariff structure to be cost-reflective and thus mirror the cost that a consumer inflicts on the network due to its connection and its actions (i.e., the withdrawal/injection of electricity from/on the grid). Indeed, a tariff structure based on cost-reflective charges provides the end-user with the price signals they need to adjust their consumption behavior and thus supports the system's cost-efficiency (ACER 2021).

[12] Complementary information on the allocation of different tariffs for different types of consumers in Austria, Germany, and The Netherlands are available in ACER (2021, pp. 43–44).

Another concern is that electricity is often presented as an essential public good. Accordingly, fairness and redistributive issues also rapidly come into play in tariff design debates. Furthermore, the EU Commission's Directive 2019/944 states that regulators shall also use the tariff methodology to support efficient investments in distribution infrastructures, to provide research activities, and to facilitate innovation in the interest of consumers (ACER 2021).

Finding the right balance between the desirable principles of cost recovery, cost reflectivity, fairness, supporting investment, and favoring innovations is a complex task (Schittekatte 2018, Gomes et al. 2020).[13] These can be conflicting objectives. For example, from a consumer's perspective, volumetric tariffs are easier to understand and promote energy efficiency – because a reduction of electricity consumption would lead to lower bills – whereas, from a DSO perspective, a capacity-based tariff would be preferable to reflect cost – because the maximum peak demand determines the capacity to install, which is one of the main cost drivers for network development (Prettico et al. 2018).

3. DSOs' new challenges

This section first presents the important changes affecting the role and functions assigned to distribution in low-carbon power systems and then points out five emerging challenges.

3.1. A rapidly changing environment

a – Emerging new societal demands

Historically, electric systems were designed to supply end-users with the energy produced at large and remote power plants following a vertical and rather "unidirectional" organization. Accordingly, the flow of electricity was schematically descending from generation sites to the transmission grid and finally to the distribution networks connecting the end-users. In those years, distribution networks represented a somehow passive component of the value chain as, contrary to the transmission grid, the operations of a distribution system offered little or no opportunities for active management of the system. Despite important structural changes, the restructuring reforms of the late 1990s and early 2000s little affected the traditionally passive role assigned to distribution power networks.

[13] Furthermore, one should not overlook that reforming an existing pricing structure can have important political implications which largely explains why regulators have a marked preference for pricing schemes that are easy to communicate and explain to the various stakeholders. As these stakeholders (e.g., residential users, municipal authorities, industrial and tertiary users) are heterogeneous with different levels of understanding and expertise, building some form of social consensus among them can be challenging. This difficulty largely explains why regulators try to preserve that consensus whenever it pre-exists by favoring tariffs reforms that only generate smooth and modest variations in the bills charged to the various type of users.

Since the late 2000s, a conjunction of technical, institutional, and operational factors has challenged the traditional role assigned to distribution in power systems. That list surely includes the effects of technical changes both at the distribution level (e.g., the deployment of smart metering, automated load transfer and dynamic asset rating)[14] and at adjacent components of the value chain (e.g., the increasing penetration of decentralized generation and storage technologies, the growing demand for the development of an infrastructure for charging electrical vehicles (Metais et al. 2022) with or without smart charging bidirectional capabilities) that open up new possibilities and creates new societal demands on the distribution sector.[15]

In June 2019, these demands were explicitly stated in the EU Clean Energy Package (CEP) that ambitiously proposes a gradual transition toward a carbon-neutral economy (Florence School of Regulation 2020a). The CEP describes the consumer as the main actor in the energy transition, enabling the self-consumption of renewable energy ('prosumption') without restrictions and guaranteeing remuneration for the injection of excess energy into the grid. In addition, the 2019 European Green Deal provides the blueprint for climate, energy, and environmental actions, aiming for carbon neutrality by 2050, decoupling economic growth from natural resource use and ensuring environmental and social sustainability (Prettico et al. 2020).

Therefore, the increased participation of renewable energy sources in the European energy matrix, as well as the encouragement of technological development, innovation, and the creation of "green jobs" within this emerging market is a consequence of policies and incentives guided by European net-zero targets (Prettico et al. 2018). However, in many countries, the boom of RES connections created a challenge for the installed European distribution system: poorly adapted design, not digitalized or automated, traditionally conceived to passively supply energy, connecting the transmission grid to the final consumers, following a unidirectional power flow.

Besides the uncertain impact that decentralized generation could have on the distribution system at a structural level – bidirectional opportunities and constraints, unpredictable power flows from P.V. panels, and thus uncertain energy losses and network costs, for example – the regulatory frameworks existing in different European countries did not take into account the new roles and tasks DSOs may have to properly accommodate and manage such new technologies in order to leverage from them. In this regard, the CEP defines DSOs as neutral market facilitators and active systems operators, being therefore responsible for procuring flexibility services to the grid and smartly managing congestions.

[14] See Bunn and Nieto-Martin (2020).

