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# Pathways for the development of future intelligent distribution grids☆

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ABSTRACT

The next decade will bring several technical and organisational challenges to the electrical distribution grids, which are becoming an important pillar of the energy transition. Distribution system operators will play a crucial role and thus need to find innovative solutions that will prepare them for these changes. Acknowledging large differences between European distribution grids, this paper presents pathways for distribution system operators developed within the scope of the UNITED-GRID project, in close cooperation with distribution grids in the Netherlands, France and Sweden. Investment decision tools based on future scenarios and future-readiness assessment form the first step to steer the distribution system operators towards the necessary technical and digital innovations that increase the observability and controllability of the grid. Secondly, new types of business models are introduced that can be integrated into the operators' portfolios. Thirdly, a workshop methodology is proposed to define the new internal requirements that make distribution system operators more agile to face the fast impacts of the energy transition. Case studies from the demonstration sites in the three countries are used as examples in the paper.

## 1. Introduction

The next generation of electrical distribution grids will face several challenges on the technical, market, and regulatory level. New competitive services and technologies are needed by the future intelligent distribution grids, operating with high efficiency and reliability and minimal system losses. Some of these challenges were addressed in the UNITED-GRID project (UNITED-GRID, 2022), which aims to optimise grid operations through the development of real-time control solutions with a high level of automation and cyber-physical security. Some of these solutions were tested at the real demonstration sites and made market-ready for implementation in other European distribution grids.

For the successful integration of such smart grid solutions, the distribution system operators (DSOs) need to address larger system challenges and find suitable pathways for the implementation of innovative solutions. Therefore, this paper aims to develop a process with and for the DSOs, to understand the impact of policy, market, and technical changes on the grid and to support them in their transition towards active grid operators. These pathways include not only a technical assessment of potential solutions but also a proposition of novel business models, and a methodology for effective handling of fast transition processes.

The rest of the paper is organised as follows. The background describing the challenges for the next decade is given in Section 2. The methodology and approach used in this work are explained in Section 3. Section 4 shows the developed pathways for the DSOs. The concluding remarks are outlined in Section 5.

## 2. Background

The DSOs in Europe are facing large and disruptive changes and need to anticipate new challenges in technology, policy, and market. The DSOs as active distribution system operators will have to make different choices in planning and operation and consider new types of investments, within the framework of their regulated activities (Wilczek, 2021). Since these challenges come with greater system responsibility and also greater uncertainties, they need to be well understood and

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**Nomenclature**

| | |
|---|---|
| AMI | Advanced metering infrastructure |
| DER | Distributed energy resources |
| DSO | Distribution system operator |
| ESS | Energy storage systems |
| EV | Electric vehicles |
| ICT | Information and communications technology |
| IoT | Internet of things |
| KER | Key exploitable result |
| LFP | Load forecasting provider |
| LV | Low voltage |
| MV | Medium voltage |
| PV | Photovoltaics |
| REFP | Renewable energy forecasting provider |
| RES | Renewable energy sources |
| SAHARA | Security-aware hazard analysis and risk assessment |
| SCADA | Supervisory control and data acquisition |
| TRL | Technology readiness level |
| TSO | Transmission system operator |

taken into account when considering pathways for the next decade. An extensive analysis of the existing literature has provided an overview of the main challenges and needs for the DSOs in the coming decade and provided valuable inputs for the development of the pathways. The five major challenges which were identified in this study are presented in the background review.

### 2.1. Technical challenges due to climate goals and energy policies

Ambitious European climate and energy goals (United Nations, 2015), (European Commission, 2012), (European Commission, 2014), (European Commission, 2015), (European Commission, 2016), (European Commission, 2018), (European Commission, 2019) will have a huge impact on the electrical grids and specifically distribution grids, due to the massive deployment of intermittent renewable generation, and new and variable electricity loads from the transport, heating, and industrial sectors connected to the existing distribution grids, as discussed in (Rossi et al., 2020). The total electricity demand is expected to rise significantly by 1.8% per year by 2030 (Wilczek, 2021). According to (Fulli et al., 2019), correlated electrification, decentralisation, and digitalisation trends suggest that the share of electricity in final energy consumption can grow from above 30% by the year 2030 to nearly 40% by the year 2050. Also, the decentralised generation capacity could account for more than 30% of all generation capacity by the year 2030 and could easily exceed half of the installed generation capacity by the year 2050. At the same time, in the Clean Energy for all Europeans package which was adopted in 2019, consumers are foreseen to be empowered, to change their consumption patterns, offer flexibility, and become fully active players in the energy transition (European Commission, 2016). These changes will have a large impact on the management of the distribution grid and the choices that will be made at that level. The new Electricity Market Directive (European Union 2019/944/EU, 2019) emphasizes this focus on consumers. Specifically, at the distribution level, Member States should encourage the modernisation of distribution networks. The DSOs should be enabled and incentivised to use services from distributed energy resources (DERs) such as demand response and energy storage, based on market procedures, in order to efficiently operate their networks and avoid costly network expansions. Chapter IV of the Directive clarifies the role of the DSOs with respect to the procurement of network services to ensure flexibility, the integration of electric vehicles (EVs) and energy storage systems (ESS). Consumers should be enabled to participate in all forms of demand response and therefore should have the possibility to benefit from the full roll-out of smart metering systems, while in cases where such a roll-out has been negatively assessed, they should be able to opt for having a smart metering system and a dynamic electricity pricing contract. It is expected that flexibility markets will emerge especially from the year 2030 onwards when the DSOs will have stronger incentives to use flexibility to manage their networks. With the use of flexibility provisions to manage grid operations, the need for grid reinforcement for the already ageing network could be avoided. Therefore, technical adaptations to the future challenges in the next 5–10 years will be crucial to keep the network running smoothly in the future. Depending on different scenario characteristics, different technical impacts are expected e.g., voltage deviation, power quality issues, network congestion, phase imbalances, etc., and different requirements would be needed, e.g., voltage and frequency control, advanced forecasting methods, improved information and communications technology (ICT) solutions, etc.

