Regulatory and Policy Aspects for a Cellular Design of Electricity Markets

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***Abstract*—Future energy systems are facing an increasing number of mainly small-scale renewable energy sources (RES) and sector-coupling units. This change poses technical and market-related challenges in terms of consistent market and system operation across sectors. The cellular approach (CA) is considered a promising concept to overcome these challenges. Since energy cells are communicating to interconnected neighboring energy cells exclusively, the effort of data processing can be reduced effectively. Beyond the design of an appropriate electricity market structure, the question of integrating this concept into the status quo of the regulatory framework is a key issue. Therefore, this paper examines the relevant aspects of the regulatory and policy framework with regard to the integration of an electricity market design based on energy cells. The degree of correspondence or conformity of the proposed design with the key current European and national regulations is assessed. Relevant regulatory aspects are identified, and possible adoptions are discussed.**

Keywords—Cellular approach, independent system operator, market design, regulatory and policy framework

I. INTRODUCTION

To mitigate the effects of climate change, the decarbonization of the energy sector is required, inducing new challenges for future energy systems. For instance, increased shares of variable renewable energy sources (RES) are affecting the power grid, thus, raising the question of its long-term optimal technical and economic structure with regard to infrastructure expansions and operational opportunities for an improved operation. These questions are closely linked to future investments in system security and operation of renewables, electricity storage, other power plants and sector coupling technologies [1]. The design of future electricity markets should enhance the coordination of the overall energy system operation, involving the advantages of sector-coupled networks, storages, demand, and supply, while taking real-world information and communication technology (ICT) limitations into account.

In this context, present electricity markets are already facing two major challenges as consequences of the ongoing decarbonization: decentralization and congestion management (cf. also [2]). The decentralization of the electricity sector implies an increasing number of small-scale units, located in the lower voltage levels of the electricity network. These decentralized units, e.g., photovoltaic power plants and storages, heat pumps, electric vehicles etc., may offer valuable contributions of flexibility to the electricity markets, yet this is currently only partially usable. The reasons for the partial usage of decentralized flexibility in purely centralized electricity markets are linked to the present market design. For traders, the integration of small-scale units is only worthwhile if several of these plants are aggregated, so that the resulting uncertainty can be significantly reduced and cost advantages can be gained, due to the scale of operation. In this context, the market clearing process, which in most European member states is typically carried out based on simplified network externalities [3], induces another challenge: After carrying out the market clearing process, resulting violations of technical constraints are leading to congestions, whereby measures are typically postponed in the temporal sequence. In this context, especially renewable curtailment, redispatching and countertrading are the most relevant measures taken in European electricity markets. Instead of using flexibility to cope with local congestions, renewable power plants are currently often curtailed while conventional power plants are redispatched to serve the missing electricity. Even if the decentralized units are offering flexibility on the centralized electricity market, there is no suitable mechanism so far to provide flexibility at the local level, capable to face resulting limitations of the information and communication technology (ICT) as well. Another reason for the present challenges, related to the first reason, are distorted price signals arising from the present regulatory framework. Since, network externalities or congestions are not reflected in price signals, the latter are not incentivizing adequate operational and investment decisions. This hinders especially sector-coupling technologies and other flexibilities to become economically viable [4].

In this context the novel market design proposed by Schinke-Nendza et al. [2] may provide a framework to unfold the potential of integrating decentralized units while coping with congestions appropriately. Hereby, the electricity market is based on a two-layer market clearing process incorporating network constraints, while introducing system operators on a central and local level. In opposite to present transmission and distribution system operators (TSOs & DSOs), independent system operators (ISOs) are envisaged, which would be responsible for operating the corresponding network while organizing the market clearing based on a nodal pricing regime (thus, incorporating congestion management during market clearing). Each of the central and local ISOs takes into account the generation and demand units as well as the networks constraints units in its own territory and communicates only with interconnected entities (i.e., other ISOs or market participants). Thereupon, the market clearing can be carried out iteratively, e.g., based on distributed and parallel optimization, see [5]. Therefore, in the novel market design the computational effort may be reduced effectively for each entity, while enabling the utilization of flexibility in electricity market.

