Ontologies and JSON-LD at TenneT: The use of linked data on EU-303 projects

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Abstract

The demand and supply of electricity adheres to more complex patterns than before. TenneT, an organization which transports electricity in the Netherlands and Germany, will see work done on over 360 high voltage substations in the Netherlands over the next 10 year. For these projects, known as EU-303 projects, TenneT has opted to follow recent standards and employ digitalisation in project management and information exchange. Linked data, including the use of ontologies and JSON-LD, forms an essential part of this digitalisation strategy in facilitating efficiency and accuracy in the communication between TenneT and contractors. This paper discusses the implementation and use of these technologies on the EU-303 projects. The first half year of the programme has been promising, indicating significant time gains and, owing to the JSON-LD format, the ability of organizations to adopt the linked data paradigm even when unfamiliar with its intricacies.

Keywords

Asset management, Linked data, Exchange information requirements, Knowledge graph, Ontology, JSON-LD, High voltage

1. Introduction

The demand and supply of electricity adheres to more complex patterns than before. This development confronts TenneT, an organization which transports electricity in the Netherlands and Germany, with significant challenges. One of these challenges is the transition from traditional energy sources to durable ones. Another is that there are larger suppliers and consumers of energy in the energy network. Energy supply is also moving into relatively sparsely populated areas with limited network capacity. Additionally, there is a need for renovation of existing, aging infrastructure. Challenges such as these have, consequentially, increased the complexity of the efforts at TenneT in guaranteeing adequate supply of electricity.

In the Netherlands alone, 360 high voltage substations owned by TenneT have to be renovated, modified, expanded and/or renewed over the next 10 years. In effect, this demands a doubling of work efforts on a yearly basis compared to previous years. The existing ways of working on projects (i.e., processes and procedures) have not been designed for such volumes of work, which makes it essential for TenneT to cooperate with the market in facing the challenges.

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The collaboration between TenneT and its contractors has been anchored in the framework agreement for the European tender on these substations, titled 'EU-303 Substations',[1] which, amongst others, details the type of activities required and the manner in which contracted parties are asked to deliver their work — including the form in which information is to be exchanged. This framework will form the basis of all projects on substations for the next 10 years. For these EU-303 projects, TenneT has opted to follow recent standards and, rather than continuing a mostly document-based exchange of information that requires TenneT and its contractors to process data manually, employ digitalisation in project management and information exchange. Linked data, including the use of ontologies and JSON-LD, forms an essential part of this digitalisation strategy in facilitating efficiency and accuracy in the communication between TenneT and contractors in a software-neutral manner. This paper discusses the implementation and use of these technologies on the EU-303 projects.

The remainder of this paper is laid out as follows. Section 2 discusses related work. Section 3 explains the use of linked data on EU-303 projects, including that of ontologies (3.1), Exchange Information Requirements (3.2), and JSON-LD (3.3). Section 4 touches upon the uptake and impact of the approach, followed by the conclusion in Section 5.

2. Related work

The use of linked data and Semantic Web technology in information exchange of information has, over the last decade, seen a major uptake in a number of European countries. The Netherlands, for instance, has widely adopted these technologies in sectors such as infrastructure and construction. In these sectors, information on assets owned by provinces, municipalities, and national organizations (e.g., Rijkswaterstaat and Schiphol) are not uncommonly exchanged using a linked data format that incorporates terminology captured in an ontology [1, 2, 3, 4]. Indeed, this approach has been standardized in a national technical agreement (NTA 8035) and a normative standard (NEN 2660) and expected to develop subsequently at an international level through CEN/ISO [5, 6]. In other sectors, too, knowledge graph technology has been adopted for sharing and exchange of information. At the company Bosch, for instance, virtual knowledge graphs have been employed to integrate manufacturing data [7], and at the European Commission, linked data has been used to publish open government data [8]. Use of these technologies facilitates software-neutral communication according to clearly specified semantics, which is considered an essential pillar on the EU-303 projects for collaboration with multiple contractors.