### 2.2. New role for the DSOs in electricity market

Since the task of the DSOs is considered a natural monopoly, selling a product that is regarded as a universal service, the DSOs' role and responsibilities are regulated. Traditionally, this role includes network planning, development, operation, and maintenance. The DSOs are responsible for system security and continuity of energy supply, but also for technical data management as well as providing connection services and information to customers. The third electricity directive adds another aspect to this role by introducing smart grids (European Commission, 2009) and laying down specifications on the exchange and ownership of metering and consumption data. The regulation on the internal market for electricity in (European Union 2019/943/EU, 2019) and amending directive in (European Union 2019/944/EU, 2019) push forward an internal electricity market with a focus on consumers, new loads, and improved flexibility. The DSOs must (cost-) efficiently integrate new (renewable) electricity generation and loads. Further, they should be enabled and incentivised to use market-based services such as demand response and energy storage from DERs to efficiently operate their networks and avoid costly network expansions. Network development plans (for the DSOs serving more than 100 000 customers) should provide adequate information to system users regarding the network expansions and the use of medium and long-term flexibility. The role of the DSOs is changing from passive to active with greater system responsibility. Still, the new tasks need to be carefully analysed and included in the regulated DSO activities.

### 2.3. Innovation driven new services and activities

Innovation itself is one of the drivers in the fast-changing energy landscape. Disruptive changes are challenging the electricity grids and a large part of the innovations are incubated in the distribution systems (Fulli et al., 2019). In such contexts, electricity system stakeholders are striving to keep up with the pace of innovation and to anticipate infrastructure and market arrangements required for future electricity delivery and services. Such structural tensions can either create positive transformation pressure by stimulating innovation, or they could result in the development of a new and competing system (Johansson et al., 2020). In an extreme example, technological and digital innovations at end-user level could lead to more and more users disconnecting from the larger grid, while isolated microgrids operate solely for their users' needs. In the end, the distribution grid could even become obsolete ('utility death spiral' (Castaneda et al., 2017; Costello et al., 2014; Felder et al., 2014)). Although this concept has been contested in some other works such as (Hittinger et al., 2017; Khalilpour et al., 2015; Prata et al., 2018). It is clear that rapid changes create a need for substantial investment and innovation in modernised power systems, smart grid technology, and new business models.

At the same time, the DSOs are facing new sources of uncertainties, and have low incentives to innovate due to a strong focus on capital cost return in their regulated revenues. They have to take into account bigger financial risks, and it is not always clear how they should calculate costs (EDSO, 2016). The anticipated changes and therefore also the benefits associated with investments all have a high degree of uncertainty and may seem far from the DSOs' current practice. Some DSOs wait for clear rules or incentives or invest in incremental rather than radical innovation with results having difficulties breaking through on a larger scale (Johansson et al., 2020).

The regulatory changes open the door to performing potentially competitive activities (CEER, 2015) and encourage innovative investments to support the DSOs' changing role (EDSO, 2017). The implementation of output-based regulation (CEER, 2015) can also be part of the solution. But it is also up to the DSOs themselves to position their new business models in the vision of the future multi-domain, multi-vector ecosystem, exploring and taking into account competitive advantages and future opportunities.

### 2.4. Need to invest in digital solutions

The possibility of deploying robust smart grid technologies on the low voltage network increases because of advancements in software-defined networks and communications and the affordability of increased computing power. The technology now enables coordinated analysis and action among diverse grid devices that were not previously practical or cost-effective to solve key operational challenges (Wolf, 2015). Distribution network automation even on the low and medium-voltage (LV & MV) level allows moving from a 'blind' operation of the network to a more and more monitored and controlled one, while the management of the distribution system changes from maintaining 'acceptable' electrical conditions to optimising the overall performance using electronic, computer-assisted decision-making (Castaneda et al., 2017). Common automation features implemented by the DSOs include forecasting and dynamic rating (Argonne National Lab., 2017), but new advanced functionalities will be needed (CIGRE, 2017), which will serve utility-specific problems and constraints over long periods (Argonne National Lab, 2017). Grid modernisation will need investments that accelerate digitalisation and improve observability, predictability, and controllability on the distribution level. Integrating these advanced solutions for network management and operation but also market facilitation will turn the traditional asset-centric distribution companies into data-centric companies with smarter and more flexible grids (CEER, 2015; EDSO, 2016).

An improved ICT infrastructure, advanced measurement solutions, and distribution automation can improve efficiency and productivity, and lower losses of energy systems but they also raise new security and privacy risks, as addressed in the UNITED-GRID project (Thorsen et al., 2022). From the DSOs' side, this means that expertise must be available to understand and evaluate new solutions.

### 2.5. Need for DSO agency in the energy transition

A large-scale socio-technical transition involves deploying new technologies along with political, social, and cultural processes (Geels et al., 2017). Due to the complexity of the changes, transformations will have to happen at several levels and in different steps, as presented in existing technical road maps and tools (CEER, 2015; Colle et al., 2019). The accelerated investments in technical innovation as well as people, have to be accompanied by a cultural mindset shift and partnerships with other players (EDSO, 2016). For the DSOs to be able to actively capture existing opportunities and thereby create benefits, they have to be mentally prepared for a future that is far away from the current logic, and thus a special transition focus is needed.

A single actor as the DSO is central in the transition and at the same time has few possibilities to externally influence the transition processes. The institutional framework which constitutes the space for action consists of both formal institutions (e.g., rules and regulations) and informal institutions (e.g., attitudes, norms, values, and beliefs) (North DC. Institutions, 1990). They have interlinked meanings where one type affects the other. Informal institutions are related to developing new expectations for new innovative technology or a new technological field. These new expectations as they become more established and shared by several actors exert pressure on current policy or formal institutions to change and enable the growth of the innovative field (Schot and Geels, 2008). Therefore, the DSOs should begin making the important mental journey towards a system based on new distributed logic, i.e., update their informal institutions, and thereby potentially affect policy and regulations that create the formal operating space for the DSOs. The ability of the DSOs to take action (also called agency) is needed in the energy transition.

## 3. Methodology and approach

To cope with the challenges as described in Section 2, it was recognised in the UNITED-GRID project that solutions need to be developed at several levels, in order to support the DSOs in the transition from today's passive distribution grids to the future's active and intelligent distribution grids. Ambitious decarbonisation goals and new regulatory frameworks demand a new role for the DSOs, but how to put this into practice in the daily business had not been clearly defined. From the DSOs, it will not only require accelerated investment in innovation and digitalisation, but also upgrading internal processes and tools, and a shift in the cultural mindset.

