SOGNO

D6.4 v1.0

CSR aspects (environmental and societal impacts) of the identified value chain designs

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Abstract
The SOGNO-trialled value chain design entails business model innovations for both smart grid service providers and DSOs as, service recipients, as well as infrastructural changes, which affect a large number of sectoral actors (e.g. consumers, retailers, aggregators, DSOs, TSOs, generation companies, etc.). The identified value chain design is hence expected to exert a multitude of economic, societal and environmental impacts which are analysed in this Deliverable using the Triple-layered Business Model Canvas approach. Embedded in it, the Deliverable investigates concrete potentials of particular SOGNO service modules to contribute to improvements in DSOs operational performance while considering also the regulatory changes that can enhance sustainability-oriented business model innovation.

Keyword list
Sustainability-oriented Value Chain Design, Corporate Social Responsibility, Business model innovation, Cloud-based Smart Grid Service

Executive Summary

SOGNO envisions an IOT platform for smart grid services to be developed as an open source solution cost-effective, seamless and secure power supply for consumers that become active players while supporting DSOs and TSOs in their system responsibilities. The SOGNO solution enables business model innovations for both smart grid service providers and Distribution System Operators (DSOs) as service recipients, as well as infrastructural changes, which affect a large number of sectoral actors (e.g. consumers, retailers, aggregators, DSOs, TSOs, generation companies, etc.). The present Deliverable outlines the general role of the heterogenous actors involved in the SOGNO-typed value chains from a Corporate Social Responsibility (CSR) perspective.

The present Deliverable focusses on the business models of a vendor providing system awareness services and autonomous self-healing services "as-a-service" to DSOs and that of a DSO as service recipient. using the Triple Business Model Canvas. According to this approach, the overall business models from of both DSOs and potential service vendors are conceptualised from economic, societal and environmental perspective. The Deliverable highlights the variety of facets to be potentially considered when evaluating the use of smart grid services and shows the potentials of smart grid service utilisation to improve DSOs' operational performance while corresponding changes of cost structures are shown to affect consumer electricity prices.

The deliverable highlights the socially sensitive role of regulators in the incentivisation of DSOs to ensure that costs and benefits of smart grid technology diffusion are fairly allocated among all stakeholders. Therefore, the work report mentions guidelines for sustainability-oriented business model design and corresponding incentive schemes. Regulators are not only to incite DSOs to exploit the opportunities of flexibly testing smart grid service modules in order to innovate their operations but also to comprehensively address data interoperability related issues such as data ownership and control issues of the heterogeneous actors involved in smart grid service markets.

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Table of Contents

1. Introduction

Service Oriented Grid for the Network of the Future (SOGNO) is a 30-month project which has started in January 2018 and is funded by the European Commission in the Work Programme Horizon 2020 under the topic 'Next generation innovative technologies enabling smart grids, storage and energy system integration with increasing share of renewables: distribution network'. SOGNO trialled the implementation of cloud-based system awareness services and autonomous self-healing services for advanced distribution network management (hereinafter also referred to as smart grid services).

1.1 Motivation and objectives of the Report

Distribution network management based on cloud-based smart grid services - as envisioned in SOGNO - is a reasonable means for Distribution System Operators (DSOs) to cope with current operational challenges that arise from volatile, bi-directional electricity flows and decreasing simultaneity of electricity consumption and production. The business of DSOs and the overall system can benefit from DSOs conducting an active electricity distribution management approach which is about adaptive, intelligent grid operation with proactive voltage and distributed generation (DG) unit control, automatic fault recovery, automated reaction to unusual transient behaviour and real-time grid-monitoring driven by ICT-connected measurement devices [1]. This goes along with structural changes in the value chain, e.g., substituting or complementing software installations of existing Supervisory Control and Data Acquisition (SCADA) systems through decentralized procurement of cloud-based smart grid services via Internet of Things (IOT) platforms. These changes may entail risks and significant switching costs for DSOs, which this Deliverable contrasts with the potential overall benefits of the system [2].

Becoming active players in the energy sector requires DSOs - regulated natural monopolies - to act in an ecosystem with competitive enterprises and private households, for which the successful development is particularly dependent on the willingness of the involved heterogeneous actors to share knowledge, information and data [3] and on the design of regulatory incentive schemes [4,5]. The SOGNO solution - an open and modular platform for smart grid services - functions as data middleware with the DSO at the center of the data traffic, so playing an unbiased role between service providers, consumers and the market. The associated (infrastructural) changes are expected to exert a multitude of economic, societal and environmental impacts which lead us to analyze the SOGNO-trialled value chain for smart grid services using the Triple-layered-Business-Model Canvas approach. Embedded in it, we investigate concrete potentials of particular SOGNO service modules to contribute to improvements in DSOs operational performance and we analyze the regulatory changes that can enhance sustainability-oriented business model innovation. The undertaken approach focusses on the DSO as service recipients and on the vendor of smart grid services and aims to demonstrate the multitude of facets to be considered when evaluating smart grid services and corresponding value chain structures. Last but not least, the report underlines the importance of sustainability-oriented business model design to ensure that costs and benefits of smart grid technology diffusion are fairly allocated among all stakeholders [2].

1.2 Related Project Work

The work presented in this report has been part of the activities carried out in the WP6 of the SOGNO project, which is about "Analysis of business model and standard regulation". As WP6 is one of the cross-cutting WPs of the project, the activities here presented are the result of a deep collaboration with the other technical WPs. In particular, for the work reported in the present deliverable, WP6 cooperated with:

- WP1-WP3 to derive the impact of SOGNO use cases[1] on DSOs' operational performance

[1] We define use cases as exemplary operations relating to DSOs tasks that show how the SOGNO services could be utilised by DSOs.

- WP4 to derive the implications associated to the use of the modular and open platform promoted in SOGNO
- WP5 to collect data for the present analysis and to consider DSOs' requirements,
- WP7 to contribute to the exploitation of the project's results.

1.3 Outline of the Report

The remainder of this work report is structured as follows. Chapter 2 outlines the general role of the different actors involved in the SOGNO-typed value chains from a Corporate Social Responsibility (CSR) perspective. Thus, it motivates the application of the Triple Business Model Canvas to describe the general business models of the main actors in the SOGNO-trialled value chain from an economic, societal and environmental perspective, which is done in chapter 3. Embedded in it, chapter 3 addresses concrete use cases of the SOGNO services and investigates potential changes in consumer electricity prices as a result of changing OPEX and CAPEX. Chapter 4 subsumes the underlying results and derives guidelines for sustainable value chain design while highlighting the important role of the regulators for effective incentivisation of DSOs. Eventually, chapter 5 concludes the report providing an outlook for further investigations.

1.4 How to Read this Document

While the document has been written trying to make it as self-consistent as possible, to fully capture the underlying aspects behind the value chain and innovative business models presented in this paper, an overall view of the concepts developed in the SOGNO project is needed. In particular, additional Deliverable that could be helpful to grasp a comprehensive view of the innovative concepts promoted in the project are:

- D1.1 – Scenario & architectures for stable & secure grid (M12): it includes a description of power system scenarios investigated in the project, with motivations for the services presented in this deliverable for current and future distribution grids.

- D4.1 – Definition of the overall SOGNO system architecture (M10): it provides the high-level overview of the modular implementation of the IoT platforms used as a reference for the flexible integration of the SOGNO services

- D6.3 – Identification of economically feasible value chain designs (M12): it identifies the economically reasonable value chains arising from the new service-oriented model proposed in SOGNO for the management of smart grids.

2. Corporate Social Responsibility of Actors considered within the SOGNO-trialled Value Chain

The European Commission defines CSR as “the responsibility of enterprises for their impacts on society” [6]. The SOGNO-trialled value chain has multi-layered impacts on society, as it concerns several heterogeneous actors (e.g. DSOs, software/algorithm developers and IOT platform providers, manufacturers of monitoring devices, telecommunication enterprises, prosumers and consumers as well as European-level and national-level regulators). The conglomerate of those actors collaborating along the value chain bears shared social responsibility in that it ultimately aims to enhance DSOs’ operational decision-making quality and thus improving reliability and continuity of electricity supply as well as integration of intermittent renewable energy sources while lowering total distribution system costs. For this purpose, SOGNO trials a new business model for the provision of cloud-based smart grid services by taking components from different manufacturers and software providers, integrating them and offering system awareness services and autonomous self-healing services “as-a-service” to DSOs instead of selling the smart grid services as a monolithic SCADA system product to DSOs. In this context, SOGNO envisages a modular and open software architecture which enables DSOs to choose between software and hardware components from multiple vendors in order to obtain those that meet their requirements at highest quality and best price. If the SOGNO-trialled approach is adopted by the market, substantive knowledge gains are expected along the value chain which ultimately encourage business model innovation and job creation in the European Union. Besides those general impacts to be expected, each of the individual value chain actors bears different types of responsibility in the social, environmental and economic (sub-)systems in which they operate.

The social responsibility of regulators is closely linked to that of DSOs. Regulators are to supervise DSOs - operating as natural monopolies - to deliver electricity supply in a socially just manner and to incentivise DSOs to aim at the best possible reliability and continuity of supply. Regulators and DSOs frequently interact in order to agree on the level of DSOs’ allowed revenues. DSOs revenues are funded via electricity network charges. For instance, DSOs and regulators negotiate on CAPEX based on investments in the “regulated asset base”, non-controllable and controllable OPEX that incur for the improvement of network operation and, depending on national quality regulation design, bonuses/penalties for good/bad quality of supply. Distribution network charges make up a share of consumers’ electricity prices and are collected to finance DSOs’ expenditures and DSOs’ income. Hence, the regulators have the sensitive task to determine whether particular DSO expenditures are worth to be financed via the electricity price and thus borne by the consumer. In Germany, for example, grid fees have risen in recent years (because ever increasing network operation costs are considered to be justified for the increasingly challenging task of Renewable Energy Sources (RES) integration) and with them the electricity prices for consumers. Potential cost-reducing effects of cloud-based smart grid services must therefore be taken into account by the regulators and – from a CSR perspective - any resulting monetary gain is to be distributed fairly between DSOs and consumers. Provided that the utilization of smart grid services enhances DSOs’ operational performance [7,8] e.g. in terms of service quality and cost, regulators should not restrict the usage of new smart grid services but encourage DSOs to test and potentially use such innovative solutions through corresponding incentives in the regulatory frameworks.

The entire market concept can only create societal value when data privacy requirements are comprehensively taken into account. As DSOs control critical infrastructure, there are legitimate trust concerns over cloud-based services that integrate directly with SCADA systems, e.g., in terms of cybersecurity, systems availability and manageability. This evokes barriers to the market development of cloud-based smart grid services, as DSOs - in order to participate in an open platform market for smart grid services – could need to exchange sensitive business and grid data with the service providers. The social responsibility of service vendors, this can be a software developer itself but also, for instance, an IOT-platform provider, a telecommunication company or a device manufacturer, is thus to fulfil all data protection requirements of market participants. In this context, attacks of leaking privacy (e.g. key-based attacks, data-based attacks, impersonation-based attacks, and physical-based attacks) require the service vendors to implement privacy-preserving countermeasures which - in smart grids - mostly function based on cryptography [9].

