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THE ROLE OF DISTRIBUTION SYSTEM OPERATORS IN THE DECENTRALIZED POWER SYSTEM

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The paper aims to review some of the available literature concerning the traditional roles of DSOs and the evolution paths suggested by existing academic papers and concrete examples from the industry of what is being done in European Union countries. Furthermore, the roles of DSOs in Romania and the transition to a decentralized power system were investigated.
The research hypothesis is that in the following years, DSOs' activity must change to accommodate the shift towards a decentralized power system. The authors determined the driving factors of change for DSOs in the context of energy transition and the role of DSOs in the current centralized power system.

1. INTRODUCTION

After the initial integration of large-scale electricity production from renewable energy sources (RES) at the beginning of the 2000s, the world is now transitioning to a "Decentralized Power System". This new framework of the power system involves an increased number of consumers and distributed generation (DG) technologies that produce electricity from RES locally. The presence of renewable energy in the energy mix is expected to increase in the following years, as governing bodies have set ambitious targets for CO_2 reduction which must be achieved by elaborating policies and implementing directives. In this context, the role of distribution system operators is expected to change considerably as the number of producers will become harder to manage.

In the beginning, renewable technologies were non-competitive due to considerable investment costs and the intermittent nature of their production schedule. To incentivize RES exploitation, several measures had to be taken to ensure the gradual penetration of the energy sector for RES. The policies that had been adopted across the years ranged from introducing financial support mechanisms (feed-in tariffs, feed-in premiums, green certificate schemes) meant to provide additional revenue streams for entities willing to invest in RES production to different policies meant to discourage carbon-emitting power plants (grey certificate systems) and finally, measures meant to facilitate the development of RES plants (dispatch priority).

Twenty years after the emergence of renewable energy capacities, the state of renewable energy technologies has improved to a point where it is considered that such technologies rival conventional power plants.

Looking to the next decades, world leaders have ambitious targets. As of June 2022, wind and solar provide 10 % of power, but by 2050, to respect the Paris Agreement said share must increase to a staggering 61%, which is more daunting considering that the measures currently in place would take the countries of the European Union to 36 % [1].

Once large-scale RES technologies became cost-competitive, a process known as the "decentralization of the power system" also occurred. The increasing number of RES technologies that have started to be deployed in the past years are already overwhelming distribution service operators (DSOs), and the upcoming decade poses a particular challenge regarding the need for flexibility.

Traditionally, the DSOs need to be better equipped to manage many local energy producers. Some arguments can be made about significantly changing how DSOs run their businesses.

2. PRESENT CONTEXT OF THE DECENTRALIZED POWER SECTOR

The process of decentralization involves two converging tendencies observed in the past years. Firstly, the power load has shifted from several large industrial consumers to smaller, more numerous consumers (office buildings and smaller manufacturing and assembly buildings). Secondly, with the increased competitiveness of RES, power generation now combines traditional centralized production (attributed to large-scale power plants) and DG, which is achieved with the help of distributed energy resources (DER). DER is used to generate local power with small-scale technologies with little to no emissions (Diesel generators, biogas generators, wind power, solar power, and Stirling engines) [2].

For years, businesses from the commercial and industrial sectors worldwide have made sustainable development, zero emissions, and clean energy sourcing part of their mission and vision statements. The European Union, as well as other countries from around the globe, have set ambitious targets for the following decades to achieve a future that will be decarbonized.

The first step towards this future has been integrating RES technologies, represented by solar photovoltaic (PV) panels and onshore and offshore wind turbines, into the energy grid. Once said technologies had progressed sufficiently from a technological point of view and had proven themselves competitive in costs and efficiency for large-scale applications, the time had come to implement them at a residential level. Adding to the power generation aspect, heat can also be generated decentralized. However, due to its properties, heat can only be transported over short distances. By shifting towards decentralized power generation, heat and electricity can be produced within combined heat and power plants, thus increasing the system's overall efficiency since heat is a by-product of generating electricity [3].

Other steps have been taken, such as attempts to electrify the transport sector and the electrification of the heating and industrial sector which will lead to an estimated 63 % level of electrification of the European Union economy by 2045, judging by [4]. The scenario estimated that by 2045, onshore wind capacity will increase to more than 640 GW, while offshore capacity will reach 470 GW, and finally, solar PV capacity will increase the most, reaching 950 installed GW.

