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Design of European Balancing Power Markets

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***Abstract*— This paper presents an empirical analysis for 24 European countries that procure balancing power with auctions. We find that there is no predominant market design in Europe but qualitatively identify three key drivers for the variety in market designs: the share of volatile renewable energy sources, short-term flexibility and market coupling. The inconsistency of auction designs, however, cannot be traced back to the energy market framework conditions. We argue that this is a consequence of the applied multi-part auction mechanism and offer a brief review of auction-theoretic literature.**

***Index Terms*—Auction Design, Balancing Power, Control Power, Market Design, Power Reserve**

I. Introduction

The European electricity markets face tremendous transformations by the growing use of renewable energy sources. Volatility on the production side will increase and the power system will require additional flexibility, which can be ensured by harmonizing the European electricity markets [1]. Furthermore, a unified European electricity market will lead to a higher degree of competition and in the long-term promote efficiency. Harmonization is not restricted to energy-only markets but should also include balancing power procurement [2].

A secure operation of electric devices requires a constant frequency in alternating current power grids. If too much (little) energy is supplied to the grid, the frequency will rise (drop) . Hence, electricity supply and demand need to be bal-anced permanently. Since electricity can be stored neither easily nor cheaply, there is a necessity for an ancillary service – the so-called balancing power. If the frequency drops (rises) positive (negative) balancing power is needed, e.g. by increas-ing (decreasing) the load level of a power plant. The European Network of Transmission System Operators (ENTSO-E) discerns three “qualities” of balancing power (“three-quality pattern”), namely the Frequency Containment Reserve (FCR), the Frequency Restoration Reserve (FRR) and the Replacement Reserve (RR) [3]. First, FCR is used to limit deviations from the frequency, then FRR is utilized to restore the frequency and as a final measure RR is activated. All prequalified suppliers that are allocated for the provision of balancing power need to keep available the offered amount of power and, if called for frequency stabilization, provide balancing energy. Thus, suppliers need to be compensated for keeping balancing power available and for the actual delivery of balancing energy. This is implemented by allowing suppliers to submit two different bids: the power bid (EUR/MW) and the energy bid (EUR/MWh).

A continued Europe-wide cooperation requires a profound understanding of the current design characteristics in balancing power markets. In order to facilitate this understanding we present an overview of current European balancing power market designs. We analyze 24 European countries that are members within the ENTSO-E and procure balancing power with procurement auctions. Based on the aggregated information we conduct a qualitative analysis of potential drivers for current market designs. The analysis leads to a critical evaluation of current theoretical approaches towards the design of multi-part procurement auctions.

The paper is structured as follows: In section II, the applied method for the empirical study is presented, introducing the characteristics that are used for the analysis. Section III discusses three main drivers for the current configurations of the European market designs. Section IV reflects heterogeneity in auction design by considering applicable theoretical work. Section V concludes.

II. Method

This analysis of the European balancing power markets uses a structural framework: We analyze every market along three categories of characteristics to be described below. As market designs vary considerably, minor simplifications of the real market structures were inevitable. We provide supplementary information by way of additional download material (cf. note for Table 1).

First, general energy market characteristics have strong implications for the design of markets for ancillary services.

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Historically, the key driver for power market design is the electricity mix. Availability of different resources and energy carriers fundamentally shapes the market structure. We specifically report the share of gross electricity consumption served from volatile renewable energy sources (vRES), namely production from wind and photovoltaics. The vRES-share is used as an indicator for this increasing volatility, which could have a significant impact on required balancing power and implica-tions for the design of these markets [4], [5]. As the necessity for a flexible adjustment of production levels is sometimes known in advance, some countries implemented short-term trading options on their spot market. The spot market is com-monly divided in day-ahead and intraday markets. Day-ahead markets allow trading for the following day whereas intraday markets allow load serving entities to avoid balancing activi-ties by trading for delivery on the same day. We report the shortest time before physical delivery when a spot market trading option is still available, in order to investigate a possi-ble impact on the design of balancing markets [cf. 6].

