

POLITECNICO DI TORINO

Master's Degree in Energy and Nuclear Engineering



**Politecnico
di Torino**

Master's Degree Thesis

Economic and Reliability Assessment Tool for Smart Monitoring Solutions in MV Cable Networks

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To whoever helped make the biggest and most challenging change of my life possible, a little easier, brighter, more exciting, and far less tough...

... and to God, who showed His Grace to me through them all.

Abstract

A practical framework is presented to connect technical reliability effects in medium-voltage (MV) cable networks with financial outcomes that matter for Distribution System Operators (DSOs) and solution providers. The work was carried out within Nexans' grid-reliability activity and focuses on online MV cable monitoring based on Smart Cable Guard (SCG). The central idea is simple: feeder operational investments (those that affect positively faults, weak-spot restorations, downtime, and interruptions) are translated into annual cash flows and standard investment metrics. To make this translation transparent, the restoration process is decomposed into the stages that typically drive time and cost (localization; administrative and street-works; excavation and reinstatement; electrical repair and testing). By exposing these drivers, the link from "minutes and events" to "euros" becomes adjustable and auditable.

The objective was to formalize this technical-to-economic chain, quantify the cost of unreliability and the savings enabled by monitoring, express results in standard financial terms (NPV, IRR, discounted payback, ROI), and deliver an interactive tool that computes outcomes per feeder and in aggregate. The tool receives feeder-level inputs and country-dependent parameters, applies scenarios (from baseline with no monitoring to full SCG deployment), and reports both operational and monetary effects. Because European regulatory contexts often tie continuity indicators and unserved energy to incentives or standard compensations.

A real DSO case from Southern Europe is used to demonstrate the workflow. Results show the expected pattern under full monitoring: emergency faults and associated interruptions are reduced; weak-spot restorations increase as issues are surfaced earlier; and the time spent in localization and civil stages is also reduced. These technical shifts translate into lower restoration expenditure (OPEX) and reduced exposure to context-specific payments or penalties where such mechanisms exist. The main value for decision-makers lies in feeder-level granularity: high-impact feeders can be identified quickly, and deployment can be prioritized where the benefits are highest.

The study has limits. Reported magnitudes are case-specific and depend on local costs, practices, and regulatory parameters. Reliability compensation/penalty rates were kept neutral where policy rules or compensation rates were unavailable. The model does not claim overall SAIDI/SAIFI values; it focuses on the portion of reliability effects relevant to the cable system under the adopted assumptions. Future work should include country libraries (costs, time-shares, remuneration structures), country-specific calculation of compensation/penalty, benefit-decay modeling as networks stabilize, and support for partial feeder monitoring and branched topologies.

In summary, a clear pathway from feeder events to financial results is provided, implemented in an interactive tool, called the Value Creation Tool (VCT), and demonstrated on real utility data. The approach is intended to help DSOs and partners judge, with simple inputs and local assumptions, whether SCG-enabled monitoring represents and interesting investment.

Nomenclature

Symbol	Definition	Units
SCG Sizing		
$N_{SCG,i}$	Number of SCG systems required for full monitoring of feeder i	units
L_i	Medium-voltage (MV) cable length of feeder i	m
$\pi_i^{EPR}, \pi_i^{XLPE}, \pi_i^{PILC}$	Fractions of EPR, XLPE, and PILC cable in feeder i	–
$\lceil \cdot \rceil$	Ceiling operator	–
Event Frequencies		
F_i^0	Annual cable-related faults in the baseline for feeder i	faults/year
WS_i^0	Annual cable-related weak-spot restorations in the baseline for feeder i	restorations/year
F_i^{tot}, WS_i^{tot}	Total annual fault and weak-spot frequencies in feeder i	events/year
p_f, p_{ws}	Share of total faults and weak-spots attributable to the cable system	–
F_i^1	Annual cable-related faults with SCG for feeder i	faults/year
WS_i^1	Annual cable-related weak-spot restorations with SCG for feeder i	restorations/year
p_{int}	Intrinsic-cable-fault share	–
Restoration Costs		
$C_i^{(\cdot),0}$	Per-event cable-related restoration cost in the baseline for feeder i	€/event
$C_i^{(\cdot),1}$	Per-event cable-related restoration cost with SCG for feeder i	€/event
$C_{total}^{(\cdot),U/R}$	Known restoration cost per event in urban/rural areas	€/event
c_j	Unit joint cost	€/joint
n_j^{WS}, n_j^F	Joints replaced per weak-spot/fault restoration	joints/event
c_{cable}	Unit MV cable cost	€/m
l^{WS}, l^F	Cable length replaced per weak-spot/fault restoration	m/event
$c_{loc}^{(\cdot)}, c_{adm}^{(\cdot)}, c_{rep}^{(\cdot)}$	Localization, administrative, and repair costs by area	€/event

$C_{ann,i}^{(\cdot),0}$	Annual restoration cost in the baseline for feeder i	€/year
$C_{ann,i}^{(\cdot),1}$	Annual restoration cost with SCG for feeder i	€/year
Restoration Times		
T_i^{WS} and T_i^F	Restoration times for weak-spot/fault events	min/event
θ_{exc}^{WS} and θ_{exc}^F	Share of restoration time devoted to excavation	–
c_{exc}	Excavation hourly rate	€/h
$\theta_{adm}^{(\cdot)}$, $\theta_{exc}^{(\cdot)}$, $\theta_{rep}^{(\cdot)}$	Administrative, excavation, and repair time shares of the total resotoration time	–
T_i^{PR}	Power rerouting time under redundancy for feeder i	min/event
Downtime and Interruptions		
D_i^0 , D_i^1	Annual cable-related downtime for feeder i in the baseline / with SCG	min/year
$D_i^{0,res}$, $D_i^{0,ind}$	Residential-/industrial-user experienced downtime for feeder i the in baseline	min · user /year
$D_i^{1,res}$, $D_i^{1,ind}$	Residential-/industrial-user experienced downtime for feeder i with SCG	min · user/year
D_i^x	Downtime for feeder i under scenario x_i	min/year
I_i^0 , I_i^1	Annual cable-related interruptions for feeder i in the baseline / with SCG	int./year
I_i^x	Interruptions for feeder i under scenario x_i	int./year
N_i^{res} , N_i^{ind}	Residential and industrial users connected to feeder i	users
System-Level Indicators		
$\Delta SAIDI$	Reduction in SAIDI due to SCG	min/user
$\Delta SAIFI$	Reduction in SAIFI due to SCG	int./user
ΔENS_i	Reduction in energy not supplied for feeder i	MWh/year
$\bar{P}_i$	Average load of feeder i	kW
Monetary Effects		
R_{SAIDI} , R_{SAIFI}	Compensation from SAIDI/SAIFI reduction	€/year
κ_{SAIDI} , κ_{SAIFI}	Compensation rates for SAIDI/SAIFI reduction	€/min/user, €/int./user
R_{res} , R_{ind}	Compensation avoided for residential/industrial users	€/year

$\kappa_{res} , \kappa_{ind}$	Compensation payout rates for residential/industrial downtime	€/min
R_{ENS}	Avoided ENS cost	€/year
C_{ENS}	Client's unit cost of ENS	€/MWh
$\Delta C_{ann}^{WS} , \Delta C_{ann}^F$	Annual reduction in weak-spot/fault restoration costs	€/year
$C_{ann,i}^{WS,x}$ and $C_{ann,i}^{F,x}$	Annual restoration cost for feeder i under scenario x_i	€/year
S	Total annual additional income from SCG	€/year

Deployment Decision Variable

x_i	Binary decision variable: $x_i = 1$ if SCG is installed on feeder i ; $x_i = 0$ otherwise	–
Y_i^x	Value of metric Y for feeder i under scenario x_i	varies
$Y \in \{F, WS, C_{ann}^{WS}, C_{ann}^F, D, I\}$	Metrics represented (faults, weak-spots, costs, downtime, interruptions)	–

Financial Evaluation

INV_0	Initial investment	€
C_{unit}	Cost of one SCG unit	€
C_{sub}	Subscription cost per SCG unit	€/year
CF_0	Cash flow in year 0	€
CF_t	Cash flow in year t	€
T	Operational lifetime of SCG	years
NPV	Net present value	€
IRR	Internal rate of return	–
r	Client's discount rate	%
PB	Payback period	years
ROI	Return on investment relative to hardware CAPEX	%

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Chapter 1:

Introduction

This thesis presents a practical way to connect technical reliability improvements in medium-voltage (MV) cable networks to financial outcomes that matter for decision-makers. A clear workflow was designed so that events at feeder level (faults, weak-spot restorations, downtime, interruptions) can be translated into annual cash flows and standard investment metrics. The intent is to make the business case for online cable monitoring easy to read and easy to reuse by utility teams. The approach was implemented as an interactive tool and applied to a real DSO case study. In the thesis structure, the reader will first find the core concepts from literature, then the methodology, and finally the results and discussion for the case.

The work sits within an industry context where continuity-of-supply indicators (e.g., frequency and duration of interruptions, ENS) are widely monitored by European regulators and, in many countries, linked to incentive schemes or standard compensations. Because of this, technical gains (fewer/shorter interruptions, more planned restorations) often carry direct monetary effects for DSOs. The thesis uses that connection to evaluate whether monitoring investments create value under the rules and costs that apply locally.

Finally, the case study used in the Results chapter was drawn from a collaborating Southern European DSO and is used only to demonstrate how the method and the tool behave with real-world data. It is presented as an example of the workflow rather than a general statement about any specific utility.

1.1. Nexans' Efforts on Grid Reliability

The work was carried out in the Grid Reliability activity at Nexans, within a broader company transition toward a “full electrification” positioning. In public materials, Nexans frames this shift around improving grid performance and enabling the electrification of tomorrow. The specific focus here is MV cable network’s reliability.

Within this context, online cable monitoring is treated as part of a practical toolkit for DSOs. Smart Cable Guard (SCG) is a monitoring service developed by DNV and widely used to detect weak spots and locate faults in real time, with accuracy typically stated within $\sim 1\%$ of cable length [1]. Nexans markets the SCG solution, reflecting a collaboration where Nexans brings grid-reliability solutions to customers and DNV provides the SCG technology and expertise. This is the monitoring solution considered throughout the thesis.

For additional context, Nexans’ recent article on “Smart Accessories” explain why

implementing sensing and analytics can reduce outage durations and emergency interventions. This background motivates the thesis scope on MV underground cables and the economic value of earlier detection and faster localization [2].

1.2. Context of the work

DSOs know very well the performance and potential improvements of monitoring solution deployments with respect to restoration times and continuity indices. The hard part, especially early in a project, is turning those technical gains into money: effects on regulated revenues, customer compensations, and internal costs. In many European countries, regulators use continuity indices to adjust allowed revenue and to trigger payments after long outages. This makes cutting minutes or interruptions not just a technical win, it can be direct savings. This thesis makes that translation.