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Renewable generation should be able to provide 80 % of Europe's expected energy demand.

Aiding these technologies, consumers (both non-industrial and industrial and commercial) are expected to provide around 150 GW of flexibility through demand-side response. Even though DG is the main pillar of a decentralized power system, its greatest weakness is the intermittent nature of the production schedule of RES technologies.

Traditionally, DSOs oversee the management of supply-related aspects, but thanks to new technologies that allow for real-time overview, control, and fast response to developing events within the grid (smart metering and smart grid), grid activity can be optimized through the active participation of consumers or even prosumers and correlated discussions between them and producers.

Finally, adding to the DG and demand response (DR), the final component of the decentralized energy system is represented by storage systems that tie all the parts together by providing an increase in power generation and consumption stability. While the continuous installation of DG is seen as a positive aspect, this can also lead to difficulties in managing supply to satisfy existing demand. Storage solutions such as batteries, compressed air, pumped hydro storage, and even using electric vehicles (EVs) as mobile storage systems may increase grid stability by offering the necessary power output during peak hours. The previously mentioned generation technologies and loads will all be integrated within the distribution grid, leading to an active grid.

Reference [5] presents examples of countries where decentralized generation is underway. For countries like Sweden, Germany, Austria, Finland, Italy, and Spain, the DG is already widespread. The biggest challenge that countries that have started the transition towards DG have to face is related to energy availability since the production of renewable energy technologies is intermittent. As previously explained, storage solutions must compensate for low-performance intervals throughout the day (*e.g.*, days with no wind or too much wind, seasons when the sun sets early, and nighttime). Before committing to the transition towards a decentralized power system, the available resources must be analyzed. The sheer number of power generation systems that need to be installed and maintained may seem daunting, but it is an effort that every citizen and company can contribute to.

As much as these changes will safeguard a better future regarding environmental impact, they are now starting to pose significant challenges to the existing participants who offer their services within the power sector, as indicated in [6].

3. THE ROLE OF DISTRIBUTION SYSTEM OPERATORS IN THE POWER SECTOR

Distribution operators or DSOs are natural or legal entities that own, under any title, the infrastructure of a distribution network (low and medium voltage grid) and are responsible for its maintenance, exploiting it, and, if necessary, expanding on it in a certain area as well as the interconnecting points with other networks in some cases, and ensuring the required long-term capacity to satisfy a reasonable level of energy demand (Fig. 1). The number and size of DSOs vary depending on each country. In [7], different sizes of DSOs are explored, such as Enel, which is a company that operates on multiple continents, amounting to millions of customers. In contrast, other DSOs operate at a local level. They can have as few as tens of thousands of customers (in 2020, around 900 DSOs were present in Switzerland, serving a population of 8.5 million. Furthermore, DSOs differ in legal status and can be split into privately or publicly owned entities. This status impacts the degree to which these entities are subjected to regulations.

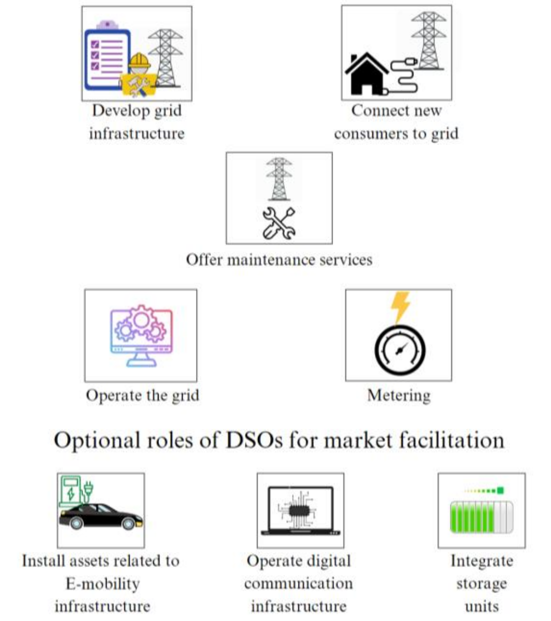

Fig. 1 – Roles of DSOs. Adapted after: EWEnetz (2017).