[15] For example, power and mobility sectors contribute 66% of greenhouse gas emissions worldwide, (IEA 2018). An efficient decarbonization of the power system is fundamental to achieve a low-carbon future as it directly impacts every other sector. For instance, electric vehicles charged with electricity generated from fossil fuels would, at the very least, jeopardize the effective reduction of GHG emissions at the global level (Gomes et al. 2020). As a result, in recent years, the EU has promoted the settlement of distributed generation (DG) and other DERs (Cambini and Soroush 2019), aiming at a leading role in the clean energy transition.

However, to do so, the digitalization of the grid is imperative: monitoring and controlling the DSO network now characterized by bidirectional power flows, a high number of DER connections, and higher energy demand by the current electrification of many economy sectors, requires a smarter operation of the grid at least at the same level as the TSO network's operation. That said, the cost of equipping every single line and interconnection point of the distribution system with controllable devices is likely to be prohibitive.

If the amount of capital that can be invested by the DSO is bounded, it will be crucial to prioritize digitalization investments in the most congested areas (i.e., in areas where such an investment will provide the largest benefits). The identification of these areas and the design of the incentives needed to achieve an efficient level of investment will surely motivate important regulatory debates in the coming years, and some innovations are starting to provide flexibility for DSOs that need it.[16]

So far, the diffusion of smart meters has been the central pillar of distribution networks digitalization, allowing DSOs to effectively manage the quality of service of the network even at low voltage levels, thanks to the bidirectional communication between utilities and market participants, and consequently enabling DSOs to provide new services and optimal network management, shifting the power industry from being infrastructure-driven to being more service-driven (Eurelectric 2020). They are also responsible for consumer empowerment by allowing users to make optimal decisions about their energy consumption by reacting to future real-time tariffs (Prettico et al. 2018). In order to promote the wide-scale deployment of smart meters in Europe, E.C. Directive 2019/944 states that "*where the deployment of smart metering systems is assessed positively, at least 80 % of final customers shall be equipped with smart meters either within seven years of the date of the positive assessment or by 2024 for those Member States that have initiated the systematic deployment of smart metering systems before 4 July 2019*".[17]

Finally, the clean energy transition pioneered by the EU emphasizes three factors: (i) decarbonization, (ii) decentralization, and (iii) digitalization – aka the 3Ds. Each of these factors causes significant impacts on both the DSOs' business model and its function in the entire power system. As previously presented, policies encouraging decarbonization through low-carbon energy generation have led to the massive integration of RES in the distribution network, introducing bidirectional power flows, the need for better management, control, and monitoring and the need for flexibility. Decentralization is the effect of increasing customer participation, as prosumers and potential ancillary service providers, through the integration of various DERs in the grid, such as solar panels, E.V.s, home battery systems (Freitas Gomes et al. 2021), smart heat pumps and others. Lastly,

[16] See more details on these points in Gonzalez Venegas et al. (2021a, 2021b).
[17] We refer to Eurelectric (2020) for recent facts and figures regarding the penetration of smart meters in Europe.

the digitalization of the distribution network enables the active participation of consumers in the energy market and allows a better coordination between TSOs and DSOs (Silvestre et al. 2018; Prettico et al. 2020).

b – DSOs' new tasks and roles

Altogether, this changing environment requires DSOs to take on new roles and responsibilities, which *de facto* challenge the traditional representation of distribution as a passive component of the entire power system (Pollitt et al., 2021).

Besides the traditional responsibility of ensuring "*the long-term ability of the system to meet reasonable demands for the distribution of electricity*" in a reliable, secure, and efficient way (E.C. Directive 2009/72, Article 25(1)), the role of DSOs in Europe was to emphasise the urge for a significant evolution in order to reach climate-related goals, in a new power system environment characterized by digitalization, decentralization, and increasing DERs integration. The new tasks of the distribution entity have been extensively discussed in the literature in the last few years (e.g., Ruester et al. 2014; Vasiljevska et al. 2016; Perez-Arriaga et al. 2017; Küfeoğlu et al. 2018) and have finally been legally addressed at the European level in the revised Directive on Common Rules for the Internal Market for Electricity (E.C. Directive 2019/944).

According to the Directive, DSOs are responsible for the system's operating flexibility, by allowing the integration of renewable energy sources, E.V.s and other DERs and actively managing them to avoid congestion and reduce network costs. At the same time, DSOs must provide non-discriminatory access to their network for other system users (Eurelectric 2020), acting as neutral market facilitators, allowing the optimal use of traditional generations and decentralized energy resources (Küfeoğlu et al. 2018), and are therefore not allowed to own and operate DERs.[18] In many EU countries, DSOs own and manage (smart) metering infrastructures. In this sense, the Directive mandates DSOs to ensure appropriate data management, guaranteeing non-discriminatory access to data either upwards in the value chain or downwards (Prettico et al. 2020).