This market design can be implemented as part of the cellular approach (CA) leading to a cellular energy system (CES), which is currently developed as part of the project ZellNetz2050, cf. [6]. This project aims at developing a cellular energy system for the year 2050, based on a brownfield approach taking the present regulatory framework into account. Subsequently, the concept a CES is therefore subsequently introduced in a first step, including also the intended market clearing process. Thereupon, the relevant regulatory and policy aspects of the European framework are analyzed and evaluated with regard to the market design in a structured manner. Finally, the key findings regarding the solution of the previously introduced issues are highlighted.

II. Cellular Energy System

In the following, the CA is considered as the cross-sectoral integrated energy system planning and operation [6, 7] and serves as a basis for a novel market design, cf. [2]. The concept of the CES is based on hierarchically organized energy cells applying the energetic subsidiarity principle, thus, providing the possibility to handle the ICT limitations of centralized electricity markets effectively [6].

A. *Energy cells and cell levels*

Each energy cell is defined as a spatially delimited[1] part of a multisector energy system and is operated by an energy cell management (ECM) with a *system operator* (SO) carrying out the market-based processes and a *system controller* (SC) handling the technical processes.

In this context, the CES is organized by three energy cell levels (A to C), where all individual units, i.e., generation, load and storages, providing different kinds of flexibility, are comprised as the energy cells of Level A. These Level A energy cells are operated by the unit operator (UO) and are connected to different networks (electricity, gas and heat) belonging to an energy cell of Level B or C. Thereupon, the Level B energy cells cover areas corresponding to a given electricity distribution system while the superimposed Level C energy cells cover the transmission system. In addition, all related heat and gas networks of the covered area belong to the same energy cell of Level B or Level C.

The individual units of the Level A energy cells are optimized by the UO according to an individual (corporate) objective function of the incorporated units. Since the SOs of the Level B and C energy cells include the network infrastructure exclusively, they are comparable to an *independent system operator* (ISO) in other market designs [8]. Hence, the SO of Level B is named *local ISO* (LISO) and the one of Level C is named *central ISO* (CISO).

B. *Two-stage market design*

The general structure of the electricity market design of the CA proposed in [2] is depicted in Fig. 1. The focus is thereby on the contractual relations, power flows as well as the trading and coordination processes between the relevant entities. The CES includes a hierarchical structure with multiple unit managers and operators, several LISOs and one central CISO. Similar to several ISOs covering different parts of the US [8], several interconnected CISOs may be envisaged within Europe, too. However, as mentioned beforehand each LISO is exactly connected to one superimposed CISO.

1) *Market clearing and market segments*

Besides the previously mentioned UO responsible for operating units of energy cell Level A, this structure introduces the *unit manager* (UM) serving as (electricity) trader, i.e., the aggregator. Hence, UMs are taking over the responsibilities of individual UOs, and act as traders to the different submarkets of the electricity system. Therefore, UO of an individual unit has the following duties: to purchase, sell and buy energy, capacity, balancing services and ancillary