In a unidirectional grid, the DSO is responsible for adapting the grid better to accommodate consumption, generation, or both increases. The final consumer in the energy bill supports costs associated with developing and managing the infrastructure.

To have a clear overview of consumption and, in recent years, the production of consumers and prosumers, respectively, the DSO is also responsible for purchasing (in some countries, such as Romania) and installing electricity meters. Furthermore, the data, which is recorded by the meters, is used by energy suppliers to bill consumers and reward prosumers. Finally, the DSO is responsible for offering maintenance services for distribution network components such as power lines, substations, transformers, and electricity meters. By adding smart technologies into the grid that can record, interpret, and communicate data from the grid to command centers, the time needed by DSOs to intervene in case of power outages or other issues can be drastically reduced.

A grid with no DER is passive (the flow of the electrical current is unidirectional) since customers integrated into distribution networks are supplied with electricity solely from the national grid. However, in recent decades, the power sector paradigm has shifted to a decentralized power system that integrates elements that differ from the traditional model. Once DG is added, a grid becomes active since bidirectional electricity flows can occur. DG uses PV panel systems, wind energy, biomass energy, small hydro plants, geothermal energy, and gas turbines. Another component that will influence the future of DSO activities is electrification. Since the current trend is that of turning electricity into the main energy carrier (using electricity for heating in buildings and switching from vehicles powered by internal combustion engines to EVs), the DSO will become increasingly involved in integrating certain technologies into the grid (storage units, assets related to e-mobility, *etc.*).

Moreover, other factors contribute to the ongoing shift in how distribution grids are managed by DSOs [8]: customer expectations, emerging customer-centric competitors, demand uncertainty, technological aspects, unpredictable changes in policy and regulation, and fuel security. Their role was always that of a passive final consumer when it comes to customers. However, beginning with the adoption of the “Clean energy for all Europeans package”, back in 2019, which overhauled the energy policy framework, customers were offered the possibility to have a more active role within the power sector. This opened the way for a new participant from the power sector, the aggregator, who can reward consumers for their flexibility while indirectly helping DSOs manage the increasing number of small producers.

Finally, in the context of the recent push for phasing out fossil fuels, issues of fuel security and unpredictability in policy and regulation changes became more severe in 2023.

According to [9], the role of DSOs must change to enable the energy transition. Thus, it is the DSO’s responsibility to promote the development of market-based services provided by third parties, ensure the reliable operation of the network, coordinate its efforts with the transmission system operator, increase both the security of supply and that supply reliability, protect customers' data, and plan the development of their network to accommodate new technologies (EVs and smart grid solutions) [10].

Reference [11] makes a point of how incumbents are typically inert and resistant to change but may also support change due to their position. The major changes that DSOs must undergo have to do with the fact that, along with transmission system operators (TSOs), they are used to operating within a centralized power system governed by predictability.

The decentralized power system framework forces DSOs to tend to new issues, such as strengthening the existing infrastructure, properly managing the emergence of prosumers and their corresponding capacities, grid congestions, and balancing issues. Furthermore, [11] remarks on how DSOs in the Netherlands have a somewhat paradoxical activity since they are both working towards ensuring the stability and status quo of the energy system and actively disrupting the same system by challenging its efficiency and legitimacy in the face of the ongoing transition.

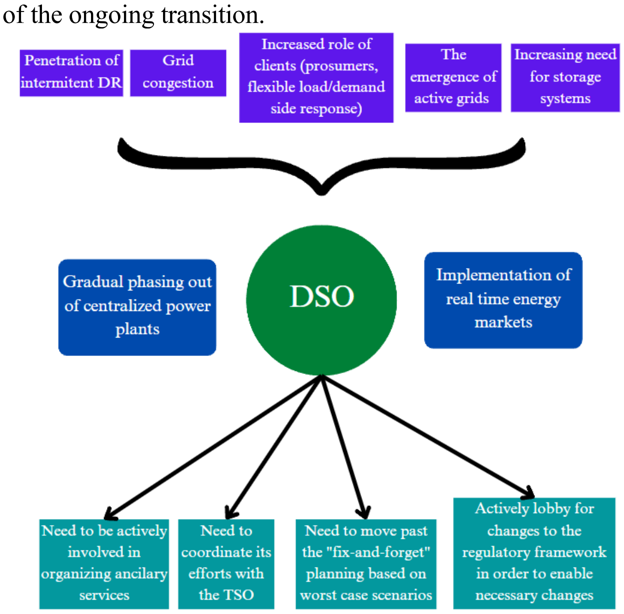

Fig. 2 – Centralized view of the changing role of the DSOs. Adapted after: Corsetti, E. *et al*. (2020).

