

# Challenges facing distribution system operators in a decarbonised power system

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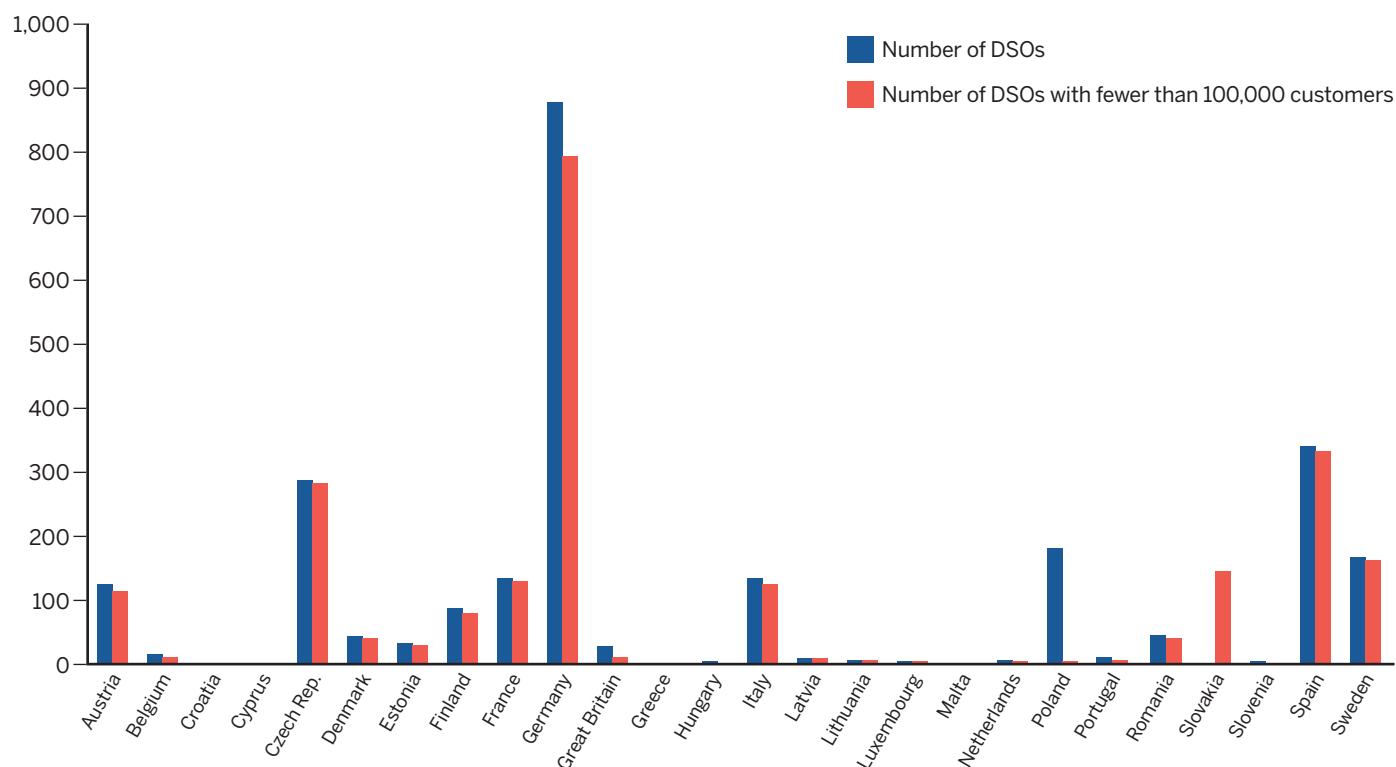
# Distribution system operators in a decarbonised power system

Europe's distribution networks are undergoing fundamental change. The need to accommodate increasing amounts of variable renewable generation such as wind and solar, the growth in prosumerism and active consumers, and the electrification of the heat and transport sectors are posing major challenges that will only intensify in the years ahead. Addressing these challenges and ensuring that the energy transition can progress cost-effectively will not only require the owners and operators of these networks to embrace innovation and develop new ways of working but could also result in significant structural change.

## Where are we now?

Distribution system operators (DSOs) across European countries vary considerably in number and size. Some, such as Enel, operate across continents and have many millions of customers. At the other end of the spectrum, some DSOs are very small, with only tens of thousands of customers. Switzerland, for example, with a population of just 8.5 million, has around 900 DSOs. As shown in Figure 1,<sup>1</sup> Europe had approximately 2,400 DSOs from 2012 to 2015, many with fewer than 100,000 connected customers for the same time period.

Figure 1. Electricity distribution system operators in European Member States, 2018



Source: Council of European Energy Regulators. (2019). *Status review on the implementation of TSO and DSO unbundling provisions*.

1 Council of European Energy Regulators. (2019). *Status review on the implementation of TSO and DSO unbundling provisions*. Retrieved from <https://www.ceer.eu/documents/104400/-/-/f69775aa-613c-78a5-4d96-8fd57e6b77d4>



Some DSOs are privately owned and heavily regulated. Most, however, are publicly owned and subject to less intrusive regulation. Although all DSOs share common core activities such as distribution asset ownership and network management, many are also responsible for related activities such as metering and data management. In addition, many utilities operate supply businesses or own and operate gas networks. Some provide non-energy services such as telecommunications, cable television, water and sewerage. The extent to which networks are unbundled from other energy businesses varies across Europe. In the Netherlands, all DSOs are ownership unbundled, while most Member States have implemented the legal unbundling required by EU regulation. A significant number of European DSOs, however, are only organisationally unbundled under the EU *de minimis* exceptions.<sup>2</sup> For example, more than 700 of the 880 DSOs in Germany are unbundled and have supply and other businesses.

Despite considerable variation in the range of activities undertaken by utilities involved in electricity distribution, we do see a high level of homogeneity in electricity distribution asset ownership and network management. In contrast to transmission systems, distribution networks are almost invariably radial and tapered<sup>3</sup> in nature, traditionally designed only to handle unidirectional flows. Generally, they are passively operated as so-called fit-and-forget networks, having little or no reliance on any generation or other connected resource for security. At the medium-voltage and low-voltage levels, there is little supervision or metering, and in general, DSOs currently have little need for any system management capability. The generally radial nature of the distribution networks leads to low utilisation rates. Together with the use of fixed-tap or off-load tap changing facilities for voltage control on medium-voltage and low-voltage transformers, this often results in voltage constraints that prevent full use of the available thermal capacity.