An article by Pieter Pauwels et al. provides a comprehensive literature review on use cases for Semantic Web technology in the domains of architecture, engineering, and construction [9]. Scholarly work on this topic, as the article indicates, focus on three main aims for the use of this technology: (1) interoperability, (2) linking across domains, and (3) logical inference and proofs. Indeed, all three aims are in line with those at TenneT. Interoperability is sought in order to enable vendor-neutral model exchange between TenneT and its contractors (cf. [10, 11, 12, 13, 14, 15]), minimizing document-based information exchange, and to combine different information representations (both Systems Engineering and BIM on the EU-303 projects,

[1] See https://ted.europa.eu/udl?uri=TED:NOTICE:334228-2019:TEXT:EN:HTML.

cf. [13, 16, 17, 18, 19, 20]. With respect to linking across domains, the EU-303 projects opt for ontology-based information management and sharing (cf. [21, 22, 23, 24, 25, 26]). Lastly, the model coherency and consistency of the ontology, and the completeness of data deliveries on the projects themselves, are being verified using Semantic Web technology (cf. [17, 27, 28, 29, 30, 31]). The current paper differs from the aforementioned ones in that it details a case in which the involved parties can opt to utilize either Turtle or, instead, the more recent JSON-LD format [32] to share data on assets — a choice aimed at lowering the threshold for contractors to share data in a digital, linked data form. Additionally, this paper offers preliminary insights into the reception of the described approach amongst contractors operating in the energy sector.

3. Approach

The approach on EU-303 projects for exchanging asset data is informed by national and international open standards. The national technical agreement NTA 8035 describes the practice of capturing asset terminology in ontologies and how these ontologies can be applied in capturing alphanumeric information on asset data proper [5]. Thus, types of assets and their characteristics are identifiable and can be referred to and shared in both a human-readable and machine-interpretable manner based on the linked data underlying the knowledge graph.

For the exchange of asset data proper, ISO 19650 dictates the use of Exchange Information Requirements (EIR) to specify which data is requested and in what form it is to be exchanged [33]. The use of linked data as exchange form can be part of an EIR and, in cases where an ontology provides the asset terminology required, facilitates the interpretation of the asset data (cf. NTA 8035). This approach has been adopted on EU-303 projects at TenneT in the digitalisation of its information exchange.

3.1. Ontology

TenneT employs an ontology on EU-303 projects in order to share asset terminology that is recognised and used by TenneT and its contractors (e.g., for projects where a contractor has been asked to extend the capacity of a power station owned by TenneT). The terminology captured in the ontology contains types of assets (e.g., a powerline, a transformer) and characteristics (e.g., diameter, capacity) that are defined in standards specific to the sector and have a proven record in use at TenneT in projects and requirements on assets, albeit mainly in written documentation rather than digitised asset data. Terminology is incorporated in an ontology only when relevant for use on EU-303 projects, which hinges on the occurrence of terms in use cases that are distilled and have to be covered in exchange of digital information and/or project requirements. These terms are then captured, managed, and published using software developed for this purpose. The purpose of this methodology is to focus efforts on the most relevant use cases only. If other types of projects are to adopt the same approach at a later stage, the terms can be expanded to cover the corresponding needs. Owing to the software-neutral form in which the ontology is published, it is possible to manage the knowledge within in a variety of applications. For the EU-303 projects, TenneT has opted to utilize the Laces software suite, while leaving its partners free to use their own tooling. The Laces software suite allows domain experts — including those without prior experience with linked data technology — to define their terminology and subsequently publish it as linked data.[2]

Next to terminology for physical objects (assets), the TenneT EU-303 ontology focuses on activities, requirements and documents. Types of activities are defined to standardize project management (e.g., communication on risks) or construction activities (e.g., leveling ground). Standardized requirements are linked to both asset and activity types, to facilitate all parties to find the appropriate requirements more easily. Finally, document types are captured based on the IEC 61355-1 in order to formalize their definitions and to assign metadata to individual documents in a more structured manner [34].