To achieve this, the paper developed pathways in close cooperation with three demonstration sites that are related to three DSOs: Göteborg Energi (Sweden), Sorea (France), and Enexis (the Netherlands). The pathways include the following three aspects: technology, business models, and internal adaptation. They are developed based on interviews, discussions, data collection, and workshops. They synthesise activities and outputs from different tasks and work packages in the UNITED-GRID project, as tested and implemented within the demonstration sites. The goal is to integrate and align investment decisions for technical solutions with the adoption of new business models and to support the DSOs in their transition process. The discussions with the involved DSOs clearly showed that there is no one solution that fits all. The large difference in organisational structure, technical differences in the networks, and different regulatory frameworks among the European DSOs calls for individually adapted tools and pathways. Therefore, the pathways describe a methodology that can be implemented by the DSOs as presented in Fig. 1.

First, technical solutions were developed to provide new functionalities, which support the DSOs in the transition towards active distribution grids in scenarios with high amounts of renewable energy sources (RES). By assessing the current status and future-readiness of the DSOs, implementing the tools which have the highest business potential, and analysing the end-user acceptance, the most efficient solutions can be selected. This method was applied to the advanced solutions that were developed within the UNITED-GRID project for better operation of the grid and the ability to participate in the market. The assessment framework could be used by other DSOs to adopt the best business opportunity.

For fully capitalising on those investments, new innovative business models need to be developed. The paper therefore proposed two potential business models, that would allow the DSOs to become more flexible and react to market developments when needed. The two business models are i) DSO as a service provider, and ii) DSO as a market platform operator. Considering those new opportunities, within the existing or future regulatory framework, would entail a shift from asset management to service management by the DSOs. This step was included since it was considered that the DSOs need to start taking into account these future opportunities, even if the advantages are not

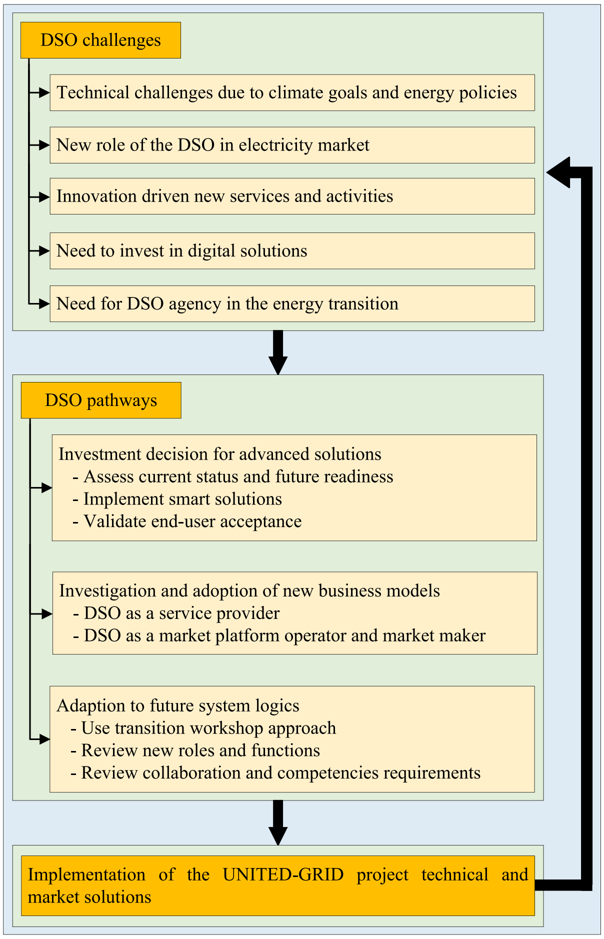



**Fig. 1.** The framework of the proposed methodology.

always visible in the short term.

As a final part of the pathways, it was considered that such a shift in new requirements would need an adaptation to future system logics. A transition workshop approach was developed to review new roles and functions, collaboration with other stakeholders as well as the need for new competences. This final step concludes how the implementation of new solutions must go hand in hand with adopting the organisational culture and business models.

## 4. Pathways for the DSOs

The developed tools and methods are described step-by-step in the following pathways.

### 4.1. Investment decision for advanced solutions

The need for investments in grid technology and ICT solutions will depend on the current status and future-readiness of the networks and the end-user acceptance. Several tools were developed to support the DSOs' decision-making in investments for grid modernisation that enable automation and control of the network.

#### 4.1.1. Assess current status and future-readiness

For the assessment of the current status of the network infrastructure and the future-readiness, a self-assessment framework was developed in (Srivastava et al., 2019b) and (Tran et al., 2019), based on a set of key indicators, and case studies have been carried out for the DSOs in the three European countries (the Netherlands, France, and Sweden).

First, a list of indicators was developed as presented in Table 1,

**Table 1**
List of indicators and sub-indicators used in the future-readiness assessment framework.

| Indicators | Sub-indicators |
|---|---|
| Technical | - Distributed energy resources<br>- Level of monitoring and control<br>- System status<br>- Cyber-physical description |
| Market | - Markets and services<br>- Tariffs<br>- Business models |
| Policy | - Level of unbundling<br>- Roll-out of smart meters<br>- Impact of winter package on DSO tasks<br>- Impact of new network codes and guidelines<br>- National/Regional policies on DERs |

which were vital to identify the areas of development that the DSOs should focus on. As an example, this framework evaluated that the Swedish DSO (Göteborg Energi), at the time of the assessment, had a considerable amount of decentralised renewable production in the grid, full roll-out of smart meters, no provisions for flexibility, and only a few possibilities for the introduction of new tariffs. There were no issues yet with the reliability of supply, and the level of monitoring and control was sufficiently high. The results further showed that there was a motivation to invest in flexibility provision and new digital solutions but the possibilities for innovative investments based on new business models were limited. Also, the amount of RES could easily be managed and did not require immediate changes in the grid. A detailed comparative assessment among the studied DSOs is presented in (Srivastava et al., 2019b), suggesting that the size, number of customers, different market rules, and policies at the national level vary considerably among the studied DSOs, resulting in different needs and requirements.

In the next phase, the impact of established scenarios with a high penetration of RES for the next 5–10 years was studied in the partner countries, and the impact on the operation of different types of future distribution grids was analysed in (Tran et al., 2019). For example, the evolution of the power sector will affect the DSOs managing urban or rural areas differently and thus will require a different set of solutions. According to the ambitious scenarios that were analysed, the key challenges that will affect the technical operation of the grid are the increasing penetration of decentralised RES, increased adoption of ESS, the rising number of new types of electrical loads, growing number of EVs connected to the grid, and lastly the electrification of heating and transportation sectors. The summary of the scenarios' characteristics that were taken into consideration, their impacts on the distribution grid, and the list of general requirements that can answer to the impacts are presented in Table 2.