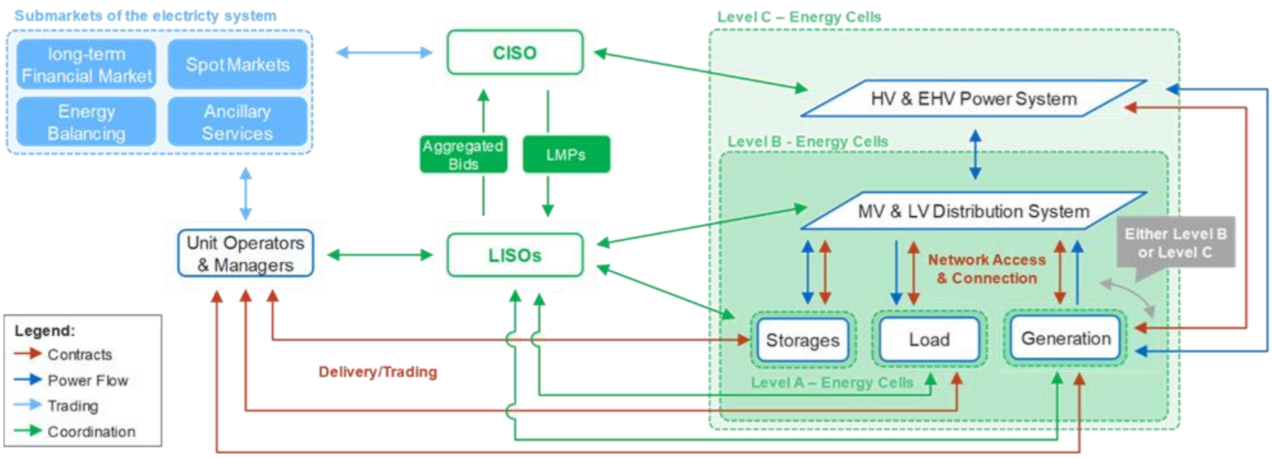

Fig. 1 Overview of the electricity market design with local ISOs and central ISO in the cellular approach. Note that ECs on level A can also contain sector-coupling units or more than one unit, e.g., a load with an PV and a storage.

[1] Cf. [7] for the definition of the EC boundaries.

services, as well as to report ex-post realized power flows for the ISO to settle the energy balance.

Regarding energy cell Level B, several LISOs are operating the corresponding distribution systems of the electricity system, thus integrating the underlying energy cells of Level A. Furthermore, the LISOs are integrated into the overall market clearing process by transmitting aggregated bids (including, e.g., exchange powers and operational information) to the connected networks, i.e., to the superposed CISO. In this context, the LISO is carrying out a pre-market-clearing process taking local restrictions into account to obtain the aggregated bids. Therefore, underlying units of energy cell Level A are capable to participate in submarkets procuring energy balancing and ancillary services. Furthermore, with respect to the proposed market design, LISOs are able to dissolve local congestions and incorporate other network restrictions immediately.

On energy cell Level C, the CISO receives the aggregated bids and performs the central market clearing and dispatching process resulting in locational marginal prices (LMPs). Therefore, the clearing of the energy market can be carried out, incorporating a market-based procurement of balancing and ancillary services simultaneously [5]. Hence, the restrictions and requirements of the other submarkets are taken into account by the CISO together with the system operation. Regarding the market segments, the CISO coordinates the spot markets and related submarkets required for the secure system operation in his energy cells, exclusively. The long-term, purely financially settled derivative markets are overseen by a separate authority, thus enabling UOs and UMs to trade power derivatives until one day in advance to the physical delivery. Therefore, appropriate hedging instruments can be incorporated while ensuring a secure, competitive, flexible and non-discriminatory system operation.

2) *Governance structure of the ISOs*

To ensure the competitive, transparent, and non-discriminatory coordination of the ISOs, the governance structure of all ISOs in the proposed market design should follow the principle of independence. Hence, no market participant or subgroup of participants of the market should be able to control decisions, procedures and criteria of the market and system operation [9]. This separation of the market and system operating entity (i.e., the ISO) and the asset owning entities (e.g., the network owners) is intended in line with [10]. Hereby, the governance structure proposed by Schinke-Nendza et al. [2] does not only ensure a transparent and non-discriminatory competition.

III. Regulatory and Policy Aspects

When developing a novel market design for the CA, the key regulatory aspects in the present regulatory and policy framework of electricity markets have to be reflected. Focusing on the previously mentioned challenges, cf. Section I, we address this for the case of Germany which is integrated into the European framework of electricity markets. In addition, the relevance to and the impact on the proposed market design is evaluated subsequently for each aspect.