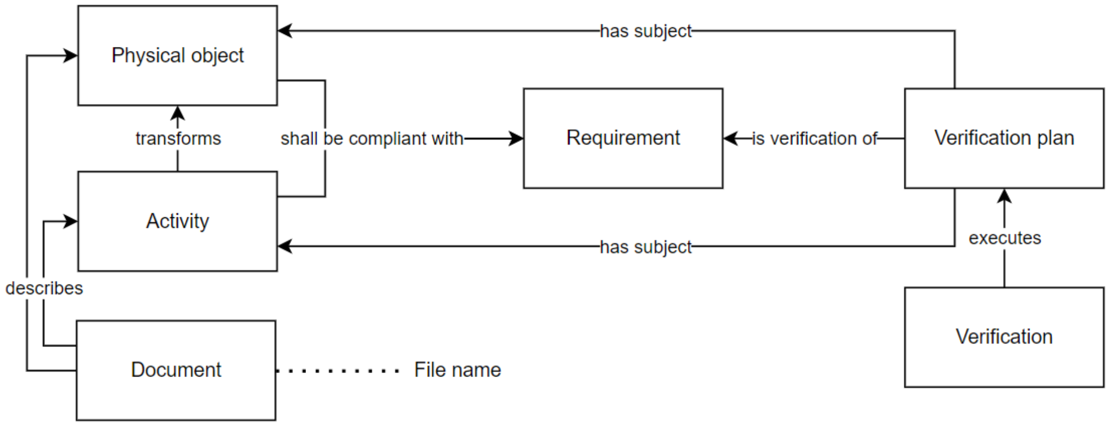

Figure 1: Main components of the TenneT ontology

The use of linked data and Semantic Web technology in sharing an ontology offers the means to describe the asset terminology in an ontological manner and ensures individual terms are identified by means of Uniform Resource Identifiers (URIs) once published. Such URIs allow one to reference a term unambiguously and employ it in data exchanges. Both TenneT and contractors on EU-303 projects can access the relevant ontology in a machine-readable and human-readable form. Automated access to the ontology for direct use in applications is provided through SPARQL endpoints, which allow queries to be executed using a standardized REST API (e.g., requesting the parts out of which a certain asset type, such as a transformer station, typically consists) [35, 36]. Parties involved can use these means to incorporate the ontology terminology and URIs in their project environment. In fact, the human-readable form of the ontology is dynamically generated using the same SPARQL endpoint. A web application acts as viewer and provides documentation on each term, its characteristics, and its relation to other terms.

3.2. Exchange information requirements

Exchange Information Requirements (EIR) specify the form in which data is to be exchanged — in this case between client and contractor when working with digital asset data. Figure 2

[2] https://laceshub.com/

provides a schematic overview of such data exchange between TenneT and its partners. Both parties can connect to the endpoint of the EU-303 ontology in order to use the same shared terminology. Moreover, both are able to work with the tools they prefer, as long as they exchange information according to the EIR specification. The EIR in use on EU-303 projects distinguishes between various kinds of project data conform ISO 19650: alphanumeric information, geometric information, and documentation [33]. Each of these has its own characteristics and a range of suitable formats in which they could be captured.