Nexans positions itself as an electrification company. Its Smart Cable Guard (SCG) developed by DNV aims to reduce outage risk and restoration effort. To support adoption, those technical benefits must be shown in euros at feeder and system level. This thesis builds a clear, step-by-step link from events to costs and savings. A real Southern European DSO case shows how the tool runs with local inputs, local costs, and local regulatory placeholders.

1.3. Objectives of the work

- **Formalize a clear technical-to-economic link**
To map feeder-level events reduction (in faults, downtime, interruptions) to monetary impacts, with restoration stages (localization, administrative/street-works, excavation/reinstatement, electrical repair/testing) defined as adjustable drivers.
- **Quantify the cost of unreliability and monitoring-enabled savings**
To compute annual restoration costs and estimate how online monitoring shifts emergencies to planned work and shortens localization/civil stages, producing OPEX savings and fewer exposure points to payments/penalties.
- **Translate technical impacts into standard financial metrics**
To build a discounted-cash-flow view (NPV, IRR, discounted payback, ROI) using client parameters and extreme scenarios (baseline vs. full monitoring).
- **Deliver an interactive feeder-level decision tool**
To implement the workflow in an application that ingests feeder inputs, computes/aggregates results, and highlights high-impact feeders for prioritization.
- **Demonstrate the method on a real DSO dataset**
To run two reference scenarios (no monitoring, full monitoring) and report operational and financial outputs under country-dependent assumptions.

Chapter 2:

Literature Review

2.1. Smart Monitoring in Medium-Voltage Networks

Smart monitoring in medium-voltage (MV) cable networks means keeping a constant eye on the condition of the cables: tracking insulation health issues like partial discharges, monitoring fault activity, and analyzing trends to guide timely maintenance. Unlike traditional periodic tests, online monitoring works in real time, making it possible to spot weak points earlier and locate faults much faster. This not only cuts down on unexpected outages but also improves key reliability indicators such as SAIDI and SAIFI. Many distribution system operators (DSOs) and industrial networks have already adopted this approach, often using specialized systems like DNV's Smart Cable Guard (SCG). [1].

2.1.1. Evolution of Monitoring and Maintenance Strategies in Distribution Systems

In the past, medium-voltage (MV) distribution networks mainly relied on corrective, or reactive, maintenance. Equipment was repaired only after it failed (often in emergency situations) leading to long fault localization times and costly outages. Preventive strategies later emerged, introducing time- or usage-based inspections and refurbishments to reduce the risk of major failures, though this sometimes meant unnecessary interventions on still-healthy assets. More recently, the growth of online monitoring and diagnostic tools, such as partial discharge (PD) measurements on live cables, has made condition-based and predictive maintenance possible. These approaches focus maintenance efforts where measurable degradation or signs of imminent failure appear. This shift (from reactive to scheduled, and now to data-driven maintenance) is well documented in both maintenance research and the broader power systems field. [3], [4].

From a cost perspective, condition-based and predictive maintenance outperform corrective strategies by reducing emergency repairs, downtime, and spare-parts inefficiencies, thereby lowering operating expenses (OPEX). Studies consistently show that acting on asset health indicators (rather than failures or fixed schedules) improves both costs and availability, though the gains vary by asset type and failure modes. In distribution networks, online MV-cable monitoring applies the same logic: it detects defects earlier and speeds up fault localization, cutting restoration times and outage-related costs. [3], [5], [4], [6].

2.1.2. Smart Cable Guard (SCG): principle of operation and features

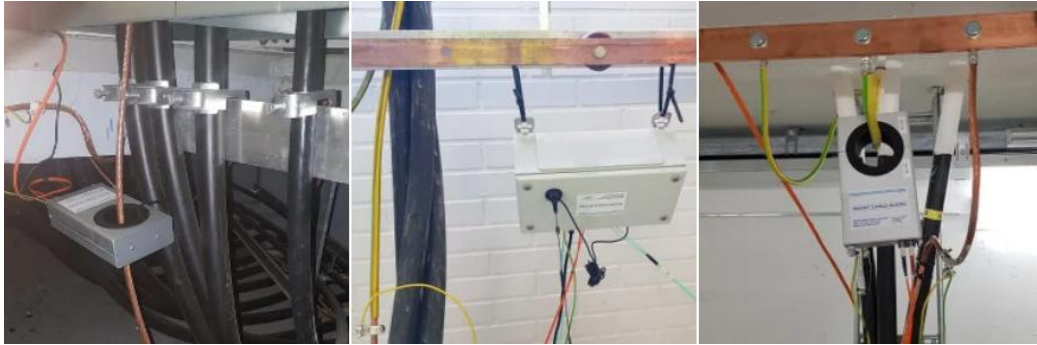


Figure 2.1-1 Smart Cable Guard (SCG) Parts. From left to right: Sensor 1, Control Unit, Sensor 2. A control unit is installed at each side to obtain the data from each sensor. Obtained from [7].

- Principle of operation: SCG is an online, 24/7 monitoring and analytics system for MV cable circuits. Sensors installed at cable terminations capture high-frequency signals associated with partial discharges, weak-spot activity, and fault transients. Time-of-arrival and waveform analysis are used to locate events; the platform reports real-time alarms and diagnostics via a cloud service. The manufacturer specifies fault and weak-spot location to within $\sim 1\%$ of cable length, with deployments exceeding 3,000+ systems and 8,000+ km monitored globally. [1], [8].
- Key features for MV cable systems: Continuous monitoring of energized circuits; no outage for measurement, and actionable alarms for incipient defects. Rapid localization that shortens excavation and switching time, thereby reducing downtime and associated compensation. Condition-based decision support tools, such as dashboards and reports, help utilities prioritize weak-spot restorations instead of letting faults run to failure. These capabilities have already been validated through long-term use by DSOs, including operators like Alliander and Helen. [1], [6], [7].
- Reported field benefits: Cases from utilities indicates that online PD monitoring with SCG enabled accurate fault/PD location, early weak-spot detection, and operational improvements (shorter repair times and avoided outages). CIRED/IET reports from utility experience describe SCG as effective for online detection and location of intermittent faults and PD in MV cables; DNV case studies document successful validation against offline PD in live networks (e.g., Helen's feeders). [6], [7].
- Application for insulation types (EPR, XLPE, PILC): Table 2.1.1 summarizes SCG's application performance across common MV cable insulations (EPR, XLPE, and PILC) covering underground and pole-mounted installations and both radial and branched topologies, typically in the 3–69 kV range. In practice, the monitorable span between sensor locations depends on insulation type and site noise/attenuation. Documented utility tests report 5–6 km feeder monitoring (Helen), and other technical sources indicate spans up to ~ 10 km for XLPE under

typical noise conditions, with shorter effective ranges for PILC owing to signal attenuation characteristics. These published ranges are consistent with the idea that feasible monitoring length is insulation-dependent. [7], [1], [9].

Cable Types	Under ground	Pole Mounted	Radial	Branched	kV	km/miles
EPR	Yes	Yes	Yes	Yes	3-69	5/3
XLPE	Yes	Yes	Yes	Yes	3-69	5/3
PILC	Yes	Yes	Yes	Yes	3-69	10/6

Table 2.1.1 SCG application for different insulation types. [10].

The practical implications of online monitoring for medium-voltage feeders can be summarized through the decision pathways shown in Figure 2.1-2. In the absence of monitoring, anomalies remain undetected until a fault occurs, requiring emergency repairs with high costs and penalties. By contrast, when a monitoring solution is installed, feeder activity is continuously observed and anomalies can be detected at an early stage. If preventive action is taken, weak-spot restorations replace fault repairs, and repair times are reduced.

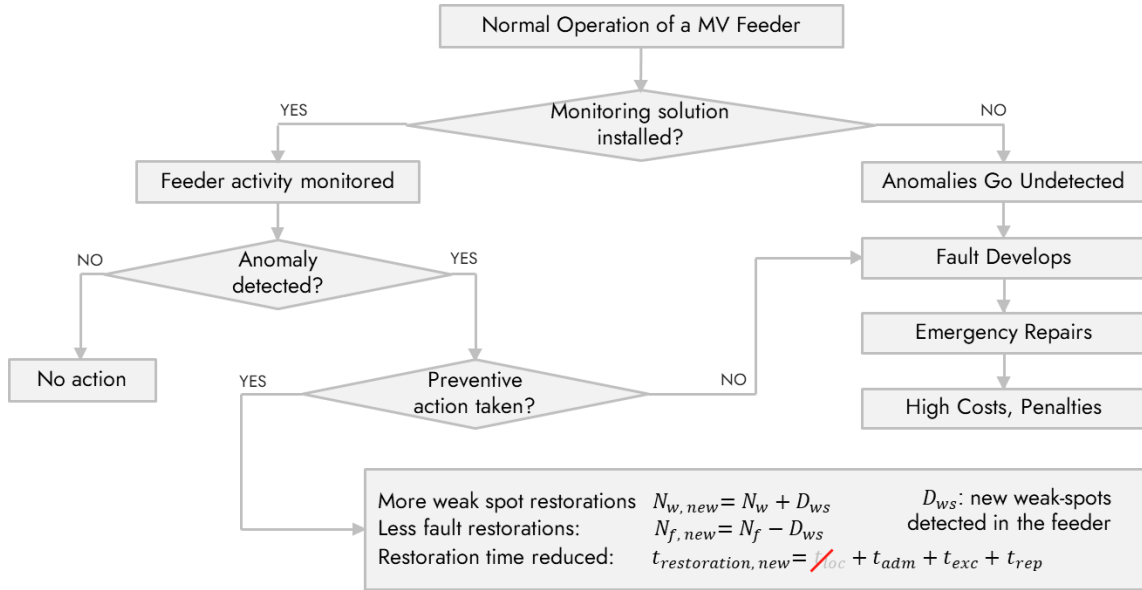


Figure 2.1-2 Schematic of Anomaly Detection and Maintenance Pathways in MV Cable Feeders

2.2. Medium-Voltage Cable Systems and Failure Mechanisms

This subchapter provides concise background on MV underground cable types and dominant failure mechanisms to motivate the monitoring and modeling choices used later in the methodology. The focus remains on distribution-class, extruded-insulation and legacy

PILC systems typically covered by IEC 60502-2. [11].

2.2.1. Overview of MV cables in distribution grids and cable insulation technologies (EPR, XLPE, PILC)

MV distribution networks today are built with extruded polymeric cables, which include a conductor, semiconductive screens, XLPE or EPR insulation, a metallic screen or armor, and an outer sheath. In older urban areas, however, many old paper-insulated, lead-covered (PILC) circuits are still in service. The design, materials, and type-test requirements for MV cables in the 6–36 kV range are standardized under IEC 60502-2. [11].