A further responsibility of the cloud-based service vendors is not to undermine the benefits of the open market architectures for smart grid services through contractual conditions or exclusive data ownership and control [10]. This potentially happens as investment risk moves away from DSOs but does not completely disappear from the value chain, suggesting actors to apply risk-minimizing techniques in a different place, e.g. decreasing the risk of customer churn by provoking vendor lock-in [10]. As DSOs can benefit from market conditions that allow them to flexibly test and potentially deploy new software services and, as such an open market approach fosters business model innovation [11], regulators are required to ensure data interoperability which means to put mechanisms in place to guarantee that all enterprise data processed in the cloud can be easily and securely removed, e.g. for reasons of integration with another cloud service or switching to another Cloud Service Provider, etc [10].

Eventually, the manufacturers of monitoring devices bear, in the first place, an ecological responsibility. This concerns, first, the life-cycle costs of raw materials they procure. That is, taking procurement decisions that account for the pollutant emissions and human distress occurring in the mining and transportation of the raw materials. Second, it concerns the emissions occurring during the production phase at the site. Pollution prevention technologies can be implemented in order to achieve positive environmental effects with increasing production efficiency [12].

Once the general societal and environmental impact of the value chain actors and its interlinkages have been described, the next chapter rolls out the CSR aspects of the SOGNO-trialled value chain and business model changes in more detail. In order to conceptualize and assess the SOGNO-trialled chain changes, we use the Triple-layered Business Model Canvas methodology, as it allows us to express a “holistic and integrated view of a business model” [13] and to explore sustainability-oriented business model innovation [13].

3. Triple-layered business models of Actors in the SOGNO-trialled Value Chain

A business model is defined as “a conceptual tool that contains a set of elements and their relationships and allows expressing the business logic of a specific firm. It is a description of the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, to generate profitable and sustainable revenue streams [14]”. The Triple Layered Business Model Canvas extends the original business model canvas by an environmental layer and a social layer [13] and thus allows for the investigation on how not only economic but also environmental and social value are created in the SOGNO-trialled value chain. In the following, this approach is applied to analyze the economic, environmental and social value created by the SOGNO model for service vendors and DSOs, which are the main actors in the SOGNO value chain.

3.1 Service Vendor

The value chain envisioned by SOGNO foresees the interaction of different types of actors, such as DSOs, telecommunication companies software/service providers, IoT platform providers, plus possible other third parties like research institutions, consultancy enterprises. It suggests smart grid services to be accessible for DSOs via remotely or self-hosted IOT platforms on which different service modules from different developers can be installed. Complementarily, the deployment of monitoring devices in the grid was de-centrally coordinated and implemented. SOGNO envisages future markets for smart grid services to function in a way that DSOs can access smart grid service modules (e.g. system automation and awareness functions) via (open) IOT platforms potentially in parallel to their own technical platform. The IOT platform potentially represents a form of marketplace via which the DSOs get access to various service modules in an agile and unbureaucratic way while at the same time being able to choose and use the components of various suppliers. All actors can potentially act as the central contact for the DSO, who coordinates access rights and, if necessary, installations of monitoring devices in the physical grid. In the following of this Deliverable, when referring to the *‘service vendor*’, we mean the specific actor that the DSO transacts with in order to being able to use a particular smart grid service module. This concerns, e.g., the tasks of device installation, communications signal testing and full data transfer validation to ensure the functionality of particular service modules. During the project, SOGNO has developed the service modules of Load & Generation Prediction, Power Control, State Estimation & Power Quality Evaluation and FLISR based on traditional models as well as using last generation machine learning algorithms. These have been deployed, tested and validated in the field trials of ESB, CEZ and RWTH, following the IOT concepts presented above, as reported in Deliverable D5.2.

3.1.1 Economic Layer

The overall value proposition of the service vendor’s business model is the provision of a modular IOT platform that facilitates DSOs to deploy and/or test new system awareness and autonomous self-healing services and thus to innovating existing distribution network management systems. In particular, it enables small DSOs with limited experience to quickly access optimized, up-to-date smart gird services with limited risk and investment. SOGNO envisages that DSOs can access smart grid service modules via an IOT platform, which functions as an (open) marketplace for those, while paying periodic service fees as long as they use particular service modules. The platform enables DSOs and service vendors to flexibly contract with each other and fosters service contracts without vendor lock-in to enable trial-and-error learning which is conductive to business model innovation [15]. It is key for the functionality of the platform that all partners involved – namely IOT platform provider, manufacturer of monitoring devices, software/service implementer and mobile communication companies - coordinate their efforts in order to offer full-service solutions to DSOs. The core competency of service vendors is software deployment and continuous improvement, maintenance and organization of smart grid service integration to the DSOs operation. It is based on skilled IT personnel in combination with research and development activities. Hence, the cost structure is dominated by OPEX in form of personnel costs. CAPEX are mainly incurred for the production facilities on which the monitoring devices are manufactured and for accessing the communication infrastructure. With the evolving market for smart grid services parts of the OPEX will be somehow distributed among the different customers of smart grid service vendors (for example, if the same IOT platform is used for several DSOs, part of the costs to maintain the platform etc. can be split among the different customers) allowing to reduce individual costs and to remain competitive with respect to possible other competitors finally leading to lower fees for the DSO, with a chain effect that finally arrives at electricity consumers.

3.1.2 Environmental Layer

The environmental layer conceptualises how a business model generates more environmental benefits than negative environmental impact. The functional value of the service vendor's business model is the provision of a working service module which necessitates both the operational accessibility of the algorithm behind the service module for the DSO (via corresponding interfaces in combination with the monitoring devices deployed in the grid) and on-going (real-time) data exchange. During the use phase, the DSOs access the full functionality of particular service modules distributed via an IOT platform. The service modules might be updated remotely. The dominant negative environmental impacts occurring in the sphere of the service vendor are energy consumption of ICT - e.g. communication networks, personal computers and data centres - [16] and negative external effects (e.g. pollutant emissions released to air, water and soil) occurring during raw material sourcing and processing as well as during transport and production of monitoring devices. Further negative environmental impacts to be minimized – e.g. through recycling of input materials - are those that occur at the end-of-life of particular monitoring devices. Positive environmental effects are, in general, incurred when the utilisation of smart grid services renders physical network extension obsolete [17]. That is, the deployment of smart grid services potentially allows DSOs to face the challenges via software solutions rather than through the reinforcement of the grid. This implies that installing new electrical lines, replacing transformers or other physical components in the grid can be avoided to a certain extent. At some point, to face the current challenges of the distribution grids, either physical network expansion or smart grid service deployment has to be adopted while the latter option is less invasive and leads to minor environmental impact. Hence, from a societal perspective, the environmental and economic effects of smart grid service deployment should be evaluated in relative terms – in comparison to the other option available to DSOs. In addition, material throughput is reduced if the total number of hardware devices installed in the grid decreases with the growing proportion of advanced monitoring devices used. The SOGNO services have been conceived to work with a minimal number of sensors and measurement units. For instance, for the Irish trial at, data for the FLISR service is coming from existing network devices, reducing the need to install new hardware and gaining greater value from existing grid assets.So, the hardware required to deploy the SOGNO solutions is in any case really minimal. This is environmentally beneficial provided that life-cycle emissions of the latter do not exceed those of conventional hardware components. Specifically, environmental benefits occur when particular service modules - such as the SOGNO Power Control algorithm which minimises curtailment of renewable energy sources – facilitate the integration of renewable energy sources and therewith reducing the demand for electricity from fossil fuels and, ultimately, CO_2 emissions.

3.1.3 Social Layer

The social layer conceptualises the social impacts of the service vendor based on capturing its mutual relationships with various stakeholders and the social value creation potential that derives therefrom [13]. The SOGNO solution - an open and modular platform – functions as data middleware with the DSO at the centre of the data traffic, so playing an unbiased role between service providers, consumers and the market. The solution breaks down the barriers in the flexibility market and allows the massive participation also of residential customers connected to the low voltage grid. This approach enables the active participation of prosumers connected to the distribution network and therewith to optimise distribution network management [18]. The SOGNO-trialled approach requires massive data exchange and thus necessitates the service vendor and, in particular, IOT platform providers to strictly comply with critical privacy requirements of all actors involved in the value chain. Hence, long term integrative relationships between DSOs, consumers, distributed generators (incl. private prosumers), algorithm implementers, manufacturers of monitoring devices, IOT platform providers and mobile communication companies are required to establish mutual trust. From the service vendor's perspective, the main organisational stakeholders are those employees possessing expert competencies in terms of software development and power network engineering. The platform approach aims to establish an innovation-driven, inclusive and participative societal culture in which, inter alia, DSOs' clients become active players while supporting DSOs in their system responsibilities. Such an open philosophy potentially requires individual enterprises to forego private intellectual property rights and not to take advantage from contractual vendor lock-in [10]. While it hence requires open-mindedness regarding knowledge sharing from all actors involved, it creates social value in form of publicly accessible knowledge while it lowers the entry barriers of smart grid service markets and therewith contributes to business start-ups and job creation.

3.2 DSO

DSOs are "natural or legal person[s] responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area (…) for ensuring the long-term ability of the system to meet" the electricity demand of "end-users [connected to the medium-voltage grid (MV) and the low-voltage grid (LV)] in a secure, reliable and efficient manner" [19]. The daily work of operational staff in grid operating companies encompass all activities necessary to continuously ensure a reliable operation of the electricity grid such as monitoring and balancing of voltage and current or asset maintenance and repair. DSOs are exclusively responsible for all - strategic and operational - grid-related decision-making.

3.2.1 Economic Layer

Electricity distribution is not coordinated by the principles of competitive markets but functions as a natural monopoly. Therefore, DSOs' operations are exposed to regulatory control. Although regulatory frameworks vary from country to country, they usually bridge DSOs' overarching operational goal attainment (cost-efficiency, reliability and continuity of supply as well as minimal RES curtailment) and DSOs' economic success. In two-thirds of all European countries, DSOs are rewarded or penalised by the regulators according to their operational performance in terms of continuity of supply [20]. Regulatory regimes differ in that they are implemented as macro-level incentives and/or penalties (e. g. Denmark / France) or micro-level incentives and/or penalties (e. g. Italy / Estonia) [21]. For instance, DSOs could be obliged to compensate for e.g. bad quality of supply (interruptions, power quality) or RES curtailment, or could be rewarded for improving cost-efficiency or quality of supply as compared to certain benchmarks.