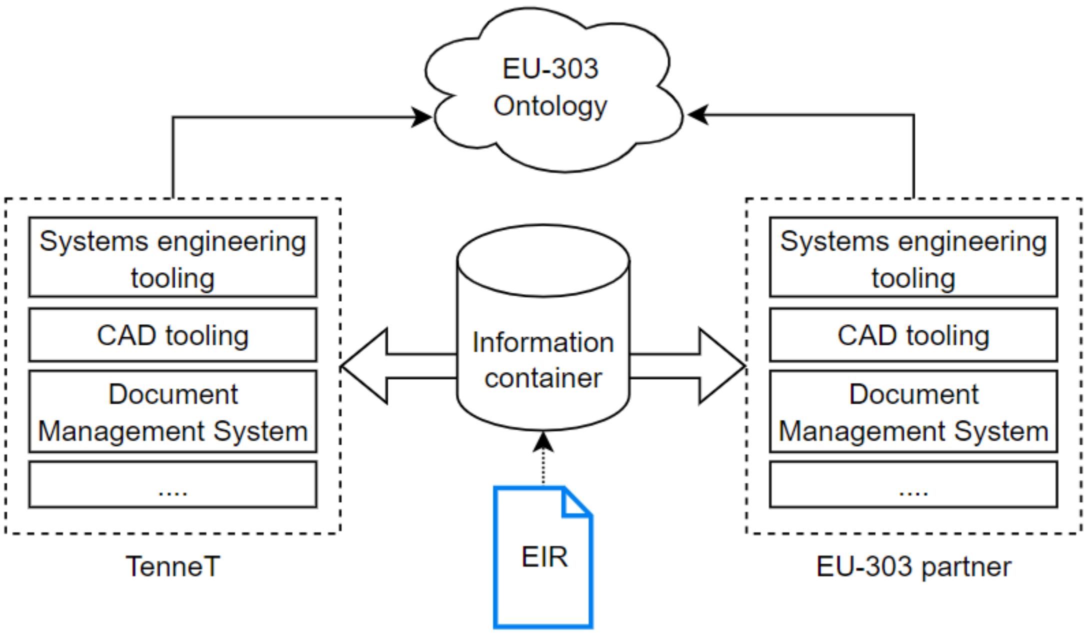

Figure 2: The TenneT architecture for data exchange

Alphanumeric information is to be captured in the form of linked data. This information must conform to the structure defined by the TenneT EU-303 ontology, to ensure that both TenneT and the contractor are able to interpret the data in the same, unambiguous way. That means that project information should be classified to the ontology first of all (e.g., 'this transformer in the substation design' is of the ontological type 'transformer'). Contractors can also aid the further development of the ontology by indicating more specific types that ought to be incorporated in the ontology, too. There always ought to be a generic type in the taxonomy to which information can be classified, however. The second main requirement is that information is interrelated using the predefined relations from the ontology, which are based on the NTA 8035 where possible (e.g., 'relay A *is part of* transformer X' or 'transformer X *should comply with* requirement 01).

TenneT prescribes two serializations which can be used to capture alphanumeric information: the commonly used Turtle format and the more recent JSON-LD format. The aim with the latter as one of the options is to lower the threshold of applying linked data. This will be covered in more detail in the next section (3.3). Finally, the Unique Resource Identifiers (URIs) of all project information should follow a standardized structure, independent of the party that coined them. This practice will allow for an asset register to be maintained by TenneT.

Geometric information should also be shared according to open standards in order not to limit any party to the use of specific software. For this reason, the IFC exchange format has been adopted by TenneT for the exchange of 3D models, following the ISO 10303-21 STEP file standard [37]. Besides the use of an open standard, the most important requirement on the geometric information is that it is related to the alphanumeric information. To this end, all model elements should be classified to the OTL and contain the same URIs as their counterparts in the alphanumeric information. This practice facilitates end users in quickly identifying elements and combining information from the two sources, without any complex logic.

The third information type, documentation, refers to all files that are not expressed as alphanumeric or geometric data. This includes a wide variety of document types, including pictures, 2D drawings, and manuals. The alphanumeric information should contain a reference to each document by means of a unique identifier. The same identifier should be used as the document name. This requirement ensures that documents are linked to their context (i.e., there is a link to each asset or activity for which the document is relevant; see Figure 1).

All three information types described above are bundled in a single information container. This container takes the form of a zip-archive containing three folders: alphanumeric, geometric and documentation. As the data inside is already coherent, the purpose of the container is to bundle the information in a single file that is straightforward to exchange. The approach is inspired by the ISO 21597 standard, also known as ICDD, which was still a draft at the start of the EU-303 projects. An adoption of the full standard may be explored in the future.

3.3. JSON-LD

The EIR allows alphanumeric information to be captured in either Turtle or the JSON-LD format. Turtle is an established format of linked data in the sector (e.g., see NTA 8035, which contains examples in this format). Contractors that have worked with linked data in earlier projects are therefore not unlikely to have developed and invested in software solutions that incorporate this format for exchanging information. For organizations new to using linked data, however, the Semantic Web standards and the Turtle format are often perceived as a high barrier for capturing and working with RDF [32, 38]. Employing JSON-LD, as alternative to Turtle, in the EIR of TenneT EU-303 projects is meant to offer organizations benefits from this format that can express the same data. JSON-LD, according to its official specification, was designed with simplicity in mind [32]. Indeed, as JSON-LD builds on the JSON format, popular amongst Web developers, expectations were that organizations would opt for adopting this format over Turtle for their first foray in using linked data.