The results derived from the assessment framework for the French distribution network under the 2035 future scenario (WATT) showed that there is a considerable decommissioning of nuclear power and the proportion of RES increased from 18% in 2017 up to 71.3% by the year 2035. Particularly, the generation from hydro-power, wind, and solar photovoltaics (PV) generating units will account for 21.7%, 51.5%, and 18.5%, respectively, while other RES including ESS will contribute to the rest 8.5%. As a result, grid flexibility is required to accommodate the high share of distributed RES. Also, it is anticipated that about 5.5 million EVs with multiple charging modes whose consumption could go up to 11 TWh can be connected to the grid, requiring the grid to be ready to host them by developing and managing the EV charging infrastructure. The demand response with the participation of ESS will also be crucial, while the high penetration of distributed RES and ESS present challenges to the reliability of power supply. It also shows the need of new solutions for the French DSOs such as operation, control, and protection tools, advanced ICT solutions, and with those, the development of new business models for ancillary services.

**Table 2**
Impacts and general requirements of scenarios characteristics.

| Scenario characteristics | Impacts | General requirements |
|---|---|---|
| Significant penetration of decentralised RES | - Voltage variations<br>- Phase imbalances<br>- Power quality issues: harmonics, flicker, etc<br>- Impact on protection: bidirectional fault currents, unconventional fault waveform, etc.<br>- Unintentional islanding<br>- Frequency and voltage stability in case of microgrids<br>- Network congestion<br>- Demand for participation in providing ancillary services | - Voltage control<br>- Frequency control<br>- Advanced protection<br>- Congestion forecasting and management<br>- Advanced measurement and control<br>- Improved ICT infrastructure<br>- Advanced DMS features<br>- New operation models to accommodate flexible demand and production from end-users |
| Increased adoption of ESS, demand response, and self-consumption | - Demand for participation in providing ancillary services | |
| Increased amount of new electrical loads, growing number of charging EVs, and electrification of heating and transportation sectors | - Added stress on the network<br>- Increased consumption peaks<br>- Power quality issues<br>- Phase imbalance<br>- Advanced measurement and control<br>- Contribution to ancillary services<br>- Network congestion | |
| General operation impacts | - More complex operation of the grid<br>- End-users contributing with flexibility and production | |

#### 4.1.2. Implement smart solutions

When the requirements have been defined, new technical functionalities can be developed and implemented by the DSOs. As an example, the set of functionalities that were developed in the UNITED-GRID project are presented to address the defined current and future needs and to be implemented in a flexible, scalable toolbox (Fonteijn et al., 2018; Wahlström et al., 2021). The core of the developed solution (toolbox) is an advanced distribution management system that interacts with the existing supervisory control and data acquisition (SCADA) system, through an inter-operable cross-platform which can communicate securely with all the actors in the system. It is an example of a modular solution that provides the ability to add numerous advanced features for better operation of the grid and the ability to participate in the market. For the functionalities with the highest technology readiness level (TRL) i.e., 6 or above, the business potential was evaluated. The barriers to market impact were studied, and through the key exploitable result (KER) method, the real value for DSOs was evaluated in the project (Wahlström et al., 2021). The outcomes showed that the different features that can be combined in the toolbox support the DSOs in their transition from being 'analog and passive' toward 'digital and active'. The positively validated functionalities that are considered for further market development and implementation are presented as follows:

- A renewable (solar PV) production forecasting tool with high prediction accuracy including a day-ahead forecasting module based on meteorological data and a very short-term forecasting (1-min ahead) module based on a camera equipped with a fisheye lens to capture sky images. This tool would support the DSOs to balance supply and demand, especially in the network with a high share of solar PV. For instance, the day-ahead forecasting module may enable the DSOs to provide market analytic service, while outputs from a 1-min module can be the inputs for the advanced congestion forecasting tool run by the DSOs. This tool was demonstrated at Sorea's demonstration site in France.
- A congestion forecasting tool that can forecast network congestion and node voltage deviations in distribution systems with high penetration of solar PV and intermittent load. The tool determines the probability of congestion to occur in a distribution network as well as at the individual elements (i.e., transformers, lines, and nodes). Currently, most of the DSOs as indicated in Subsection 4.1.1, are not equipped with similar tools, but their need is expected to grow in near future (Srivastava et al., 2019a, 2021). This tool was demonstrated at the Gothenburg demonstration site in Sweden.
- An advanced measurement solution to obtain situational awareness of the distribution grid, which can help the DSOs with monitoring, protection, control utility functions, etc. (Smart State Technology, The Netherlands, 2022). Currently, the distribution grid is hardly measured, but it is the most dynamic part of the grid with the ongoing electrification and increasing share of DERs. This tool was demonstrated at the demonstration sites in the Netherlands and Sweden.
- A distributed state estimator is an advanced functionality that uses the topological information retrieved from the network and the available analogical measurements at the field to provide a precise network condition at a given time. It is based on a robust distributed method, capable of identifying and compensating corrupted measurements from the field as well as providing fast results about the network's state. This tool was demonstrated at the demonstration site in the Netherlands.

In order to identify and reduce safety and cybersecurity risks for ICT architectures used in future intelligent distribution grids, a comprehensive method was developed in the project (Thorsen et al., 2022). This adaptation of the SAHARA method (Security-Aware Hazard Analysis and Risk Assessment) was used by the developers of the tools to evaluate safety-related cybersecurity threats of the ICT architecture. Moreover, during an interactive workshop both internal and external stakeholders (engineers, ICT experts, grid operators, and others) from different fields and organisations, engaged in discussions on the importance of cybersecurity. It was a good method to raise awareness and get better insights into safety measures related to the implementation of tools in future intelligent distribution grids.

#### 4.1.3. Validate end-user acceptance

The end-user acceptance of the solutions and in general, acceptance of innovative smart grid solutions by individual DSOs, was evaluated through questionnaires and interviews. The term *acceptance* could be defined as the willingness of the stakeholders to invest in a certain solution for a specific scenario given a set of barriers and opportunities.