A. *Status quo of the regulatory framework*

The corner stone for the liberalization of the electricity sector in Europe has been laid in 1996 by directive 96/92/EC concerning common rules for the internal market in electricity [11]. Thereupon, the EU adopted various legislative packages in 2003 and 2009, cf. [12, 13], to support the liberalization of the energy market and to establish an internal market for electricity. In terms of recent enactment, the so-called *clean energy package* repealed the former regulatory framework and introduced further steps towards an internal market in electricity in 2019. As part of the *clean energy package*, regulation 2019/943 on the internal market for electricity [14] has been introduced as a binding legislative act, thus applicable in its entirety in all member states while overruling national laws. Furthermore, the common rules for the internal market for electricity have been adopted as well by directive 2019/944 [15], setting objectives that all EU countries must reach and translate into their national legislation by January 1st, 2021. In addition, the establishment of a EU agency for the cooperation of energy regulators (ACER) with extended competences has been addressed by Regulation 2019/942, see [16]. Especially directive 2019/944 ensures an open electricity market, based on the following principles:

- an open access to the electricity system for customers and independent producers, respectively,
- the unbundling of vertically integrated system operators
- and the establishment of objective and non-discriminatory criteria for the dispatching of power.

The beforehand mentioned process of liberalization in the electricity sector in Europe has formed a zonal market structure in the different member states, thus the internal market in electricity consists of individually cleared bidding zones. These zonal market clearings are coordinated through an intra-zonal a cross-zonal capacity allocation process, whereby the latter is carried out using the so-called Flow-Based Market Coupling (FBMC). However, in these processes of capacity allocation, typically simplified network externalities are considered [3].

B. *Electricity markets and market coupling*

When considering electricity markets, directive 2019/944 clearly defines these as "*markets for electricity, including over-the-counter markets and electricity exchanges, markets for the trading of energy, capacity, balancing and ancillary services in all timeframes, including forward, day-ahead and intraday markets*" [14]. Furthermore, the directive requests competitive, consumer-centered, flexible and non-discriminatory electricity markets for all member states, while extending the scope of application to the cross-border trade of the internal market as well. The directive claims transparency, proportionality and non-discrimination regarding market rules, fees, and treatment in general. Furthermore, these rules apply especially to the following aspects [15]:

- access to wholesale markets and to data,
- balancing responsibility and switching processes,
- billing regimes and if applicable, licensing.

In addition, customers' free choice of suppliers and market-based supply prices, with minimized public interventions, form another cornerstone of the organization of electricity markets. Hereby, public interventions in the pricing of electricity supply must pursue a general economic interest while being clearly defined, transparent, non-discriminatory and verifiable for market participants, see [15].

In a broader view, there are two basic organizational patterns for electricity markets: pool-based trading and bilateral trading, both observable with national modifications in European member states [17]. The first pattern implies that all (or most) of the trading activities are coordinated and observed by the responsible system operator [18]. In opposite, the bilateral trading typically relies on decentralized and voluntary markets, organized as over the counter (OTC) markets or power exchanges. There consumers, generators and traders are capable to trade electricity in an unrestricted manner [18]. Both are typically supplemented by an imbalance settlement process. Exchange-based trading is typically mandatory in pool-based trading for the spot market while it there may be competing marketplaces including OTC markets in bilateral trading systems [17, 18]. In terms of pool-based trading [2] already directive 96/92/EC required that eligible customers should have the possibility to conclude supply contracts with producers to cover their own needs, to ensure at least some possibility of bilateral trading. This requirement for instance was satisfied in the UK in the 1990ies by implementing a voluntary forward market to trade bilateral contracts combined with the obligation for participating in the Pool when trading electricity [18]. This requirement has even been tightened by regulation 2019/943 since long-term OTC trading is made an obligation explicitly for all member states "*in order to allow market participants to be protected against price volatility risks on a market basis, and mitigate uncertainty on future returns on investment*" [14].

When assessing the conformity of the previously introduced market design with the basic European requirements, there are two major aspects to be considered. On the one hand, the novel market design would introduce the pool-based trading as organizational pattern for the electricity market. Although the obligation to facilitate OTC trading intends to support bilateral trading as organizational pattern in the EU, it would be possible to integrate this requirement into the above-mentioned market design. As long as market participants are obliged to report physical flows resulting from OTC trading to the responsible system operator and a participation in the imbalance settlement process is binding, an efficient allocation of capacity would be possible. On the other hand, the novel market design is capable to match the basic principles of transparency, proportionality and non-discrimination for electricity markets together with customers' free choice of suppliers and market-based supply prices with minimized public interventions. Considering the existing frameworks for such multi-staged market clearing processes, e.g., by Caramanis et al. [5], further work on the foundations is yet required to ensure transparency and proportionality, especially in terms of the balancing responsibility of individual market participants.