From a materials point of view, XLPE is the most used insulation thanks to its low dielectric loss and high dielectric strength. EPR is valued for its flexibility and strong thermal performance. Studies often report that EPR has higher dielectric losses than XLPE, which can translate into higher operational losses for otherwise similar cable designs, though the impact is application-dependent. [12].

PILC types remain serviceable but are susceptible to moisture ingress if the lead sheath is damaged, which accelerates paper degradation and partial-discharge (PD) activity; corrosion or cracking of the sheath is a recurrent precursor. [13], [14], [9].

Reliability data for underground distribution cables show variation depending on the utility and the mix of components in service. A frequently cited range for cable section failure rates is about 0.7–2 failures / 100 miles / year, highlighting the importance of condition monitoring and targeted replacement strategies. In practice, the performance of accessories (like joints and terminations) often plays a decisive role in overall reliability. [15], [16].

2.2.2. Degradation processes and typical failure mechanisms in underground cables

In MV cables, insulation aging is influenced by electrical, thermal, mechanical, and environmental stresses acting on the dielectric and its interfaces. For extruded XLPE and EPR systems, long-term AC service in moist soils can lead to water treeing branch-like micro-channels that form at defects or interfaces and gradually weaken the insulation's breakdown strength. If the stress continues, these can evolve into electrical trees and partial discharge activity, eventually causing dielectric failure. These aging mechanisms are well documented in both review studies and field investigations. [17], [18].

A common way to classify faults in MV cables is by distinguishing between intrinsic and extrinsic causes. Intrinsic faults arise from weaknesses within the material or interfaces (manufacturing defects or design non-conformities) that gradually evolve under normal service stresses until failure occurs. Extrinsic faults, by contrast, are triggered by external factors like third-party excavation damage, poor installation practices, or localized overstressing. This intrinsic–extrinsic distinction is used in the insulation aging literature and provides a framework for creating maintenance strategies. [19], [12].

Weak spots are best understood as incipient, localized degradations (e.g., PD-active sites at voids, interfaces, or accessory edges) that may be intermittent and persist for weeks or months before escalating to a sustained fault. In operational terms, weak spots are the actionable targets of online monitoring: detecting and localizing them enables planned weak-spot restorations instead of run-to-failure. [20].

Accessory and sheath issues deserve emphasis. PD problems in PILC are frequently associated with dry insulation or water ingress through deteriorated lead sheaths, leading to carbonized tracks and progressive dielectric failure; Similar problems can arise at MV joints, where long-term performance depends on installation quality and the effectiveness of stress control. [14], [20], [16].

2.3. Reliability Concepts in Distribution Grids

Reliability in electricity distribution expresses the continuity of supply delivered to end-users and is tracked through standardized indices that regulators use to set targets, compare utilities, and design incentives. In Europe, regulators regularly benchmark reliability performance across countries and DSOs to guide policy and incentives. [21].

2.3.1. Reliability as a regulated performance dimension

In many European jurisdictions, reliability is an explicitly regulated output. Regulators monitor continuity of supply and implement incentive schemes (financial and reputational) that reward or penalize DSOs based on performance versus targets (e.g., interruptions per customer and minutes lost). CEER's benchmarking shows widespread adoption of such schemes across Member States. [21], [22].

2.3.2. SAIDI and SAIFI: key indices and interpretations

The IEEE Guide for Electric Power Distribution Reliability Indices (IEEE Std 1366) provides the standard definitions used by regulators and utilities. Two principal indices are: SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index). [23], [24].

SAIDI quantifies the average outage duration per customer over a period (typically minutes/customer·year) as shown in Eq. (i).

$$SAIDI = \frac{\sum_{k=1}^K (\text{customers affected}_k \times \text{outage duration}_k)}{\text{total costumers served}} \quad (i)$$

where k is the number interruption events; outage duration is usually in minutes. A higher SAIDI indicates longer average outages. [24].

SAIFI quantifies the average number of interruptions per customer over a period (interruptions/customer·year). As shown in Eq. (ii).

$$SAIFI = \frac{\sum_{k=1}^K (\text{customers affected}_k)}{\text{total customers served}} \quad (ii)$$

Higher SAIFI indicates more frequent customer interruptions. [23], [24].

2.3.3. Energy Not Supplied (ENS) and its economic impact for DSOs

Energy Not Supplied (ENS) measures the energy (MWh) not delivered due to interruptions over an observation period $[t_0, t_f]$. A general definition is: total unserved energy resulting from load not supplied during outages as expressed in Eq. (iii). [25], [21], [26].

$$ENS = \int_{t_0}^{t_f} P_{\text{load not supplied}}(t) dt \quad (iii)$$

ENS has direct financial impacts for DSOs. Regulatory incentive schemes adjust revenues based on reliability, with penalties for poor performance and rewards for outperformance (e.g., Ofgem's IIS). In addition, DSOs must compensate customers under Guaranteed Standards when outages exceed set thresholds, creating further cash outflows. Reducing ENS (driven by lower SAIDI and SAIFI) therefore limits both revenue risk and compensation costs. [27], [28].

2.4. Restoration Costs and Regulatory Incentives

A brief overview is provided of how underground MV-cable outages are restored and why total restoration time matters for reliability performance and revenue. Emphasis is placed on the civil and administrative stages that often dominate restoration time, while Section 2.4.3 summarizes how European regulators incentivize reliability using SAIDI/SAIFI/ENS-type indicators.

2.4.1. Stages and Cost Drivers of Cable Restoration (Weak-Spot vs. Fault Interventions)

When a weak-spot (incipient defect) is indicated by on-line monitoring or diagnostics, the intervention can be planned proactively; when a fault occurs, an urgent corrective intervention is required. In both cases, restoration proceeds through four stages:

- **Localization:** The faulted span or weak-spot is located using pre-location and pinpointing methods (e.g., TDR/radar, thumper/ICE, etc.). Accurate pre-location reduces time and civil cost by limiting excavation to one dig. Trade and manufacturer guidance notes that pre-location can “save hours of walking the line” and reduce thumping time, and that multiple exploratory excavations can cost $\approx$ £1,000 each, which modern localization technologies aims to avoid [29], [30], [31].
- **Administrative:** Street-works permits, traffic management approvals and coordination with highways authorities are also considered. In Great Britain, permit

schemes under national regulations set rules for advance notice, permits, durations and reinstatement, with emergency works allowing immediate start but still requiring permit notification and compliance with reinstatement rules [32], [33], [34].

- **Excavation:** Excavation to expose the cable, creation of joint bays to utility specifications, and full reinstatement of the surface are performed. DNO technical specifications detail joint-bay dimensions and reinstatement requirements for 6.6/11 kV repairs, showing that civil works are often the longest stage [35].
- **Repair/testing/return to service:** Defective joints/sections are cut out, joints installed to utility standards, tests performed, and supply restored [35].

Accordingly, the restoration time for a single event can be expressed as the sum of stage durations as expressed by Eq. (iv).

$$T_{restoration} = T_{localization} + T_{administrative} + T_{excavation} + T_{repair} \quad (iv)$$

2.4.2. Influence of restoration times on downtime

Total restoration time directly influences customer downtime and thus the continuity indices reported by DSOs. In GB, Ofgem approved Electricity North West's (ENWL) "Dig, Fix and Go" incentive to cut average restoration time from 5.1 days to 3 days for emergency street-works following unplanned interruptions, with a symmetric financial rate per day above/below the target. This clearly recognises that civil works and associated coordination drive most of the elapsed days, hence the focus of the incentive [36].

In this context, most of the total restoration time is usually spent on administrative and civil activities. Tasks like permits, traffic management, and excavation or reinstatement can take several days, while the actual electrical repair and testing often require only a few hours to less than a day under standard utility procedures. [32], [35]. A practical European illustration is the GB case above: moving the mean from 5.1 to 3 days implies that reductions in civil/administrative durations (rather than the core repair) are necessary to achieve real improvements in average restoration time [32], [36].

In parallel, deployment of accurate pre-location/pinpointing reduces excavation count and duration, further reducing downtime by avoiding "search digs." Industry reports emphasize that combining TDR with localization limits excavation to one dig in many cases, thereby shortening both the localization and civil stages [29], [31].

2.4.3. Regulatory frameworks and compensation schemes linked to reliability

Across Europe, regulators integrate reliability into revenue frameworks through incentive schemes that benchmark DSOs using continuity metrics such as SAIDI and SAIFI, and in some cases ENS or power-weighted variants. The table below summarizes examples from major countries, based on the 7th CEER–ECRB Benchmarking Report (2022), highlighting where SAIDI, SAIFI, or ENS are applied in reliability assessments. [21].

- Germany: Quality-based regulation rewards/penalises DSOs against an individual reference, using SAIDI at LV and ASIDI at MV; the reward/penalty is computed by $(\text{SAIDI}^* - \text{SAIDI}) \times \text{Customers} \times \text{Price of quality}$.
- France: ENS is used as a fixed parameter to calculate the penalization amount that is directly given to the end-users of the DSOs.
- Great Britain: Incentives are based on “minutes lost per customer per year” and “number of interruptions per customer per year” for planned/unplanned events (effectively SAIDI/SAIFI constructs under GB definitions).
- Belgium (Brussels): The tariff methodology (2020–2024) includes incentive regulation using SAIDI and SAIFI for MV/LV; supplementary remuneration is granted when KPI targets are met.
- Finland: Rewards and penalties are applied with explicit consideration of continuity-of-supply (CoS) indicators, both long and momentary, using a macroeconomic approach to assign monetary value like in France where end-user compensation for very long individual outages is also regulated through standard payments, though in Finland this operates alongside the broader incentive mechanism rather than replacing it.

Overall, SAIDI/SAIFI remain the core distribution-level indices in most regulatory frameworks, with ENS used directly (e.g., France, Finland). Incentive formulas convert deviations from targets into monetary adjustments that affect allowed revenue, thereby aligning DSO financials with continuity outcomes.

2.5. Economic Evaluation of Monitoring Investments

In MV cable networks, the economic case for online monitoring is established by mapping technical reliability improvements (fewer/shorter interruptions; pre-fault weak-spot restorations) into cash-flow impacts and then applying standard discounted-cash-flow (DCF) tests (NPV, IRR, discounted payback). In European contexts, continuity metrics (SAIDI/SAIFI and, in some jurisdictions, ENS) are the base for regulatory incentives, so technical gains translate into higher revenue and avoided penalties, alongside operational savings.

- Main sources of positive cash flow:
 - Regulatory incentive/penalty effects: Reductions in SAIDI/SAIFI (and where applicable ENS) improve allowed revenues or avoid penalties under national schemes, producing a net revenue item in annual cash flows. [21].
 - Monetized ENS reduction: Lower ENS is valued as an annual benefit as compensations to end users are reduced or incentives are linked to this metric are increased. [21].