Regardless of the similarities in design and operation, the variation in DSO size, ownership and activities presents difficulties in envisioning the future DSO — there may not

be a “one size” to fit all. However, focussing on the core DSO activities of distribution asset ownership and operation, we can attempt to identify the challenges that all DSOs will face in facilitating the energy transition. We can also consider how the consequences of addressing those challenges might influence the shape and role of DSOs in the future.

## Challenges, impacts and implications

It is estimated that Europe’s distribution networks will require between 230 and 350 billion euros<sup>4</sup> of investment during the next decade. The funds are meant not only to accommodate the forecast growth in electric vehicles (EVs), increased electrification of the heat sector and growth in distributed renewable energy sources but also to replace aging network assets. Managing this scale of investment will be a major challenge in itself, not least because of the considerable uncertainties about the timing, scale and pace of change. This investment challenge, however, also presents a huge opportunity to progress from the radial, passive networks we have today to networks that are more interconnected in nature. We can also embrace emerging technologies designed to both accommodate and take advantage of the distributed resources and more flexible demand that will be connected to the network in the future.

To determine what this implies for the DSO of the future, we consider a range of probable challenges below, together with some possible implications. For convenience, and despite considerable interaction between specific challenges, these are grouped under the headings of

- Accommodating the growth of distributed renewable energy sources, prosumers and active consumers.
- Electrification of the heat and transport sectors.
- Community energy.
- The development of local, versus national, markets.

Although the list of specific challenges is long, it is not exhaustive and other challenges may exist or emerge that are not listed here.

2 Exemptions from the EU legal and functional unbundling requirements are possible for DSOs serving less than 100,000 connected customers.

3 In tapered networks, network capacity decreases with voltage level and distance from primary substations.

4 European Parliament, Directorate-General for Internal Policies. (2017). *European Energy Industry Investments*. Trinomics and Öko-Institut. Retrieved from [http://www.europarl.europa.eu/RegData/etudes/STUD/2017/595356/IPOL\\_STU\(2017\)595356\\_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/STUD/2017/595356/IPOL_STU(2017)595356_EN.pdf)

## Accommodating the growth of distributed renewable energy sources, prosumers and active consumers

### A move to actively managed networks

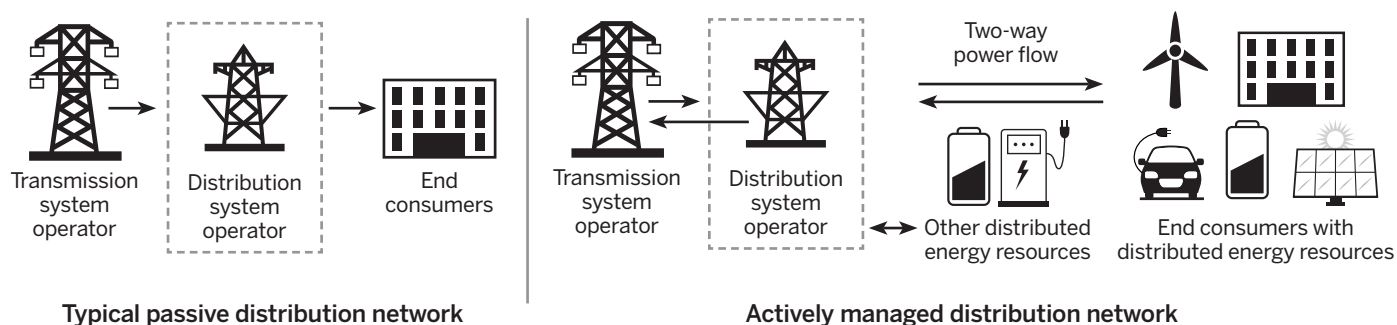
The Clean Energy for All Europeans legislative package<sup>5</sup> makes very clear that consumers are to be at the heart of the energy transition. Increasing numbers of domestic consumers will become active market participants, producing energy for their own consumption and exporting surpluses to the distribution network. They will also adjust their demand via storage or other means in response to price signals or other incentives. In addition, generators will connect increasing amounts of commercial, higher-capacity photovoltaics (PV), wind, storage and other generation resources to the medium-voltage or high-voltage distribution networks. Collectively, the growth in distribution connected generation capacity will radically change the nature of power flows on the distribution networks. As shown in Figure 2,<sup>6</sup> the flows will become more volatile and bidirectional. It should also be noted that the growth in distributed generation capacity will reflect an ongoing transfer of generation capacity from the transmission to the distribution networks. These distribution connected resources will become increasingly important for overall supply, energy balancing and security and resilience. In this context, targeting demand-side management solutions

for specific geographic locations will become increasingly valuable, particularly where it addresses local grid constraints.

Managing this transition in a cost-effective fashion will require distribution networks to become dependent on these distributed resources for security and quality of supply — much in the same way that transmission systems are dependent on transmission-connected generation. The alternative of maintaining a fit-and-forget culture, with distribution networks continuing to be independent of those resources for security purposes, would be prohibitively expensive and could pose a real threat to the economic viability of the energy transition.

To achieve this integrated approach to security, DSOs will be required to develop many of the system management skills currently deployed by transmission system operators (TSOs). They will be required to develop or utilise market-based solutions to procure, schedule and dispatch the necessary connected resources in order to manage constraints and maintain network security. DSOs will need advanced supervisory control and data acquisition network management facilities to provide real-time monitoring and control of network assets and to provide the intelligence necessary to support the procurement process. In fact, as DSOs will be dealing with many thousands of prosumers and active customers — rather than the hundreds of customers typically served by a TSO — the network management task will be that much greater than TSOs are currently seeing. Managing a highly decentralised electricity system to traditional levels

Figure 2. Traditional and modern distribution networks



Source: International Renewable Energy Agency. (2019). *Future role of distribution system operators*.

5 European Commission. *Clean energy for all Europeans package* [Webpage]. Retrieved from <https://ec.europa.eu/energy/en/topics/energy-strategy/clean-energy-all-europeans>

6 From Anisie, A., Boshell, F., and Ocenic, A. (2019). *Innovation landscape brief: Future role of distribution system operators*. International Energy Agency. Copyright 2019 by International Energy Agency. Retrieved from [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA\\_Landscape\\_Future\\_DSOs\\_2019.PDF?la=en&hash=EDEBEDD537DE4ED1D716F4342F2D55D890EA5B9A](https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Landscape_Future_DSOs_2019.PDF?la=en&hash=EDEBEDD537DE4ED1D716F4342F2D55D890EA5B9A)

of security and resilience will be a huge challenge. The successful transition to actively managed distribution networks will largely be dependent on DSOs' ability to successfully embrace digitalisation<sup>7</sup> for both operational management and market operation.