In order to allow parties to adopt JSON-LD for exchanging information with TenneT on EU-303 projects, the first step was to make the terminology in the ontology used on these projects available as a JSON-LD context. The first implementation of creating this context, in which URIs from the ontology are given a shorthand phrase for use in JSON-LD, employed an automated method that uses SPARQL queries on the endpoint of the ontology in order to retrieve all object types, properties, and so on, and assign their URIs a shorthand phrase based on their (human-readable) labels. Thus, “Transformer” could be used in a JSON-LD file to mean “http://data.tennet.eu/def/aa17cb97-1de1-37cd-b0b4-8e09d6080908”. The resulting use for specific asset data for JSON-LD, as can be seen in Listing 1, may be considered less opaque than using their equivalent URIs in the Turtle format, shown in Listing 2.

```
{
  "@context": "https://.../jsonld/otl-v1.jsonld",
  "@graph": {
    "content": {
      "physical object": [
        {
          "id": "http://data.tennet.eu/id/b8da5570-...",
          "type": "Distribution system for 380 kV ≤ Un ≤ 420 kV",
          "name": "Distribution system 380 kV veld 12",
          "code": "T001=ACA112",
          "price": { "value": "1000", "unit": "euro", "type": "quantity value" },
          "restore time": { "value": "240", "unit": "minute", "type": "quantity value" },
          "CBS code": "K501034",
          "material": "Metal",
          "planned start date": "2021-01-01",
          "planned end date": "2021-01-01",
          "VNB status": true,
          "ground": "http://data.tennet.eu/def/4522a624-...",
          "has part": [ "http://data.tennet.eu/id/3028637c-..." ]
        }
      ]
    }
  }
}
```

Listing 1: Example of information exchanged in JSON-LD on a specific physical object

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
@prefix schema: <https://schema.org/> .
@prefix base: <https://w3id.org/def/basicsemantics-owl#> .
@prefix tennet: <http://data.tennet.eu/def/> .
@prefix id: <http://data.tennet.eu/id/> .