Regarding the outcome of the evaluation, the UNITED-GRID toolbox has the highest acceptance potential in the medium urban DSO segment. Some of the key findings from the evaluation of end-user acceptance are as follows:

- Small-sized DSOs (with less than 15.000 customers or delivery points) in the demonstrations were hesitant to take financial risks and instead prefer ready-to-deploy functions that are already validated. They opt for cost-efficient solutions with installation close to the DSOs' central distribution management systems. They would also be interested to implement new business models and partnerships which would support the innovation process.
- Medium-sized DSOs (between 15.000 to 150.000 customers) with more advanced systems have shown the highest acceptance potential. They opt for a solution located close to the field where the algorithms could be executed locally. This architecture would also be suitable for facilitating communication capabilities with prosumers or third parties in the new markets and business models. For these medium-sized DSOs, the price of the solution must be sized to their expectations and their financial capacity for investment.
- Large-sized DSOs (with more than 150.000 customers) are not much interested in the full solution, but they could take advantage of partnerships with solution providers for research, development, and field testing of the solutions (without necessarily looking for a strong guarantee about the results and benefits).

In general, the size of a DSO is an important parameter for willingness to innovate. It is mentioned in (Johansson et al., 2020) that large-sized DSOs have more space to work with innovation and the development of new business models, although they might be reluctant to implement solutions directly as it could affect a large number of customers. Small-sized DSOs, on the other hand, feel that they are too small to be early adopters and take the risk of investing and testing new technologies. The willingness also depends on the ownership model. Municipal DSOs, such as the ones in Sweden, have close relations with the local community, which increases the acceptance of new solutions. It has been observed previously that the municipal DSOs proactively engage in innovation following their owners' expectations of bringing innovation to the local region. In this case, innovation is not only a matter of financial incentives but also a matter of obtaining incentives from the owners, in this case, the municipality (Johansson et al., 2020).

#### 4.1.4. *Recommendations on technical assessment for investment decisions*

For the individual DSO, it is a challenge to manage the wide range of new grid challenges and needs and to make the right investment decisions. Within the UNITED-GRID project, several solutions and functionalities are developed and integrated into a toolbox, and an assessment framework was developed to understand current and future needs and to make the right investment decision. This methodology using a set of indicators for defining future-readiness related to a range of scenarios can be useful for the self-assessment of other DSOs in Europe. The business potential and the benefits of the solutions for the DSOs were studied and for the positively evaluated solutions (based on the KER method) a Canvas business model was developed. However, it was observed that end-user acceptance of the solutions was not only dependent on the technical needs and constraints, but also on the organisational structure, risk assessment, and size of the DSOs.

### 4.2. *Investigation and adoption of new business models*

In the context of multi-market players and multi-vector ecosystems, the current business models which rely mainly on charging consumer consumption to compensate for the investment, operation, and management expenses will appear to be insufficient soon. With the mass deployment of advanced metering infrastructure (AMI) and improvement in ICT infrastructure for IoT (Internet of Things), the authors expect the future distribution grid to be more flexible in operation and to enable new solutions such as advanced optimisation, coordinated protection, etc. These tools contribute to improving the quality of service and securely hosting more RES. It also allows the implementation of new business models, offering advanced network services aiming at lower distribution cost, enhanced reliability, satisfactory power quality, available access service, and market facilitation services.

**Table 3**
Key factors driving the need for the transition to the new business models.

| **Regulation-related factors** |
|---|
| - Economic policy – austerity vs. fiscal expansion |
| - Deregulation/liberalization of the energy markets |
| - Policy for energy mix, $CO_2$ emissions, dynamic pricing, etc. |
| - Decentralisation of electricity supply (Di Silvestre et al., 2018) |
| - Revenue incentives to the DSOs |
| - The trend for further autonomy to the energy consumers |
| **Technology-related factors** |
| - Unavailability or limited access to primary resources for electricity production (e.g., fossil fuels) |
| - Urban development and digitalisation call for the need of new methods for exchanging goods and services through new business models (Di Silvestre et al., 2018) |
| - Breakthroughs in key enabling technologies (e.g., compact and cheap storage assets) |
| - Technological uncertainties about RES hosting capability |
| - Grid security and resiliency to natural and human threats |
| - Demand growth, new loads (e.g., EV), and effects on load distribution |
| - Outdated energy system |
| - Absence of an intelligent energy management |
| - Transformation of energy consumers to prosumers |
| - New services to grid and clients |
| - New stakeholders in the energy value chain |

The key factors that drive the need for the transition from the traditional business models to the new ones are identified in Table 3.

Given the investment needs outlined in Section 4.1, two business models were developed and proposed, supporting the transformation from asset providing to offering advanced network services aiming at lower distribution cost, satisfactory reliability and power quality, available access service, and market facilitation services.

#### 4.2.1. *Business model 1: DSO as a service provider*

The massive integration of distributed RES increases the level of production intermittency, requiring energy service and balancing operations, to maintain the power quality as well as the full functionality of the grid. Implementing the aforementioned UNITED-GRID functionalities, such as advanced renewable and load forecasting, congestion forecasting, advanced real-time measurement tools, as well as distributed state estimation, can give DSOs significant competitive advantages to provide energy services to their customers but also to the adjacent DSOs or even facilitate balancing operation on the transmission system operator (TSO) levels through TSO-DSO interconnections. Therefore, a business model which is based on providing services to market participants would allow the DSOs to gain benefits. Following potential services which can be offered by the DSOs were identified.

- *Personalised customer engagement service*: Utilising the data collected by the AMI to provide the consumers with their personalised consumption profile and the proposal of a demand-response mechanism for optimisation of the electricity payment.
- *Market analytic service*: In the future electricity framework, energy providers usually conduct real-time analysis of the wholesale and retail markets to determine the return on investment for deriving optimal profitability or decreasing costs. With forecasting and state estimation tools, combined with expertise in market analysis such as prediction of electricity and gas market prices, risk management of uncertainties like weather forecast, consumption forecast, and unpredictable events, the DSOs can provide consultant services for energy market design, trading mechanism, the structure of ancillary services, etc.
- *Advanced forecasting service*: It is well-known that RES-based energy production and load consumption are highly intermittent. Within the future energy market, prosumers/electricity providers may be faced

with financial penalties if there are errors in renewable production and load demand prediction. With the implemented forecasting solutions, the DSOs can provide forecasting services as a third party to support electricity providers or prosumers in preventing/mitigating the risks of punishment.