Secondly, balancing market characteristics describe the implementation of each balancing power market quality (FCR, FRR and RR). First, we examine whether the three-quality pattern is applied or if certain market qualities are non-existent. If existent, we report for each market quality whether the provision of balancing energy is a compulsory service or is procured with the help of an auction. In case of the latter, we present the bid elements (power and/or energy bid) and whether positive and negative balancing power are distin-guished. Furthermore, the auction frequency (yearly, monthly, weekly, daily) as well as the activation strategy (merit-order or pro -ratio/parallel) are discussed. Lastly, the number of deliv-ery time slices, their duration (e.g. 24x1h for a daily procure-ment) and the minimum power offer are stated, since these are fundamental to assess a particular market's flexibility.

Finally, auction characteristics discuss pricing and scoring rules of the respective markets. Pricing options are uniform pricing, pay-as-bid or a combination of these, and have significant impact on the bidding behavior of suppliers [7]. The scoring rule describes how the winners of the auction are determined.

Leaning on the detailed analysis of the relevant characteristics of balancing markets in Europe, we deduct main drivers for their design. The factual information is qualitatively ag-gregated into tangible findings and illustrated through the use of specific market examples. In addition to the compilation of fundamental characteristics of balancing markets on a Europe-an scale, identifying main drivers for balancing market design can contribute to the discussion on future regulation efforts.

III. Findings

In this chapter we present our main findings. Table 1 depicts an extensive comparison of 24 European balancing power market designs. After the discussion of descriptive findings, we identify three key drivers for the current configurations of the balancing power markets. Furthermore, we examine the remarkable heterogeneity in auction designs.

A. *Descriptive Results*

We find a wide range of gross electricity consumption served from vRES among the 24 evaluated countries, spanning from 0% in Serbia and Iceland to almost 45% in Denmark. In 21 countries there are intraday trading options for energy which, however, does not imply equal levels of flexibility: More than half of these countries have trading options of 60min or less before delivery, whereas especially southern European countries such as Portugal, Spain and Italy can trade only up to 195min before delivery. 19 countries apply the three-quality pattern introduced by the ENTSO-E. While FRR is part of nearly every market, FCR and RR are not as abundantly used. Especially smaller countries often compel market players to supply FCR or even rely on larger neighboring countries for this service, such as Russia for the Baltic states. Both manual and automatic activation of balancing energy occurs.[1]

Regarding auction design, nearly every constellation of power bid and/or energy bid is applied throughout the three qualities. 23 countries generally distinguish positive from negative balancing power, especially for FRR and RR. One exemption is the FCR -cooperation between Austria, Germany, the Netherlands and Switzerland which procures FCR without the distinction of positive and negative balancing power (symmetric product). Only Italy is not distinguishing between the products at all. The frequency of balancing power procurement is highly diverse, ranging from a daily to a yearly auction. The activation strategy for balancing energy on the other hand is almost consistent throughout the European markets: Merit-order activation is used unanimously, merely Serbia activates pro- ratio/parallel. The number of time slices, their duration and the minimum size of the power offer vary greatly between the countries and balancing power qualities. With regard to the applied pricing rule, the picture is also incoherent: In ten countries uniform and in eleven countries pay-as-bid pricing is used. If uniform pricing is used for the delivery of balancing energy, this price either depends on an exogenous market price or on the submitted energy bids of the suppliers. The scoring rule is either based on a total price for balancing power and energy, only on the price for balancing power or on a stochastic optimization program minimizing total costs.

B. *Share of Volatile Renewable Energy Sources*

Generally, integrating vRES into the power system can have two opposing effects on the balancing market: On the one hand, more vRES generally induce higher production fluctuations and more balancing power is needed. As a result, the price for balancing should increase. On the other hand, vRES with low marginal costs reduce spot and intraday prices and may push the existing power plants out of the merit-order. As a consequence, displaced conventional production capacity pushes onto the balancing market and reduces prices there. However, an isolated operation on the balancing power market is not viable for conventional base-load power plants with high ramp-up costs. If regulators do not want to subsidize de-

[1] Note that we report details for automatic activation for both FCR and FRR markets by default, since it is more common for these qualities. For further market details please refer to the supplementary download material.

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ficient conventional power plants, balancing energy must in the long-run be supplied by vRES. The balancing market inte-gration of vRES can reduce balancing costs [8] along with further omitting carbon emissions by conventional production.