Given the ongoing transfer of generation capacity from the transmission to distribution systems, distributed resources will increasingly be required not only to support distribution network needs but also to provide transmission system services previously provided by plants connected to the transmission system.<sup>8</sup> DSOs, together with third-party aggregators or virtual power network operators, will have a role in providing these replacement services. However, as many of these services could be used to manage either transmission or distribution network issues — the requirements of which may on occasion be in conflict — TSOs and DSOs may find themselves in competition. Some means of identifying how best to utilise particular services in particular circumstances will therefore need to be found. How to resolve these issues and how best to manage an increasingly complicated and active TSO-DSO interface will be a critical issue going forward.

## The role of regulation

Regulation will be key to facilitating the changes in DSO behaviour necessary to deliver a successful energy transition. DSOs must be appropriately incentivised to embrace digitalisation and innovation in the operation and design of distribution networks. Consumers, on the other hand, will need encouragement to move consumption away from network peak periods to keep investment requirements to a minimum.

Encouraging consumers to shift demand will require tariffs that reflect the costs consumers impose on the network as well as the value they can offer to the network. Incentivising DSOs will require a move from regulatory

mechanisms that are primarily based on capital expenditures (CAPEX) to those based on total expenditures (TOTEX). The latter objectively values traditional asset-based investment and operational alternatives to that investment involving prosumer and flexibility services. The goal is to ensure that DSOs are indifferent in choosing between asset-based and operational alternatives. To achieve this, regulation will need to (a) recognise that we will need to reduce cost recovery and depreciation periods for operational solutions, (b) take into account the increased risk of innovative investments and (c) provide specific financial opportunities to trial innovative, but unproven, solutions.

Given the natural bias of DSOs toward asset-based solutions, it will also be necessary to adopt other measures that ensure a more objective and transparent approach to network planning and operation. Network needs must be made apparent to the market, giving potential providers the opportunity to tender services that will meet those needs. All major network development proposals should be tested against non-wire solutions before expenditure is approved or the network is expanded. In addition, network planning and operational standards must be developed to ensure that the contribution to security made by prosumer and flexibility providers is properly valued. Only then can proper economic assessments between traditional asset-based schemes and operational alternatives be made.

Providing DSOs with the appropriate incentives is also likely to require a shift from input-based regulatory mechanisms, which focus primarily on investment, to output-based mechanisms or performance-based regulation. The outputs against which DSO performance is assessed and revenues are earned should be designed to reflect both what customers value most, such as security and quality of supply, good customer service and the like, together with desired energy and environmental policy outcomes.

7 Digitalisation will involve a number of facets, including: the deployment of smart metering as a means of accommodating prosumerism and demand flexibility and providing a more detailed understanding of customer behaviour; customer access to that data; exploiting the inherent capacity of network assets through the widespread deployment of sensors and big-data analytics; transparency of network capability and constraints via market platforms; cybersecurity; the introduction of digital network technologies and the automation of operational processes.

8 For example, National Grid's electricity system operator estimates that distributed generation capacity in Great Britain could amount to 39% of total capacity by 2030 and 55% by 2050. National Grid Electricity System Operator. (2019). *Future energy scenarios*. Retrieved from <http://fes.nationalgrid.com/media/1409/fes-2019.pdf>



## Paying for network services

The growth of prosumerism is raising issues over how network services should be charged. Most DSOs, and the national regulatory authorities that regulate them, will have a duty to ensure that charges for network use are generally cost-reflective and avoid cross-subsidies between network classes wherever possible. In fact, the recently adopted Electricity Regulation requires that network tariffs must reflect actual costs and must be applied in a nondiscriminatory fashion.<sup>9</sup>

Traditional thinking about network cost causation and pricing, long a matter of debate, is now seriously undermined.<sup>10</sup> Until the emergence of prosumerism, a consumer's consumption, summated over short periods, provided a good proxy for peak consumption, therefore justifying volumetric charges. With the growth of distributed PV in particular, the relationship between consumption over network peak demand and total consumption metered on a net basis has changed. New arrangements are needed to fairly allocate the recovery of allowed network costs. In fact, the emergence of a world where consumers are no longer a homogeneous group — they may be PV customers, EV customers, customers who have embraced energy efficiency measures or just plain customers, all having different consumption and network cost profiles — is causing NRAs across Europe to reconsider how to recover network costs.<sup>11</sup> In addition to incentivising customer behaviours that are consistent with the energy transition, future tariffs will need to take into account the costs and benefits that individual consumer classes impose on or bring to the network. The deployment of smart metering will provide the data necessary to allow a consumer's impact on network costs to be determined and cost recovery to be allocated more fairly among emerging customer classes, so avoiding unwanted cross-subsidisation.

## Electrification of the transport and heat sectors

### Electrification of transport

The electrification of the transport sector offers significant opportunities; it could also lead to significant increases in peak demand. This rise could potentially result in a need for increased investment in generation capacity and in both transmission and distribution network capacity. The impact on networks from electrifying the transport sector, however, is likely to be most keenly felt at the low-voltage or medium-voltage level. Clusters of individual households charging their vehicles at 7kW, 11kW or even 22kW/hr (three-phase supply) could clearly have significant implications for distribution systems that are generally designed around customers having a low simultaneous peak demand contribution — typically around 1.5kW. Consequently, in order to limit investment needs due to an increase in network peak demand from the electrification of transport, DSOs will need to encourage demand flexibility and shift demand from network peak to off-peak periods through the use of smart network charging, responsive demand and more economically efficient time-varying rates.