- OPEX savings: Continuous monitoring (e.g., SCG) shortens localization and enables planned weak-spot restorations; case evidence reports significant outage-time reductions ($\approx 55\%$), which also reduces administrative costs and outage-linked charges. [37].
- Investment in monitoring: Upfront capital expenses (CAPEX) (sensors/installation) and recurring OPEX (platform/subscription, operations) are recognized as outflows; these are offset by the benefits above to form annual net cash flows for evaluation.
- Methods to assess: Benefits and costs are aggregated into an annual stream and evaluated via DCF metrics: NPV (using the client's discount rate/WACC), IRR, and discounted payback, in line with EU appraisal guidance. [38].

Chapter 3:

Methodology

The methodology establishes a structured framework to evaluate the value of Smart Cable Guard (SCG) deployment on medium-voltage feeders. Faults and weak-spots are considered only when they cause supply interruptions requiring restoration, while latent conditions that do not affect continuity of supply are excluded. The analysis focuses exclusively on cable-related events, as these can be directly addressed by the implementation of SCG and have an impact on downtime, user experience, and compensation costs. The framework integrates technical reliability modeling with financial evaluation to capture both operational and economic outcomes of SCG implementation.

3.1. Approach

A scenario-based modeling approach was adopted to evaluate the technical and financial impact of deploying SCG on medium-voltage feeders. The analysis considered two reference cases: a baseline scenario, in which no feeders are equipped with SCG, and a full-deployment scenario, in which all feeders are equipped with SCG. These two extremes allow any intermediate configuration to be represented as a combination of results, thereby enabling the evaluation of mixed deployment strategies defined by the client. Within this framework, quantitative formulations were applied to estimate the number of faults and weak-spots, the associated downtime and interruptions, the resulting restoration and compensation costs, and the main financial indicators of the investment. Unless otherwise specified, all variables referring to faults, weak-spots, downtime, interruptions, and ENS are understood to be restricted to events attributable to the cable system. Events originating from other components of the distribution grid, such as substations, transformers, or overhead lines, are excluded from the scope of this methodology.

3.2. Software Environment

The model was implemented in Python, using Streamlit to design the interactive interface and manage client input. Data handling and numerical operations were performed with the pandas and numpy libraries, while financial evaluations such as discounted cash flow analysis were carried out with numpy-financial. Visualization of results and key performance indicators was supported through Altair, which enabled the creation of interactive charts and figures.

3.3. Data Inputs and Imputation

Feeder-level inputs, including topology, number of users, restoration times, cost parameters, reliability indicators, redundancy configuration, and financial or regulatory parameters, were collected through a structured CSV template. In addition, some parameters are not provided in the CSV and must be entered directly by the client through the interface, such as the share of cable-related faults and weak-spots, intrinsic fault percentages, unit material costs, excavation rates, compensation schemes, and financial parameters¹.

3.4. Analytical Framework and Equations

3.4.1. Sizing: Number of SCG Systems per Feeder

To estimate how many SCG systems are needed on a feeder given its cable mix, the required units were computed per insulation type and summed, then rounded up as implemented in Eq. (1). The model takes monitoring density requirements of 1 unit per 5 km for EPR and XLPE segments and 1 unit per 10 km for PILC segments from Table 2.1.1. The mix shares are provided by the client as percentages.

$$N_{SCG,i} = \left\lceil \frac{L_i \cdot \pi_i^{EPR}}{5000} + \frac{L_i \cdot \pi_i^{XLPE}}{5000} + \frac{L_i \cdot \pi_i^{PILC}}{10000} \right\rceil \quad (1)$$

Where,

- $N_{SCG,i}$ = number of SCG systems required for full monitoring of feeder i ;
- L_i = medium-voltage (MV) cable length of feeder i (m);
- $\pi_i^{EPR}, \pi_i^{XLPE}, \pi_i^{PILC}$ = fractions of EPR, XLPE, and PILC cable on feeder i (0-1);
- $\lceil \cdot \rceil$ = ceiling operator.

It is assumed that feeders are either fully monitored or not monitored at all. Partial monitoring of feeders is not considered in the present methodology.

3.4.2. Baseline (No SCG) Incidence and Costs

Annual faults and weak-spot events attributable to the cable system are obtained by applying the cable-related shares to the total observed frequencies of the mentioned events. These shares correspond to the proportion of total faults and weak-spots caused by the cable system. As outlined in Section 2.4.1, the restoration process for MV cables is divided into four stages: localization, administrative tasks, excavation, and repair. The four per-event cost parameters used here are derived from this decomposition, with urban and

¹ When certain inputs are unavailable, the tool automatically substitutes them with predefined defaults or country-specific presets. The collection and integration of these country-specific parameters remain part of the tool's future development.

rural variants reflecting the differences in civil works. These metrics are given by Eq. (2) and Eq. (3). In what follows, subscript '0' denotes baseline values without SCG, whereas subscript '1' denotes values under full SCG deployment.

$$F_i^0 = F_i^{tot} \cdot p_f, \quad WS_i^0 = WS_i^{tot} \cdot p_{ws} \quad (2)(3)$$

Where,

- F_i^0 = annual cable-related faults in the baseline on feeder i (faults/year);
- WS_i^0 = annual cable-related weak-spot restorations in the baseline on feeder i (weak-spots/year);
- F_i^{tot}, WS_i^{tot} = total annual fault and weak-spot frequencies on feeder i (events/year);
- p_f, p_{ws} = share of total faults and weak-spots attributable to the cable system (0–1).

If the total restoration cost per cable-related event is known, it is entered by the client who enters this cost directly by area type (Urban = U / Rural = R). This cost is considered for all the feeders according to their respective area.

$$C_i^{WS,0} = \begin{cases} C_{total}^{WS,U}, & \text{if } area_i = U \\ C_{total}^{WS,R}, & \text{if } area_i = R \end{cases}, \quad C_i^{F,0} = \begin{cases} C_{total}^{F,U}, & \text{if } area_i = U \\ C_{total}^{F,R}, & \text{if } area_i = R \end{cases}$$

Where,

- $C_i^{(\cdot),0}$ = per-event cable-related restoration cost in the baseline for feeder i (€/event);
- $C_{total}^{(\cdot),U/R}$ = known restoration cost per event in urban/rural areas (€/event).

If the total restoration costs $C_{total}^{(\cdot),U/R}$ for urban or rural areas are not known, the tool requires the client to provide a detailed breakdown of the underlying cost components. In this case, the restoration cost is not taken as a fixed value but is reconstructed from individual parameters, including the number of joints replaced, the length of cable to be substituted, the unit costs of materials, the hourly excavation rate, and the administrative, localization, and repair costs. Furthermore, feeder-specific restoration times (T_i^{WS}, T_i^F) are incorporated together with the client-defined shares of time allocated to excavation, administration, and repair. This procedure results in restoration costs that are feeder-dependent. Eq. (4) and Eq. (5) integrate the provided breakdown to calculate the per-event weak-spot and fault restoration cost in the baseline.

$$C_i^{WS,0} = (c_j \cdot n_j^{WS}) + (c_{cable} \cdot l^{WS}) + c_{loc}^{WS}(area_i) + \left(T_i^{WS} \cdot \theta_{exc}^{WS} \cdot \frac{c_{exc}}{60}\right) + c_{adm}^{WS}(area_i) + c_{rep}^{WS}(area_i) \quad (4)$$

$$C_i^{F,0} = (c_j \cdot n_j^F) + (c_{cable} \cdot l^F) + c_{loc}^F(area_i) + \left(T_i^F \cdot \theta_{exc}^F \cdot \frac{c_{exc}}{60}\right) + c_{adm}^F(area_i) + c_{rep}^F(area_i) \quad (5)$$

Where;

- c_J = unit joint cost (€/joint);
- n_J^{WS}, n_J^F = joints replaced per weak-spot/fault restoration (joints/event);
- c_{cable} = unit MV cable cost (€/m);
- l^{WS}, l^F = cable length replaced per weak-spot/fault restoration (m/event);
- $c_{loc}^{(\cdot)}, c_{adm}^{(\cdot)},$ and $c_{rep}^{(\cdot)}(area)$ = localization, administrative, and repair costs by area (€/event);
- T_i^{WS}, T_i^F = restoration times for weak-spot/fault events (min/event);
- θ_{exc}^{WS} and θ_{exc}^F = share of restoration time devoted to excavation (0-1);
- c_{exc} = excavation hourly rate (€/h).

Finally, the annual restoration cost for feeder i is obtained by multiplying the per-event cost by the expected events as given by Eq. (6) and Eq. (7).

$$C_{ann,i}^{WS,0} = C_i^{WS,0} WS_i^0, \quad C_{ann,i}^{F,0} = C_i^{F,0} F_i^0 \quad (6)(7)$$

Where,

- $C_{ann,i}^{(\cdot),0}$ = annual restoration cost in the baseline for feeder i (€/year).

3.4.3. Baseline Downtime and Interruptions

Downtime is computed as the total time required to restore faults and weak-spots, or, in the presence of redundancy, it is reduced to the time necessary for rerouting power as described by Eq. (8). Weak-spots, although not complete failures, represent degradations in the cable system that require corrective intervention before they evolve into full faults.

$$D_i^0 = \begin{cases} F_i^0 T_i^F + WS_i^0 T_i^{WS}, & \text{if } Redundancy_i = 0 \\ F_i^0 T_i^{PR}, & \text{if } Redundancy_i = 1 \end{cases} \quad (8)$$

Where,

- D_i^0 = annual cable-related downtime for feeder i in the baseline (min/year);
- T_i^{PR} = power rerouting time under redundancy for feeder i (min/event).

Users-experienced downtime multiplies feeder downtime by the number of users as shown in Eq. (9).

$$D_i^{0,res} = D_i^0 N_i^{res}, \quad D_i^{0,ind} = D_i^0 N_i^{ind} \quad (9)$$

Where,

- $D_i^{0,res}$ = residential-user experienced downtime for feeder i in the baseline (min·user/year);

- $D_i^{0,ind}$ = industrial-user experienced downtime for feeder i in the baseline (min·user/year);
- N_i^{res} and N_i^{ind} = residential and industrial users connected on feeder i .

Interruptions are counted as the number of service-affecting events. Without redundancy, both faults and weak-spots cause interruptions, whereas with redundancy only faults are registered, as per Eq. (10), since weak-spots can be bypassed through rerouting.

$$I_i^0 = \begin{cases} F_i^0 + WS_i^0, & \text{if } Redundancy_i = 0 \\ F_i^0, & \text{if } Redundancy_i = 1 \end{cases} \quad (10)$$

Where,

- I_i^0 = annual cable-related interruptions for feeder i in the baseline (interruptions/year).

It is assumed that each downtime event affects all users connected to the feeder simultaneously, without differentiation by user category or load profile. Likewise, each interruption event is considered to involve all users of the feeder.