1) Operational principles

Regulation 2019/943 clearly indicates the binding principles for operating electricity markets in the EU, see [14]. Furthermore, member states, regulatory authorities, system operators, market operators and delegated operators are responsible for ensuring these principles for all market participants. While member states must translate and address these objectives in the corresponding national legislation, the regulatory authorities are mainly responsible for monitoring and ensuring compliance of market and system operators as well as market participants with the rules.

In this regard, *regulatory authorities* are obliged, following directive 2019/944, to ensure the most cost-effective, safe, reliable, and efficient systems that are non-discriminatory and consumer oriented. These systems should promote system adequacy, energy efficiency and the integration of large and small-scale distributed renewable generation into transmission and distribution networks. Furthermore, the electricity system shall facilitate its operation in relation with other energy networks for gas or heat [15].

These operational principles as well as the obligations of the regulatory authority, especially with regard to the sectorial coupling, are matching the incentives and principles of the previously introduced market design. In detail, the proposed market design allows for a much better implementation of these predefined operational principles, e.g., by facilitating the development of more flexible demand and generation while delivering appropriate investment incentives for a sustainable and decarbonized generation and ensuring a fair competition.

2) Cross-border electricity trade

While regulation 2019/943 and directive 2019/944, set out the basic framework for cross-border electricity trade and assign duties and tasks for the relevant entities in the energy market, regulations 2019/942 and 2015/1222 define detailed operational rules and methods in this context. To improve the cross-border electricity trade the EU has granted ACER additional competences in those areas where national decisions, with relevance to the cross-border trade of electricity, may lead to problems for the internal energy market, see [16]. Thus, the jointly developed and published network codes of the system operators become regulations.

Especially, the guideline on capacity allocation and congestion management (CACM), incorporated by regulation 2015/1222, defines the relevant methods for calculating cross-border electricity flows, based on trading of market participants, while ensuring system security. This procedure is known as flow-based market coupling (FBMC). Furthermore, the operation of European cross border markets is harmonized [19]. In terms of cross-border electricity trade, a *market coupling operator* (MCO) is responsible to match bids and offers from different bidding zones, for day-ahead and intraday markets in an optimal manner, while publishing the FBMC results on a non-discriminatory basis to all power exchanges, see [19]. The beforehand mentioned cross-border electricity trade relies on accurate bidding zones reflecting the distribution of supply and demand. Hereby, bidding zones may be modified by adjusting, merging, or splitting zone borders. Nevertheless, this configuration should be consistent for all market timeframes, i.e., for single day-ahead and intraday electricity trading, see [19].

There are two perspectives on integrating the novel market design in a subset of countries or bidding zones in the EU, when assessing conformity in terms of cross-border

[2] The so-called single buyer procedure, cf. [13].

electricity trade. On the technical side, the FBMC process carried out by the MCO can be maintained, e.g., by applying distributed parallel optimization techniques [20]. In this context, the algorithms of the corresponding regulation 2015/1222 may need to be adopted to the novel design. However, the general structure will not change while an optimal capacity allocation for cross-border electricity trade can be achieved. However, further investigation in this field is required since there might be some counterintuitive effects arising when coupling multiple markets for cross-border trading when the individual market design relies on different organizational patterns. On the institutional level, regarding the regulatory and policy side, the question arises whether the proposed market design matches the implicitly defined idea of an internal market for electricity or not. On this side, the current legislation definitely offers the possibility to introduce the required changes mentioned beforehand. However, the implementation of these changes strongly depends on the idea and the understanding of the internal market on electricity, thus affecting the political will to promote the novel market design. Therefore, a precise and unambiguous assessment at the institutional level requires further investigations.