Yet, DSOs have to carefully invest in plans for the expansion and/or upgrade of the grid – as do TSOs – intending to achieve decarbonization targets, avoid congestion, preserve network reliability, improve network capacity, and guarantee a smart, efficient, and digitized grid management (Gomez San Roman 2017; Prettico et al. 2020). The Directive also sets the guidelines for Citizen Energy Communities and Renewable Energy Communities and established the creation of a soon-to-be operational European DSO Entity.

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[18] DSOs shall not own, develop, manage or operate recharging points for electric vehicles or storage facilities. However, some specific conditions may allow them to do it. (EC Directive 2019/944, Articles 33 and 36).

Therefore, such a decentralized management of the grid indicates that the DSO business model is transforming from "pipe-based" to "platform-based," aiming at meeting the expectations of customers and efficiently bringing all market parties together (Eurelectric Vision 2019). According to an MIT report, implementing markets for network services at the distribution level could generate additional revenue for DERs and create new business opportunities to respond to DSOs' or other upstream stakeholders' needs (MIT 2016).[19]

In summary, according to Küfeoğlu et al. (2018), the new core functions of DSOs provide: (i) a more active system operation; (ii) market platforms; (iii) data management through data hubs. However, that transition from "pipes" to "platform," or from network-ownership to system operation, raises at least five challenges.

3.2. Challenge #1: Rethinking the coordination with TSOs

The transition from "passive" distribution utilities to "active" distribution system operators challenges the roles and responsibilities assigned to TSOs and DSOs. In particular, the traditional delineation between the roles and functions of TSOs and DSOs is getting blurry: while DSOs are now conceivably able to leverage on decentralized energy resources to provide system services traditionally procured by TSOs, the transmission system operators are also moving forward by expanding their SO functions to lower voltages (MIT 2016; Küfeoğlu et al. 2018). Therefore, the roles and interaction processes between DSOs and TSOs need to be redefined in order to increase the integration of DERs within the power system (IRENA 2020) and obtain the full value of services that can be provided by them (MIT 2016).

The effective coordination between TSOs and DSOs is of utmost importance for the electricity system to obtain full value from the services provided by DERs (Pérez-Arriaga 2016). As pointed out by IRENA (2020), a greater coordination and interaction between DSOs and TSOs enables a better utilization of DERs in the system and allows an increase in flexibility while reducing expenditures on network reinforcements. Sharing information and collecting metering data is, therefore, essential for allowing a symbiotic planning and operation of these systems (Migliavacca 2018).

DSOs, being responsible for the smart metering data collection, should exchange real-time information with TSOs,[20] providing the transmission operator with increased visibility of DER capabilities and consumption patterns, for example, being able to use such data to provide ancillary

[19] The Distribution System Platform (DSP) developed by the New York Energy Reform in 2014, in the United States, is the prime materialization of the DSO as a market platform concept. We refer to NY (2014) and MIT (2016) for further details on the New York State Distribution System Platform.

[20] That communication requires smart meters with adapted real-time communication capabilities. It is not certain whether the devices that have been installed so far meet this pre-requisite.

services to the system and avoid load and generation forecasting errors. Yet, as neutral market facilitators, DSOs can also provide ancillary services to TSOs, for instance, via aggregators, contributing to the optimal use of the connected resources (DERs) to balance the system (IRENA 2020; WindEurope 2017). The cooperation and coordination between TSOs and DSOs also enables synergized network expansion planning that could result in significant cost savings at an infrastructural level. At the same time, the better use of the DERs allowed by such interactions between system operators enable an effective congestion management, avoiding unnecessary infrastructure investments (IRENA 2020; CGI 2017).

Consequently, policymakers and regulators are taking actions to deepen the cooperation between TSOs and DSOs with the goal of guaranteeing a safe, reliable, and cost-efficient use of flexibility-based services (Gerard et al. 2016*)*. As part of the CEP legislative package, the Article 32(2), at E.C. Directive 2019/944 states that: "*Distribution system operators shall exchange all necessary information and shall coordinate with transmission system operators in order to ensure the optimal utilization of resources, to ensure the secure and efficient operation of the system and to facilitate market development*." Yet, the EU regulation 2019/943 contains the rules on the cooperation between the ENTSO-E[21] and the EU DSO entity. That said, one wonders whether the proposed rules are being adapted. Against this background, the question "*How should the coordination of the operations conducted by TSO and DSO be organized to yield an efficient utilization of the resources?*" should attract further research in the coming years.[22]

3.3. Challenge #2: DER and the users' migration to off-grid solutions

The encouragement of technological development and innovation within the market of renewable energy sources, as well as the increasing adhesion of DERs in recent years, are consequences of the policies and incentives guided by European net-zero targets and of the significant decrease in the price of such technologies worldwide. Following the marked declines observed during the last decade in the costs of solar panels and batteries, the diffusion of these technologies turns the end consumer of electricity into 'prosumers' increasingly able to react firmly to price signals (Schittekatte 2018, Hoarau and Perez 2019).