3.4.4. System Performance under Full SCG Implementation

With full SCG deployment, intrinsic cable faults are detected at an early stage and consequently reclassified as weak-spots rather than being observed as complete failures. This transformation reduces the number of fault events while increasing the number of weak-spot interventions. Such reclassification reflects the preventive maintenance character of the technology; whereby potential failures are identified before escalation and can therefore be addressed through targeted interventions under controlled conditions. At the same time, restoration costs and durations are reduced, as the localization stage is no longer required, further enhancing operational efficiency. It is important to emphasize that the total number of restoration events remains unchanged; however, their nature is altered, with a portion of costly fault restorations being substituted by less expensive weak-spot restorations. This mechanism constitutes one of the principal sources of savings associated with SCG deployment. [39].

Eq. (2) and Eq. (3) are hence modified to Eq. (11) and Eq. (12) which model this reclassification of the intrinsic cable faults into weak-spots restorations.

$$F_i^1 = F_i^{tot} p_f (1 - p_{int}), \quad WS_i^1 = WS_i^{tot} p_{ws} + F_i^{tot} p_f p_{int} \quad (11)(12)$$

Where,

- F_i^1 = annual cable-related faults with SCG for feeder i (faults/year)
- WS_i^1 = annual cable-related weak-spots restorations with SCG for feeder i (restorations/year);
- p_{int} = intrinsic-cable-fault share (0–1).

When SCG is deployed, restoration costs are computed as in the baseline but with the localization component removed, since the SCG pinpoints the exact location of the fault and thus reduces the localization cost to zero [39]. However, a license fee must be paid for the use of the system, and this cost is accounted for later in the financial analysis. The calculation again depends on whether the client provides total per-event costs (urban/rural) or a component breakdown. If the total per-event costs (urban/rural) are known, this reduction is applied to come up with Eq. (13) and Eq. (14).

$$C_i^{WS,1} = \begin{cases} C_{total}^{WS,U} - c_{loc}^{WS}(U), & \text{if } area_i = U \\ C_{total}^{WS,R} - c_{loc}^{WS}(R), & \text{if } area_i = R \end{cases} \quad (13)$$

$$C_i^{F,1} = \begin{cases} C_{total}^{F,U} - c_{loc}^F(U), & \text{if } area_i = U \\ C_{total}^{F,R} - c_{loc}^F(R), & \text{if } area_i = R \end{cases} \quad (14)$$

Where

- $C_i^{(\cdot),1}$ = per-event cable-related restoration cost with SCG for feeder i (€/event).

If the total per-event costs (urban/rural) are not known, the restoration costs are then calculated using Eq. (4) and Eq. (5) and using the provided breakdown, with the difference that the localization costs are not included anymore. This modification is applied to come up with Eq. (15) and Eq. (16).

$$C_i^{WS,1} = C_i^{WS,0} - c_{loc}^{WS}(area_i), \quad C_i^{F,1} = C_i^{F,0} - c_{loc}^F(area_i) \quad (15)(16)$$

Finally, with the presence of SCG, the annual restoration costs for feeder i with SCG is obtained by multiplying the per-event costs with SCG by the expected events with SCG, turning Eq. (6) and Eq. (7) into Eq. (17) and Eq. (18).

$$C_{ann,i}^{WS,1} = C_i^{WS,1} WS_i^1, \quad C_{ann,i}^{F,1} = C_i^{F,1} F_i^1 \quad (17)(18)$$

Where,

- $C_{ann,i}^{(\cdot),1}$ = annual restoration cost with SCG for feeder i (€/year).

Downtime with SCG is calculated by adjusting the original restoration times by multiplying them with the non-localization share of the process, denoted as $\phi^{(\cdot)}$. This parameter represents the fraction of restoration time devoted to administration, excavation, and repair activities as is shown in Eq. (19) and Eq. (20). (see that localization is not included). Since the SCG pinpoints the exact location of the fault, the localization stage is eliminated, which reduces the total restoration time and makes $\phi^{(\cdot)}$ strictly lower than one.

$$\phi^F = \theta_{adm}^F + \theta_{exc}^F + \theta_{rep}^F, \quad \text{with } \phi^F \leq 1 \quad (19)$$

$$\phi^{WS} = \theta_{adm}^{WS} + \theta_{exc}^{WS} + \theta_{rep}^{WS}, \quad \text{with } \phi^{WS} \leq 1 \quad (20)$$

Where,

- $\theta_{adm}^{(\cdot)}, \theta_{exc}^{(\cdot)}, \theta_{rep}^{(\cdot)}$ = administrative, excavation and repair time shares of the total restoration time, respectively (0–1).

In practice, this means that the baseline restoration times T_i^F and T_i^{WS} are multiplied by ϕ^F and ϕ^{WS} , redefining Eq. (8) to Eq. (21), to reflect only the activities that remain necessary once localization is no longer required. This adjustment ensures that downtime estimates are more accurate and highlight the operational improvement enabled by SCG deployment.

$$D_i^1 = \begin{cases} F_i^1 T_i^F \phi^F + WS_i^1 T_i^{WS} \phi^{WS}, & \text{if } Redundancy_i = 0 \\ F_i^1 T_i^{PR}, & \text{if } Redundancy_i = 1 \end{cases} \quad (21)$$

Where,

- D_i^1 = annual cable-related downtime for feeder i with SCG (min/year);

The same logic applied in Eq. (9) to obtain the users-experienced downtime in the baseline applies to obtain that for the full-deployment scenario, as shown in Eq. (22).

$$D_i^{1,res} = D_i^1 N_i^{res}, \quad D_i^{1,ind} = D_i^1 N_i^{ind} \quad (22)$$

Where,

- $D_i^{1,res}$ = residential-user experienced downtime for feeder i with SCG (min·user/year);
- $D_i^{1,ind}$ = industrial-user experienced downtime for feeder i with SCG (min·user/year);.

Interruptions with SCG are calculated in the same manner as in the baseline scenario as per Eq. (23) (see Eq. (10)).

$$I_i^1 = \begin{cases} F_i^1 + WS_i^1, & \text{if } Redundancy_i = 0 \\ F_i^1, & \text{if } Redundancy_i = 1 \end{cases} \quad (23)$$

Where,

- I_i^1 = annual cable-related interruptions for feeder i with SCG (interruptions/year).

3.4.5. Client Choice (Selective SCG per Feeder)

In addition to the baseline and full-deployment scenarios, the tool also allows the client to define mixed configurations, where SCG is selectively installed on specific feeders. This flexibility is introduced through a binary decision variable x_i , which activates SCG on a feeder when set to one. The resulting value of each performance or cost metric is then computed as a weighted combination of the baseline and SCG outcomes, depending on the deployment choice, as described by Eq. (24).

$$Y_i^x = x_i Y_i^1 + (1 - x_i) Y_i^0 \quad (24)$$

Where,

- x_i = binary decision variable: $x_i = 1$ if SCG is installed on feeder i ; $x_i = 0$ otherwise;
- Y_i^x = value of metric Y for feeder i under scenario x_i ;
- $Y \in \{F, WS, C_{ann}^{WS}, C_{ann}^F, D, I\}$, i.e. faults, weak-spots, costs, downtime, and interruptions.

3.4.6. System-Level Reliability Contributions

As mentioned previously in Section 2.3, the reliability indices SAIDI and SAIFI are standard indicators in power system performance assessment. In practice, SAIDI and SAIFI can be affected by problems across all components of the electricity distribution system, including transformers, overhead lines, substations, and the cable network [40]. The present work, however, focuses exclusively on outages caused by faults and weak-spots in the cable system. For this reason, absolute values of SAIDI and SAIFI cannot be recalculated in full, as not all sources of interruptions are included. Instead, the methodology quantifies the reduction in SAIDI and SAIFI attributable to SCG deployment, isolating the incremental benefit linked to improved monitoring and localization of cable-related failures.

To quantify the overall reliability improvements, system-level contributions are expressed in terms of per-customer reductions. The tool computes SAIDI and SAIFI reductions through Eq. (25) and Eq. (26) by aggregating the experienced downtime and interruptions across all users and dividing by the total number of customers.

$$\Delta SAIDI = \frac{\sum_i [D_i^0 (N_i^{res} + N_i^{ind}) - D_i^x (N_i^{res} + N_i^{ind})]}{\sum_i (N_i^{res} + N_i^{ind})} \quad (25)$$

Where,

- $\Delta SAIDI$ = reduction in SAIDI due to SCG (min/user).
- D_i^x = downtime for feeder i under scenario x_i (min/year).

$$\Delta SAIFI = \frac{\sum_i [I_i^0 (N_i^{res} + N_i^{ind}) - I_i^x (N_i^{res} + N_i^{ind})]}{\sum_i (N_i^{res} + N_i^{ind})} \quad (26)$$

Where,

- $\Delta SAIFI$ = reduction in SAIFI due to SCG (interruptions/user);
- I_i^x = interruptions for feeder i under the scenario x_i (interruptions/year).

3.4.7. ENS Reduction

As with SAIDI and SAIFI, ENS can be caused by failures across all parts of the electricity system. The present analysis restricts its scope to outages originating in the cable system. Consequently, absolute ENS values cannot be recalculated comprehensively. Instead, the methodology focuses on the reduction in ENS achieved by SCG deployment,

which reflects the avoided undelivered energy associated with fewer or shorter cable-related interruptions. The reduction is computed feeder by feeder as per Eq. (27).

$$\Delta ENS_i = \left(\frac{D_i^0 - D_i^x}{60} \right) \frac{\bar{P}_i}{1000} \quad (27)$$

Where,

- ΔENS_i = reduction in energy not supplied for feeder i (MWh/year);
- $\bar{P}_i$ = average load of feeder i (kW).

For simplicity, the evaluation of ENS reduction is based on the average load of the feeder i ($\bar{P}_i$) and not on the time-dependent real behavior of the load as shown in Eq. (iii). Consequently, the temporal variability of demand is not considered, and interruptions are treated as if they occur under constant average loading conditions.

3.4.8. Monetary Effects

The operational improvements achieved by SCG deployment translate into several monetary effects. These include (i) compensation or potential penalty reductions linked to SAIDI and SAIFI, (ii) avoided customer payouts due to downtime reduction, (iii) savings from ENS, and (iv) direct reductions in restoration costs. The combination of these effects constitutes the new annual income attributable to SCG.

The compensation related to SAIDI and SAIFI is computed as per Eq. (28) and Eq. (29).

$$R_{SAIDI} = \Delta SAIDI \cdot \left(\sum_i (N_i^{res} + N_i^{ind}) \right) \cdot \kappa_{SAIDI} \quad (28)$$

$$R_{SAIFI} = \Delta SAIFI \cdot \left(\sum_i (N_i^{res} + N_i^{ind}) \right) \cdot \kappa_{SAIFI} \quad (29)$$

Where,

- R_{SAIDI}, R_{SAIFI} = compensations from SAIDI/SAIFI reduction (€/year)²;
- $\kappa_{SAIDI}, \kappa_{SAIFI}$ = compensation rates for SAIDI/SAIFI reduction (€/interruption/user).