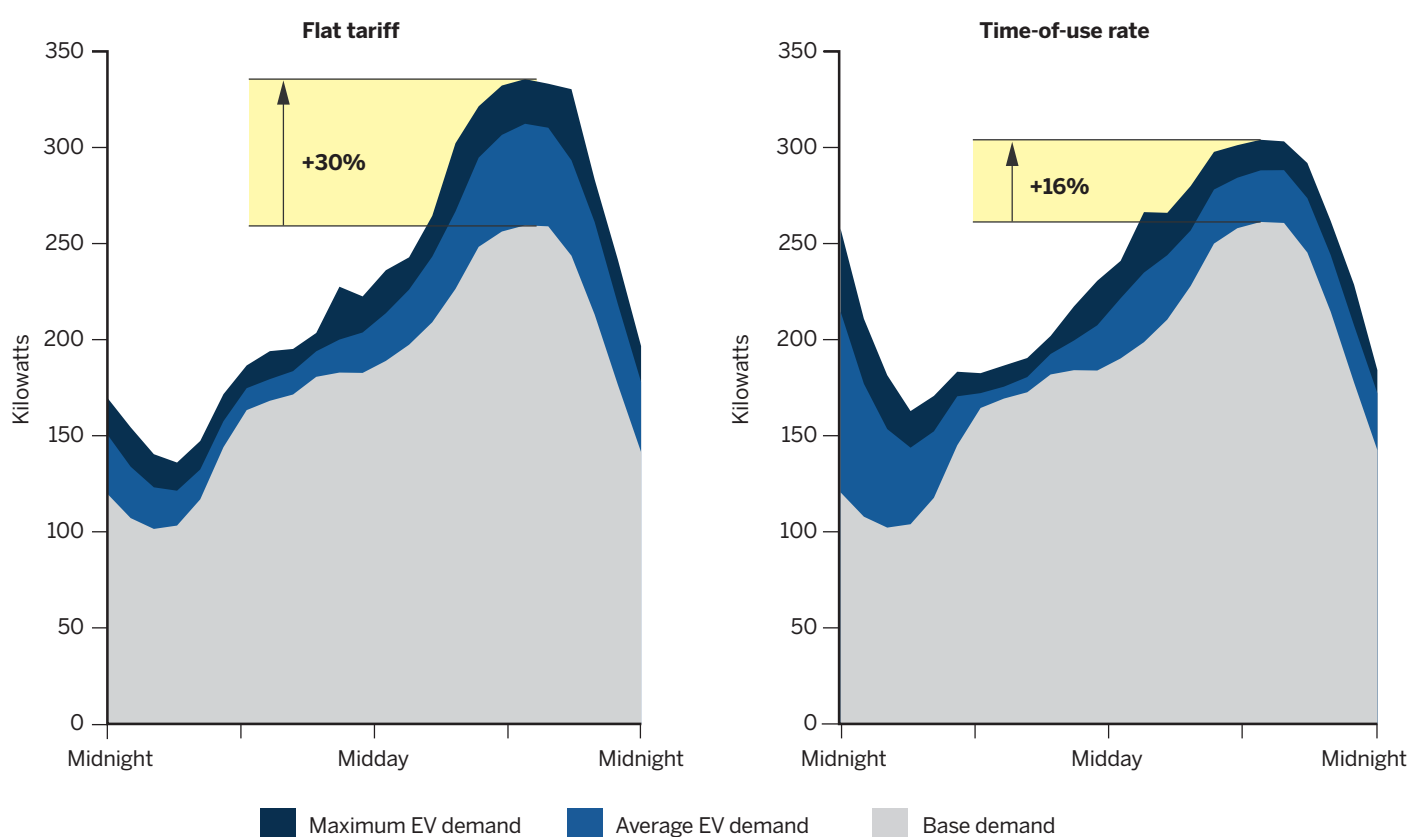
Evidence from a number of pilots in Europe indicates that smart charging or flexible charging — meaning shifting the time of charging to periods when the grid is under less stress — has the potential to considerably reduce network overloading and the consequent need for reinforcement. The My Electric Avenue pilot in the UK, for example, indicates that, taking slow inflexible charging as a base, fast inflexible charging would reduce the number of EVs able to connect to a typical low-voltage network by two-thirds before overload. Fast *flexible* charging, on the other hand, would almost double the number able to connect.<sup>12</sup> However, just how

9 European Parliament and Council of the European Union. (2019, June 5). Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (recast). Article 18 (7). Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943&from=EN>

10 The debates revolved around the nature of an individual customer's contribution to system peak and to the shared costs of the network. The simplifying assumptions that planners have historically made deserve scrutiny in this new environment.

11 Just how charging methodologies will change is unclear. However, there is general recognition that simple volumetric charging is no longer applicable and that the charges customers face should fairly reflect the costs that they impose on the system. This suggests a move toward time-of-use charges based on demand (or consumption) at the time of network peak, with any residual revenue recovered in a fashion that least distorts the economic signals delivered through those time-of-use charges.

12 Office of Gas and Electricity Markets (Ofgem). (2018, July). Ofgem's future insights series: Implications of the transition to electric vehicles. (Paper 5). Retrieved from <https://www.ofgem.gov.uk/publications-and-updates/ofgem-s-future-insights-paper-5-implications-transition-electric-vehicles>

**Figure 3. Illustration of potential impact of time-of-use charging on feeder circuit loading**

Source: Engel, H., Hensley, R., Knufper, S. and Sahdev, S. (2018). *The potential impact of electric vehicles on global energy systems*.

effective smart charging will be in the real world is likely to depend on customer acceptance. This, in turn, is likely to be influenced by the financial incentives DSOs are able to offer via network tariffs, incentives that will presumably need to reflect the avoided cost of network investment. An analysis by McKinsey & Company based on U.S. data, shown in Figure 3,<sup>13</sup> suggests that “smart” time-of-use network tariffs could almost halve network peak loads, significantly reducing, but not eliminating, the need for reinforcement of the medium-voltage and low-voltage networks.

In addition, DSOs will also need to design and operate the distribution networks so that available thermal capacity is more fully utilised. This is likely to involve

- A shift from radial to a more interconnected network design.

- Enhanced network supervision, particularly at medium-voltage and low-voltage levels, where supervision is typically limited.
- Advanced voltage control that can manage the impact of more volatile and bidirectional flows.
- Self-healing networks.
- The management of fault levels through the use of automatic switching or smart fault-limiter devices.

This all points to a radical shift in the manner in which distribution networks are designed and operated. With this shift, digitalisation can provide both increased visibility of network status and network demand, leading to increased network utilisation. DSOs should not expect to use the EV transition as a mechanism to justify traditional investment if more cost-effective alternatives exist. In addition, if well planned, this shift in network design could be integrated

<sup>13</sup> Calculations assume 150 households per feeder, two vehicles per household and 25% EV penetration. The local shape for a typical feeder with 150 houses at 8 MW/year; example shown for Midwestern United States on a typical September day. Midnight time-of-use rate; 90% of users adopt; users begin charging immediately if time-of-use benefit is more than 10 hours from trip end. The average plug power is assumed to

be 3.7 KW, with an average trip of 62 kilometres. Averages and percentiles calculated for 50 days. Engel, H., Hensley, R., Knufper, S., and Sahdev, S. (2018, August). *The potential impact of electric vehicles on global energy systems*. McKinsey & Company. Retrieved from <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-potential-impact-of-electric-vehicles-on-global-energy-systems>

into established network investment cycles, minimising additional costs.

It may also be necessary to rethink how we define customers' right to access the network. Unlike for larger customers, access rights for domestic customers are not usually well defined, being effectively capped by the size of the service cut-out fuse. As fuse sizes can range up to 100 amp, equivalent to around 25kW, and distribution systems are generally designed around a 1.5kW simultaneous customer contribution to peak demand, DSOs may in future need to retain the ability to curtail EV charging or consumption in certain exceptional circumstances.