C. *Congestion management & market-based redispatch*

In terms of intrazonal congestion management, Hirth and Glismann [21] reviewed applicable measures in European electricity markets available to avoid congestions. Addressing the case of Germany, as it is integrated into the European framework, redispatching, including curtailment, and countertrading are the most relevant measures that incurred annual costs of more than one billion Euro over the past three years[3]. In this context, regulation 2019/943 defines the regulatory framework for intrazonal redispatching of generation and load, see [14]. The resources used for redispatching, shall be selected based on a market-based mechanism among generation assets, energy storages, or demand response. Balancing units utilized for redispatching, are omitted when settling the balancing energy prices.

However, in terms of the present market design in Germany, research unveiled the possible threats and disadvantages of a market-based redispatch, due to inc-dec-gaming in the case of coexisting zonal electricity markets and local redispatch markets, see [22]. Thus, the coexistence offers participants of the corresponding markets incentives for strategic bidding and arbitrage opportunities. Thus, policy makers decided in close coordination with the regulatory authority, transmission system operators and experts to proceed using the cost-based redispatch[4], see [23].

In this context, the proposed market design of Section II would be capable to reduce the drawbacks identified in [22] inherently. Since, the market clearing is carried out based on a nodal pricing regime, congestions are taken into account in a market-based manner while the coexistence of zonal electricity markets and local redispatch markets can be precluded.

D. *Electricity balancing & reserve procurement*

Considering the balancing responsibility of market participants, both, regulation 2019/943 and directive 2019/944, request transparent proportionate and non-discriminatory market rules, fees and treatment [14, 15], as already mentioned in Section B. In addition, regulation 2019/943 defines the regulatory framework for balancing markets, including e.g., the prequalification processes, pricing methods, and dimensioning of reserve capacity. In this context, the applicable areas of the imbalance prices (reflecting the real-time value of electricity) should correspond to the previously introduced bidding zones. However, in terms of central dispatching models, e.g., used by independent system operators, imbalance price areas constituting partial biddings zones are allowed [14].

With respect to the proposed market design of Section II, the interrelation of the market design with energy balancing is still under investigation. In general, the novel market design definitely fulfills the generic requirements especially, e.g., in terms of prequalification processes, pricing methods, and dimensioning of reserve capacity. However, regarding the balance responsibility of individual units the question arises how to ensure non-discrimination and transparency. As proposed by the novel market design bids must be made on a unit level and not on a balancing group level. Hence, aggregators in the novel market design will face a higher volatility for the scheduled power demand and supply, e.g., regarding intermittent RES, compared to the status quo. Even though, existing frameworks for multi-staged market clearing processes incorporate reserve procurement as part of the energy balancing, cf. [5], further research in this direction is required to derive appropriate instruments for UMs and UOs.

E. *Market-based procurement of ancillary services*

Distribution and transmission system operators are obligated, according to directive 2019/944, to procure ancillary services based on non-discriminatory, transparent, and market-based procedures [15]. This also incorporates non-frequency ancillary services, e.g., steady state voltage control, inertia for local grid stability and black start capability, unless the regulatory authority granted a derogation. However, prior to a derogation the market-based provision of non-frequency ancillary services must be evaluated as economically inefficient. In terms of the present market design in Germany, non-frequency ancillary services have been subject to research, serving as a basis for the decision for a partial market-based solution of some services, see [24].

Therefore, the proposed market design of Section II would complement the market-based short-term procurement of some ancillary services, by incorporating the requirements in the market clearing process. For instance, additional LMPs, e.g., for reserve procurement or for reactive power to provide a steady state voltage control, see [5], would enable transparent and verifiable financial incentives for UMs and UOs to ensure security of supply and local grid stability. Furthermore, the long-term auctioning or contracting of other ancillary services, such as black start capability or inertia for local grid stability, can be carried out regardless of the underlying market design.

[3] The procurement of reserve capacity is not taken into account, since, reserve is intended mainly for system security, frequency containment and restoration, hence, not mentioned in CACM, i.e., regulation 2015/1222 [16].

[4] Non-market-based downward redispatching, see regulation 2019/943 [13].