In the present formulation, κ_{SAIDI} and κ_{SAIFI} represent generic compensation rates (€/min-user and €/int-user) introduced to monetize reductions in reliability indices. As highlighted by the CEER-ECRB Benchmarking Report (2022) [21] and as exposed in Section 2.4.3, there is no single harmonized mechanism across Europe for converting SAIDI

² In practice, compensations associated with reductions in SAIDI and SAIFI are triggered once, immediately after the reduction is achieved in the first year of SCG operation. To align with the financial evaluation framework, these one-time benefits are modeled in the tool as if they were distributed evenly across all years of the operational lifetime. This assumption ensures consistency with the annual cash-flow structure, but it should be noted that, in reality, the full compensation would be received only once at the beginning of the project.

and SAIFI improvements into monetary adjustments, with approaches varying significantly by country. Consequently, these rates are left as user-defined inputs in the tool, allowing calibration to national regulatory contexts.

The reductions in the compensations to be paid to residential and industrial users associated with the downtime in the service are expressed as per Eq. (30) and Eq. (31).

$$R_{res} = \left(\sum_i (D_i^0 - D_i^x) \cdot N_i^{res} \right) \cdot \kappa_{res} \quad (30)$$

$$R_{ind} = \left(\sum_i (D_i^0 - D_i^x) \cdot N_i^{ind} \right) \cdot \kappa_{ind} \quad (31)$$

Where,

- R_{res}, R_{ind} = compensation avoided for residential/industrial users (€/year);
- $\kappa_{res}, \kappa_{ind}$ = compensation payouts rates for residential/industrial downtime (€/minute).

The ENS is reduced as shown in Eq. (27) and the avoided cost associated is defined by Eq. (32).

$$R_{ENS} = \left(\sum_i \Delta ENS_i \right) c_{ENS} \quad (32)$$

Where,

- R_{ENS} = avoided ENS cost (€/year);
- c_{ENS} = client's unit cost of ENS (€/MWh).

Finally, direct savings in restoration OPEX are calculated by Eq. (33) and Eq (34).

$$\Delta C_{ann}^{WS} = \sum_i (C_{ann,i}^{WS,0} - C_{ann,i}^{WS,x}) \quad (33)$$

$$\Delta C_{ann}^F = \sum_i (C_{ann,i}^{F,0} - C_{ann,i}^{F,x}) \quad (34)$$

Where,

- ΔC_{ann}^{WS} and ΔC_{ann}^F = annual reduction in weak-spot/fault restoration costs (€/year);
- $C_{ann,i}^{WS,x}$ and $C_{ann,i}^{F,x}$ = annual restoration cost in feeder i under scenario x_i (€/year).

The total new income attributable to SCG is therefore defined by Eq. (35)

$$S = R_{SAIDI} + R_{SAIFI} + R_{res} + R_{ind} + R_{ENS} + \Delta C_{ann}^{WS} + \Delta C_{ann}^F \quad (35)$$

Where,

- S = total annual additional income from SCG (€/year).

3.4.9. Financial Evaluation

The financial viability of SCG is assessed using standard investment indicators, which are essential for justifying the deployment of the technology and supporting investment decisions on the client's side.

The financial assessment is based on the investment costs of SCG and the annual savings obtained. An initial payment must be made to Nexans for the purchase of the SCG systems, which represents the hardware investment, while an additional annual fee is charged per unit as a subscription cost for the continued use of the system.

The initial investment is therefore calculated by multiplying the total number of SCG systems to be installed by the DSO, obtained by the sum of Eq. (1), with the cost of one SCG unit and the subscription cost per unit as per Eq. (36).

$$INV_0 = \left(\sum_i N_{SCG,i} \right) \cdot (C_{unit} + C_{sub}) \quad (36)$$

Where,

- INV_0 = initial investment (€);
- C_{unit} = cost of one SCG unit (€);
- C_{sub} = subscription cost per unit (€/year).

The subscription cost is charged at the beginning of each year, starting at commissioning (year 0). Consequently, over a T -year lifetime, T subscription payments are considered. Operational savings are recognized annually. The annual cash flows are therefore defined by Eq. (37) and Eq. (38).

$$CF_0 = S - INV_0 \quad (37)$$

$$CF_t = S - \left(\sum_i N_{SCG,i} \right) \cdot C_{sub}, \quad t = 1, 2, 3, \dots, T-1 \quad (38)$$

Where,

- CF_0 = cash flow in year 0 (€);
- CF_t = cash flow in year t (€);
- T = operational lifetime of SCG (years).

From these cash flows, the financial viability of SCG deployment is assessed through standard indicators: the Net Present Value (NPV) compares discounted benefits to upfront costs, the Internal Rate of Return (IRR) compares the resulting profitability against the client's required one, the payback period shows the time needed to recover the investment, and the Return on Investment (ROI) expresses overall profitability relative to hardware costs. Equations from (39) to (42) show how these common metrics are obtained.

$$NPV = \sum_{t=0}^T \frac{CF_t}{(1+r)^t} \quad (39) \quad PB = \min \left\{ t : \sum_{j=0}^t \frac{CF_j}{(1+r)^j} \geq 0 \right\} \quad (40)$$

$$0 = \sum_{t=0}^T \frac{CF_t}{(1 + IRR)^t} \quad (41)$$

$$ROI = \frac{\sum_{t=0}^T CF_t}{(\sum_i N_{SCG,i}) \cdot C_{unit}} \quad (42)$$

Where,

- NPV = net present value (€);
- IRR = internal rate of return (%);
- r = client's discount rate³ (%);
- PB = payback period (years);
- ROI = return on investment relative to hardware CAPEX (%).

³ The client's discount rate r represents the client's expected rate of return, which is used to evaluate the profitability of investment projects. In practice, this is typically the Weighted Average Cost of Capital (WACC), although companies may apply other benchmark rates depending on their internal financial policies.

Chapter 4:

Results Case of a DSO in Southern Europe

This chapter presents the results obtained from the application of the Value Creation Tool (VCT) to distribution network data that were constructed with the support of a national Distribution System Operator (DSO) in Southern Europe. The company is responsible for the operation, development, and maintenance of medium- and low-voltage electricity networks in its territory.

During the internship, a field visit was conducted to supervise the installation of Smart Cable Guard (SCG) units and to present the preliminary version of the VCT to engineers from the DSO. The discussions focused on aligning the tool's outputs with the information that would be most valuable for potential users, both in terms of financial indicators and operational reliability metrics.

The operator did not provide raw datasets from its network but contributed to the work by sharing indicative values, including typical feeder lengths, average loads, event frequencies, restoration times, and unit costs (e.g., cable joints, excavation, and administrative fees). These inputs were used to construct a representative set of feeders reflecting a close-to-reality operating environment.

To demonstrate the methodology, results are shown for an extreme case scenario in which full deployment of SCG was assumed across all feeders. It is acknowledged that, in practice, DSOs would prioritize selective deployments depending on reliability concerns and financial objectives. The analysis of such targeted schemes remains part of the future work.

4.1. Input Data

4.1.1. DSO-Provided Data

All operational inputs were constructed based on indicative values shared by the collaborating DSO during the internship. Rather than full datasets, the operator provided typical figures for costs, restoration practices, and event frequencies, which were used to assemble a representative sample of 100 medium-voltage feeders. For each feeder, the dataset includes:

- MV cable length,
- insulation mix (EPR/XLPE/PILC),
- number of joints and secondary substations,
- area type (urban/rural),
- average load,
- numbers of residential and industrial users,
- restoration times for cable-system faults and weak-spots,
- annual frequencies of faults and weak-spot restorations,
- redundancy flag,
- and power-rerouting time.

A high-level characterization of the sample is presented in Table 4.1.1.

Total MV cable length (km)	1,267 km across the 100 feeders
Aggregated average load (MW)	151.7
Connected users	56,715 residential and 2,854 industrial.
Redundancy	100% of feeders are marked as redundant (with alternative supply).

Table 4.1.1 Characterization of the dataset provided by the collaborating DSO.

The full dataset is present in *Annex I: Topology and Operational Data of DSO's Network*.

4.1.2. Country-Dependent Parameters

The full list of input parameters employed in the analysis is reported in *Annex II: List of input parameters provided by DSO*. For the present chapter, only the assumptions concerning the Smart Cable Guard (SCG) costs are highlighted. The SCG unit cost was set to €10,000 and the annual subscription to €1,500 per unit. These figures were used as working assumptions for the case study and do not represent commercial fees that Nexans or DNV might agree on in future SCG contracts.

For the case study application developed in the next chapter, κ_{SAIDI} and κ_{SAIFI} were set to zero, since no explicit compensation parameters of this type were available in the regulatory framework of the considered country. Nevertheless, these coefficients remain part of the tool structure, ensuring that potential future regulatory implementations can be readily integrated.

It was also documented during the internship that the preparation of a national compensation scheme for residential users is ongoing. To reflect this development, a nominal placeholder of €0.005 per min-user was included in the sensitivity runs, while industrial-user compensation was kept at zero.

4.2. Operational Performance

4.2.1. Baseline Scenario (No SCG)

In the baseline case, no Smart Cable Guard (SCG) systems are installed. The representative dataset was analyzed exhaustively to quantify cable-system incidents, downtime, interruptions, and restoration expenditures at feeder level.

Across the 100-feeder sample, total cable-system downtime amounts to 9,973 minutes/year, entirely driven by fault events under universal redundancy. Since every feeder is redundant, weak-spots do not cause supply interruptions and downtime equals the product of cable-related fault counts and the feeder's power-rerouting time. The average rerouting time is around 40 minutes and the average feeder downtime is 99 minutes/year, with the top 10 feeders contributing $\approx 21\%$ of aggregate downtime.

Restoration expenditures are substantial even without monitoring: total annual restoration costs reach $\approx \text{€}3.94$ million/year, split $\approx 50.6\%$ faults and $\approx 49.4\%$ weak-spots. Typical per-event costs are higher for faults than for weak-spots (medians $\approx \text{€}7,721$ /fault vs $\approx \text{€}4,038$ /weak-spot). Baseline exposure is predominantly rural: rural feeders (94% of the sample) contribute $\approx 94\%$ of downtime, $\approx 95\%$ of events, and $\approx 94\%$ of restoration costs.

Notably, no significant correlation is observed between MV-cable length or number of joints and downtime in the results ($|r| \lesssim 0.10$), indicating that, under redundancy, rerouting time and event frequency are the dominant drivers of the downtime experimented by the users.