Our analysis shows that countries with higher shares of vRES predominantly have flexible auctioning procedures as apparent in a greater number of time slices with shorter maximum durations. Furthermore, auction frequencies are higher and the minimum size of power offers tends to be smaller.

We discuss two exemplary markets, France and Denmark, to elucidate the transition from a market with a high share of conventional production towards a market with a very high share of wind power plants. While both countries have sub-stantially reduced their CO_2-emissions in recent years [9] they achieved this with very divergent production mixes, market structures and liberalization levels. In France less than 6% of the electricity consumed is supplied from vRES while about 77% of the electricity consumed is produced in nuclear power plants, the highest share in the world [10]. Consequently, these power plants are obliged to provide FCR and FRR to the grid. The French auction-based market for RR has changed very little since 2003 [11]. The auction takes place once a year al-locating blocks of positive and negative RR. Since just two big power plant operators operate on the market the surcharg-es are flexibly allocated to the power plants within each port-folio. Therefore, the operator is able to compensate unavaila-ble production capacity within their portfolio.

Denmark on the other hand, driven by a very high share of wind power integration, opened the balancing market for vRES. Wind power generation in Denmark corresponded to a share of about 42% of the Danish electricity consumption in 2014 (cf. Table 1). The wind parks are owned by various companies. Balancing power procurement like in France would not be suitable since the small suppliers are not able to provide balancing power for a whole year with their limited production capacity and volatile production. Therefore, Denmark changed their markets towards vRES market integration in three steps: (1) Denmark installed a system to easily prequalify wind power plants for balancing provision, (2) made the auction process available for more participants by performing auctions daily and (3) reduced the traded time slices to a length of four (FCR) and one hour (FRR and RR) [12]. The wind energy feed-in forecasts are reliable enough to estimate wind production for the following day and to precisely assess available gas power capacity to be placed on the balancing market. The Danish system was the first to integrate vRES into the energy system and now serves as an innovation example for future, flexible market structures.

C. *Short-Term Flexibilty*

Except for the Czech Republic, Iceland and Serbia, all European countries introduced intraday markets that are either based on a regular auction (e.g. Spain and Portugal in order to bundle liquidity) [13] or on continuous trading (all others) during the day of delivery. The TSO receives binding produc-tion plans of every power plant operator within its grid area. Depending on the market structure, operators are allowed to change this plan until a certain time before delivery. Changes in production have to be balanced on the intraday market for as long as possible. Only the resulting imbalances after the market closure are balanced by the TSO, who in turn procured the balancing energy earlier on the balancing market.

In Germany two different intraday markets are available: The intraday auction and the intraday continuous market [14]. The former was introduced at the end of 2014 and is an additional measure to balance the increasing power supply from solar power plants on the day before delivery [15]. The latter allows trading until 30min before delivery within the entire market area since 2011 and therefore is especially relevant for fluctuations in wind energy supply. By introducing two complementary intraday markets, the German electricity market became highly flexible and can balance volatile supply without an increased demand for balancing power [16]. In fact, the procured balancing capacity fell by 20% between 2008 and the end of 2015 [17].

As the example of Germany shows, we argue that **s**hort-term flexibility on intraday markets reduces the demand for balancing power in other European countries. Nevertheless, a more rigorous evaluation of this hypothesis is a promising topic for further research.

D. *Market Coupling*

Beyond the consideration of individual national market designs, we want to address a trend for international cooperation via coupling of national electricity markets. Market coupling describes the act of joining physically connected but systematically separated markets via implicit auctions on the respective trading platforms. In coupled markets cross-border transmission capacity is not traded in explicit auctions but rather part of the pricing procedure on national power exchanges. Infrastructure can therefore be used more efficiently and the resulting greater market area has more participants and a higher liquidity. On the spot market coupling is already being applied and should result in increased competition and lower prices. Nevertheless, this trend is relevant for all power markets and is a stepping stone towards a single European market [6], [18]. In the case of balancing power a positive balancing requirement in one balancing region can often be compensated with a negative one in another. By coupling balancing markets, this pooling effect can be harnessed through an economic mechanism and lead to higher supply security. The effect was e.g. observable upon the introduction of cooperation mechanisms between the four TSOs in Germany in the springs of 2009 and 2010: Immediately after introduction, dispatched balancing energy significantly dropped along with monthly volatility [19].