A centralized view of the forces that push for the change of the role of DSOs, their main tasks, and the obstacles to overcome is represented in Fig. 2. Several reflections from the industry were shared in [12], which seem to strengthen the assumptions made by the previously mentioned sources related to the need for change in the role of the DSO. It appears that, in practice, the coordination between DSOs and TSOs is less efficient within a decentralized system compared to a centralized one. Furthermore, small DSOs may need to pool up since local congestion markets require enough participants to ensure the necessary competition to prevent scarcity of liquidity. Finally, since investments in storage solutions and flexibility seem to be done by private investors mainly, it is up to regulatory bodies to determine the suitability of said solutions and the proper incentive mechanisms for potential investors, not the system operators who were normally in charge of planning such aspects.

4. SUGGESTED EVOLUTION FOR THE NEW ROLE OF DISTRIBUTION SYSTEM OPERATORS

Academic and industry papers present multiple views on the evolution of DSOs' role in the transition to a decentralized system in the following years.

Beginning with the future collaboration between the DSO and TSO, the industry opinion, represented by [4], is that the two operators should work together to envision markets that create value and allow all network customers to interact by exchanging energy services. [4] envisions this process in three phases, which can be summed up as follows: The first phase should focus on strengthening the grid to withstand all elements that come together to form the decentralized system (DER, EV-charging, DR). The second phase should see the mass deployment of digital solutions, which will allow customers to have an active role by offering to increase or decrease their consumption to best match the grid's needs. The role of the operators will be to shape the market in such a way as to enable ancillary services offered by aggregators and DER owners with tariffs that better reflect costs. The third and final phase should focus on enabling European active networks to confer grid stability, smart networks, and microgrid platforms [4].

On the side of academic papers, the dynamic between DSOs and TSOs is explored in multiple articles in the context of decentralization and decarbonization.

Firstly, when it comes to the penetration of RES, the importance of collaboration is explored in [13] through the lens of optimally using the existing resources and their synergies as closely as possible to real-time events. TSOs must always balance supply and demand, but DSOs oversee capacities and DG interconnection requirements since they are situated within the distribution network. Thus, with the growing penetration of DER, the role of DSOs should evolve from having a detailed overview of all existing assets from the distribution network to having clearly defined procedures regarding load forecasting, deployment, and managing congestions and other hazards to the system's functioning. Eventually, DSOs may need to be involved in setting and coordinating local constraint prices with those of the TSO. However, although DSO and TSO collaboration will be important in managing the existing DER capacities, ultimately, the success of the DER penetration will be decided by clear market rules that offer the proper compensation for the services DER owners offer.

On the same subject, [14] offers a centralized view related to the DSO and TSO coordination efforts: the traditional coordination of the two operators cannot function in the same way in the context of a decentralized system since visibility over a large number of RES would imply high computational requirements [15] which the TSO does not poses; furthermore, a decentralized system is prone to imbalances and instability.

In terms of implementing the DSO and TSO coordination model, most problems are expressed as optimization problems. The main advantages are its flexibility (easy connection and disconnection of DER), its non-costly communication, and the fact that data privacy may be ensured. Detailed examples of these problems may be found in [16,17].

Going back to the point of view of the industry, in terms of new technologies that DSOs will have to consider while managing the grid, [18] lists the following technologies and the corresponding solutions and recommendations from the perspective of cost and innovation:

Distributed generation – although on paper it sounds attractive to have as many homes equipped with RES technologies, in practice, it only makes long-term sense to invest in places where it is economically viable (*e.g.*, areas where constraints related to land use, congestion, and other factors are in place). Furthermore, incentives should be granted based on outcome, not by favoring certain technologies to encourage innovation.