- *Flexibility capacity forecasting service*: Aggregators need the data derived from the forecasting of flexibility capacity to determine the most appropriate control strategy for market participation and portfolio optimisation. The data can also be utilised to find the best candidates for a certain demand-response program. The congestion forecasting tool along with the data collected from the AMIs can allow the DSOs to provide real-time forecasting services and charge the clients for subscription fees or commissions according to the forecasting accuracy.
- *Trust service and information broker*: The participants in future energy markets may be more likely to face fraud transactions or cheating customers. The DSOs as a trusted party can provide trust and insurance services for peer-to-peer parties. On the other hand, the increasing deployment of machine learning and artificial intelligence technology for energy management and the accuracy and reliability of collected data (historical or real-time) both play a vital role for developers to obtain precise algorithms which in turn leads to better profits. Because of having an agreement with the data owners in advance as required by the data protection regulation, the DSOs in role of the network operators and owners of the advanced measurement solutions and distributed state estimators can make benefit by providing accurate and reliable data to the above developers.
- *Advanced controlling service*: The high level of DERs are challenging the prosumers or microgrid owners to ensure the security and reliability of grid operations and voltage quality. The DSOs with extensive experience and highly effective algorithms can make a benefit by providing advanced control services to these potential clients, which would cost less than developing the solutions by themselves. Additionally, these algorithms can be packed and made available for sale to interested parties beyond the DSO's designated zones.

In order to show an example, a Canvas model for the business model of the advanced forecasting service is presented in Table 4. The proposition of this business model was based on the advanced forecasting tool that was developed within the scope of the UNITED-GRID project and demonstrated at the Sorea network in France. The forecasting tool consists of different modules providing day-ahead, hour-ahead, and minute-ahead forecasting that were implemented at different solar power plant sites connected to the Sorea network. The forecast results were also sent to the real-time supervision platform that is integrated into the network SCADA system for monitoring and control purposes.

Although the business model was not implemented beyond the demo site, end-user acceptance was discussed with the stakeholders such as DSOs and energy suppliers. As it is still not mature enough to be implemented, it was anticipated that in the future liberalised retail electricity market, the RES owners will need the advanced RES generation forecasting tools provided by the DSOs for building day-ahead market bidding strategies to maximise the short-term profits. In addition, as aforementioned, these forecasting services also support electricity providers or prosumers in preventing/mitigating the risks of punishment. The DSOs would also benefit from the forecasting service, thanks to better integration of RES generation and better service for consumption which increases the grid flexibility.

#### 4.2.2. Business model 2: DSO as a market platform operator and market maker

In this business portfolio, the DSOs can hold the role of market platform operator and market maker. The benefits for the DSOs no longer come from energy supplying compared to the traditional model, but rather come from the different charges from transactions, membership and extra services.

- *Commission*: The most popular business model for modern marketplaces is to charge a commission for each transaction. The biggest benefit of this model is that providers are not charged anything before they get some value from the marketplace which is attractive for the providers.
- *Subscription fee*: Platform users should pay a membership fee for being able to access the marketplace where they could make all their exchanges. The value proposition of this model is to provide advice to customers and save money.
- *Listing fee*: A fee could be added when providers post a new listing of their products. This advertisement could include the promotion of smart appliances, their installation, and calibration.
- *Lead fee*: A tax between the listing fee and the commission models is introduced where customers post requests on the platform, and providers pay to make a bid for these customers.

**Table 4**
Business model: advanced forecasting service based on canvas model.

| Key partners | Key activities | Value propositions | Customer relationships | Customer segments |
|---|---|---|---|---|
| - DSO: responsible for grid operation and development<br>- Renewable energy forecasting provider (REFP)<br>- Load forecasting provider (LFP)<br>- Weather forecasting<br>- DERs: flexibility (storage, EVs)<br>- ICT provider: ICT infrastructure, provide information and data<br>- Electricity consumer | - DSO: provide a good forecast of renewable production and load consumption<br>- REFP: reducing renewable production uncertainties<br>- LFP: reducing load variation uncertainties | - Improved operation of the distribution grid<br>- Increased performance of advanced management and control systems for DSOs<br>- Better integration of renewable generation<br>- Better service for consumption | - Services focused on relationships of DSOs, DERs, and consumers | - DSO<br>- Electricity provider<br>- Aggregators<br>- DER owners<br>- Consumers |
| | **Key resources** | | **Channels** | |
| | - LV and MV grids<br>- DERs<br>- Consumers<br>- ICT infrastructure<br>- AMI | | - The market for distribution with high renewable penetration<br>- Any future local energy market<br>- Application for DSOs | |
| **Cost structure** | | **Revenue Streams** | | |
| - Installation costs of advanced forecasting tools<br>- Maintenance and operation cost<br>- ICT infrastructure to enable features of the advanced forecasting<br>- Training DSO staff to use the new systems servers to the storage of forecasting data | | - Selling of forecasting services<br>- Selling of forecasting solutions<br>- Selling of measurement equipment | | |

#### 4.2.3. Recommendations on new business models and roles for the DSOs

A challenge with the implementation of advanced tools for grid observability and controllability is to integrate those investments into the regulated cost structure of the DSOs.

Investing in innovation and considering alternative business models to realise the potential benefits of DERs should be considered alongside conventional investments. However, their implementation should be carefully analysed and included in the DSO's regulated activities. The shifting from conventional DSO tasks of planning, operating, and maintaining the distribution network, to a set of DSO services, necessary for the functionality of the new business opportunities, requires new types of investments and the development of internal competencies across different functional areas.

It is also important that the DSOs explore new services and business opportunities within the framework of their future role in the energy transition, and that they start taking into account the advantages and future opportunities of becoming an active grid operator in the long term, even if they are not visible yet.

The potential values of these business models can be identified by using the Canvas business model. The values of the advanced forecasting service business model are indicated in Table 4. To obtain more comparable values of the proposed business model, the evaluation methodology reported in Díaz-Díaz et al. (2017) can be adopted. This evaluation methodology was described in much detail and was validated through two case studies as well as reviewed by eleven external experts. Moreover, Díaz-Díaz et al. (2017) used the non-profit Canvas business model which is similar to the one used for the new business models in this paper. Lastly, this tool also provides a simple equation incorporating six parameters for obtaining a single quantitative indicator showing the value for each business model, making the comparison between different business models easier. Meanwhile, these parameters can be evaluated separately by using a Radar chart.

An example of how DSOs can evaluate one of the newly developed business models, that of a DSO as a service provider, was shown with the implementation of the business model based on the advanced forecasting service by using the Canvas model. It shows how the DSOs can improve the operation of their distribution grid as well as the performance of the advanced management and control systems. Additionally, with better renewable forecasting, the hosting capacity of the grid can be improved, increasing the amount of integrated RES generation, and improving the services for electricity end-users.