These irreversible changes toward consumer empowerment through decentralized generation technologies highlight the need to remodel the current tariff methodology, initially designed for merely energy-consuming agents when decentralized generation was just a minor exception (Ruester

[21] European Network of Transmission System Operators for Electricity

[22] On that specific question, note that research on this topic has already begun as illustrated by IRENA (2019a) and the EU-funded SmartNet Project that compares the merits and limitations of five alternative coordination schemes with different market designs and different responsibilities assigned to the system operators (see Gerard et al. 2016 & 2018; SmartNet 2019; Rossi et al. 2020).

et al. 2014*).* As discussed in Section 2, most of the European Member States adopt electricity tariffs composed of a volumetric component with either capacity or lump-sum components (or both), where the energy-based charges have a larger weight (ACER 2021), being therefore responsible for the most of the DSOs' revenues. Yet, regarding compensation methods for DER owners, net energy metering (NEM) is the most used in Europe, being employed by 11 countries as a P.V. support system (RES-LEGAL 2017; Cambini and Soroush 2019). Given the new environment, such methodologies are deemed to not respect cost-reflectiveness, cost-recovery, and fairness principles, as well as to over-incentivize D.G. adoption while under-incentivizing self-consumption, leading to higher distribution costs and lower DSO revenues.

Volumetric-based tariffs are good price signals for consumers in the sense that the amount of consumed energy (kWh) is directly proportional to the bill price and, therefore, are of easy comprehension and predictability. Recently, being able and willing to react to price signals more firmly, grid users have increasingly been investing in solar panels to lower their electricity bills through the self-production of electricity (Schittekatte 2018). Yet, under NEM, the excess electricity produced (net energy) is credited to the consumer's account to be used later as compensation (Cambini and Soroush 2019*).* In this sense, the combination of an inadequate cost-reflective tariff with NEM methodology could incentivize the adoption of DER beyond the optimal level from a system point of view, over-rewarding the richest group of consumers who are able to actively react to such price signals (Schittekatte 2018). Still, if prosumers reduce their bills to a greater extent than they reduce the costs they inflict on the distribution system network, the full recovery of these costs would require an increase in the volumetric charges, further encouraging the deployment of decentralized generation (MIT 2016) and increasing cross-subsidization (Ruester et al. 2014), i.e., unfairly forcing passive consumers to contribute more.

This problem, where a poorly adapted volumetric tariff promotes the high penetration of DER, leading to lower electricity consumption from the grid and therefore lower DSO revenues, forcing a tariff increase in order to cover the distribution costs, and further incentivizing the deployment of decentralized generation is casually known as the "Utility Death Spiral" effect (Cambini, and Soroush 2019). Different cases have been assessed in the literature. The Wallonia case in Belgium, for instance, was studied by Gautier and Jacqmin (2018). One of the main conclusions was that, keeping other conditions constant, "*an increase by one eurocent per kWh of the volumetric tariff leads to an increase in the number of installations by around 5%*" of P.V. panels. Simshauser (2014) analyzed the South Queensland case in Australia, where high volumetric tariffs and high P.V. panel penetration led to a rampant cross-subsidization, forcing the poorest group of people to pay around 40 percent more in their electricity bill than the active consumers. Regarding this last example, Pollitt (2018) argues that this case is rather unique and extreme, due to its particular conditions of high volumetric tariffs, high solar radiation, and high P.V. penetration. He concludes by saying that, even though unlikely to happen in most places, the Death Spiral effect may be an issue in some parts of some networks.

Besides, as pointed by Cambini and Soroush (2019), the aforementioned tariff structure (i.e., metering system associated with volumetric-based tariffs) is such that prosumers are compensated with the same tariff rate that they are charged for electricity consumption from the grid, and they therefore become indifferent to consuming their self-produced electricity and injecting it into the grid. However, lower self-consumption rates lead to higher electricity injection, higher energy losses and consequently, higher costs for the distribution system operators, furthering the Death Spiral effect. In this sense, it is important to remember that different levels of D.G. penetration can lead to different outcomes regarding distribution network costs: if the use of DERs in the distribution grid management can decrease OPEX compared to business as usual, how the use of DERs will impact CAPEX is not obvious (Ruester et al. 2014). Still, according to Cambini and Soroush (2019), while low penetration levels of D.G.s may decrease distribution network costs, including distribution losses and avoiding capacity constructions, high penetration levels of prosumers would lead to higher connection costs and energy losses, and the need to invest in the network infrastructure. Therefore, a cost-reflective tariff structure that incentivizes self-consumption would contribute to the decrease in DSOs' operational and capital expenditures.[23]

3.4. Challenge #3: Redesigning tariffs

The need for new tariff methodologies that efficiently reflect the costs that each consumer inflicts on the grid – especially with the advent of active consumers that connect D.G. technologies into the distribution network and inject the surplus into it – is imperative to avoid cross-subsidization issues and unfair over-rewarding of prosumers, allowing a cost-efficient outcome. Beyond sending clear signals to the end-user, such tariffs should recover the DSOs' operational and capital expenditures. Introducing transmission network type charging methodologies in the distribution system,[24] adopting capacity-based tariffs, setting injection charges, and remodeling DER owner compensation methods are among the most promising proposals presented in recent literature.