Further efforts aim to promote the international cooperation between TSOs and eventually drive joining of markets. Table 1 shows that the fundamental structure of balancing markets in Europe is homogenous: Most employ the categorization into three quality levels and differentiate between positive and negative balancing power. With the help of the ENTSO-E further convergence in market design is foreseeable. Such reconciliation would lead to additional cost reductions and efficiency gains in the procurement of balancing power. In an initial step, the “International Grid Control Co-operation” (IGCC) of TSOs in Denmark, Germany, the Netherlands, Belgium, Switzerland, Austria, the Czech Republic

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and most recently France, closely cooperate for the minimization of FRR-activation. Their respective net balancing needs are communicated and cleared, therefore compensating opposite requirements [20]. Austria, Germany, the Netherlands and Switzerland also have a joint market for 793 MW of FCR. A maximum of 30% (at least 90 MW) of the national FCR-need can be exported to partnering countries, which has led to significant cost reductions after initiation [21]. Especially smaller markets may profit from more participants and higher liquidity through joint markets. In fact, Denmark currently considers participating in the existing scheme [22].

If balancing markets continue to converge, a further cost reduction for balancing power can lead to a higher market efficiency and therefore to an increase in public welfare. The ENTSO-E offers a viable platform for this process.

IV. Inconsistency in auction design elements

As seen in the previous sections, some of the market de-sign elements can be traced back to the respective conditions of the power system. However, the greatly varying scoring and pricing rules do not directly correspond to the framework conditions. Moreover, they have a direct impact on the bid-ding behavior of the suppliers. We approach this discontinuity by considering the relevant theoretical auction design litera-ture. From a theoretical stance, balancing power is procured in multi-part auctions since bidders must be compensated for both reserving capacity and delivering balancing energy if called for. This type of auction is discussed for the procure-ment of a wide range of goods, e.g. for highways construction
[23] or for weapon system tenders [24]. Procuring balancing power with multi-part auctions was first analyzed by [25]. They develop necessary conditions for scoring rules that result in efficient winner selection. Based on this work, [26] find that a scoring rule using only the power bid will incentivize bidders to reveal their true costs, if the uniform spot price is paid for actual energy supply. However, this specific design is not applied in any of the 24 European countries. There are countries that base the scoring rule on the power bid exclusively and apply uniform pricing, e.g. Portugal and Spain for FRR procurement. Yet here, the uniform price is based on the utilization of RR.

Current scientific work comments on the theorized auction design by [26] and argues why it is not applied in practice. Reference [27] states that efficiency problems occur when applying the proposed scoring rule. Reference [28] shows that power plants with variable costs above the spot price would generate losses if they provided balancing energy and were paid the spot price. Hence, the theorized pricing rule is only beneficial for power plants that have variable costs below the spot price and therefore it only provides an incentive for market participation in this specific case.

Furthermore, we argue that efficient balancing activation cannot be achieved with this pricing rule: If no energy bids are submitted, activation according to variable costs is not possi-ble. But even if energy bids were submitted, there is no incen-tive for suppliers to bid their true variable costs. In the case of pro-ratio/parallel activation, every load serving entity would be utilized equally for the delivery of balancing energy and in consequence does not enable efficient activation. If merit-order activation is applied, rational suppliers with variable costs below the spot price should be willing to provide balancing energy as often as possible. A high probability of being called for the provision of balancing energy is connected to a low position in the merit-order and can be achieved by submitting a low energy bid. However, under the proposed pricing rule bidders receive a uniform spot price regardless of their submitted energy bids. Thus, rational suppliers with variable costs below the spot price should submit the lowest energy bid allowed. In this equilibrium, all suppliers submit an energy bid of 0 EUR/MWh and thus an efficient activation is, again, not possible.

In conclusion, the heterogeneity in auction design could be a consequence of the complexity of multi-part auctions for balancing power procurement. National regulators define their own design due to the lack of theoretical research on robust and thus applicable auction designs.