F. *Independent system operators in the EU*

Regarding the operation of transmission systems, member states of the EU are permitted to designate an independent system operator (ISO). In opposition to ISOs in the US, cf. [8], European ISOs are typically historically grown by vertically integrated companies and might be fully state owned [17, 25]. Therefore, the operational principles and long-term planning in systems with ISOs in the EU typically differ from the US American markets [9] and even the conceptualization of ISOs is partly diverging. However, to match the differing market design of the member states, the entire European legislation is designed to fit for both organizational structures: for TSOs and for ISOs with separate network owners. For the latter, the regulatory authority is obligated to ensure an adequate remuneration for network owners via network access tariffs collected by the ISO. Therefore, an appropriate remuneration of the network assets can be ensured while offering incentives for new investments. Yet, the permission of member states to establish new ISOs is only foreseen where the transmission system belonged to a vertically integrated company by September 3rd, 2009, thus restricting the future establishment of ISOs [15].

In this context, regulation 2019/943 does not explicitly prevent the proposed market design from being implemented, but directive 2019/944 intends the implementation of ISOs for previously vertically integrated TSOs exclusively. Hence, the directive would have to be adopted in two ways:

- Permitting the implementation of ISOs while replacing previously TSOs and separating the network owners according to the proposed governance structure, cf. Section II.B.2).
- Permitting the implementation of ISOs for distribution system operators (DSOs) similar to the TSOs, while the regulatory authority may grant exemptions regarding the governance structure, with regard to the establishment of committees, subcommittees and task forces.

In this context, again the question arises whether the proposed market design matches the implicitly defined idea of an internal market for electricity or not. Therefore, the implementation of the required adoptions strongly depends on the idea and the understanding of the internal market on electricity, thus affecting the political will to promote the novel market design.

IV. Conclusion & Outlook

This paper introduced and assessed the relevant aspects of the regulatory and policy framework applicable to the novel design of cellular electricity markets. In accordance with the European legislation, the proposed market design is able to cope with the existing main principles and rules for electricity markets. Furthermore, the market design facilitates opportunities for an improved market-based congestion management, by utilizing a nodal pricing regime instead of cost-based redispatching, and for the market-based procurement of ancillary services. Therefore, inefficiencies and limitations of present market designs could be addressed appropriately by unifying the advantages of central markets and subsidiary energy cell approaches. Furthermore, regarding the novel market design operational and investment incentives are provided appropriately, leading to a coordinated flexibility supply. Introducing novel organizational patterns for electricity markets, utilizing a pool-based trading scheme seems to be in line with the European legislation, if the possibility for OTC trading is ensured. Finally, the incorporation of local and central ISOs into the European framework requires an amendment of the current legislation. Yet, most of the considered legislation does not preclude the implementation of such a market design, hence, offering enough flexibility for national policy makers to prepare first steps. However, in the longer term, adoptions are required, and the implementation process strongly depends on the political willingness at the European level. On this institutional level, the decision on the market design depends on the European Commission's ideas on the future of the internal electricity market and the willingness of the member states to adopt the cross-border trading mechanisms.

Nevertheless, enabling an economically efficient integration of millions of mostly small-scale units (RES, storages etc.) into a central ISO market under consideration of network restrictions and real-world ICT limitations would capture the evolving demand of a future energy system. Thus, the novel market design could provide significant improvements in comparison to other approaches. Consequently, even though changes in the European and national regulatory framework are required, the beforehand opportunities would justify such changes. Therefore, future work needs to evaluate the proposed market design, especially in terms of the following aspects. The proposed market design requires bids on a unit level, hence, forecasting errors affecting the settlement of energy imbalances potentially increase. Furthermore, the cross-sectoral market coordination (comprising the electricity, heat and gas sector) needs to be addressed in more detail.

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VI. References

[1] L. van Nuffel, J. Gorenstein Dedecca, T. Smit and K. Rademaekers, "Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonise?," European Parliamen, Brussels, 2018.

[2] A. Schinke-Nendza, G. Blumberg and C. Weber, "A Novel Design for Electricity Markets based on the Cellular Approach," *17th International Conference on the European Energy Market (EEM),* 2020.