Most commonly, regulatory frameworks allow DSOs to obtain "a maximum total allowed revenue (TAR) in return for […] (electricity distribution) services in one year, with the TAR in one year being equal to the TAR in the previous period corrected for (i) a requirement on improved efficiency performance, (ii) change in overall price level (inflation), and (iii) optional compensation schemes for adverse developments in demand. […]. (The TAR) in the starting year is dependent on the total regulated asset base (RAB), the weighted average cost of capital and operational expenditures [22]." In this way, regulators determine DSOs' revenue streams to allow DSOs to cover non-controllable OPEX (e.g. for utilisation of higher-level TSO power lines) and controllable but efficient (as compared to certain benchmarks) OPEX as well as CAPEX including the returns to shareholders and depreciation of assets [23]. Hence, DSOs level of income depends on, the volume of allowed expenditures, its operational (cost-)efficiency and its measured quality of supply.

The following excerpt from the Decision Paper on DSO Distribution Revenue for 2016 to 2020 (Table 1) published by the Commission for Energy Regulation of Ireland [24] shows exemplarily the types and volumes of OPEX allowed in the Ireland context. Similar to the regulation process in other countries, there is a negotiation process over allowed expenditures in a certain period at the beginning of which the DSO estimates its costs for the regulation period while the regulator approves them fully (i.e. in the given example non controllable costs and asset management costs) or only to a limited extent. For instance, in Table I, 581.1 million € of network operation and maintenance costs have been requested upfront but only 537.7 million € have been approved by the regulator.

Table 3.1: Allowed operating costs in Ireland for the 2016-2020 period [24]

Operating Costs (€m 2014)	DSO PR4 Requested	CER reductions	PR4 Allowance
Network O&M	581.1	-43.4	537.7
Asset Management	72.3	0	72.3
Metering	180.1	-21.3	158.8
Customer Service	90.2	-3.2	87.0
Provision of Information	63.3	-2.9	60.4
Corporate Costs	51.4	-3.0	48.4
Telecoms	67.7	-48.4	19.3
Sustainability & R&D	15.6	-4.5	11.1
Other	98.2	-17.3	80.9
Non Controllable	286.1	0.0	286.1
Total	1,506.0	-143.9	1,362.1

The negotiation process of requesting and approving planned costs between the DSO and the regulator is similar with regard to CAPEX. In sum, the TAR for the regulation period covers all allowed expenditures (OPEX and CAPEX incl. shareholder returns) and also includes variable components that provide incentives for efficiency, quality of supply and innovation. The use cases below demonstrate how the implementation of beyond-state-of-the-art grid monitoring and autonomous self-healing services potentially affect DSOs' from an economic perspective.

3.2.1.1 Use case 1: Better operational decision-making preventing asset stress and reducing maintenance time through State Estimation & Power Quality services

The algorithms of State Estimation and Power Quality Evaluation enable highly reliable grid observability and thus assist the DSOs in the detection or prediction of anomalies (e.g. voltage unbalance, under- or over-voltages, etc.) through advanced monitoring data. Consequently, the implementation of those services exhibits a certain potential for DSOs to prevent asset erosion and failure which could take place, e.g., when equipment is destroyed in overload conditions. Consequentially, potentially less reinforcement or replacement investments in the grid are necessary. In this regard, maintenance time, which is directly linked with OPEX in form of personnel costs, required to repair or replace physical assets in the grid can be expected to decrease as well.

Based on historical data from ESB Networks, we calculated the hardware cost for broken devices (e.g. pole transformers) per client per annum of a total of 8804 clients connected to several feeders and aggregated this value to get an estimate of the total distribution network cost for broken devices per annum. As illustrated in Figure 1, assuming the price of a 37.5 kVA Pole Mount Transformer [25], total CAPEX potentially decrease with the reduction of broken transformers per annum since less replacement investments are necessary. Given sufficient data quality, similar but more detailed calculations can be made for other assets whose stress can be reduced via the State Estimation and Power Quality services.

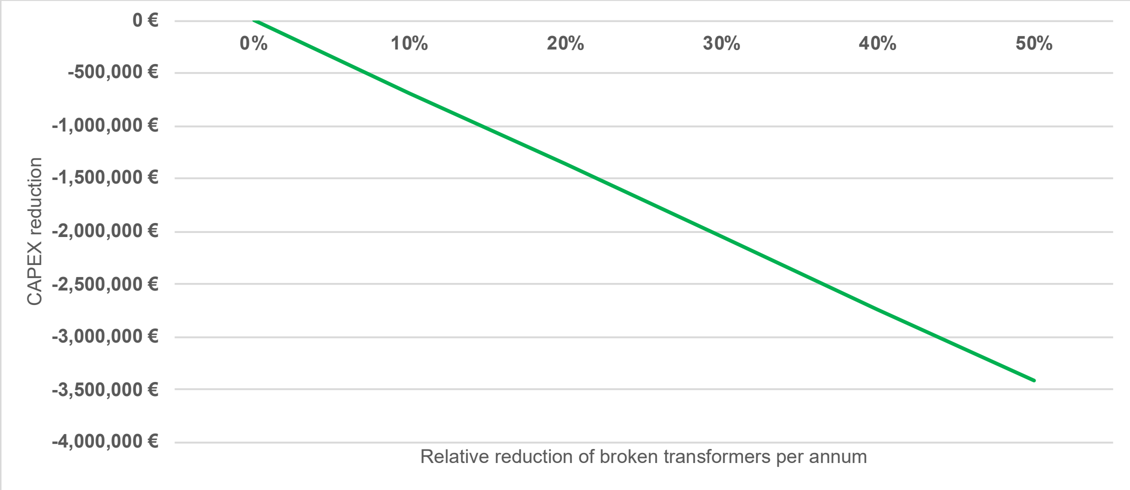

Figure 3.1: CAPEX reduction in relation to the relative reduction of broken transformers per annum

In countries where quality regulation is in place, there are monetary incentives that accompany the regulation of expenditures. In Ireland, for instance, the regulator sets a target for the number of and the customer minutes lost (CML) due to planned and unplanned interruptions. The average CML target for planned interruptions between 2013 and 2015 was equal to 55.7, which means that planned interruptions should not prevent electricity supply for more than 55.7 minutes per client per year [26]. Depending on whether and to what extent the distribution system operator exceeds or falls short of this target, the TAR of a year is regulatorily adjusted. The corresponding annual payment or penalty is set by the regulator in relation to the TAR and was limited to 1.5% of TAR in the period of review [26]. In this regard, data from ESB Networks also allow demonstrating that a reduction of maintenance not only leads to OPEX savings in terms of personnel costs, as less working time is needed for this, but also to improvements of quality of supply indicators such as CML that are directly linked to DSOs' income and distribution network financing.

Figure 2, shows the CML values of a particular feeder in relation to the relative number of planned interruptions due to maintenance reasons. Although annual (CML) performance is calculated on aggregated values over all feeders, it can be observed through the pattern of this specific case that a reduction of planned interruptions, potentially resulting from a reduced need of maintenance work thanks to the implementation of smart grid services, positively affects the regulated income of DSOs. In the given example, this is because performance values that would have driven penalty payments (CML > 55.7) are reversed into drivers of monetary rewards (CML < 55.7) through a reduction of the number of planned interruptions due to maintenance reduction by around 20% or more. Even though there are also other reason than maintenance causing planned interruptions, it can be observed the potential of predictive maintenance to improve operational performance.

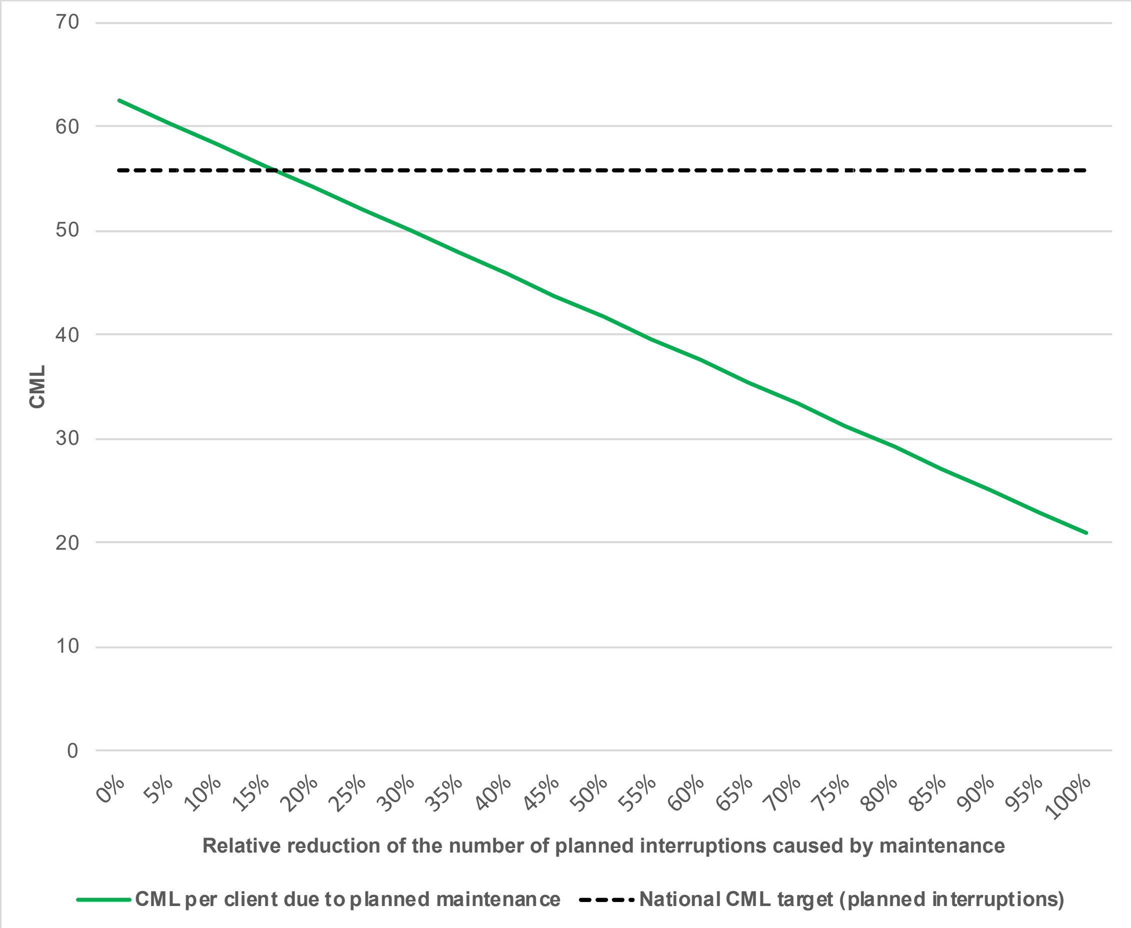

Figure 3.2: CML reduction in relation to relative reduction of planned interruptions

The performance in terms of number and duration of interruptions - and therewith DSOs' income - can also be improved through the implementation of autonomous self-healing services. The next use case demonstrates how one of the SOGNO service modules potentially affects the number and duration of unplanned interruptions.