id:b8da5570-..
  a tennet:0dfed401-212c-4a3f-a33d-2b41ee347a23 ;
  skos:prefLabel "Distribution system 380 kV veld 12" ;
  skos:notation "T001=ACA112" ;
  tennet:1abf5e56-ad7c-4d8b-8887-4c4e618dc0af [
      a base:QuantityValue ;
      rdf:value "1000" ;
      schema:unitText "euro" .
  ] ;
  tennet:2ee76514-38fe-4e41-a5be-0394d46d51bd [
      a base:QuantityValue ;
      rdf:value "240" ;
      schema:unitText "minute" .
  ] ;
  tennet:ea172b25-18d5-450a-97bf-2510be29adf2 "K501034" ;
  tennet:6113ac03-e674-499c-be06-0d110162d6a3 "Metal" ;
  tennet:5eecdcd1-f355-4e1d-90e9-f50f69c9feea "2021-01-01"^^xsd:date ;
  tennet:70d4b524-fa73-4268-82fc-ac12ef9c4a94 "2021-01-01"^^xsd:date ;
  tennet:e0433461-06c2-468a-88ff-fc30d90342af "true"^^xsd:boolean ;
  tennet:abe0a2a7-7957-4719-baa9-ef7795e45859 tennet:8b9a1b1d-ff7d-4148-bee2-3691db1bd6a6 ;
  base:hasPart id:0dc53424-4bb0-431b-b82b-691661e52cb2 ;
.
```

Listing 2: Example of information exchanged in Turtle on a specific physical object

In implementing JSON-LD for data exchange on EU-303 projects, the goal of the chosen data structure was to minimize complexity and maximize transparency for developers. By using the `@graph` keyword, multiple resources can be described in a single JSON-LD file. A so-called type map is used in order to provide clarity on the type of objects. Rather than interspersing objects of all types in the JSON-LD format, they are grouped on the basis of the top element identified by the technical agreement NTA 8035. Data on all physical objects of a project are thus subsumed under the key “physical object”; all activities under the key “activity”; and so on. The identification of each object is done through the `id` key instead of through JSON-LD id maps. This approach, effectively, captures URIs in the JSON-LD format as data attributes of an object rather than as their indexing mechanism. The resulting structure is expected to increase transparency for parties who do not have substantial experience with linked data and URIs.

4. Uptake and impact

Although steps towards digitalisation were desired by TenneT on EU-303 projects, such steps were not of primary concern in offering work to contractors. Work done on high voltage substations needs to be satisfactory and safe, first and foremost. Potential contractors were therefore asked, in a tender, to provide evidence of their ability to perform in such a manner. If, additionally, they demonstrated a capability in delivering their information digitally (i.e., conform the EIR), they would obtain bonus points. Thus, digitalisation has been an optional component in working with TenneT on EU-303 projects so far; one that allowed potential contractors to distinguish themselves beyond their main activities. However, digitalisation will become mandatory in the future.

The tender resulted in a selection of nine contractors with which TenneT will collaborate on EU-303 projects for the next ten years.[3] The majority of these contractors (seven) showed that they can offer their information in a digital manner; their bids included example hand overs of information that demonstrated that all EIR criteria — including exchange using linked data principles — could be fulfilled by these contractors. In fact, there were indications that many of these organisations would be investing in digitalisation over the next few years or already had, e.g., in their software landscape, available expertise, and possible collaborations with TenneT on this front. This positive stance towards digitalisation offered TenneT insight into the current situation as to whether such ambitions are realistic. Over the next ten years, then, TenneT intends to exchange data on their EU-303 projects using linked data — some projects will exchange alphanumeric information in the Turtle format, others in JSON-LD. In fact, two contractors used the Turtle serialization to exchange alphanumeric information; five chose to adopt the JSON-LD format instead and can be said to use linked data without requiring intricate knowledge of the technology.

Evaluating the methodology outlined here on projects will be an ongoing process over the next ten years. We intend to report our findings every few years, charting the change in duration of project activities, perceived quality of outcomes, and the investment required in adopting and/or learning the new methodology. Here, we present preliminary results of the first half year of its implementation, in which TenneT and contractors have set up a number of projects and had experience with the exchange of information on requirements surrounding projects (on the objects and on the activities to be performed) specifically. The indications are that the approach saves contractors a significant amount of time on requirement management in comparison to previous approaches for communication with TenneT. Instead of having to scrutinize all TenneT standards in order to find the relevant requirements for the project at hand, contractors can access the ontology and find relevant requirements linked to types of objects and activities. According to contractor SPIE, this linked (or "cleaned") set of requirements allows contractors to save a considerable amount of time on a project for TenneT: three to four weeks. Although too early to extrapolate these figures for the 360 and more substations that will have work done in the next ten years, the time reduction on this aspect is significant and much needed to manage the demand and supply of electricity. Moreover, EU-303 project management staff at TenneT indicate that the digital data exchange on projects ensures that far less information has to be entered into their systems manually. The exchange accelerates the process of verification and validation of requirements being met on projects, too, since the EIR facilitates overviews of all requirements relevant for a given project alongside whether these have been assessed and taken into account by the contractor or are absent from their project data. Linked data thus enables more efficient and accurate requirements management in the initial phase of a project and is designed to enable an audit trail throughout subsequent phases, too (e.g., design, maintenance).

[3] See https://www.tennet.eu/nl/tinyurl-storage/nieuws/tennet-presenteert-negen-partners-voor-uitbreiding-en-vernieuwing-van-360-hoogspanningsstations/ (in Dutch).

5. Conclusion and future work

The renewal and expansion of Dutch high voltage substations owned by TenneT involves a substantial increase in work load compared to previous years. This increase necessitates improvements in methods and processes used on projects. The digitalisation efforts on EU-303 projects at TenneT, which resulted in Exchange Information Requirements that employ linked data, are part of these improvements in order to facilitate efficiency and accuracy in data exchange. A number of organizations have demonstrated their willingness and capabilities to adopt the data exchange, leading to a selection of contractors with which TenneT will adjust, renew, or expand the 360 existing high voltage substations. Lessons learned on the EU-303 projects will be valuable for future efforts, including projects in Germany and projects that deal with subjects other than high voltage substations (e.g., EU-300 Engineering & Spatial Services, EU-301 Lines, EU-302 Cables). There, too, improvements in work methodology and data exchange are desired in order to cope with the increase in work load compared to previous years. The first half year of the programme has been promising, indicating significant time gains and, owing to the JSON-LD format, the ability of organizations to adopt the linked data paradigm even when unfamiliar with its intricacies. In the next ten years, further evaluation will take place of these changes towards digitalisation — changes that are aimed at greater collaboration, empowering and energizing those involved in supplying electricity.

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