Demand response – for DR to become attractive to consumers, especially residential ones, a series of factors must come into play. Firstly, the experience of the consumers while benefiting from DR should be seamless and intuitive and offer transparent details on what is happening and why. The World Economic Forum remarks that, ideally, automated, and self-learning technologies should be used, but this gives rise to certain risks that may very well deter the average customer from investing in DR [18]. Secondly, interoperability between devices should be ensured. This would make DR more accessible, as single technology standards work in favor of the customer and limit inconveniences and confusion. Thirdly, independent aggregators should integrate DR into their portfolios to ensure an increase in the bargaining power of consumers. Finally, price signals should be used to inform clients when their flexibility may be most profitable.

Energy efficiency – a key component in reducing long-term costs and energy consumption, and implicitly the pressure exerted on the grid, energy efficiency may seem daunting for most consumers since costs are high initially and investments tend to pay off after long periods. However, with the right tools in place, such as gradually opting out of using less efficient technologies and customized offers for energy-conscious clients, energy efficiency can become more accessible for the average consumer.

Storage – the next major step in ensuring the reduction of CO_2 emissions and distributed storage must be included in system planning along with other smart grid options.

Electric vehicles – in a simplified way, EVs are a form of mobile storage presently not exploited enough by both their owners and system operators. Since cars are mostly unused during their lifetime (most of the time, vehicles are just parked), their potential remains unexploited. EV batteries are becoming more technologically advanced every year, so charging vehicles during nighttime. At the same time, prices are lower to unload some energy during the day in exchange for monetary revenue may soon become very accessible. To truly make use of the potential of EVs, mass electrification of private sector fleets should be encouraged.

Digitalization – one of the most important steps on the path of digitalization is the development of data laws that allow for safe data transfers among market actors. Integrating data used in existing and future business models is also essential. Finally, continuing the recommendations for DR, interoperability standards among devices should be established.

The previously described technologies should be considered for DSOs to continue functioning properly in a decentralized system. In [19], it is noted that the transition to a decentralized power system won’t be easy since the financial efforts related to the interconnection of DER would involve considerable costs, which will be reflected in consumers' energy bills. However, a new business model that can take advantage of DER is proposed. The DSO-grid services platform coordinator model involves a shift from the traditional way a DSO provides value to that of a market platform provider.

In [20], it is considered that the spread of DG represents a threat to the current business model of DSOs since their integration can pose a real challenge. However, by evolving its business model and switching to an active network operation, the DSO can surpass the potential challenges and turn threats into opportunities. The use of advanced information exchange between producers and consumers, providing ancillary services like what is described [21] at the distributed level, and improving clients' lives by reducing costs and improving their overall benefits is described in [20].

In [4], it is written about how DSOs are at the heart of energy transition and considered crucial. However, as mentioned in [20], along with the DSO, regulations must also evolve.

In [22], an industry specialist criticizes the fact that although the need for investments in the grid cannot be denied, regulators do not approve necessary investments or incentivize such actions. However, during the ongoing energy crisis, increasing energy bills would only be possible to further burden the consumer by making complex changes to the grid, which would translate into higher costs for the end consumer.

Regarding the future collaboration between DSOs and their clients, since the role of DER and prosumers will only increase in the upcoming years, DSOs must plan how to tackle an active consumer. In [23], the role of emerging energy communities is explored in depth by using an example of planning for a microgrid in Malmo. Although the conclusion of [23] is that the microgrid itself is not feasible, considering its high costs, low environmental benefits, and above all, the fact that the current legislation does not support it, what stands out is the poor relationship between the developer of the project and the local DSO.

5. **OUTLOOK OF DSOS IN ROMANIA**

In Romania, six DSOs split based on geographical regions (Fig. 3). Starting in the early 2000s, the governmental bodies of that time split said company into eight, each corresponding to a geographic region. Out of the initial eight companies, nowadays there are five private DSOs and one state-owned DSO. Their role, in their capacity as concessionaires, is to provide electricity distribution services. Their activities are fully regulated.

Fig. 4 – Romanian distribution system operators divided by geographical regions.

Considering the three phases described in [4] regarding the transition towards a decentralized power system, Romania is right before the first phase. This is reflected in [24] by the fact that starting in 2021, there has been an exponential increase in installed small (less than 100 kW) production capacities.

At the same time, the construction of new small nuclear reactors is underway. At the same time, the number of EVs that need charging from the grid continues to grow. Thus, it will become of the utmost importance for the DSO to focus on strengthening the grid's resilience so that it can withstand the increased supply and demand. As stated in [25], the pace of the transition varies depending on the rate of DER growth.