3.2.1.2 Use case 2: Lower number and shorter duration of supply interruptions through Fault Location, Isolation and Service Restoration service

The FLISR algorithm automatically detects the location of faults in the grid, isolates the fault location and restores power supply for remaining clients by transferring them to adjacent circuits, where possible. This leads to a lower number of customers affected by a fault and lower number of interruptions recorded as interruptions. Commonly interruptions are only recorded as such when they last for a certain time (e.g. 3 minutes in Ireland) while the FLISR service potentially restores power supply within seconds. Additionally, through automated fault location, operational staff working time to manually resolve the fault is reduced, e.g., because technical crew is aware of the fault location more quickly resulting in lower durations of interruptions [27]. So, the FLISR algorithm, reduces significantly the number of customers that are affected by the fault as well as the duration of faults. Similar to the Ireland context, the income of DSOs' in Germany varies with a quality indicator that records operational performance in terms of CML. The so-called quality element is a formula to calculate annual rewards/penalties for a certain DSO and contains three factors. The estimated value of lost load - an indicator expressing "the average willingness of electricity consumers to pay to avoid an additional period without power [28]" - the number of clients served and the difference between benchmarked CML and actual CML in a given year.

Data on power supply interruptions in distribution networks in Germany, publicly available from the German Federal Network Agency, allowed us to calculate monetary rewards and penalties per DSOs. Figure 3 exemplary shows for the average DSO in Germany in 2017 how the relative reduction of CML potentially translate into monetary penalties and rewards per annum. We observe that the average is driven by few under-performing DSOs as the majority German DSOs performing relatively well.

In Romania, quality regulation differs in that the monetary incentives are penalty-based and that DSOs are obliged to compensate - not according to benchmarked CML per annum - but for single interruptions when an interruption exceeds a certain time limit depending on grid characteristics.

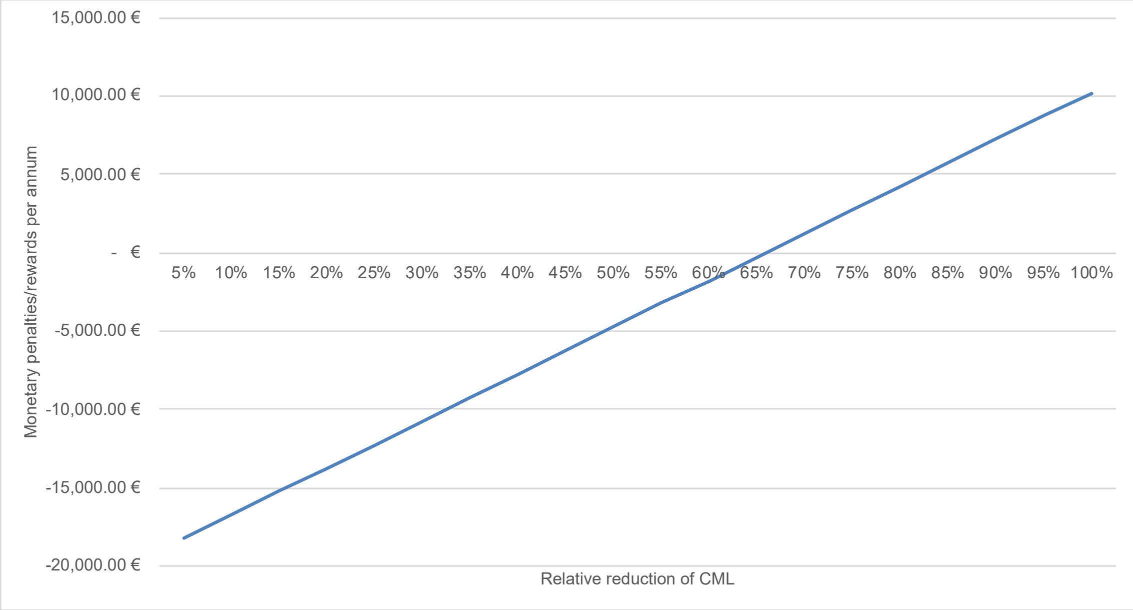

Figure 3.3: Penalties/Rewards in relation to relative reduction of CML in Germany

As Figure 4 shows for the Romanian context, the implementation of FLISR can also translate into income increases (through penalty cost reduction) if it enables the DSO to reduce the number of interruptions which exceed the regulated time limit and therewith necessitates less compensation payments. Those compensation payments are calculated based on the number of all clients affected from single long (time-limit-exceeding) interruptions.

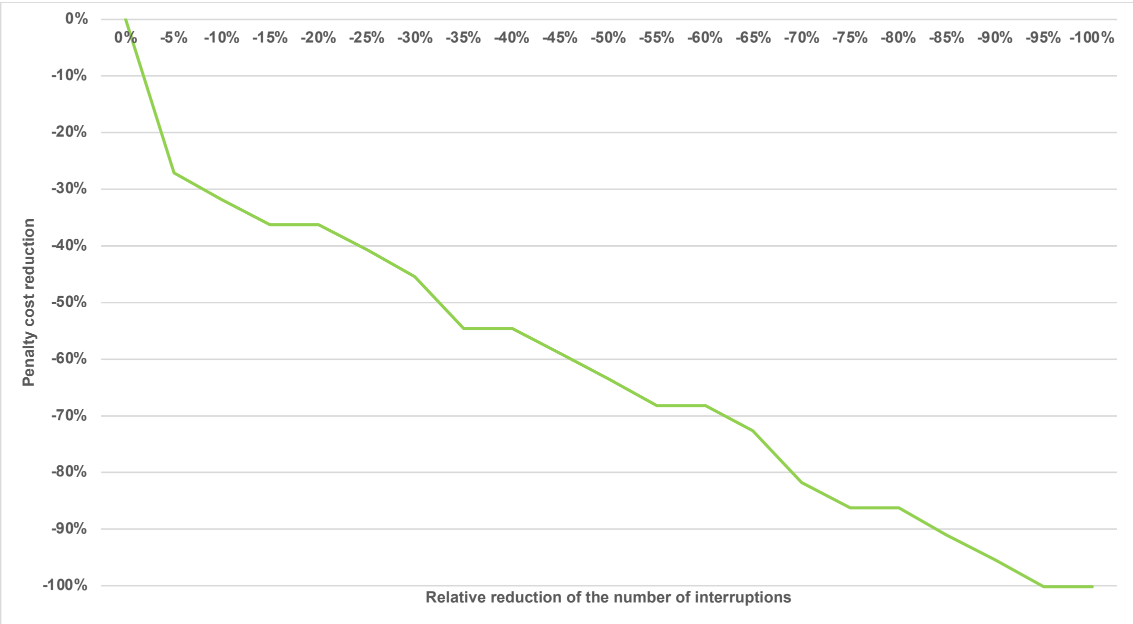

Figure 3.4: Penalty cost reduction in relation to relative reduction of unplanned interruptions in Romania

3.2.1.3 Use case 3: Lower estimation error and higher accuracy in electricity purchase decisions through Load and Generation Prediction services

SOGNO's machine learning-enhanced Load and Generation Prediction algorithms enable highly effective grid planning through advanced processing of historical data and possible additional information (e.g. weather data). This leads to lower error rates in estimation processes for future states of the grid provided that the operational staff processes the information output by the algorithms optimally. DSOs as CEZ Romania, being responsible for purchasing electricity to balance the power losses in the controlled grid area, can therewith increase the accuracy in electricity purchase decisions. For example, if CEZ Romania would have 100 MW losses volume in one hour, it is usually purchased through yearly products contract to around 50%-60%, quarterly products contract to around 10%-15%, with monthly products contracts and electricity from the Day-Ahead and short term Balancing Markets constituting the rest. The more precise information on future load and generation volumes is available, the more sophisticated electricity purchase decisions can be made, taking into account the prices of the different markets. With better information about losses forecast, part of the volumes bought on the Day-Ahead market will be bought on contracts and part of the balancing market volumes will be bought on the Day-Ahead Market. This enables DSOs to exploiting potential price advantages between the markets through less need for short-term action to compensate for losses.

Figure 5 shows for a specific day how price difference between the markets can potentially be exploited. For every hour in which a discrepancy between electricity supply and demand was balanced by purchases on the balancing markets, while considering that at the same time the electricity price on the balancing markets was higher compared to the day-ahead market, there is the potential to shift electricity purchases from the balancing markets to the day-ahead markets in the amount of the missing MW (right axis). A similar pattern can be observed when considering shifts in purchases from the Day-Ahead market to monthly contracts.

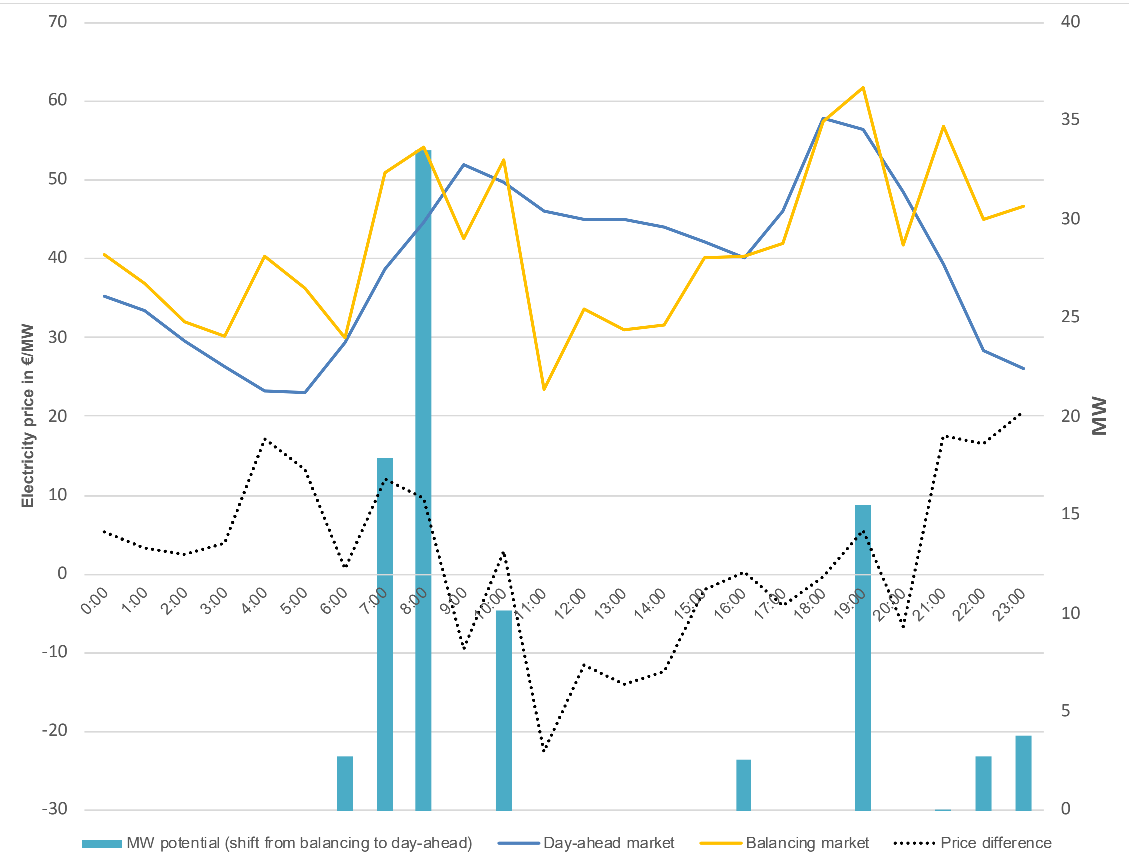

Figure 3.5: Example of daily pattern of cost savings potential through optimised timing of electricity trade processes