V. Conclusion

This paper presents an overview of existing balancing power market designs in Europe. We investigate the 24 countries that are members of the ENTSO-E and procure balancing power with the help of public procurement auctions. We find that there is no predominant market design. Certain elements of this heterogeneity (e.g. auction frequency, timing, duration of time slices) seem to be influenced by the framework conditions of the respective energy market. We identify three key drivers for these conditions: the share of vRES in the energy mix, the short-term flexibility for energy trading and pan-European market coupling. On the other hand, the inconsistency in auction design seems to be caused by the complexity of multi-part auctions for balancing power procurement.

Further research could focus on a quantitative investigation of balancing power market performance under different auction designs. In e.g. Germany there is an on-going debate whether uniform pricing is superior to pay-as-bid pricing with respect to possible cost reductions [29], [30]. Secondly, a comprehensive quantitative analysis of the hypothesized key drivers for balancing power design is necessary.

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TABLE I. EMPIRICAL FINDINGS FOR 24 EUROPEAN POWER MARKETS

	Energy market characteristics		***Balancing power market characteristics***			***Auction characteristics***	
	vRES share (2014)[1]	**Shortest possible trading option**	**FCR (automatic)**	**FRR (automatic)**	**RR**	**Pricing rule**	**Scoring rule**
Austria	7.3%	30min	PB; s; w; m.-o.; 1x168h; 1MW	PB&EB; ±; w; m.-o.; Mo-Fr 8am-8pm, rest; 5MW	PB&EB; ±; w; m.-o.; 42x4h; 5MW	PaB	lowest PBs
Belgium	9.2%	5min	TP; ±; m; *n/a*.; base, peak, offpeak; 1MW	PB&EB; ±; m; m.-o.; base, peak, offpeak; 5MW	PB&EB; ±; y; *n/a*.; base, peak, offpeak; 5MW	PaB	SP
Czech Republic	4.4%	*Day-ahead*	PB; s; d; *n/a*; 24x1h; *n/a*	PB; ±; d; m.-o.; 24x1h; *n/a*	PB; s; d; m.-o.; 24x1h; *n/a*	UP	lowest PBs
Denmark (DK1/DK2)	44.7%	60min	PB; ±; d; *n/a*; 6x4h; 0,3MW	PB; s; m; m.-o.; 24x1h; 0,3MW	PB&EB; ±; d; *n/a*; 24x1h; 10MW	UP (DK1), PaB&UP (DK2)	*n/a*
Estonia	8.7%	60min	*provided by russian TSO*	TP; *n/a*; *n/a*; m.-o.; 24x1h; 5MW	TP; ±; *n/a*; *n/a*; 24x1h; 5MW	PaB	*n/a*
Finland	1.4%	60min	*n/a*; s; *n/a*; *n/a*; 24x1h; 1MW	EB; ±; *n/a*; m.-o.; 24x1h; 10MW	*non-existent*	UP	*n/a*
France	5.6%	30min	*compulsory, regulated prices*	*compulsory, regulated prices*	TP; ±; y; m.-o.; *n/a*; 10MW	PaB	*n/a*
Germany	18.2%	30min	PB; s; w; m.-o.; 1x168h; 1MW	PB&EB; ±; w; m.-o.; Mo-Fr 8am-8pm, rest; 5MW	PB&EB; ±; d; m.-o.; 6x4h; 5MW	PaB	lowest PBs
Hungary	1.9%	120min	PB; ±; *n/a*; *n/a*; 24x1h; *n/a*	PB&EB; ±; *n/a*; m.-o.; 24x1h; *n/a*	PB&EB; ±; *n/a*; m.-o.; 24x1h; *n/a*	PaB	*n/a*
Iceland	0.0%	*Day-ahead*	TP; s; w; m.-o.; 24x1h; 1MW	TP; s; w; m.-o.; 24x1h; 1MW	TP; ±; w; m.-o.; 24x1h; 1MW	UP	lowest TPs
Italy	13.1%	250min	*compulsory, regulated prices*	EB; s; d; m.-o.; 24x1h; 1MW	EB; s; d; m.-o.; 24x1h; 1MW	PaB	*n/a*