As previously discussed, the main cost driver of the distribution network is the maximum peak demand that determines the necessary installed capacity, and therefore capacity-based tariffs would be more cost-reflective, avoiding discrimination between active and passive customers, and cross-subsidization, breaking the Death Spiral effect (Simshauser 2014). Yet, as distribution networks

[23] See Frías et al. (2009) for a comprehensive discussion of the impact of self-consumption rates in the variation of energy losses.

[24] That view implicitly call for an adaptation to the distribution context of the nodal pricing methodology that considers spatial and temporal differentiation for price assignment that was originally proposed for high-voltage transportation by Schweppe et al. (1988).

increasingly behave like transmission networks, extending TSOs' pricing methodologies to the distribution level, such as peak-based used charges, fixed capacity connection charges and nodal pricing, may be a solution (Pollitt 2018). If poorly formulated, however, a capacity-based tariff could inflate the value of the facility's peak load, giving even more incentive for battery storage systems[25] (Gomes et al. 2020) or even unravel the quantity-based discounts enjoyed by low-consumption users, e.g., elderly households *(*Pollitt 2018). According to IRENA (2019b), demand-side flexibility is key for a renewable-powered future. In this sense, time-of-use (ToU) tariffs enable demand response and incentivize load adjustment, either manual or automated, allowing consumers to save money with lower energy expenses while benefiting the system with reduced peak loads and investments in the grid infrastructure.

The cost of providing energy to users throughout the power system can significantly vary by location and period (MIT 2016). While distribution locational (marginal) prices (DLMP) could help alleviate congestions by reflecting short-run congestion costs (Schittekatte 2019), time-differentiated tariffs could be a valuable tool for reducing distribution network peak-load, thereby promoting network efficiency (ACER 2021). Still, MIT (2016) stresses that an increased granularity in energy prices is a sound way to identify DER investments that can help mitigate network problems. However, achieving such granularity is complex and requires DSOs to invest in automation, digitalization, and adapted data transfer capabilities to disseminate the information needed by market participants. It could negatively impact transparency, predictability and simplicity principles if poorly implemented (ACER 2021). Furthermore, Pollitt (2018) underlines that such methodologies are not optimal per se at the transmission level because they do not ensure the full recovery of the network cost (Perez-Arriaga 1995) and therefore questions their applicability to distribution systems.

Recently, some charging methodologies used to promote RES have been challenged for the significant side effects and overall system drawbacks they may cause. Feed-in tariffs, for instance, have been widely implemented to boost the installation of P.V. panels (and wind power) in countries such as Germany, Italy, the UK, Spain, or the US. However, the over-incentive of DER led to the duck curve problem in California (Gomes et al. 2020) and the over-reward of prosumers in other jurisdictions, furthering the Death Spiral Effect threat. Consequently, many countries decided to abandon this mechanism in the last few years (Cambini, and Soroush 2019; RES-Legal 2019). Despite being the most commonly used methodology in Europe, as previously seen, NEM also asymmetrically values behind-the-meter generation (MIT 2016), especially when simultaneously combined with volumetric tariffs that do not incentivize self-consumption, leading to higher distribution costs and a socially non-optimal outcome. Cambini and Soroush (2019) argue, however, that NEM is the most

[25] When associated with PV panels, battery storage systems can significantly increase the self-consumption rate. However, the massive adoption of such technology depends on the further decrease in its prices, mainly due to the EV industry.

compatible mechanism with the current metering methodologies, and propose a multi-part distribution tariff under the net metering scheme that better reflects D.G. externalities (especially connection costs and energy losses) and could mitigate unintended outcomes such as the Death Spiral effect.

Unlike NEM, in the net-purchase system the amounts of electricity generation and consumption are compared at each moment, constantly, and the electric utility (or grid company) only purchases the surplus generation, at a rate equal to the wholesale's (Yamamoto 2012). The adoption of such a scheme, however, depends on the proper data exchange between active consumers and system operators and therefore requires an extensively automated and digitalized network (Cambini and Soroush 2019). In an environment where countries like Sweden, Italy, and Finland already have a smart meter penetration rate over 90 percent and are proceeding to the rollout of second generation smart meters (Eurelectric 2020), a widespread implementation of the net-purchasing system in Europe does not seem too far away.

Finally, another fashion to minimize the over-rewarding of D.G. owners and increase cost-reflectivity, while promoting cost-recovery, is to charge active consumers for electricity injection, either through energy-based, power-based or lump-sum tariffs (or even a combination of them). Electricity export charges are already applied by 10 EU member states[26] (ACER 2021).