Hence, the Load and Generation prediction algorithms bear potentials for monetary savings through the exploitation of price differences between the electricity markets. Estimating the patterns observed in three months of data from CEZ Romania for the entire year, there are a total of 3130 hours of non-optimal prediction (X-axis in figure 6) when considering potential shifts from day-ahead market to monthly contracts and slightly less when considering shifts from balancing to day ahead market. Assuming that purchase decisions could have been optimised by 100% so that there was no hour the losses in which CEZ Romania has to compensate through purchases at the market respectively more expensive, the DSO exploits a total saving potential of 822,850.59 € through shifts from Day-Ahead market to monthly contracts and a total saving potential of 204,702.75 € through shifts from balancing to Day-Ahead market. As shown in figure 6, the extent to which savings potential can be exploited decreases with the number of hours for which the purchase decision is not price-optimised. According to expert statements from the SOGNO consortium the Load and Generation algorithm has the potential to improve accuracy and therewith the purchase decisions by at least 50%.

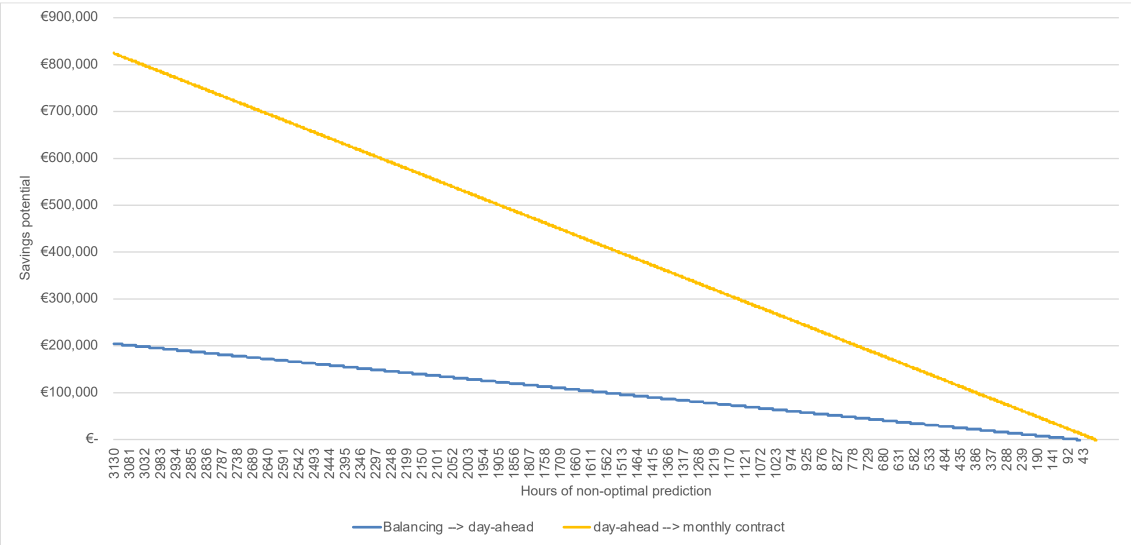

Figure 3.6: Annual cost savings potential through optimised timing of electricity trade processes

3.2.1.4 Use case 4: Less curtailment of electricity from renewable energy sources and lower feed-in management cost through Power Control service

The SOGNO Power Control algorithm enables smart control of active and reactive power in the grid. The algorithm defines the optimal set points of active and reactive power for the converters interfacing (…) DG units to the distribution grid” (see SOGNO Deliverable 2.2). Power Control reduces both overvoltage and renewable active power curtailment by controlling DG units accordingly. Consequently, there are potential improvements of DSOs’ performance. First, if the compliance with voltage ranges according to EN 50160 increases, customer satisfaction is expected to increase. Second, in countries where curtailment is penalised by the regulatory authority, the DSO avoids corresponding fines. The reduction of RES power curtailment also decreases the need for grid expansion and thus reduces DSOs’ CAPEX in the long run. Additionally, total CO2 emissions of electricity production generally decrease with increasing integration of electricity from RES enabled by Power Control algorithm.

Important at this point, are the costs for the integration of renewable energies including feed-in management. The expansion of renewable energy plants is often in rural areas and is usually concentrated in specific zones of the grid. As an example, the northern areas of Germany have a significant expansion of wind power plants, while in southern Germany there is a huge expansion of PV plants. Feed-in management measures will become more frequent in the future as the number of decentralised feed-in of renewable energy systems increases and the networks are not expanded in parallel (e.g. to avoid grid congestions). For any unit of renewable energy curtailed, the RES operator concerned is compensated in the extent of potential supply. The necessary compensation payments are financed via the grid charges, respectively [29].

Based on historical data from 2011 to 2018 [30,31], the volumes of wind energy to be curtailed until 2030 and the increasing cost of feed-in management associated therewith are forecasted as shown in Figure 7. Without any changes in curtailment patterns, the cost of feed in management of 635 million € in 2018 is forecasted to increase of around three times to a level between 1651 and 2075 million € in 2030, while at the same time the volume of curtailed electricity is expected to increase from 5.9 TWh to 16.4 TWh. If the implementation of the Power Control algorithm leads to reduction of feed-in management costs by 10% as compared to the level of 2018, the corresponding savings would be of 63.5 million, which is equal to the yearly electricity bill of a total of 84667 households (given 0.3 €/KWh and a demand of 2500 KWh per household). The effect of feed-in management cost savings is expected to increase over the years. Assuming that only 10% of the curtailment can be avoided in 2030 while this electricity can also be stored or re-allocated for later utilization, the saving potential is equal to 1.6 TWh, which corresponds to the yearly electricity demand of 640000 households.

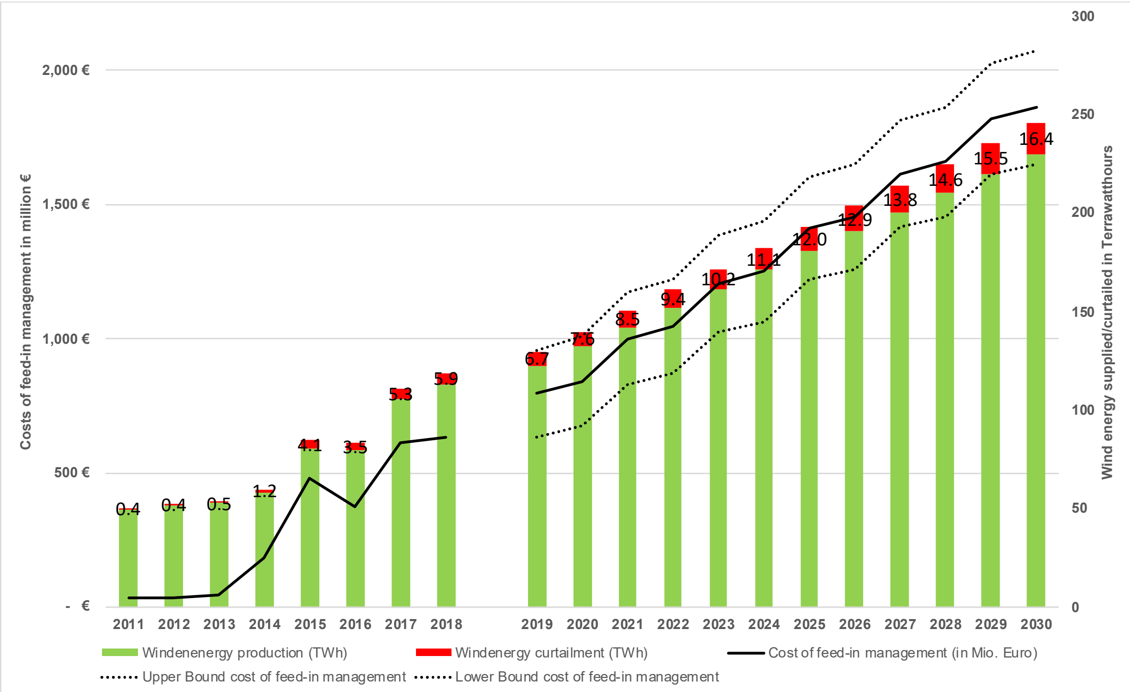

Figure 3.7: Cost of feed-in management and curtailment patterns in Germany over time

This section has shown that particular service modules as those developed in SOGNO, (i.e. FLISR, Load and Generation Prediction, Power Control, State Estimation & Power Quality Evaluation) have large potentials to optimise DSOs operations and to positively influence DSOs' income and quality of supply indicators. However, even if the evaluation of the parameters considered in the use cases above lead DSOs to perceive the advantages of smart grid service utilisation, this type of solution is different from the traditional view of grid management, and therefore it needs first to conquer the trust of DSOs to be successful. Having in mind that the perceived risk of purchasing from third-party service vendors commonly influences DSOs decisions, this section has shown that the use of smart grid services through the DSO is also dependent on, first, whether the allowed revenue stream covers the periodic service fee (OPEX) to be paid to the service vendor, second, whether the utilisation of particular service modules has a measurable positive effect on operational performance which potentially leads to lower penalties or higher rewards.

As payments to DSOs are publicly funded (in general, via network tariffs that constitute a share of consumers' electricity price), changes in DSO compensation potentially affect private incomes and are thus also relevant to be considered from a broader societal point of view.

3.2.2 Social Layer

From a societal perspective, basically three issues are relevant when considering smart grid services and its potential effects on DSOs' business models. First, are the costs of purchasing Software-as-a-Service regarded as allowed expenditures within the regulatory framework? Second, if so, how does it affect network tariffs and consumer electricity prices when OPEX in form of periodic service fees are allowed expenditures funded via end-user prices? Third, do the improvements in terms of operational decision-making quality as a result of smart grid service utilisation lead to measurable improvements in terms of performance indicators (such as customer minutes lost) or cost efficiency and therewith directly affect DSOs' income and customer satisfaction? The next paragraphs will successively address these questions highlighting the sensitive role of regulators guiding the creation of value for society as a whole.