These results characterize the “business-as-usual” condition in which excavation and repair activities are reactive and localization relies on standard practices, with downtime governed by rerouting capability and total restoration costs split almost evenly between weak-spot and fault interventions. The full feeder-level table for the baseline scenario is provided in the *Annex III: Results For the Baseline Scenario*

4.2.2. Full SCG Deployment Scenario

Results for the full-deployment scenario were analyzed to quantify event incidence, downtime and interruptions, and the associated restoration expenditures and monetized effects.

A pronounced shift from corrective to preventive interventions is observed. Cable-related faults fall to 20.3 events/year, while weak-spot restorations rise to 709.2/year, indicating that incipient defects are predominantly addressed through planned works rather than run-to-failure repairs. Despite the higher volume of weak-spot restorations, system downtime reduced to 797.9 min/year. At feeder level, downtime is highly improved (average 7.9 min/year), and concentration remains moderate (top 10 feeders account for $\approx 21.3\%$ of total downtime; top 20 for $\approx 38.0\%$). All feeders remain redundant; therefore, interruptions reflect the reduced fault volume: 20.3 interruptions/year in total, with 12,132 int-users/year when weighted by connected users. Experienced outage time sums to 465,628 min-users/year

(residential 441,843, industrial 23,785).

Restoration expenditure decreases under SCG since planned restorations are higher now. Annual restoration costs total $\approx \text{€}2.69$ million/year, of which $\approx \text{€}2.55$ million corresponds to weak-spots and $\approx \text{€}0.14$ million to faults. Typical per-event costs remain lower for weak-spots than for faults (average $\approx \text{€}3,538$ /weak-spot vs $\approx \text{€}6,821$ /fault, i.e., $\sim 1.93\times$ higher for faults). The net restoration-cost reduction amounts to $\approx \text{€}1.25$ million/year, this is because $\approx \text{€}1.85$ million/year are being saved on fault repairs and additional $\approx \text{€}0.60$ million/year are now dedicated to weak-spot restorations.

In this case study, SAIDI/SAIFI reduction remuneration and ENS monetization are set to zero, so the new income ($\approx \text{€}1.28$ million/year) is almost entirely explained by restoration-cost savings ($\approx \text{€}1.25$ million/year) plus a modest reduction in residential downtime compensation ($\approx \text{€}25.4$ thousand/year). The full feeder-level tables for both the baseline and the full-deployment scenarios are provided in the *Annex IV: Results For the Full Deployment Scenario*.

4.2.3. Comparative Reliability Contributions

A direct comparison between the baseline (no SCG) and the full SCG deployment scenarios was carried out to highlight the reliability and financial impacts of system-wide monitoring. The most relevant aggregate metrics are summarized in Table 4.2.1.

Metric	Baseline	Full SCG	Comment
Cable-system faults (events/year)	254	20	−234 (−92.0%)
Weak-spot restorations (events/year)	475	709	+234 (+49.2%)
Downtime (min/year)	9 973.4	797.9	−9 175.6 min (−92.0%)
Interruptions (events/year)	254	20	−234 (−92.0%)
Experienced downtime (min-users/year)	5 820 354.2	465 628.3	−5 354 725.8 min (−92.0%)
Experienced interruptions (int-users/year)	151 651	12 132	−139 519 (−92.0%)
Restoration cost – faults (€/year)	€1 991 983	€140 754	−€1 851 229 (−92.9%)
Restoration cost – weak-spots (€/year)	€1 948 104	€2 547 091	+€598 986 (+30.7%)
Restoration cost – total (€/year)	€3 940 087	€2 687 845	−€1 252 243 (−31.8%)
SAIDI reduction (min/user-year)	0.0	89.9	Improvement of 89.9
SAIFI reduction (int/user-year)	0.0	2.3	Improvement of 2.3
ENS reduction (MWh/year)	0.0	238.6	Improvement of 238.6
Residential downtime compensation avoided (€/year)	€0	€25 406	New benefit: €25 406

Table 4.2.1 Comparative reliability and cost metrics under baseline and full SCG deployment.

4.3. Economic Impacts

4.3.1. Monetary Effects

A system-wide shift from corrective to preventive interventions is observed when SCG is deployed. In the baseline, annual restoration expenditures amount to $\approx \text{€}3.94$ million/year, almost evenly split between faults and weak-spot repairs. Under full deployment, weak-spot restorations increase (planned works) and fault repairs are largely avoided, yielding $\approx \text{€}2.69$ million/year in total restoration costs and a net reduction of $\approx \text{€}1.25$ million/year (-31.8%).

Operationally, customer-experienced is overall improved. At system level this corresponds to a SAIDI reduction of 89.89 min/customer/year, a SAIFI reduction of 2.34 faults/customer/year, a total downtime reduction of 9,175.55 min/year, and 238.60 MWh/year less undelivered energy. These effects translate into annual savings of $\text{€}1,277,648.56$.

4.3.2. Financial Evaluation

The investment case for full deployment was evaluated over the 10-year operational horizon used in the tool. The initial investment is $\text{€}3,231,500$, comprising $\text{€}2,810,000$ for hardware and $\text{€}421,500$ /year in operating costs. The discounted-cash-flow results indicate strong viability: NPV = $\text{€}4,131,499.81$, IRR = 41.95% , payback = 4 years, and ROI = 204.68% . As seen in Figure XX, Year-by-year cash flows show an initial outlay followed by sustained positive net savings that drive the cumulative discounted cash flow above $\text{€}4$ million by the end of the analysis period.

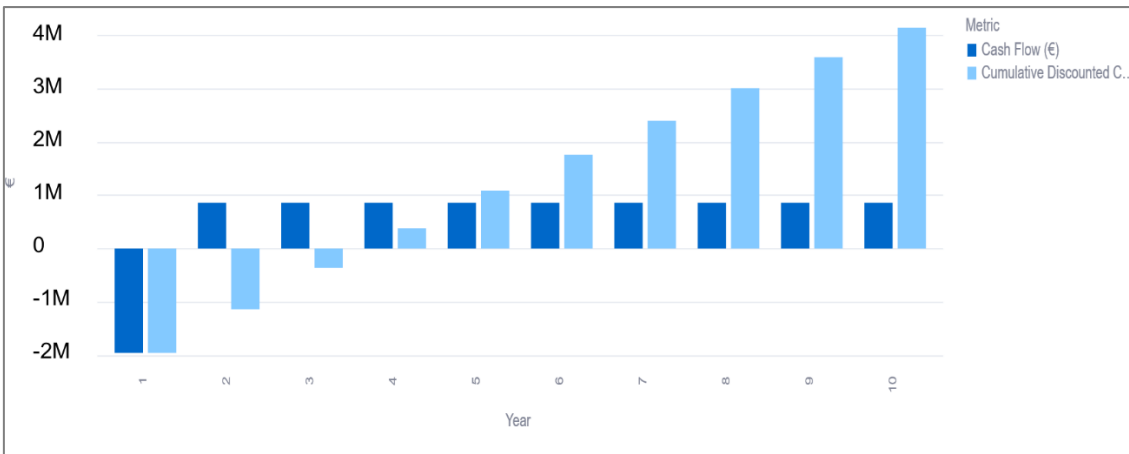


Figure 4.3-1 Yearly cash flow and cumulative discounted cash flow (Full SCG deployment).

Conclusions and Future Work

This work bridges the gap between technical reliability metrics and financial performance in MV cable networks by developing an economic and reliability assessment tool for smart monitoring solutions. The objectives were met through a methodology that (i) quantifies the cost of unreliability, (ii) assesses and monetizes the savings enabled by grid monitoring, (iii) converts these effects into a standard financial evaluation framework, and (iv) implements the whole workflow in an interactive tool. The main conclusions are summarized below.

- A transparent techno-economic chain from events to monetary values
A clear pathway was established from feeder-level events (faults, weak-spot restorations, downtime, and interruptions) to their monetary impacts (restoration costs, avoided compensations, and incentive effects). Restoration was broken down into its main stages—localization, administration and street works, excavation/reinstatement, and electrical repair/testing—to show which activities drive time and cost. This breakdown clarified how online monitoring (e.g., SCG) creates value: earlier defect detection, more faults replaced by weak-spot restorations, and shorter localization and civil works.
- Significant improvements in performance are achieved with monitoring
In the case study, all cable-related reliability indicators improved under full monitoring. Faults and interruptions decreased, while weak-spot restorations increased as planned interventions replaced emergencies. As a result, both downtime and user-experienced downtime declined significantly. Although the exact values are case-specific, the trend is clear: early detection and localization reduce emergency repairs and shorten outages, confirming the technical value of online monitoring in MV cable networks.
- Economic benefits increase due to new income sources
First, OPEX savings come from fewer emergency faults and more efficient civil works (single-dig localization, fewer excavations, faster permits), which lower both the cost per event and the total annual restoration budget. Second, revenue protection/benefit arises where regulatory frameworks place a financial value on continuity indicators or Energy Not Supplied (ENS). In many countries, such compensation and penalty mechanisms are already in place, while in others they are expected to be introduced soon. In both cases, less downtime means lower exposure to payouts and penalties. And yet a third can be mentioned: risk reduction comes

from reducing the likelihood of cascading failures thus avoiding reputational damage among the DSOs users.

- **Decision support with feeder-level detail**
Because the tool calculates inputs and results at feeder level, the technical aspects of reliability can now be expressed in monetary terms. This means that downtime, excavation delays, or redundancy gaps are not just seen as technical weaknesses but as clear financial impacts. By showing which feeders contribute most to unreliability costs, the tool helps prioritize investments and provides a solid economic justification for grid monitoring deployment. In this way, a purely technical problem is translated into a business case that supports decision-making.
- **Implications for the energy transition are concrete.**
The tool supports faster, better-targeted deployment of smart monitoring and contributes to the readiness of distribution grids to host more electrification and distributed energy resources.

Future Work

Building on the conclusions above, several developments are proposed to enhance accuracy, decision value, and practical integration into DSO workflows.

- **Country-dependent parameter libraries**
It is recommended that a library be assembled to auto-populate country-specific inputs: typical restoration time shares (administrative/civil/electrical), urban/rural civil costs, excavation rates, unit material costs, and regulatory remuneration structures (SAIDI/SAIFI/ENS). This would reduce user burden.
- **Case-specific regulatory and compensation engines**
Regulatory frameworks should be integrated so that monetary effects are computed under the exact rules of each country (thresholds, caps, symmetric/asymmetric, event exclusions, standard customer payments). With these modules in place, technical outputs would be translated immediately into more accurate cash flows.
- **Benefit-decay modeling as networks stabilize**
Because online monitoring enables a finite number of weak-spot restorations, decreasing marginal savings are expected as defects are repaired. A decay multiplier should therefore be introduced (e.g., a saturating function, for example) to adjust annual benefits to a more realistic case.
- **Partial-monitoring and topology-aware modeling**
The tool should also support partial feeder monitoring (for example, focusing on critical segments) and branched feeder layouts with different spans and redundancy levels. This would better reflect how MV feeders are built and operated, allowing investments to target the most problematic sections first and deliver benefits faster with lower investments.