3.5. Challenge #4: Electrification and DER's Integration

While the massive integration of D.G. technologies in the system due to volumetric-based tariffs and poorly adapted compensation charging schemes may lead to higher distribution costs, lower revenues, and cross-subsidization, the uptake of EVs and electric heaters – in a context of the "electrification of everything" – could attenuate such unintended effects, by increasing the general electricity consumption through the contribution of wealthier households, allowing the utility to recover its costs and potentially reducing electricity charges for the lower consumption consumers, therefore breaking the Death Spiral effect (Küfeoğlu et al. 2018; Pollitt 2018; Gomes et al. 2020).

Increasing DG surplus injection into the grid and huge electricity withdrawal due to EVs and electric heating, however, challenge the DSO network infrastructure and require the proper management, coordination, and integration between decentralized energy resources (e.g., batteries, EVs, PVs). This is needed in order to provide flexibility to the distribution grid, avoid network reinforcements and attenuate congestions, while being profitable to system operators, regulators, and consumers, and complying with the decarbonization targets (Burger et al. 2019; Gomes et al. 2020). In this sense, according to Pollitt (2018), there is no need for time and space varying charges in order

[26] AT, EE, FI, FR, LT, LU, MT, NL, SK, SE. Besides, BE applies injection charges only in the regions of Flanders and Wallonia (ACER 2021).

to increase or reduce demand in certain nodes of the grid at a certain moment, managing congestions and alleviating peak loads. Instead, efficient markets for flexibility or ancillary services contracts for DER flexibility could already enable such an effect. Besides, he affirms that new products and services like domestic P.V. export, fast E.V. charging, and distributed ancillary services provision, are opportunities for introducing new cost-reflective charges that would allow the recovery of part of the network's fixed costs inflicted by new users of the network.

3.6. Challenge #5: Supporting digitalization

The rising amount of DERs connected to the distribution grid associated with the ongoing digitalization of the system (smart grids) have been dramatically transforming the power industry. As the energy market moves toward a vast number of suppliers and buyers (Petri et al. 2020), the complex interaction between them demands a reliable, safe, transparent, and direct platform. The use of Blockchain for peer-to-peer (P2P) energy trading – an imperative step for D.G.'s self-sufficiency – can lead to the eradication of intermediaries between generation and consumption, the monetization of energy surplus, and the development of integrated community energy systems (Kouveliotis-Lysikatos et al. 2019; Gomes et al. 2020). Since it works as a transparent and highly secure distributed ledger that records all transactions using a consensus algorithm to avoid a central point of authority or validation (Gomes et al. 2020), depending on the chosen business model the blockchain technology is likely to reduce the roles of utilities, retailers, aggregators, and/or the wholesale energy markets, and by doing so energy costs for the end-user may drop (Brilliantova and Thurner 2019). Yet, Abdella and Shuaib (2018) stress that decentralized energy trading, especially P2P trading, could also increase the system efficiency and promote the penetration of RES.

While the use of blockchain for a P2P energy exchange in microgrids is a long-term prospect due to the lack of regulatory framework to support it, in the short term the upcoming expectations of the implementation of blockchains in the power system are associated mainly with E.V. charging and V2G (vehicle-to-grid) solutions (Brilliantova and Thurner 2019*).* Finally, the blockchain technology "*has the potential to leverage the benefits of decentralized energy systems and enable an environment where everyone can trade, pay, and even deliver energy to others*" (Petri et al. 2020).

4. Emerging research questions

Having identified these many contemporary challenges, a question of utmost importance emerges: are the arrangements inherited from the restructuring reforms of the 2000s still being adapted? In this section, we identify two issues pertaining to the market structures and the institutional framework that should attract further research in the coming years.

4.1. Horizontal industry structure: What desirable degree of concentration?

Section 2.4 has already pointed out the substantial national differences in the market structures prevailing in Europe and has discussed their relative merits and limitations. Yet, that discussion was essentially based on the traditional arguments inherited from the regulatory discussions of the 1990s and 2000s. At that time, industry restructuring was a hot topic and one of the leading public policy concerns. Over the years, policymakers have shifted their attention. Nowadays, environmental concerns are preeminent in contemporary energy policy discussions, and accelerating the deployment of low-carbon technologies is recurrently presented as a chief social objective. Because of these changes, a reappraisal of the merits and limitations of these different market structure options is timely to understand whether concentration or fragmentation can yield greater economic welfare. Ideally, that discussion should consider the following questions.

First, do concentration – and the scale and scope economies it provides – result in lower prices (including the effects of other side transfers to DSOs)?