The purpose of regulatory control is to ensure that DSOs do not exploit their powerful market positions (e. g. by charging monopoly prices or by discriminating clients) and to incentivise them to execute measures necessary to attain overarching operational goals - maintain continuity of electricity supply, ensure power as well as commercial quality, integrate RES and avoid curtailment of electricity from RES [4]. In this context, the TAR represents a budget which is available to the network operator during the regulatory period for the operation and maintenance of the network. The TAR is funded via network tariffs that constitute a share of the electricity price and are collected through clients' final electricity bills (see figure 8, taken from [32]). Network tariffs are based on the costs incurred by DSOs for the operation, maintenance and expansion of the networks. The network tariffs shall ensure that these costs are passed on to network users in a non-discriminatory and, as far as possible, appropriate manner. The main cost driver is the simultaneous annual maximum load of the network, as this is relevant for grid dimensioning. The fee system then determines how the allowed revenues are distributed among the user groups [29]. In both Germany and Ireland, network tariffs account for around 25% of the average electricity price [24,32]. In recent years, the trend of increasing electricity prices was basically driven by increasing network tariffs that were granted by the regulators because the challenges (resulting from more volatile and bidirectional electricity flows) DSOs have to face were considered to justify higher network operation costs.

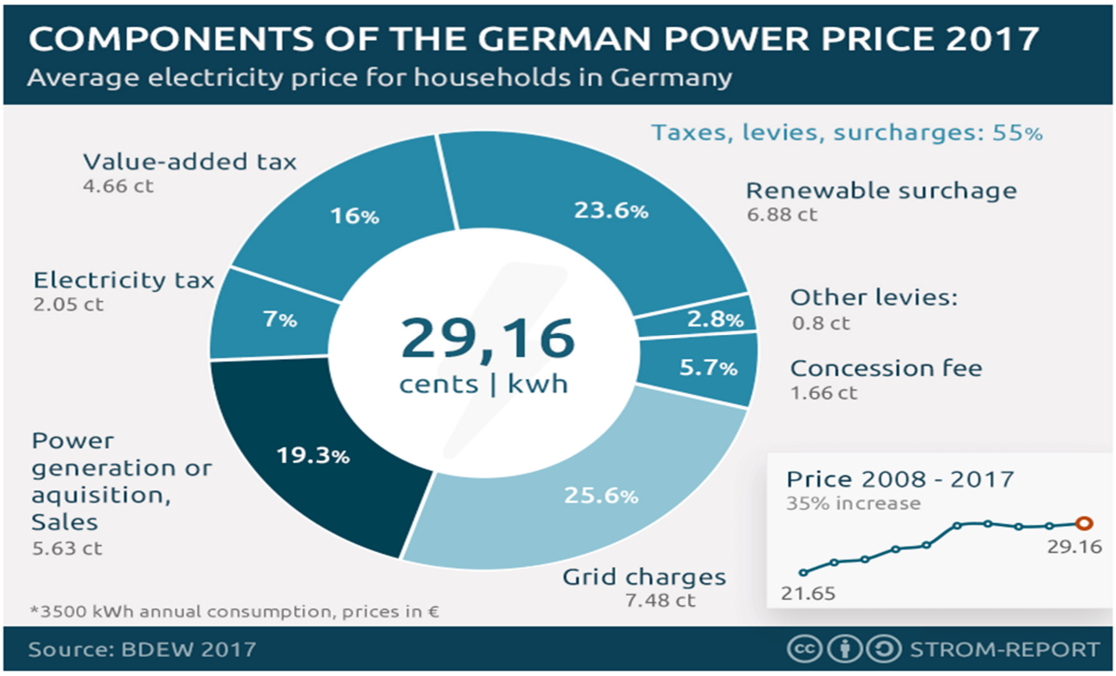

Figure 3.8: Components of the German power price 2017

Provided that periodic service fees for smart grid services are treated as allowed OPEX, ceteris paribus, these affect network tariffs and therewith electricity prices are expected to increase. Assuming that the smart grid service utilisation can be proved to save 10% of network maintenance work, the regulator is able to take this potential reduction into account by declaring correspondingly fewer OPEX efficient and compensating the DSO to a correspondingly lower extent. In the Irish example previously shown, this could have meant that the regulator allows only 483.93 (=537.7*0.9) million € in terms of operation & maintenance costs. In Germany, there are nearly 900 DSOs and those that are similar (e.g. in terms of peak load, geographical conditions or RES) are grouped and benchmarked. From a group of comparable DSOs, only those that perform network operation at a level of costs considered as efficient from the Federal Network Agency, obtain full TAR.

In countries where quality regulation is in place (e.g. Ireland and Germany), there are monetary incentives that accompany the regulation of expenditures. In Germany, for instance, DSOs' income varies with a quality indicator that records operational performance in terms of customer minutes lost. The so-called quality element is a formula to calculate annual rewards/penalties for a certain DSO and contains three factors. These include the estimated value of lost load, the number of clients served and the difference between benchmarked customer minutes lost and actual customer minutes lost in a given year.

The calculation scheme in Table 2 illustrates how changes in DSOs cost structures, regulatory changes and performance-related changes translate into changes in TAR and DSOs' income as and therewith into changes in network tariffs and consumer electricity prices. Changes as compared to the Baseline scenario (1), in terms of DSO income and electricity price effects, are marked in green while changes in terms of cost, regulation and performance, as respectively compared to the column left of a particular scenario, are marked in yellow.

As compared to the Baseline scenario, scenario 2 considers a situation in which a periodic service fee of 10000 € - potentially paid for utilisation of a particular smart grid service module - increases DSOs OPEX while the regulator does not grant the additional costs as efficient leading to lower DSO income. Additionally, in scenario 3, there is an observable performance improvement (reduction of CML) - potentially emerging as a result of service utilisation - leading to additional, quality-of-supply-dependent, rewards which, if also financed via network charges, would increase DSOs income and the TAR. In the given example, the TAR always corresponds to the sum of network charges to be financed via the electricity price which would also increase in scenario 3. Scenario 4 considers the regulator to approve additional cost as efficient and to grant additional OPEX while it requests higher service quality by lowering the CML benchmark. To increase its income as compared to the Baseline, the DSO would have to improve operational performance. Even without performance improvement, electricity prices are positively affected under this scenario. In scenario 5, situation changes in that the regulator expects OPEX to decrease in line to the extent the DSO actually achieves in terms of cost savings – potentially through the utilisation of smart grid services. In this situation, electricity prices are expected to decrease while there is no deterioration of DSO's income as compared to the Baseline. Scenario 6 is a hypothetical one as it reflects a situation in which the risk assessment of a potential equity investor and that of the regulator differ. This is a simplified illustration of the risk potentially perceived by DSOs when considering the utilisation of cloud-based smart grid services. In such a situation, differences in risk preferences potentially avoid capital provision at all. In the 7^{th} scenario, the regulator grants higher risk premiums which would result in higher DSO's income and increasing electricity prices. Eventually, scenario 8 illustrates a situation in which both OPEX and CAPEX decrease and are considered as efficient while also the quality of supply increases above the regulatory benchmark. This leads to both higher DSO income (as compared to the Baseline) while at the same time there is the highest electricity price-decreasing effect among the scenarios investigated. The calculation scheme shows the importance of regulators to be aware of the potential of smart grid services to reduce total system costs or to increase (rewarded) quality of supply. Regulators are to determine the extent periodic service fees can be allowed in future regulatory frameworks while at the same time the therewith expected gains in terms of cost-efficiency or quality of supply are to be considered within the regulatory framework (e.g. via incentives) in a way that the total amount of network charges does not tend to increase. This is vital for the development of smart grid service markets. Further regulators are to consider the economic trade-off between physical grid extension and smart grid service deployment in general. With the increasing penetration of RES, DSOs have in any case to choose between software services and grid expansion. As shown in SOGNO Deliverable 6.5, network charges are expected to decrease with smart grid service deployment if smart grid services can substitute physical network expansion to only a small extent.

Providing that the use of smart grid services improves operational decision-making quality, it ultimately lowers the frequency and duration of planned and unplanned interruptions. The social value created in this regard can be expressed by the value of lost load - an indicator expressing “the average willingness of electricity consumers to pay to avoid an additional period without power [28]”. In the case of Ireland, for instance, the value of lost, which differing by sectors, as well as by time of year, day and week, was highest in the residential sector. For 2008, the weighted average value of lost load was estimated at 12.9 € / kWh [28]. Looking only at one of the feeders in Waterford where ESB Networks serves 1158 clients with a total load of 5765 KW, the social value creation potential can roughly be estimated. In 2018, the operational performance of the ESB Networks in terms of unplanned interruptions was such that the average client connected to that feeder was without electricity for 60.4 minutes (customer minutes lost). Assuming that the average load per client per hour is equal to 0.2283 kW (2000 kWh/year / (365 days * 24 hours)), an operational improvement leading to a one-percent decrease of customer minutes lost to 59.796, creates social value of 34.33 € (0.01007 hours/client * 1158 clients * 0.2283 kW * 12.9 € / kWh) for the total of clients connected to that particular feeder in the Waterford area. The presented effect seems to be of minor importance but, obviously, worse performing DSOs can exhibit a much higher potential for improvement and social value creation while also the relative performance improvement might be higher than 1%.