As mentioned, the growth of EVs also represents considerable opportunities for DSOs. For example, the development of a vehicle-to-grid (V2G) capability or "second-life" battery storage applications will provide an additional source of ancillary services for use at both a system and a local level. Static second-life battery projects are already making a significant contribution to ancillary services such as enhanced fast frequency response. They are also in the early stages of contributing to balancing and intraday markets.

V2G is currently less well developed but could in time compete with static battery applications in the provision of ancillary services or in the balancing and intraday markets. This may, however, depend on the incentives available. Nissan and Nuvve<sup>14</sup> have suggested that the annual V2G earnings potential could be as high as 1,800 euros per EV, although a recent report by Cenex suggests a lower earnings potential of around 440 euros per EV.<sup>15</sup> What is clear, however, is that, ultimately, the electrification of transport will massively increase the storage capacity available to the electricity markets, in the form of either plugged-in EVs or static second-life batteries.<sup>16</sup> This is likely to have a fundamental

impact on the operation of those markets by attenuating some of the price volatility associated with the continued deployment of intermittent renewable energy sources, reducing curtailment of renewables and also providing some of the network services currently supplied by conventional generation. In terms of providing local distribution network services such as constraint management, it may be that the dispersed nature of V2G can provide a significant advantage over large, static, second-life applications.

## Electrification of heat

Although the route to decarbonising the heat sector is currently uncertain, it is clear that electrification will play a significant role.<sup>17</sup> Compared with the electrification of transport, however, heat sector electrification could potentially have an even greater impact on the distribution networks, if air source heat pumps are deployed without coordination. Without countermeasures, experts estimate that the nonoptimised deployment and operation of air source heat pumps could raise the average customer contribution to simultaneous peak demand by up to 4kW. This would nearly triple the currently assumed contribution.<sup>18</sup> We can avoid these peak periods through automation to make use of heat pumps' inherent flexibility. A study by Dong Energy Distribution/Orstedt illustrated the willingness of consumers to allow periodic control of their heating systems to avoid peak load.<sup>19</sup> The authors conclude that cascading heat pumps would be the most effective way to avoid excessive contributions to peak load.

As Europe increases the use of air source heat pumps, it is critical to know that they not only increase overall household electricity demand but also the network peak coincidence factor<sup>20</sup> because heat pumps operate over network

14 Andersen, P. B., Toghroljerdi, S. H., Sørensen, T. M., Christensen, B. E., Hoj, J. C. M. L., and Zecchino, A. (2019). *The Parker project: Final report*. Retrieved from [https://parker-project.com/wp-content/uploads/2019/03/Parker\\_Final-report\\_v1.1\\_2019.pdf](https://parker-project.com/wp-content/uploads/2019/03/Parker_Final-report_v1.1_2019.pdf)

15 The energyst. (2019). *2019 EV report: EVs, smart charging, V2G*. Retrieved from <https://theenergyst.com/wp-content/uploads/2019/04/The-EV-Report-2019-1.pdf>

16 Element Energy Ltd. (2019, 10 May). *Batteries on wheels: The role of battery electric cars in the EU power system and beyond; Technical appendix*. Retrieved from [https://www.transportenvironment.org/sites/te/files/publications/2019\\_06\\_Element%20Energy\\_Batteries\\_on\\_wheels\\_Technical\\_appendix.pdf](https://www.transportenvironment.org/sites/te/files/publications/2019_06_Element%20Energy_Batteries_on_wheels_Technical_appendix.pdf)

17 Rosenow, J., and Lowes, R. (2020). *Heating without the hot air: Principles for smart heat electrification*. Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/heating-without-hot-air-principles-smart-heat-electrification/>

18 DELTA Energy & Environment. (2016). *Managing the future network impact of electrification of heat: Final report for ENWL*. Retrieved from <https://www.delta-ee.com/downloads/30-consultancy-downloads/873-managing-the-future-network-impact-of-electrification-of-heat.html#>

19 DONG Energy Eldistribution A/S. (2012). *The eFlex project*. Retrieved from <https://de.slideshare.net/JonathanDybkj/the-eflex-projectflow>

20 Coincidence factor is the fraction of the peak demand of a population that is in operation at the time of system peak. Thus, it is the ratio of the population's demand at the time of the system peak to its noncoincident peak demand. Stern, F. (2013, April). *Chapter 10: Peak demand and time-differentiated energy savings cross-cutting protocols*. The uniform methods project: Methods for determining energy efficiency savings for specific measure. National Renewable Energy Laboratory. Retrieved from <https://www.energy.gov/sites/prod/files/2013/05/f0/53827-10.pdf>

peak and for sustained periods. This is particularly the case during cold weather, when the efficiency of air source heat pumps declines. Clearly, the mass introduction of air source heat pumps could have a considerable impact on the need for distribution network capacity reinforcement. Analysis suggests that planning for a 1-in-20 network peak could result in an increase in required investment of 3.3 billion pounds sterling, or 3.78 billion euros, and 21,500 interventions by 2030 in just one UK DSO alone. For Great Britain as a whole, analysis suggests a total increase in DSO costs of 21 billion and 30 billion pounds sterling (24 billion and 34 billion euros, respectively), if we assume the installation of air source heat pumps in 10 million homes, some 38% of the total possible.<sup>21</sup> Clearly, the measures referred to in the previous paragraph would need to be deployed if these costs are to be mitigated.

Energy efficiency measures, together with increased thermal storage in buildings that would allow preheating, could also help significantly reduce network investment needs associated with the electrification of heat. The new generation of hybrid heat pumps, electric storage heaters (smart electrical thermal storage), thermal stores and heat batteries using phase-change materials offer increased efficiency and the ability to store heat generated during low-demand periods. The deployment of these emerging technologies will not only reduce the need for heat-related network reinforcement but will also provide enhanced flexibility and allow the increased deployment of intermittent renewables.