By nature, that question calls for a quantitative identification of the optimal scale and scope in that industry. Ideally, such an evaluation should consider both the multifaceted gains concentration can provide (e.g., through standardization, centralized purchases, or facilitated access to capital) as well as its side effects (e.g., the managerial slack inherent to large organizations, the impacts of a lower degree of transparency on cost structures that can adversely impact regulatory effectiveness). Hence, the studies conducted on the cost structure will also have to verify whether the gains resulting from these scale and scope effects outweigh the potential adverse effects of concentration. Conducting that analysis can be challenging because the horizontal boundaries of a firm are likely to be influenced by a series of elements that can hardly be measured and thus included in empirical models such as the role played by local and historical factors (Nillesen and Pollitt 2019).

Second, does concentration provide a higher quality of service to users?

On the one hand, large European DSOs recurrently claim that their size allows them to provide a better quality of service (e.g., to moderate the adverse consequences of a natural disaster by mobilizing dedicated mutualized intervention forces capable of rebuilding the disrupted infrastructure quickly). That said, it would be interesting to quantitatively measure these tangible benefits relative to the counterfactual case of an area controlled by a small DSO.

Third, does concentration support an efficient level of investment in the distribution system?

That question boils down to checking whether a single DSO managing two adjacent distribution systems is more efficient or not in investment planning than two separated ones. Conceivably, the contemporary answer is likely to differ from the one obtained in the late 1990s. Indeed, DSOs are now conceivably equipped with an enriched set of techniques (e.g., active demand response, local battery storage) capable of alleviating local congestions and thus with the potential to provide an alternative to investments in network deepening. To the best of our knowledge, the combined effects of these new technologies and the degree of concentration on investment efficiency in distribution networks still have to be evaluated.

Lastly, does concentration affect the emergence and diffusion of innovation?

That question is multifaceted and calls for a series of specific investigations regarding the firms' investments into R&D, the performances of these investments, and the facilitating/hampering role DSOs can have on the diffusion of new technologies in the system. To begin with, it is important to stress that DSOs can hardly engage R&D expenses absent any dedicated regulatory allowances (e.g., Pollitt et al. 2021). That said, for a given total R&D allowance provided by the regulator, one can wonder whether considerations related to market structure affects the efficiency of these investments in R&D. To the best of our knowledge, the interactions between the size of the regulated firms and the performance of the allowed investment into R&D still has to be examined. On the one hand, the very small DSOs observed in countries with a highly fragmented market structure are unlikely to be capable of developing an efficient R&D department, as it typically requires a variety of skills, a long-standing effort needed to attract and retain skilled engineers. In that case, an obvious alternative is to partner and opt for a shared R&D effort supported by many DSOs, a solution that *de facto* yields coordination and administration costs. Furthermore, in a rather extreme – and somehow caricatural – case, the R&D allowance could end up being perceived by the small, regulated firm as a "regulatory gadget" that funds exogenously decided external projects with few direct implications for the firms' own operations. On the other hand, a large DSO is likely to have the size, the organization, and the ability to attract and retain the human capital needed to conduct R&D activities. It also certainly has the potential to transform these investments into tangible benefits for its operations. Yet, the R&D is likely to be conducted internally at a dedicated department. Because of the lack of commercial rivalry, that activity can be subjected to insidious bureaucratization, which adversely affects the innovation performance.

4.2. Ownership Unbundling: Is it a good alternative?

The review in Section 2 recalled that the European legislation is mandating a Legal and Functional Unbundling of DSOs and pointed out the heterogeneity of the situations prevailing in the member states. In the early years of the restructuring reforms, there were heated discussions on the need to impose some form of ownership separation on DSOs. During the last decade, these discussions seemed a bit "*passée*" but this topic is now resurfacing. In a recent work, Nillesen et al. (2021) recall that there have been several cases of voluntary ownership separation of the DSO and that

New Zealand and the Netherlands imposed a mandatory separation in 1998 and 2009. In these two countries, the separation was aimed at improving competition, increasing network quality, and reducing distribution costs by increasing efficiency. Following that recent study, it can thus be opportune to: (i) examine whether the traditional arguments presented for and against mandated ownership still hold when considering the challenges posed by the transition toward decarbonized, decentralized, and digitalized power systems, (ii) investigate the impacts that the new power system environment has on the benefits of DSO ownership separation, and (iii) review the earlier literature on ownership unbundling of distribution networks in order to compare their assessments on the impact of such restructuring on competition, quality of service, and costs.

Nillesen et al. (2021) conduct a literature review and stress that most papers are either not in favor or inconclusive on the benefits induced by ownership unbundling. However, a closer examination of that literature suggests that most of the cited works – i.e., 11 out of 23 – exclusively study the New Zealand and Netherlands cases that, for being quite specific, can hardly be invoked as representative of all the European countries. Still, when considering the papers that exclusively analyze the cases of the US, Switzerland, Spain, or Italy (8 out of 23), the results on the impact of DSO ownership unbundling on competition, quality and costs are either inconclusive or not assessed. Therefore, there is a lack of theoretical or empirical studies to support an assertive conclusion on whether or not the ownership unbundling of DSOs brings positive results, especially when considering the specificities of each country's power system structure and overall conditions. Subsequently, a question to be addressed in future studies emerges: given the heterogeneity of the European distribution system structure, is there a fertile environment where the ownership unbundling of DSOs could thrive?