To overcome the initial thresholds, while markets are still under development, regulatory sandboxes or other incentives could support the new business models that are positioned in the vision of the future multi-domain, multi-vector ecosystem. The regulators should provide room and incentives for the DSOs to include investments in technology as well as human capacity in their regulated incomes, as long as the most efficient business strategy is promoted. An output-based regulation or Totex-approach could also allow for this kind of investment.

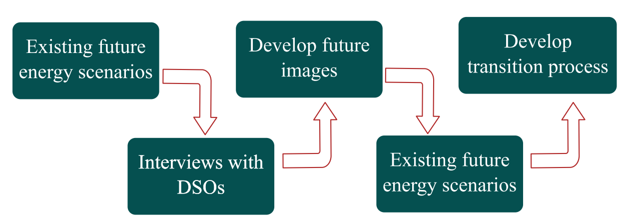
In the future multi-actor electricity market, the proposed business models can be adopted not only by the DSOs but also by third parties such as aggregators who have a relationship with the DSOs. For instance, as shown in the process of implementing the UNITED-GRID solutions at different demonstration sites in the Netherlands, France, and Sweden, the realisation of demand flexibility requires the operational coordination between the involved aggregators and the DSOs. In this case, the DSOs may need the agreement from the aggregators on certain consumption profiles to achieve the desired demand flexibility. Another example is congestion management in which the end-users can provide demand-shifting services to gain incentives from the DSOs.

### 4.3. Adaptation to future system logics

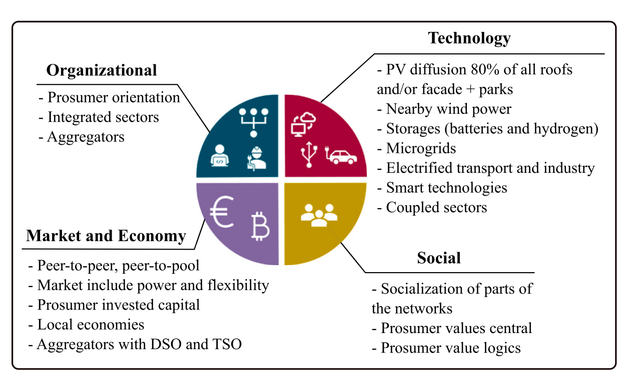
The DSO transition process from a passive distribution grid operator to an active distribution grid manager is highly complex. As discussed in Section 2, the DSOs not only need to take into account new regulations but also to adapt their planning processes and makes new business plans. They also need an internal adaptation to manage the uncertain future at a much faster pace than expected and to react to those changes so that the true value of the investments and changes can be concretised in the longer term. Due to the large differences between the DSOs in Europe in terms of size, organisation, and technical characteristics, it is an individual process where individual methods need to be developed to achieve a preferable scenario, including milestones and critical resources.

#### 4.3.1. Use transition workshop approach

One way to guide the DSOs through the transition process, as developed in the UNITED-GRID project, is through action-oriented workshops, using transition theory and future studies as the conceptual framework. In energy transition research, the regime (which is how the energy system is operated today, including existing technologies and actors) is challenged from both the niche level (through innovative technologies and new business models) and the landscape factors (such as climate change measures and digitalisation). Probable, preferable, possible futures (Amara, 1981) or even more challenging radical futures that move away from incremental changes based on current systems (Ahlqvist and Rhisiart, 2015; Inayatullah, 1990) all require different approaches and tools. For this study, an action-oriented method (back casting) was used within the structural framework of a set of transition parameters that are used as departure points in the 2.5-h long DSO-specific workshops, as shown in Fig. 2a. A future image was developed to challenge the DSOs, based on the status and scenario analysis (Section 4.1.1) in combination with dedicated interviews. The presented ambitious scenario connects four areas: technology (e.g., ambitious levels of electrical transport and distributed smart meters), organisation (e.g., prosumer-oriented systems and integrated sectors), market and economy (e.g., increased transactions between users, trading of electricity, power, and flexibility) and social (e.g., prosumer-oriented value logic), as in the example presented in Fig. 2b. After the presentation of the future image, a structured back casting and future value model discussion with people from different domains within the DSOs, resulted in a description of necessary steps for several categories. The methodology was tested for two DSOs in Sweden, one in a dense urban setting and another in a small rural setting. It resulted in a summary of roles and functions on different time frames, and what they




(a) Transition workshop process




(b) Develop future images: example for the year of 2040

**Fig. 2.** Back-casting workshop approach for imagining a future role for the network operator.

imply for the DSOs in the framework of collaborative efforts, competence requirements, and business and value models.

#### 4.3.2. Review new roles and functions

Many of the challenges discussed in Section 2 are reflected and updated in the workshop discussions related to the role and function of the DSOs, both down the value stream (towards the users and local operations) and up the value stream towards the TSOs.

For the creation of favourable conditions for using local flexibility, new key functions for the DSOs include bringing objective knowledge, trust-building, and facilitating collaboration between local stakeholders. This facilitator role requires a closer and more active relationship with different users: starting with larger customers and in the longer term, building relations with all types of users. These closer ties already exist to some extent in the rural DSO as personal relations are more common. It creates a good starting point for increasing active relations in the future development of the electricity grid. For the larger urban DSO, more efforts are needed to initiate relations, however, opportunities are larger with more potential flexible resources.

Another related role is the communicator role which is needed in the added complexity of managing different distributed resources efficiently and avoiding or postponing costly investments in the grid. As communicators, the DSOs can increase knowledge and discuss efficient demand behaviour with the users, thereby providing greater flexibility in system. A condition for this role is to provide an incentive for customers to be flexible, and to understand the customer needs and value chains, so relations are crucial again and could be more complex in larger urban settings.

Upstream, interaction with the TSOs will become more and more important, as the DSOs will take a more active balancing role. It does not only require the new DSO-TSO interaction schemes for the use of flexibility and local flexibility markets, but also clear agreements and adapted roles for the use of data from monitoring and control devices and aggregated information from end-users and applications. The urban DSO has a clearer market focus, although expressing uncertainties about how the market can be designed efficiently with physical constraints in the DSO grid. For the rural DSO, there are even more uncertainties expressed and doubts as to whether this market should be hosted externally or integrated into the extended DSO function.