DSOs and regulators need to recognise the potential of these technologies to reduce the need for network reinforcements. Under current legislation, DSOs, other than those falling below the de minimis exception threshold, would be prevented from actively marketing energy efficiency or heating systems or undertaking any activity that

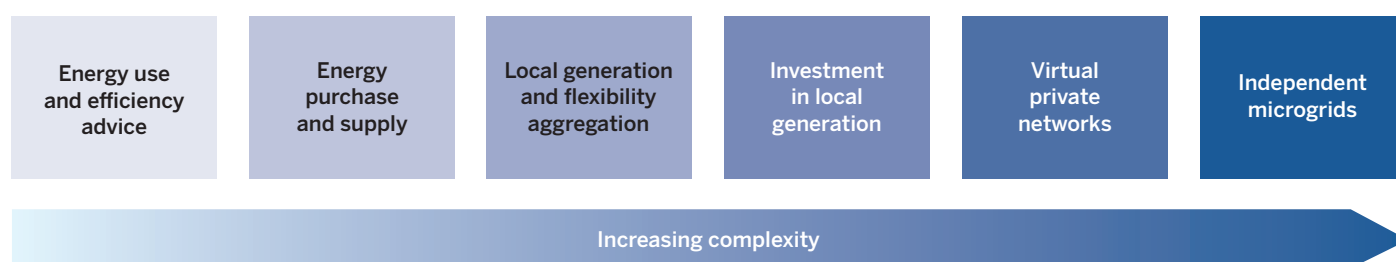
might undermine competition in the delivery of services. It is unclear whether this position will be appropriate in the longer term, given the need to electrify the heating sector. However, assuming that this prohibition remains in place, it will be important that the use of network tariffs fully reflects the costs that technologies such as air source heat pumps are likely to impose on the distribution networks and the collective benefits available from alternative technologies. Only then will customers be able to make informed judgments about which technologies to purchase.

## Community energy

The Clean Energy for all Europeans package supports the development of “citizens’ energy communities,” enabling those customers who wish to participate collectively in the energy transition to do so. Community energy encompasses a range of possible activities and initiatives, as illustrated in Figure 4. On a scale of increasing complexity, community energy may involve simply providing local advice on energy efficiency or energy use, or investment in local generation projects, right up to operating a microgrid independent of the public electricity network. Despite this diverse range of activities and complexity, a common theme of community energy schemes is that they all aim to bring benefits to the local community in one form or another.

Some community energy projects, such as local generation investment, local energy purchasing and local supply, may have relatively limited impact on the shape of the future DSO, with DSOs able to accommodate community initiatives within their current structures. Others, such as virtual private networks, local aggregation and microgrids, may, however, have more fundamental implications for both DSOs and regulators.

Figure 4. Possible activities and initiatives for community energy



21 MacLean, K., Sansom, R., Watson, T., and Gross, R. (2016). *Managing heat system decarbonisation: Comparing the impacts and costs of transitions in heat infrastructure*. Imperial College. Retrieved from

<https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-annexes.pdf>

Virtual private networks, for example, involve a third party aggregating local resources and flexibility to balance energy locally or achieve early network access for additional resources by managing congestion. This requires DSOs to surrender some of their system management role while still having overall statutory responsibility for maintaining quality and security of supply. This suggests something of a conflict, with the DSOs' continuing statutory responsibilities likely to constrain the operation of the virtual private network to some extent. Operators of microgrids that are disconnected from the local distribution network, on the other hand, would presumably inherit DSOs' statutory responsibilities for security and safety of the microgrid, removing the DSOs' local monopoly both for asset ownership and network management. Issues of customer choice and customer protection may arise in this situation. How, for example, can customers supplied via a microgrid detached from the public network exercise their right to choose their supplier?

Microgrids that remain connected to the local distribution network also raise similar customer protection issues, although presumably customer choice could be preserved. Will microgrid operators be subject to the same regulation as DSOs, inheriting DSO responsibilities for security of supply, customer service and the like? Being "fit and proper persons" to own and operate distribution networks, will they just become mini-DSOs?

A significant issue for community energy projects that involve peer-to-peer trading or microgrids connected to the distribution grid would be what network charges should be applied. The financial viability of peer-to-peer trading can often depend on the avoidance of charges for those parts of the network not involved in the transaction, for example, the transmission or higher-voltage distribution networks. Although at first sight the avoidance of some network charges may well be justified, the fact that network costs are largely capacity based suggests that the scope for avoidance may be limited. It may be warranted, of course, if those involved in local transactions can balance their energy requirements perfectly and continuously and forgo any possible use of the remainder of the network. Even if this is

the case, we need to recognise that actions at one point on an interconnected network may well have implications at higher-voltage levels. Failure to recognise these implications and ensure a fair allocation of cost recovery could ultimately threaten TSO and DSO revenues, or at least result in unfair cost allocations or even cross-subsidisation between customer groups.

The concept of a microgrid and citizens' energy communities also raises the issue of whether the general European model of unbundled supply, network ownership and network operation is appropriate in all circumstances. Similarly, the general supplier hub model, where the primary customer interface is with a customer's energy supplier, is also called into question. DSOs, energy suppliers, third-party aggregators and vehicle manufacturers may all need to develop energy-based relationships with customers as well as energy suppliers in future. One interesting means of gathering evidence to highlight the need for future changes in the legislation and regulation to support the growth of community energy is the "regulatory sandbox" process offered by the Office of Gas and Electricity Markets (Ofgem) in Great Britain.<sup>22</sup> Recognising the uncertainties about the need for regulatory change in a rapidly changing energy environment, the regulatory sandbox offers innovators the opportunity to trial new services or business models outside existing rules. This allows them to test viability and identify possible need for regulatory change.

The concept of an independent microgrid implies surrender of a DSO's geographic monopoly for asset ownership and sets up the possibility of new-entrant third parties building, owning and possibly operating network assets. This would allow a "contestable" approach to asset provision, with potentially significant benefits in reduced investment costs. An independent distribution system operator that is responsible for the operation of the network but owns no assets could identify the potential need for new network capacity to comply with network security standards, after having taken into account alternatives to traditional reinforcement such as non-wire solutions. A tender process could then be used to identify the most cost-effective proposals and award a contract to build, with costs recovered through regulated tariffs.

22 Office of Gas and Electricity Markets (Ofgem). (2018, September). *What is a regulatory sandbox?* [Fact sheet]. Retrieved from [https://www.ofgem.gov.uk/system/files/docs/2018/09/what\\_is\\_a\\_regulatory\\_sandbox.pdf](https://www.ofgem.gov.uk/system/files/docs/2018/09/what_is_a_regulatory_sandbox.pdf)



## The development of local markets

The growth of prosumerism and consumer demand flexibility seems likely to require the development of geographical local markets for both energy and network services. In addition to providing a venue for local buyers and sellers of energy to trade, local markets would facilitate the growth of prosumerism and flexibility by providing signals for investment. Two broad categories of markets can be identified: energy supply, including energy balancing, and networks services, including local constraint management and non-energy services such as voltage support, resilience, black start and the like.

### Energy supply and energy balancing

Local energy market platforms that enable peer-to-peer trading are being trialled throughout the world.<sup>23</sup> In the many different approaches that can be observed, diversity in design is good in that different approaches should help reveal best practices. In this process, however, we need to ensure market interoperability through regulation and the adoption of standard protocols. It is also important to avoid the development of incompatible market designs.