Looking at the second phase described by [4], Romania may possess an unexpected advantage in deploying digital solutions since the country is currently regarded as a hub for digital innovation.

Following the application of regulation 2019/943 of the European Parliament and the Council of the European Union on the internal electricity market [26] from the 1st of January 2020, an entity of distribution system operators in the European Union (EU DSO entity) was established. The entity was established because of the DSOs' representation regarding the development of network codes and guidelines. Besides strengthening DSO cooperation, the entity facilitates the cooperation between DSOs and TSOs. Since establishing the entity, all six DSOs from Romania, with a cumulated number of over nine million customers, have joined as members of The EU DSO entity.

Furthermore, in October 2022, the Romanian regulator released an order [27] for congestion management through the market-based use by network operators of the flexibility of resources in the distribution networks and those in the transmission network, which aims at deepening the cooperation between DSOs and the TSO in the context of shifting to a decentralized power system characterized by an increased number of prosumers, DG and increased need for flexibility.

After further analyzing the Romanian energy system, the following challenges have been identified:

– Due to the large number of new prosumers, the DSOs are facing major difficulties in connecting newly added production capacities to the grid, as strict deadlines are enforced by the regulatory framework.

– DSOs must also purchase IT systems that collect data regarding onsite production and process said data later.

– From a technical point of view, following the recent increase in the number of prosumers, overvoltages at the invertor level are being denounced by clients more frequently.

Such issues can be solved with large investments, but a major constraint DSOs face is that all expenditures must be supported by the final consumer, who is already burdened by the increased energy price.

Judging by the present context, although shifting towards a decentralized power system will continue in the upcoming years, it is highly unlikely that the DSO will be able to take the necessary steps toward changing its role due to the high expenses associated with the incurred investments.

In decentralized energy innovation and transition, grid operators cannot contribute positively to institutional change due to the European financial and socio-political context. This limitation is not exclusive to Romania, as all member states face similar challenges.

6. CONCLUSIONS

Regardless of the background of the sources in question, most of the literature under review concludes that DSOs can only continue their activities in the upcoming framework if they change their current business models. With a transition driven by environmental and, more recently, socio-political factors, the shift to a decentralized power system is underway. DSOs are the key entities from the power sector that can either facilitate or impede its course.

The DSO's roles in the current centralized power system are owning, running, managing, maintaining, and expanding a distribution network and interconnecting points with other networks.

The research hypothesis has been validated by the fact that there is an extensive collection of papers that discuss the need for changes in the way DSOs manage their businesses in the context of shifting towards a decentralized power system. Furthermore, governing bodies such as the European Union push for changes in the activity of participants in the power sector (including DSOs) by releasing directives that anticipate and mitigate the challenges associated with DG and DR.

For the DSO to maintain its relevance in the decentralized power system, it must:

- actively collaborate with the TSO to ensure the smooth operation of the power system and avoid congestion and blackouts;
- actively lobby for changing the regulatory framework in such a way that its role may evolve, expand its service portfolio to organizing ancillary services;
- closely collaborate with its customers by encouraging and appropriately rewarding their active involvement in the energy markets.

Existing literature, as well as new directives, also suggest that such challenges may be met by DSOs by either:

- working closely with TSOs and aggregators;
- or by scaling down their operations to smaller areas (microgrids).

Digitalization and smart grids will help DSOs conduct their maintenance services promptly by providing real-time information regarding the state of the grid. To ensure the safe operation of the grid, investments must be made in the existing infrastructure so that overall resilience is increased. To do so, DSOs must lobby for an increase in the budget towards regulators while ensuring that these costs do not make the energy bills unbearable for consumers.

In section 5, the model presented in [4] was adapted to identify where Romania is situated among the phases of transitioning towards a decentralized power system. For future research, the author advises extending the research made in this article to other countries to find alternative solutions to increase grid investments without impacting energy bills [28]. Furthermore, after uncovering the surface-level situation in Romania related to energy poverty, the author considers that this topic should be analyzed in depth in a separate article. Finally, given that the energy sector is tightly intertwined with multiple industries, future articles are encouraged to identify the impact that the shift to a decentralized power system may bring to the respective industries regarding price increases, technological innovation, and investment opportunities.

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