The role as a sustainable developer having an increased social responsibility is mentioned in two ways: how should the DSOs facilitate users to become more sustainable in the energy field, and how should the DSOs act to ensure social sustainability for its users? There is a risk of a social imbalance between end-users that can afford investments in distributed technologies and those that have to absorb higher grid tariffs. Another concern is the unfair cost difference between rural areas, with larger possibilities for building renewable supply leading to higher local grid costs, and urban areas that could profit from the imported energy. To take up these social responsibilities, the DSOs could start collaborations with nearby DSOs for efficient balancing of local and regional grids, with opportunities to share investments. These described social responsibilities differ from current roles and require a greater understanding of various types of users, and an active involvement in issues beyond energy. In the short term, there should be increased scope for social responsibility, while in the long term the role should be to provide a sustainable energy system for all users. The urban DSO has a focus on the added role as a sustainable developer, while the rural DSO focuses on just transition and an increased user perspective.

#### 4.3.3. Review collaboration and competencies requirements

The new role of the DSOs shows the need for new actions such as collaborative efforts, building new in-house competencies, and new ways of creating value.

Much of the future roles and functions described by the DSOs require good relations and collaboration with users, third parties (e.g., local market providers and aggregators), other DSOs, and TSOs, to create a mutual understanding between user needs and grid constraints, and facilitating a development that is more resource-efficient and valuable to all actors. It requires new efforts in collaborative development and entails the creation of trust in the DSO as an independent actor aiming to provide the best overall system. Hence, there is a need to reach out to customers, engage and learn about their businesses. The building and strengthening of collaborations and more established partnerships with actors providing and developing ancillary services as well as with nearby DSOs is also needed to efficiently balance local and regional grids and to open opportunities for shared investments in technologies that will facilitate future management of the distribution grid. These collaborative efforts require additional resources in terms of the increased number of employees and specific competencies. These competencies should also be seen in the light of changing regulations and the need to adapt to the new rules of the game, not only in terms of skills and expertise, but also in attitudes and behaviour. Some competencies discussed in the workshops were:

- *New technical competencies*
  - Digitalisation: ICT engineers, software developers, artificial intelligence experts, machine learning, etc.
  - Cross-sector competence: heat-electricity and ICT-energy
  - Local market development: electricity market experts, platform developers, etc.
  - Additional fields: transport and automotive industry, and buildings
- *New social competencies*
  - Relations: communication experts
  - Dual competence: behavioural scientist and engineer

Whether the new competencies are the result of internal education or are based on consultants, it will add operational costs to the DSOs, which have to be covered in the regulated incentives and resources.

The way future DSOs should create value and operate their business will be heavily impacted by new technological solutions as well as regulatory frameworks. It is however also the DSOs' behaviour within the existing framework that will be crucial to steering the transition. The workshops showed that different ways of transition could be possible in the DSOs' view. A cautious approach would be to make small incremental changes in the tariff structure, which in the existing regulation is the way for the DSOs to generate an income and is based on capital expenditures. Including specific operating costs in the tariff structure would solve some of the problems. However, it would not capture all the existing transition opportunities. Another option that was discussed is the DSO as an enabling service company that understands user needs and collaborates to find good solutions for all included actors. Besides the technical and data services already described in Section 4.2, it also includes advising users on how their investments and behavioural change can solve their needs in a cost-efficient and additional value perspective, while at the same time providing benefits to the distribution network. It requires that the DSOs are regulated based on performance and also a revision of the unbundling rules, as described in Section 2. A more radical proposed profile includes the reorganisation of a DSO to one or several energy communities. Similar roles and functions are still needed, but the ownership means differently that all users also own the distribution network in a cooperative organisation. It has implications such as how the costs and revenues are distributed, although regulations will remain similar to a private or municipally owned DSO.

#### 4.3.4. Transition workshop recommendations

Large differences exist amongst DSOs in Europe, even within one country. For example, in Sweden, the ways of ownership differ between private, municipal, or cooperative, which will require different strategies to enter into the future. Therefore the workshop outcomes are DSO-specific and the recommendation is to apply the methodology to other DSOs to gain insights into their transition pathways. However, the transition workshops have helped to shed light on the following are general recommendations for DSOs aiming to maintain an important position within the future electricity grids:

- As planned central energy resources become variable, distributed, and to a great extent held by users, establishing deeper relations and collaborations to find solutions that benefit both sides are necessary to achieve greater flexibility opportunities and efficient grid developments. The key is to create trust among and in between the users, which requires great effort and continuous development work.
- The future distribution grid holds new technologies and routines which need to be reflected in the competence of the DSOs. Whether all competence should be in-house or jointly held together with partners, depends on the size and resources available to the DSOs.
- With the electrification trend in industry and transport, increase the vision of the DSOs and view the future role as an enabling partner for sustainable development within the distribution area. With this view, it is easier to detect and realise greater value and services for actors in the future electricity grid.

## 5. Conclusion and policy implication

The challenges and opportunities for the DSOs in the next 5–10 years are bigger, faster, and more important than ever before. The way in which the DSOs react to these changes will have an important impact on the energy transition but also on their own transition pathways and future. This path is still unclear and no simple guidelines can be written for all due to the high diversity in technical characteristics among the distribution grids, the national regulatory developments, and the uncertainty regarding the future scenarios. Yet this paper, based on the results of the UNITED-GRID project, presents a set of tools and guiding principles that support the DSOs in three European countries in the transition towards future intelligent distribution grids, and it can also be seen as a solution for other DSOs in Europe. The first recommendation is to implement advanced digital solutions to automate and control the network and to help the DSOs to optimise and secure the grid in real-time with automatised solutions as well as anticipating future situations by using advanced forecasting methods. The need for these solutions can be derived from an assessment of the current status as well as future-readiness based on scenarios. Innovation also drives the need for new DSO services and activities, and two novel business models (as a service provider and market platform operator) are proposed to support the DSOs in their new role and relationship with other stakeholders. To prepare for a future that will be completely different from the current logic, DSO agency in the transitioning environment is created based on transition workshops. The outcomes show that there is a need for increased collaborative efforts between the DSOs and stakeholders both up-and downstream and that new technologies but also social competences have to be developed within the DSOs. The paper concludes that the DSOs should not only accelerate investments in innovation and implement novel business models but they should also view their role as an enabling partner for the energy transition to realise greater value for the future electricity grid.

## CRediT authorship contribution statement

**Joni Rossi:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Ankur Srivastava:** Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Tran The Hoang:** Data curation, Writing – original draft, Writing – review & editing. **Quoc Tuan Tran:** Methodology, Validation, Writing – original draft, Writing – review & editing. **Martin Warneryd:** Methodology, Investigation, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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