In Europe's "unbundled" world, the sale of energy is not a natural role for DSOs. We need to ascertain how much they need to be involved in local market platforms used to trade energy. Although DSO involvement is likely to be influenced by a number of factors, a significant issue will be whether those markets are constrained or unconstrained. The typical European wholesale energy market is unconstrained, which means that market participants are able to trade without the need to consider the physical capacity of the network. Essentially, the markets assume a commercially infinite network and any consequences of unconstrained trading are dealt with via separate balancing or redispatch markets. An unconstrained market design operating at distribution network level would allow peer to-peer trading over wide areas and in parallel with the conventional retail market. In other

words, a customer could choose to buy energy from a local energy producer — a PV array or community wind turbine, for example — or from a national supplier buying energy on the wholesale market. The operation of unconstrained local energy markets would seem to require little DSO involvement other than the need to physically accommodate local resources, as normal network access arrangements would apply. The DSO would be facilitating the local energy market in the sense that the distribution network allows physical delivery, but it would not need to have any other direct market involvement. An example of a local market platform is the peer-to-peer energy trading platform Piclo, which is being trialled in the UK, Italy and the Netherlands.<sup>24</sup> Other examples of local markets being implemented in Europe are Enera, GOPACS and NODES.<sup>25</sup>

The operation of unconstrained local markets, where trading takes no account of actual network capability, would, however, require DSOs to operate a postmarket constraint management process to ensure that networks operated securely in real time. Using local network services markets (see below), DSOs would be required to resolve any unacceptable network flows thrown up by unconstrained energy trading, operating in much the same fashion as TSOs in balancing time scales.

There would be a greater case for DSO market involvement if the local energy market is constrained rather than unconstrained. In this case, energy trading at the distribution level would be subject to network constraints, and the DSO would need to be closely involved in the operation of the market. Constrained trading also gives rise to the question of how to interface a constrained local energy market with an unconstrained national wholesale or retail market.

An example of a constrained market approach with greater DSO involvement is New York's Reforming the Energy Vision initiative. In addition to performing traditional tasks, such as asset ownership, network operation and planning, the DSO is also responsible for developing and operating a distributed service platform that provides a transparent interface for distributed energy resource sellers,

23 Zhang, C. (2017). *Peer-to-peer energy trading in electrical distribution networks* [Doctoral thesis, Cardiff University]. Online research at Cardiff. Retrieved from <https://orca.cf.ac.uk/109074/1/2018ZhangCPhD.pdf>

24 Mission Innovation. Piclo peer-to-peer energy trading platform [Webpage]. Retrieved from <http://mission-innovation.net/our-work/>

[mission-innovation-breakthroughs/piclo-peer-to-peer-energy-trading-platform/](https://mission-innovation-breakthroughs/piclo-peer-to-peer-energy-trading-platform/)

25 Schittekatte, T., and Meeus, L. (2019, May). *Flexibility markets: Q&A with project pioneers*. Robert Schuman Centre for Advanced Studies. Retrieved from [https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=3401882](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3401882)

aggregators and retail customers to buy and sell energy or energy services.<sup>26</sup>

Energy balancing is an extension of the energy market and is required to resolve any energy imbalance that remains after the primary energy markets have closed. Although energy balancing is essentially a system-level activity, local prosumers or flexible consumers have the potential, and should have the right, to participate in the balancing market. DSOs could act as a local aggregator, allowing customers to pool their energy or flexibility contributions and participate on their behalf in the national balancing market. However, there is no reason why an ownership-unbundled DSO, rather than a third-party aggregator, should need to carry out this role. Both could provide the service in competition, but it is paramount that a prosumer or flexible customer should be able to sell his service to whomever he chooses. The DSO should not have any right to veto a contract between customer and aggregator. However, the utilisation of local generation or flexibility to provide an energy balancing service at system level could conceivably exacerbate local network problems, which the DSO would need to resolve. Although the DSO should have no veto over the utilisation of a contract in these circumstances, there would be a clear need for coordination and information exchange among aggregator, DSO and TSO.

## Network services markets

On an interconnected electricity grid, energy and energy balancing are essentially system-level activities, with local energy markets offering prosumers and consumers the option to trade locally or, collectively, to access the national retail and wholesale energy markets. One question to address is whether local energy markets can accommodate energy trading to address local network issues, or whether separate network services markets or flexibility markets are required.

At first sight, one market platform should be able to accommodate both as, essentially, only energy is being traded. However, energy traded for network purposes, such as constraint management, may well be subject to additional requirements for validation, dispatch and control. Piclo is

an example of a single platform being used for both energy trading and the procurement of network services, with several DSOs using the platform to run auctions within their areas of service.<sup>27</sup> The possibility also arises of utilising national balancing markets to address local constraint issues. It is common for TSOs to manage transmission constraints by accepting balancing market bids and offers. Any bids or offers accepted to manage constraints are extracted from the energy balancing stack and do not influence the energy imbalance price. Similarly, as all meters have a geographic identifier, it should be possible for DSOs to manage local distribution constraints using the same process, that is, activating geographically suitable bids or offers made to the national balancing market, without influencing the national energy imbalance price. Again, it would be important for the DSO and TSO to coordinate, as the acceptance of a balancing offer to address a local distribution constraint may aggravate an overlapping transmission constraint.

## Non-energy network service markets

Other location-dependent services that may require a separate approach include voltage or reactive power services and resilience services. Voltage management is a highly local issue made more so by the radial nature of distribution networks. DSOs are required to maintain the voltage at the point of supply within statutory limits. Local resources can assist by modifying circuit loadings and voltage profiles. To the extent that energy trades can be used to manage voltage profiles, then presumably this could be archived via local energy market platforms. However, voltage profiles are more directly influenced by reactive, rather than active, power, and separate market platforms may be required. Larger distributed generators are required to have specific reactive power capabilities, and this capability would be traded via these separate reactive energy markets.<sup>28</sup>

Local resources also have the potential to maintain local supplies when connections to the wider distribution networks have been lost, say in the event of a destructive weather event. This resilience role is likely to become more significant as the transfer of generation capacity from

26 Sullivan & Worcester LLP. (2016, 11 May). New York's reforming the energy vision — Opportunities and obstacles on the horizon. *Lexology*. Retrieved from <https://www.lexology.com/library/detail.aspx?g=bbeb89a4-810f-47fc-bae1-c6271e366f99>