Table 3.2: DSO financials and its potential electricity price effects

Annual Figures	1 Baseline	2 Periodic service fee; no regulatory changes; no performance effect	3 Periodic service fee; no regulatory changes; performance effect	4 Periodic service fee; regulator suggests additional cost as efficient & demands higher service quality	5 Periodic service fee; regulator suggests periodic service fees as efficient but expects total OPEX to decrease	6 Investor considers business with service vendor as risky and demands higher return on equity	7 Regulator approves higher risk premiums	8 Lower and efficient TOTEX, higher quality of supply
OPEX	€ 5,000,000.00	€ 5,010,000.00	€ 5,010,000.00	€ 5,010,000.00	€ 4,750,000.00	€ 4,750,000.00	€ 4,750,000.00	€ 4,750,000.00
Approved OPEX	€ 5,000,000.00	€ 5,000,000.00	€ 5,000,000.00	€ 5,010,000.00	€ 4,750,000.00	€ 4,750,000.00	€ 4,750,000.00	€ 4,750,000.00
Cost efficiency (OPEX)	100%	99.80%	99.80%	100.00%	100.00%	100.00%	100.00%	100.00%
Capital requirement excl. return on equity	€ 10,000,000.00	€ 10,000,000.00	€ 10,000,000.00	€ 10,000,000.00	€ 10,000,000.00	€ 10,000,000.00	€ 10,000,000.00	€ 9,000,000.00
Shareholder return required	5%	5%	5%	5%	5%	8%	8%	5%
Shareholder return approved	5%	5%	5%	5%	5%	5%	8%	5%
Requested CAPEX	€ 10,500,000.00	€ 10,500,000.00	€ 10,500,000.00	€ 10,500,000.00	€ 10,500,000.00	€ 10,800,000.00	€ 10,800,000.00	€ 9,450,000.00
Approved CAPEX	€ 10,500,000.00	€ 10,500,000.00	€ 10,500,000.00	€ 10,500,000.00	€ 10,500,000.00	€ 10,500,000.00	€ 10,800,000.00	€ 9,450,000.00
Cost efficiency (CAPEX)	100.00%	100.00%	100.00%	100.00%	100.00%	97.22%	100.00%	100.00%
CML	50	50	48	48	48	48	48	44
CML benchmark	50	50	50	48	48	48	48	48
Quality element	0	0	2	0	0	0	0	4
Number of clients	80000	80000	80000	80000	80000	80000	80000	80000
Monetarisation factor (€/min/client)	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Reward/penalty	€ -	€ -	€ 28,800.00	€ -	€ -	€ -	€ -	€ 57,600.00
Total allowed revenue	€ 15,500,000.00	€ 15,500,000.00	€ 15,528,800.00	€ 15,510,000.00	€ 15,250,000.00	€ 15,250,000.00	€ 15,550,000.00	€ 14,257,600.00
Income	**€ 500,000.00**	**€ 490,000.00**	**€ 518,800.00**	**€ 500,000.00**	**€ 500,000.00**	**€ 500,000.00**	**€ 800,000.00**	**€ 507,600.00**
Income effect (as compared to Baseline)		-2.00%	3.76%	0.00%	0.00%	0.00%	60.00%	1.52%
Sum of network charges	€ 15,500,000.00	€ 15,500,000.00	€ 15,528,800.00	€ 15,510,000.00	€ 15,250,000.00	€ 15,250,000.00	€ 15,550,000.00	€ 14,257,600.00
Electricity demand (MWh)	200000	200000	200000	200000	200000	200000	200000	200000
Network charges per client	€ 193.75	€ 193.75	€ 194.11	€ 193.88	€ 190.63	€ 190.63	€ 194.38	€ 178.22
Network charges per KWh	€ 0.0775	€ 0.0775	€ 0.0776	€ 0.0776	€ 0.0763	€ 0.0763	€ 0.0778	€ 0.0713
Other electricity price components	€ 0.20	€ 0.20	€ 0.20	€ 0.20	€ 0.20	€ 0.20	€ 0.20	€ 0.20
Electricity price (per KWh)	€ 0.28	€ 0.28	€ 0.28	€ 0.28	€ 0.28	€ 0.28	€ 0.28	€ 0.27
Electricity price effect (as compared to Baseline)		0.0000%	0.0519%	0.0180%	-0.4505%	-0.4505%	0.0901%	-2.2386%

3.2.3 Environmental Layer

From an environmental perspective, DSOs create value in several ways. First, environmental value is created through the increasing share of renewable energies with respect to the total volumes of electricity distributed. This can be achieved via the utilisation of particular service modules (e.g. Power Control as described in section 3.2.1.4) or through reinforcement of the physical grid [7]. Thus, second, environmental value is created when the construction of physical grid components (power lines, transmission masts etc.) can be substituted by intangible assets (e.g. particular algorithms of cloud-based smart grid services) in combination with monitoring devices. This is valid as long as life-cycle emissions of smart grid services - which are driven by electricity consumption of ICT infrastructure including cloud servers and emissions during manufacturing processes of monitoring devices and raw material sourcing - are lower than life cycle emissions of conventional physical grid components.

Beyond-state-of-the-art control strategies to increase RES hosting capacity in the distribution grid without conventional reinforcement measures are available [7] but not in widespread use. Provided that the utilisation of smart grid services lowers material throughput as less electrical grid components are necessary, positive environmental impacts can be expected in the life cycle stages of raw materials production, raw materials transportation, manufacturing, final product transportation, installation, use (power losses and maintenance), and end-of-life (e.g. less recycling processes) [33]. Following Jorge et al. [33], who conducted life-cycle assessments of electricity transmission and distribution considering transformers and substation equipment, we estimated the environmental impact of having 10% less transformers (0.315 MVA) to be produced and installed per year. Our rough estimation was based on data from 6 feeders of ESB Networks where there is a total number of 0.009 broken transformers per client per year.

As shown in Table 3, in the impact category “climate change”, for instance, there is a potential reduction of 505976 ton of CO_2 equivalent. Providing that per capita CO_2 emissions amount 8 ton per year, this corresponds to the CO_2 emissions of 63247 citizens. In comparison, the environmental impact of 500 MVA transformer is such that a 10% reduction results in CO2 emission savings in the amount of 165341700 ton of CO_2 equivalent which corresponds to the CO_2 emissions of 20667713 customers which is more than five times the population of Ireland. Based on the analyses of Jorge et al. [33], the environmental impact of even more types of transformers, other equipment and power losses can be assessed in more detail for the impact categories given in Table 3

Table 3.3 Environmental impact of electrical transformers

Transformer LCA impact categories	Impact per Transformer (0.315 MVA)	Change of environmental impact providing that 10% less 0.315 MVA transformers are to be replaced per year in Ireland aggregated at national level	Impact per Transformer (500 MVA)	Change of environmental impact providing that 10% less 500 MVA transformers are to be replaced per year in Ireland aggregated at national level
Climate change (kton CO2-equivalent)	0.27	-505.9759654	88.23	-165341.70
Fossil depletion (kton oil-eq)	0.08	-149.9188046	26.03	-48779.83
Freshwater ecotoxicity (kton 1,4-Dichlorobenzene-eq)	0.01	-18.73985057	1.11	-2080.12
Freshwater eutrofication (ton Phosphor-equivalent)	0.22	-412.2767126	74.08	-138824.81
Human toxicity (kton 1,4-Dichlorobenzene-eq)	0.15	-281.0977586	50.08	-93849.17
Marine eutrophication (ton N-eq)	0.27	-505.9759654	89.34	-167421.83
Metal depletion (ton Fe-eq.)	0.01	-18.73985057	2.05	-3841.67
Ozone depletion (kg CFC-11-eq)	0.01	-18.73985057	4.34	-8133.10
Particulate matter formation (ton PM10-eq)	0.36	-674.6346206	117.57	-220324.42
Photochemical oxidant formation (ton NMVOC)	0.59	-1105.651184	190.73	-357425.17
Terrestrial acidification (ton SO2-eq)	1.09	-2042.643712	362.43	-679188.40
Terrestrial ecotoxicity (ton 1,4-Dichlorobenzene-eq)	0.03	-56.21955171	9.81	-18383.79

The illustration of the environmental layer of the DSOs’ business models suggests the substitution of conventional grid reinforcement measures or expansion through smart grid services to be of significant potential for the reduction of negative environmental impacts of electricity distribution. In this regard, in Germany for instance, there is already the principle of “network optimisation before reinforcement before expansion” to account for the potential benefits of avoiding physical grid expansion and reinforcement.

4. Guidelines for sustainable Value Chain Design

The chapter above has shown that value chains of smart grid service modules have multiple economic, societal and environmental impacts and interdependencies. Hence, holistic approaches toward business model design are appropriate. Based on the Triple-layered Business Model Canvas structure as applied in chapter 3, Table 3 summarises the main aspects of DSOs' and service vendors' business models in smart grid service value chains from an economic, environmental and societal perspective. This constitutes the foundation for the development of guidelines for sustainable Business Model Design in the following.

The main actors in the SOGNO-trialled value chain are DSOs as service recipients and service vendors which we consider as a conglomerate of IOT platform provider, manufacturer of monitoring devices, mobile communications provider and algorithm implementer. In general, smart grid services enable DSOs to pursue an 'active network management philosophy' [1]. Contemporary ICT, machine learning based algorithm and monitoring devices will allow for electricity distribution service quality enhancement and efficiency improvement, e.g. with respect to the use of grid capacity, RES integration and, eventually, reduction of total system costs [7,22].[2] In this context, contemporary distribution networks management relies on mutually supporting (data exchange) relationships between DSOs and its target customers, i.e. private and industrial consumers + MV/LV generator (incl. prosumers). Given the security of interfaces between subsystems, further data exchange processes with (flexibility) market platforms and sectoral partners - e.g. Transmission system operators, balancing responsible parties, aggregators, electricity traders - and corresponding data analytics can further enhance operational decision-making and overall system efficiency. However, as electricity grids constitute critical infrastructure, there are substantive data security requirements and DSOs possess trust concerns towards over cloud-based solutions, for instance. Although the deployment of information technology as envisioned in SOGNO bears the potential to enhance the economic, social and ecological sustainability of electricity distribution as it e.g. allows the engagement and collective contribution of larger number of sectoral actors [3], there are **critical privacy interests of the actors involved in SOGNO-type value chains for smart grid services requiring sophisticated guidance and protection** [34]. Regulators are required to ensure secure data interoperability. That is, e.g., to put mechanisms in place to guarantee that all consumer and enterprise data processed in the cloud can be easily and securely removed, e.g. for reasons of integration with another cloud service or switching to another Cloud Service Provider, etc [10]. Privacy-preserving schemes for the prevention of attacks of leaking privacy in smart grids are mostly based on cryptography [9].

The **sensitive role of regulators in the incentivisation of DSOs** becomes clear when looking at the effects of cost-efficiency and quality of supply benchmarking. In this context, it is important for to be aware of the potential of smart grid services to reduce total system costs or to increase quality of supply (section 3.2.2). Therefore, **policy makers are to be aware that DSOs can benefit from having the opportunity to flexibly test smart grid service modules** while the development of smart grid services markets is linked with DSOs' incentivisation schemes. In addition, **regulators are to craft policies around data interoperability related issues** [10]. This concerns, for instance, data ownership and control issues of heterogenous actors involved [10] (consumers, retailers, aggregators, DSOs, TSOs, LV/MV generators etc.).

SOGNO envisions an IOT platform for smart grid services to be developed as an open source solution cost-effective, seamless and secure power supply for consumers that become active players while supporting DSOs and TSOs in their system responsibilities. It envisions that this will break the monolithic solution of conventional DMS providers, while it still allows DSOs to keep a separated section with high certified security requirements. The SOGNO solution introduces a modular approach that facilitates testing of new services which are expected to be offered as

[2] This contrasts with the conventional 'passive network management' approach, according to which investments in physical assets to reinforce or extent the grid are the main remedies to handle electricity peaks by intermittent RES ('fit and forget') [1].