[3] S. Voswinkel, B. Felten, T. Felling and C. Weber, "Flow-based market coupling – What drives welfare in Europe's electricity market design?," University of Duisburg-Essen - House of Energy Markets and Finance, Essen, 2019.

[4] R. Haffner, "Do current regulatory frameworks in the EU support innovation and security of supply in electricity and gas infrastructure?," European Union, Brussels, 2019.

[5] M. Caramanis, E. Ntakou, W. W. Hogan, A. Chakrabortty and J. Schoene, "Co-optimization of power and reserves in dynamic T&D power markets with nondispatchable renewable generation and distributed energy resources," *Proceedings of the IEEE,* pp. 807-836, 2016.

[6] B. Uhlemeyer, J. Jakob, M. Zdrallek, C. Baumann, W. Wellßow, J. Dickert, S. J. Rasti, G. Blumberg and A. Schinke-Nendza, "The cellular approach as a principle in integrated energy system planning

and operation," *CIRED Workshop, Berlin,* p. submitted and accepted for publication, 2020.

[7] VDE ETG, "The cellular Approach (Study)," VDE - Verband der Elektrotechnik Elektronik Informationstechnik e.V. | ETG - Energietechnische Gesellschaft, 2015.

[8] E. Litvinov, F. Zhao and T. Zheng, "Electricity Markets in the United States: Power Industry Restructuring Processes for the Present and Future," *IEEE Power and Energy Magazine, Vol. 17, No. 1,* pp. 32-42, 2019.

[9] W. W. Hogan, "Independent System Operator: Pricing and Flexibility in a Competitive Electricity Market," Harvard University, Cambridge, Massachusetts, 1998.

[10] N. Friedrichsen, "Governing smart grids: the case for an independent system operator," *European Journal of Law and Economics, Vol. 39,* pp. 553-572, 2015.

[11] EU, "Directive 96/92/EC - Common rules for the internal market in electricity," 1996.

[12] EU, "Directive 2003/54/EC - Common rules for the internal market in electricity," 2003.

[13] EU, "Directive 2009/72/EC - Common rules for the internal market in electricity," 2009.

[14] EU, "Regulation 2019/943 - Internal market for electricity," 2019.

[15] EU, "Directive 2019/944 - Common rules for the internal market for electricity," 2019.

[16] EU, "Regulation 2019/942 - Establishing a European Union Agency for the Cooperation of Energy Regulators," 2019.

[17] Frontier Economics, "METIS Technical Note T4: Overview of European Electricity Markets.," European Commission, Brussels, 2016.

[18] J. Bower and D. W. Bunn, "Model-Based Comparisons of Pool and Bilateral Markets for Electricity," *The Energy Journal, Vol. 21, No. 3,* pp. 1-29, 2000.

[19] EU, "Regulation 2015/1222 - Guideline on capacity allocation and congestion management," 2015.

[20] b. H. Kim and R. Baldick, "Coarse-grained distributed optimal power flow," *IEEE Transactions on Power Systems , Vol. 12, No. 12,* pp. 932 - 939, 1997.

[21] L. Hirth and S. Glismann, "Congestion Management: From Physics to Regulatory Instruments," *Leibniz Information Centre for Economics,* 2018.

[22] L. Hirth and I. Schlecht, "Market-Based Redispatch in Zonal Electricity Markets: The Preconditions for and Consequence of Inc-Dec Gaming," 2020.

[23] BMWi - Federal Ministry for Economic Affairs and Energy, "Cost- or market-based? Future redispatch procurement in Germany: Conclusions from the project "Beschaffung von Redispatch"," 2019.

[24] BMWi - Federal Ministry for Economic Affairs and Energy, "Effizienzprüfung marktgestützter Beschaffung von nicht-frequenzgebundenen Systemdienstleistungen (NF-SDL)," 2020.

[25] G. Fulli, M. Masera, A. Spisto and S. Vitiello, "A Change is Coming: How Regulation and Innovation Are Reshaping the European Union's Electricity Markets," *EEE Power and Energy Magazine, Vol. 17, No. 1,* pp. 53-66, 2019.