Latvia	2.1%	60min	*provided by russian TSO*	*manual*: *n/a*; ±; *n/a*; m.-o.; 24x1h; *n/a*	*non-existent*	*n/a*	*n/a*
Lithuania	13.7%	60min	*provided by russian TSO*	*manual*: TP; *n/a*; d; m.-o.; 24x1h; 5MW	TP; *n/a*; d; m.-o.; 24x1h; 5MW	UP	lowest TPs
the Netherlands	6.4%	5min	PB; s; w; m.-o.; 1x168h; 1MW	PB&EB; ±; d/y; m.-o.; *n/a*; 4MW	PB&EB; ±; d/y; m.-o.; *n/a*; 20MW	PaB & UP	lowest PBs *(FCR), n/a*
Norway	2.0%	60min	PB; s/±; d/w; *n/a*; 24x1h; 1MW	PB&EB; ±; w; m.-o.; *n/a*; 1MW	*non-existent*	UP	*n/a*
Poland	6.0%	180min	EB; ±; *n/a*; *n/a*; 24x1h; *n/a*	EB; ±; *n/a*; *n/a*; 24x1h; *n/a*	EB; ±; *n/a*; m.-o.; 24x1h; *n/a*	UP	SP
Portugal	27.9%	195min	*compulsory, no compensation*	PB; ±; d; m.-o.; 24x1h; *n/a*	PB; ±; d; m.-o.; 24x1h; *n/a*	UP	lowest PBs
Romania	18.4%	90min	*compulsory, no compensation*	TP; ±; d; m.-o.; 24x1h; *n/a*	TP; ±; d; m.-o.; 24x1h; *n/a*	UP	lowest TPs
Slovenia	2.1%	60min	*compulsory, no compensation*	PB&EB; *n/a*; y; m.-o.; 24x1h; *n/a*	PB&EB; *n/a*; y; m.-o.; 24x1h; *n/a*	PaB	*n/a*
Spain	28.3%	195min	*compulsory, no compensation*	PB&EB; ±; d; m.-o.; 24x1h; *n/a*	PB&EB; ±; d; m.-o.; 24x1h; *n/a*	UP	lowest PBs
Sweden	9.2%	60min	PB&EB; s; d/w; *n/a*; 24x1h; *n/a*	PB&EB; ±; w; m.-o.; *n/a*; *n/a*	*non-existent*	PaB	*n/a*
Switzerland	1.6%[2]	60min	PB; s; w; m.-o.; 1x168h; 1MW	PB; s; w; m.-o.; *n/a*; 5MW	PB; ±; w; m.-o.; 6x4h; 1MW	PaB	lowest PBs (FCR), SP (FRR, RR)
Serbia	0,0%	*Day-ahead*	*non-existent*	TP; ±; d; p; 24x1h; *n/a*	TP; ±; d; *n/a*; 24x1h; *n/a*	UP	lowest TPs
United Kingdom	11.9%	75min	PB&EB; ±; m; *n/a*; Mo-Fr, Sa, Su; 10MW	PB&EB; ±; m; *n/a*; Mo-Fr, Sa, Su ; 10MW	PB&EB; s; m; *n/a*; Mo-Fr, Sa, Su; 50MW	PaB	*n/a*

For supplementary information on the sources for this table please refer to the following document: http://games.econ.kit.edu/img/Comments_Sources_Design_of_European_Balancing_Power_Markets.pdf

Abbreviations: ***manual***=manual activation; **PB**=power bid and/or **EB**=energy bid or **TP**=total price; **s**=symmetric product (no distinction between positive and negative balancing energy) or **±**=distinction between positive and negative balancing energy; procurement: **d**=daily, **w**=weekly, **m**=monthly or **y**=yearly; **m.-o.**=merit-order activation of balancing energy or **p**=pro-ratio/parallel activation of balancing energy; **24x1h**=24 one-hour time slices per day; **5MW**=minimum power offer is 5MW; **PaB**=Pay-as-Bid pricing or **UP**=Uniform pricing (for EB and/or PB); **SP**=Stochastic Programming or **lowest PBs/TPs**=lowest capacity bids/total prices are considered until balancing demand is met; ***n/a***=not available (e.g. not published)

[1] Ratio between net electricity produced from wind and solar power and the electrical energy available for consumption.
[2] Ratio between gross electricity consumption from wind and photovoltaics and the final net electricity consumption.

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