Software-as-a-Service to enable DSOs to experiment with low risk of investment. Hence, it helps especially small DSOs with limited experience and such with its business processes less integrated to quickly access up-to-date smart grid services which are potentially better or beyond-state-of-the-art as compared to the existing distribution management system. However, it is wort highlighting that **cloud-based smart grid services could function in parallel to DSOs' existing network management system without affecting its functioning.**

The SOGNO Field trials provide further practical guidelines for the development of sustainable business models in value chains for smart grid services, especially concerning the transactions of service vendors and DSOs.

First of all, DSO and service vendors should share the same understanding in terms of terminology and its meaning as used within each other's network modelling software. Further, the transaction cost of processes for the deployment of monitoring devices in the electrical grid can be minimized by performing commissioning tasks (device installation, communications signal testing and full data transfer validation) in single site-visits. Complementarily, access rights to network assets on private land (in particular agricultural land) are to be provided on-time, so as to avoid delays with device installation. Moreover, DSOs and sensor manufacturer must agree on all technical parameters (e.g. most appropriate voltage and current sensor for the location / structure where it will be installed) while sensor manufacturers should provide the DSO copies of all type tests and routine tests performed on new sensor devices. There while, the sensor manufacturer is responsible for verifying (through additional tests) compatibility with the reference standards of DSOs pre-existing MV equipment. Further practical guidelines from the SOGNO Field trials relating to the categories of data communications as well as planning and installation of services are summarized here but addressed in more detail in the SOGNO Deliverable 5.2.

Data Communications

- Choose communications protocols that work for the specific locations where measurement devices and power monitoring devices are to be installed.
- Establish a notification system to alert technical support staff when communication issues with individual field devices arise.
- Prevent device lock-out from the communications network by accounting for communications networks response and latency times within device reconnection algorithms.
- Build-in remote access to monitoring devices to enable performance monitoring, prevent device lock-out state and enable firmware upgrades.
- During commissioning, always test communication signal strength from within metal-enclosed substations to ensure correct positioning of antennae.

Planning and Installation of Services

- When planning the installation of services, consider all requirements mandated by the vendors of the DSO's cloud environment / hosting infrastructure, e.g. for data storage.
- Clearly agree responsibilities of all parties and a list of clear deliverables by each party throughout the implementation phase.
- Use any communications testing with devices in a lab environment for validation of data format and content and to create data samples for testing of software parsing services.
- Minimize cost overruns in pilots by ensuring understanding of all partners' responsibilities at the start

Table 4.1 Triple-layer Business Model Canvas concerning DSOs and service vendors

Economic Layer	DSO	Service Vendor
Value Proposition	Reliability and continuity of electricity supply; service quality	Innovating existing distribution network management systems through modular platform that facilitates DSOs to test and implement new system awareness and autonomous self-healing services
Target Customer	Private and industrial consumers + MV/LV generator (incl. Prosumer)	DSOs
Distribution Channel	Electriciy supply via MV/LV distribution grid (natural monopoly)	(Open) (cloud-based) IOT Platform in parallel and complementary to existing DSOs' technical platform
Customer Relationship	unidirectional --> bidirectional; mutual support	Service contracts without vendor lock-in
Value Configuration (arrangement of activities and resources)	SCADA system and software installations, physical grid and related monitoring devices, personnel (new IT competencies and data processing capabilities), IOT platfom	IT competencies, R&D, enablement of trial-and-error learning
Core Competency	Active Distribution Network Management	Software development and continous improvement; organisation of smart grid service intergration
Partner Network	SCADA system providers, Consumers, MV / LV generators (incl. private prosumers), TSO, regulators, balancing responsible parties, aggregators, electricity traders, software servie vendors (IOT platform providers), ICT providers	DSOs, algorithm Implementer, manufacturers of monitoring devices
Cost Structure	CAPEX: tangible assets (physical network components) and intangible (software installations to existing SCADA system) assets + OPEX: maintenance, personnel, compensatory payments, peridodic service fees (smart grid services)	OPEX: Mainly personnel; server capacity & ICT electricity consumption
Revenue Model	Regulated revenues based on allowed CAPEX+OPEX corrected by a quality indicator in combination with individual efficiency as compared to certain benchmarks	Periodic service fees (e.g. varying with the scale of data analytics) paid during the utilisation phase of particular smart grid service modules

Environmental Layer	DSO	Service Vendor
Functional Value	Distribution of electrical energy with higher shares of renewable energy	Provision of a working service module which necessitates both the operational accessibility of the algorithm underlying the service module for the DSO via corresponding interfaces in combination with the monitoring devices deployed in the grid and on-going (real-time) data exchange
Supplies and outsouring	Decentralised purchasing of smart grid service modules via IOT platforms	Raw material sourcing and potentially manufacturing of monitoring devices
Production	Contribution to the reduction of emission-intensive energy production	Emissions during manufacturing processes of monitoring devices
Materials	Input mateials of physcial grid components (e.g. copper)	Input materials of smart measurement devises and ICT infrastructure
End-of-Life	Recycling processes of phsical grid components	Recycling of monitoring devices
Distribution	Physical electricity grid	Transportation: raw materials to production site, monitoring devices to physical grid; Servcice modules are distributed via IOT platforms
Use Phase	Maintenance of physical grid components, planned interruptions	interfaces in combination with the monitoring devices deployed in the grid and on-going (real-time) data exchange. During the use phase, the DSOs access the full functionality of particular service modules distributed via an IOT platform.
Environmental Impact	Construction of physical grid components (power lines, transmission masts etc.) + Electricity consumption of cloud-servers and corresponding construction + potential health risks of 5G	ICT energy consumption, negative external effects (e.g. pollutant emissions released to air, water and soil and human distress) occuring during raw material sourcing and processing as well as during transport and production of monitoring devices.
Environmental Benefit	Lower network losses and less curtailment due to optimised RES integration, lower material throughput due to less deployment of phsical grid components	Substitution of physical network extension due to smart grid services; potential reduction of material throughput; specific environmental benefits of service modules

Social Layer	DSO	Service Vendor
Social Value	Customer satisfaction (measureable by the value of lost load)	Open innovation and active contribution to the transition towards 100% RES
Communities	Enablement of local energy communities and active participation of prosumers	Open smart grid service market with for DSOs with various stakeholder, e.g., algorithm implementer, consumers, MV / LV generators (incl. private prosumers, electricty and flexibility traders, TSOs
Governance	Sophisticated guidance from Network Agencies , European-level and national-level policy makers, enabling socially sustainable incentive systems for the use of smart grid services	Data sharing processes require compliance with critical privacy requirements of all value chain actores
Employees	Development of IT and data processing capabilities	IT experts such as software deveopers as core organisational stakeholder
Societal Culture	Inclusive and participative; mutual support; innovation-driven; open-mindedness	Inclusive and participative; mutual support; innovation-driven; open-mindedness
Scale of Outreach	Long term, trustfully, integrative relatoionships to MV/LV generators and consumers in the distribution area	Long term, trustfully, integrative, global relatoionships between algorithm implemnters, manufacturers of monitoring devices, IOT platform providers and mobile communications companies
End-User	MV/LV private & industrial consumers; lower share of income spent for electricity, less minutes without electricity	DSO
Social Impacts	Data sharing processes require compliance with critical privacy requirements of all Value Chain actores	For individual enterprises: Forego of intellectual property, no taking of advantage from contractual vendor lock-in
Social Benefits	Potetially lower network charges and lower electricity prices; Increasing customer satisfaction through better electricity distribution service quality based on an active distribution network management philosophy	publicly accessible knowledge while lowering the entry barriers of smart grid service markets and therewith contribution to business start-ups and job creation

5. Conclusion and Outlook

SOGNO considers new value chain structures for smart grid service supply. The present Deliverable has investigated the business models of a vendor providing system awareness services and autonomous self-healing services “as-a-service” to DSOs and that of a DSO as service recipient. The investigation was structured according to the Triple-Business-Model-Canvas which allowed us to holistically explore sustainability-oriented business model innovation [13] considering economic, societal and environmental perspectives. In this context, several use cases of the SOGNO services have been analysed in terms of their impact on DSOs operational performance and system costs. Our analyses are broad highlighting the variety of facets to be potentially considered when evaluating the use of smart grid services. Basically, we delineated the potential of smart grid service utilisation to improve DSOs’ operational performance whereas the substantiation of the extent of exploitation of potential and thus the concrete benefits of particular smart grid services modules must be based on detailed performance monitoring during their use phase.

In the present Deliverable, the potential of particular smart grid service modules developed in SOGNO was quantitatively analysed and embedded into the qualitative conceptualisation of the SOGNO-trialled value chain structure. Further projects might benefit from collecting data to empirically analysing the effect of infrastructural value chain changes on overall system performance. In general, research will benefit from open data on smart grid projects while sharing experiences and results of smart grid projects might facilitate effective policy design [5]. This is purposive, since the Deliverable has outlined the sensitive task of regulators to incite DSOs in general and to exploit the potential of smart grid services. On the one hand, regulatory incentive systems need to account for the current challenges of DSOs to cope with volatile, bi-directional energy flows and decreasing simultaneity of electricity production which potentially increase total system cost and require conventional reinforcement measures. On the other hand, DSOs are to be incited to pursue an active distribution network management approach which potentially exerts the opposite effect on total system costs [5]. The present findings underline the reasoning of [5] in that regulation has to account for the changing structures and compositions of CAPEX and OPEX while incentive schemes need to facilitate DSOs to find the optimal trade-off between OPEX and CAPEX and “to deploy innovative solutions and operating procedures” [5].

In general, the development of smart grid services can be considered as conductive to sustainability as it facilitates DSOs’ roles as active players in the energy sector. Presently, DSOs are required to perform not only conventional network operator tasks but also new ones that are, e.g., related to the integration of intermittent RES, interfaces with retail markets and distributed energy resources such as local storage, electric vehicles and demand response [3,5]. Therefore, DSOs establish multiple business relationships with service vendors, prosumers, retailers, aggregators, DSOs, TSOs, LV/MV generators etc. While platform solutions - as envisioned in SOGNO - are conductive to ensuring the high data interoperability requirements of these relationships, there are critical privacy interests of the actors involved in SOGNO-type value chains which require guidance and protection. Therefore, regulators are not only to incite DSOs to exploit the opportunities of flexibly testing smart grid service modules in order to innovate their operations but also to comprehensively address data interoperability related issues such as data ownership and control issues of heterogeneous actors involved [10].

6. List of Tables

7. List of Figures

8. Bibliography

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9. List of Abbreviations

CAPEX	Capital expenditure
CML	Customer minutes lost
CSR	Corporate Social Responsibility
DSO	Distribution System Operator
FLISR	Fault Location, Isolation and Service Restoration Service
LGF	Load and Generation Forecasting Service
LV	Low Voltage Grid
MV	Medium Voltage Grid
OPEX	Operational expenditure
PC	Power Control Service
PQ	Power Quality Service
SCADA	Supervisory Control and Data Acquisition
SE	State Estimation Service
TAR	Total allowed revenue
TSO	Transmission system operator