27 Piclo Flex [Website]. Retrieved from <https://picloflex.com>

28 Hussein, T. (n.d.) Power Potential: England's first reactive smart grid project. *Smart grids*. Retrieved from [https://power.nr.digital.com/power-technology\\_jan19/power-potential\\_england\\_s\\_first\\_reactive\\_smart\\_grid\\_project](https://power.nr.digital.com/power-technology_jan19/power-potential_england_s_first_reactive_smart_grid_project)

the transmission to the distribution systems proceeds, with distributed resources required to at least match the contribution currently made by transmission-connected resources. Initially, local resilience may need to be restricted to individual buildings. However, given suitably sized local resources and flexible demand in the future, there is the prospect of those resources supporting islanded sections of the distribution systems, thereby delivering a real gain in network resilience. For local resources to provide resilience, appropriate connection protocols would be required. Currently, it is common for connection protocols to require distributed resources to be shut down upon the loss of grid supplies to both protect the resources and DSO staff. In future, local resources could be designed to disconnect from a failing grid and continue operating in an islanded mode to secure local supplies. This does, however, raise issues of compliance with statutory requirements and also liability for any damage to consumers' equipment caused by excursions outside statutory voltage or frequency limits.

## Conclusions

The energy transition has implications for the fundamental operation and design of the distribution networks and, potentially, for the role and structure of DSOs. The emergence of prosumerism and active consumers generally, together with the electrification of the transport and heat sectors, will radically alter the nature of distribution network power flows. At the same time, the growth of community energy and the development of local markets for energy and services will require DSOs to take on new roles and responsibilities while relinquishing roles they have traditionally performed. The success of this transition will require DSOs to embrace these changes, as well as digitalisation and innovation in how distribution networks are designed and operated.

**The implications of moving to actively managed networks.** The transfer of generation capacity from the transmission to the distribution systems as part of the energy transition, with much of that capacity belonging to individual domestic consumers, is well underway. This new capacity, together with increasing flexibility in customer demand, can become cost-effective resources that help ensure the security and resilience of the distribution networks. However, effectively integrating these resources will require that the

DSO actively manage the network.

DSOs will therefore need to develop the skills and facilities necessary to procure and effectively manage the contribution of potentially hundreds of thousands of prosumers, and increasingly active consumers, to network security and quality of supply. The costs of developing and maintaining these skills and facilities could lead to the consolidation of smaller DSOs to achieve economies of scale. Alternatively, smaller DSOs may be encouraged to delegate their system management responsibilities to a larger DSO, leaving them free to focus solely on asset ownership and management. This separation of asset ownership and system management, with independent DSOs providing system management services to a number of asset owners, could have significant implications. Freed from the obligations of system management, new entrants could be attracted to the world of asset provision and ownership, providing cost savings through contestability.

Fundamental questions about the role of the future DSO and the relationship with TSOs are raised by the ongoing transfer of generation capacity from the transmission to the distribution networks and the increasing dependence of both on services provided by distributed resources and services procured via local markets. One approach would be for DSOs to be heavily involved in procuring services at a local level for both national and local use, with the TSO stepping back and surrendering some of its energy balancing role to the DSO. Alternatively, the TSO could retain its full balancing role and be responsible for procuring services at a local level, with the DSO retaining responsibility for procuring services to manage local constraints.

Whichever approach decision-makers choose, the requirements of TSOs and DSOs may conflict on occasion, and some means of successfully coordinating the use of these local services needs to be found. Although TSOs and DSOs will need to cooperate closely, this should not be at the expense of customer choice. Customers should be allowed to sell their services to whomsoever they wish. Given that the interface between DSOs and TSOs will become increasingly complex and critical, there may be an advantage in merging selected TSO and DSO activities.

**The importance of regulation.** The implementation of appropriate regulatory policy will be key to driving the changed DSO behaviour necessary to deliver a successful

energy transition. Regulators will need to incentivise DSOs to embrace digitalisation and innovation in the operation and design of distribution networks. Regulatory mechanisms that focus on total expenditures rather than capital expenditures seem more likely to facilitate objective assessments of operational alternatives to traditional investment. This also addresses the natural bias of DSOs toward infrastructure investment. Regulation will also need to be more focussed on outputs designed to reflect customer needs and energy policy priorities, rewarding DSOs on their performance in delivering these outputs in the most cost-efficient fashion.

In addition, regulation will need to ensure that network planning and operational standards are developed so that the contributions prosumer and flexibility services make to security are properly valued. Only then can proper economic assessments between traditional asset-based schemes and operational alternatives be made. It will also be necessary to ensure a more transparent approach to network planning and operation, with requirements broadcast to the market in advance of need and potential providers given the opportunity to tender services to meet those requirements.

**Charging for network use.** The growth of prosumerism is already forcing changes to the way network costs are recovered, with many jurisdictions moving away from traditional volumetric tariffs to tariffs that include some capacity or demand element. Network costs are primarily related to capacity and, apart from investment costs, are largely fixed. We will need to rethink network tariff designs to ensure we incentivise consumer behaviours that are consistent with the energy transition. At the same time, they will need to be as cost-reflective as possible, avoiding unnecessary cross-subsidies among customer classes. The deployment of smart metering will provide the opportunity to incentivise appropriate customer behaviour and provide data that will allow cost recovery to be allocated more fairly among emerging customer classes.

**Transport and heat electrification.** The electrification of the transport and heat sectors offers significant opportunities for the power sector but can also have a significant impact on the investment needs and operations of DSOs. Given the potential need for additional network capacity driven by both transitions, it is imperative that DSOs introduce charging regimes that, as far as possible, minimise the increase in simultaneous network peak demand and more closely define consumer access rights. In the transport sector, DSOs will be required, presumably in concert with third parties such as suppliers, aggregators or car manufacturers, to encourage smart charging of EVs to help cost efficient EV integration. Over the medium term, they can also utilise a developing vehicle-to-grid or battery second-life capability to contribute to constraint management and other local network needs.

In terms of electrifying the heat sector, which could potentially have far greater impact on distribution networks than electrifying transport, it seems appropriate that DSOs should in future be able to promote energy efficiency, insulation and other measures designed to increase the thermal storage of buildings. Together, with the use of smart tariffs, this would reduce the potential increase in investment requirements associated with increased network peak demand.

**Community energy.** Although some community energy initiatives would seem to have little impact on the shape or future role of the DSO, others could have a significant effect. A virtual private network, for instance, implies the surrender of some network management functions to a third party, while the creation of microgrids implies the surrender of both operation and ownership of local networks and the loss of the DSOs' regional monopoly. Overall, therefore, the growth of community energy would seem to point to the evolution and possible dilution of the historic role of the DSO as a distribution network provider.











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