On the other hand, the authors argue that "*most institutionally-advanced countries have analyzed the optimal market structure and concluded on strict legal unbundling*." However, "*with the emergence of distribution network platforms, data hubs, and increasingly active DSOs, enforcing an organizational form, even disregarding the negative theoretical and empirical evidence, seems outdated. From a policy perspective, it is thus advisable to consider other policy measures to improve competition in retail, improve the quality of the network and drive down monopoly network costs*" such as improving transparency for end-users, further ring-fencing of distribution activities, decreasing or removing barriers to entry for retail activities and strengthening the regulatory framework and the regulator.

Another interesting aspect in Nillesen et al. (2021) concerns their analysis of the cases of New Zealand and the Netherlands to assess whether the reforms have achieved the goals of improving competition, increasing network quality and reducing costs by increasing efficiency. The evidence shows that, in both cases, the benefits for quality of service and retail are questionable and controversial and that associated one-off and structural costs are passed on to consumers. Finally, the controversy regarding the benefits of forced ownership unbundling is not altered when considering the new environment of the power system but reaffirmed. The increasing need for cooperation and coordination between every actor in the value chain associated with the grid digitalization "*would seem to weaken the case for disintegration by making it easier to exploit the financial and labor market benefits of joint ownership, whilst maintaining open access*" as the authors conclude.

5. Conclusion

In Europe, **the industrial and institutional frameworks governing the organization of the power distribution sector are inherited from the restructuring reforms of the late 1990s and early 2000s**. In those years, the policymakers' mindset was influenced by the technology and theoretical shifts of the 1980s that called for some form of industry de-verticalization (i..e, the vertical unbundling of generation and retail from transmission and distribution), favored private sector participation, recommended the creation of autonomous regulatory agencies, and advocated the introduction of competition in the generation and retail segments. In those years, distribution networks issues were largely overlooked. In those years, distribution issues attracted little attention as they represented a passive component of a unidirectionally-organized supply chain. However, these views are outdated for at least two main reasons. First, the main goal of the European energy policy has radically shifted and now emphasizes decarbonization and the net-zero targets. Second, new technology changes both the market environment and the business practices of distribution firms. **The fundamental public policy issue examined in this paper is, thus, whether the heterogeneous and country-specifc organizations inherited from the restructuring era are still being adapted to facilitate the transition toward green energy sources and a cost-efficient deployment of new technologies.**

To examine it, **this paper first provides a comprehensive review of the current state of the European distribution sector**. It then uses that knowledge to identify and discuss the main challenges facing that sector, including the DSOs' adaptation to new tasks and roles, the vertical interactions with TSOs, the user's migration to an off-grid solution, and tariffs problems. That analysis reveals that DSOs are particularly affected by contemporaneous changes and that their traditional roles and functions must be reconsidered. DSOs must enrich their traditional role of a grid operator (i.e., ensuring a secure, reliable and efficient electricity supply for all consumers) to also actively operate a complex distribution system, act as neutral-market facilitators favoring the active participation of RES, decentralized storage and E.V.s, and manage data in real time. In summary, **DSOs are moving from 'pipes' to 'platform,' becoming much more active than before, having a central role in the energy transition**.

That transition has many implications. For example, one can note that **the traditional delineation between the roles and functions of TSOs and DSOs is now getting blurry** and calls for a reconsideration of the coordination mechanisms between these two entities. **Another issue is in the tariff methodologies applied in the distribution sector.** They should efficiently reflect the costs that each consumer inflicts on the grid – especially with the advent of active consumers that connect DER to the distribution network and inject the surplus into it – to avoid cross-subsidization and prevent the Death Spiral. Beyond sending clear signals to the end-user, such tariffs should also allow the DSO to recover its operational and capital expenditures.

From the insights gained from these analyses, the answer to the public policy question above would appear to be no. As distribution has so far been less studied in the literature than generation or transmission issues, **we identify two research topics pertaining to the market structures that should attract further research in the coming years**. The first topic concerns the **horizontal industry structure and the size of DSOs**. Ideally, this discussion should consider the four following questions: (i) Does concentration result in lower prices? (ii) Does concentration provide a higher quality of service to users? (iii) Does concentration support an efficient level of investment in the distribution system? (iv) Does concentration affect the emergence and diffusion of innovation? The second topic is related to **ownership unbundling**. In this matter, we suggest extending the research program envisioned in Nillesen et al. (2021) and assessing the prevalent arguments for and against the ownership unbundling of DSOs under the new environment surrounding DSOs. Future research development on these two topics will usefully inform future European policies.

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