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Annex I: Topology and Operational Data of DSO s Network

Name	MV Cable Length (m)	EPR (%)	XLPE (%)	PILC (%)	N. of Joints	N. of Secondary Substations	Area Type	Av. Load (kW)	N. of Residential Users	N. of Industrial Users	Cable-System Fault Rest. Time (min)	Annual Fault Frequency (faults/year)	Cable-System Weak-Spot Rest. Time (min)	Annual Weak-Spot Rest. (rest./year)	Redundancy (YES = 1 or NO = 0)	Power Rerouting Time (min)
F001	8092	9.5	66.1	24.4	55	5	R	1250.2	640	14	9272	3	526	7	1	46
F002	8298	10	73.2	16.8	70	7	R	1393.4	462	47	6493	2.1	503	5	1	58
F003	6244	3.8	65.8	30.3	55	8	U	1962	761	10	5397	1.6	380	1	1	14
F004	11000	12.8	66.9	20.3	52	6	R	1139.9	193	39	8056	2.3	642	8	1	34
F005	5882	14.2	69.4	16.4	52	9	U	2332.3	484	14	6911	4.1	535	7	1	56
F006	18611	5.9	64	30.1	55	4	R	775.6	927	24	9663	4.7	513	7	1	23
F007	9350	10.8	73.7	15.5	65	3	R	1882	111	23	9022	2.3	613	3	1	48
F008	10125	8.1	70.4	21.5	56	1	R	2432.2	547	30	5372	0.8	836	9	1	48
F009	16720	7	78.1	14.9	60	8	R	1756.8	261	21	6677	2.8	320	6	1	39
F010	19514	15.2	63.7	21.1	50	9	R	625.5	270	34	5778	4.2	673	4	1	36
F011	18719	8	72.1	19.9	78	6	R	1120.8	361	42	4195	3	325	3	1	48
F012	9129	10.9	63.9	25.2	52	2	R	1769.9	708	48	8740	3.4	603	2	1	56
F013	14152	6.7	80.1	13.2	44	2	R	805.4	517	34	4408	1.6	716	9	1	22
F014	9786	12.2	71.3	16.5	95	8	R	2132.5	678	41	9243	2.6	357	6	1	22
F015	5092	13.5	65.5	21	83	9	R	933.4	985	12	7967	2.4	765	1	1	59
F016	18010	12.7	68.5	18.8	18	9	R	1006.6	719	42	8040	3.1	667	7	1	40
F017	18908	8.5	70.1	21.4	53	1	R	1792	553	19	6771	3	689	1	1	40
F018	19981	8.6	75.1	16.3	80	1	R	1979.9	287	34	6799	1.7	408	8	1	40

F019	11860	8.6	70.7	20.7	11	3	R	660.9	495	24	6126	1	630	1	1	12
F020	10848	14.3	76.6	9.1	75	2	R	1994.3	783	31	10066	4.9	533	7	1	36
F021	8700	4.9	70.2	24.9	63	8	R	1595.5	938	49	7173	1.7	505	6	1	48
F022	8220	8.3	69.7	22	14	6	R	1223	636	28	9879	1.9	530	3	1	14
F023	10533	10.3	67.3	22.4	57	4	R	1689.7	516	20	3408	2.2	554	4	1	48
F024	12816	5.9	67.3	26.7	43	4	R	1308.2	504	20	4476	2.2	471	9	1	48
F025	9412	12.1	64.5	23.4	41	5	R	2159.7	260	25	6073	3.8	318	3	1	48
F026	16091	2.6	67.2	30.2	16	8	R	1240.5	131	7	7393	1.6	749	8	1	19
F027	12608	7.1	74.6	18.3	70	5	R	678.6	990	8	4464	2.1	827	4	1	11
F028	11412	12.9	68.2	18.9	31	4	R	1975.1	144	29	8142	3.9	778	7	1	28
F029	8141	10.5	67.9	21.6	10	3	R	978.1	226	25	8278	4.9	410	8	1	28
F030	17733	7.1	63.2	29.7	73	2	R	1292	586	35	6271	4	705	9	1	28
F031	15017	10.3	76.1	13.6	33	9	R	1224.6	947	6	7599	0.9	417	3	1	23
F032	17665	11.1	73.1	15.8	52	8	R	2235	301	15	5489	3.6	695	2	1	30
F033	5883	10.8	67.5	21.8	21	6	U	1537.4	711	8	5935	2.9	392	8	1	51
F034	8743	10.7	71.4	17.9	94	6	R	581.7	716	25	4235	4.9	827	9	1	36
F035	13214	10.3	63.5	26.2	68	3	R	544.6	920	35	3902	1	317	8	1	42
F036	18695	10.6	74.7	14.6	22	8	R	899.9	688	46	5248	4.5	419	8	1	31
F037	16481	11.6	69.9	18.5	53	4	R	1710.6	508	24	8972	1.6	563	1	1	39
F038	10397	11.2	67.2	21.6	92	2	R	1854.8	390	29	6444	2.3	784	8	1	21
F039	17008	12.6	75.3	12.1	74	8	R	866	262	44	6877	5	620	5	1	50
F040	12233	9.3	75.7	15	91	1	R	1753.5	932	11	6592	3	740	5	1	50
F041	6489	10.2	75.1	14.7	31	1	R	789.7	708	19	5515	1.3	744	8	1	50
F042	17074	10.3	77.8	11.9	58	6	R	796.9	269	24	5353	1	741	2	1	53
F043	16276	10.1	73.6	16.3	21	7	R	2424.2	600	36	8065	5	459	4	1	41
F044	8857	12.9	70.4	16.7	52	1	R	2088.4	506	22	8129	4	534	2	1	38
F045	12188	14.3	68.4	17.3	46	5	R	2390.2	626	31	6175	1.4	539	6	1	51
F046	8892	16.2	67.9	16	30	5	R	1545.3	379	45	6561	3.4	491	9	1	17

F047	14157	10.9	60.8	28.3	74	6	R	609.1	382	34	6453	1.6	459	9	1	14
F048	15392	4.7	66.3	28.9	71	9	R	2442.1	564	20	10014	2.1	476	7	1	21
F049	12899	7.7	71	21.3	65	3	R	2028.9	553	12	6172	3.8	564	6	1	47
F050	18583	7.4	65.1	27.6	60	9	R	2407.3	599	39	6052	2.3	388	1	1	47
F051	12785	11.4	75.3	13.4	26	9	R	702.4	730	31	6666	4.1	472	5	1	59
F052	15059	11.7	70.1	18.2	81	4	R	2465.7	190	47	8325	2.9	420	4	1	28
F053	11254	11	71.4	17.6	31	8	R	2113.9	230	40	8406	1.1	383	4	1	60
F054	7499	8.3	80	11.6	97	4	R	2314.5	978	30	5261	4.2	714	7	1	15
F055	11637	14.4	67	18.6	18	1	R	1276.5	526	34	4332	2.5	442	8	1	58
F056	9241	6.1	73.4	20.5	58	4	R	1981.9	804	26	8280	3.6	527	4	1	30
F057	14559	10.4	71.4	18.3	30	1	R	2240.9	240	7	6705	4.2	724	7	1	67
F058	9780	7.7	71.3	20.9	83	4	R	1707.1	746	47	8752	4.6	487	4	1	59
F059	16501	8.3	76.9	14.9	16	7	R	2434.5	772	16	4453	1.7	405	1	1	29
F060	5709	8.8	68.2	23.1	81	9	R	1163.3	983	5	6267	3.7	765	1	1	56
F061	14855	9	60.4	30.6	18	2	R	1915.1	717	45	9307	1.9	779	5	1	22
F062	18575	9.9	73.9	16.2	72	4	R	1323.8	551	38	4522	1.9	603	8	1	56
F063	6416	8.9	67	24.1	69	9	U	1888.9	130	33	8255	3.2	692	1	1	56
F064	18631	13.9	67.8	18.3	94	1	R	601.9	741	30	7592	2.1	460	8	1	32
F065	14127	11.5	77.4	11.2	29	9	R	1596.1	319	13	7927	2	566	1	1	40
F066	8320	11.7	74.1	14.2	22	2	R	1572.6	101	43	3607	3	607	7	1	52
F067	10509	6.4	66.9	26.7	48	7	R	2459.3	373	37	6376	4.9	310	9	1	34
F068	10068	6.5	71.4	22.1	51	3	R	1608	892	16	9233	1.6	738	7	1	22
F069	13027	10.7	73.4	16	89	5	R	1243	952	38	7982	5	449	4	1	24
F070	9968	11.2	67.9	20.8	32	8	R	2469.1	304	42	8289	4.9	662	9	1	55
F071	8149	13.3	65.4	21.3	29	2	R	739.2	416	37	8738	1.5	870	4	1	58
F072	9217	9.6	66.4	24	48	8	R	652.8	866	41	3075	4.3	770	1	1	41
F073	15484	8.6	67.7	23.7	93	9	R	1337.1	115	49	6592	4.6	538	3	1	37
F074	18162	15.7	59.7	24.6	27	9	R	655.5	265	30	10093	3.7	408	5	1	36

F075	10552	10.7	60.7	28.6	33	3	R	2423	695	40	7996	2	603	4	1	36
F076	9209	15.8	65.9	18.4	53	7	R	807.9	148	43	5880	1.7	625	9	1	17
F077	13039	15	63.2	21.8	63	2	R	1145.3	604	15	9385	0.8	770	6	1	35
F078	18198	12	77.8	10.2	49	7	R	583.1	633	13	7004	3.3	653	4	1	16
F079	13002	9	60.4	30.6	16	7	R	1552.3	374	33	7367	4.4	633	6	1	47
F080	14604	5.5	64.4	30.1	13	9	R	2137.7	966	38	6530	4.2	521	6	1	47
F081	14887	8.3	69.3	22.4	58	9	R	1823.6	149	12	5075	2.7	695	8	1	47
F082	17102	7.6	73.7	18.6	83	1	R	1366.6	897	5	8986	2.9	479	3	1	13
F083	17137	10.1	73.7	16.2	78	2	R	624	783	25	5715	2.8	411	2	1	40
F084	7609	14	71.5	14.5	51	5	R	670.5	543	15	5708	3.9	689	5	1	56
F085	19613	16	77.7	6.3	70	9	R	1069.5	605	42	4752	3.4	524	8	1	56
F086	16311	12	62	25.9	41	6	R	963.1	667	43	8282	1	402	2	1	34
F087	15863	15	75.1	9.9	46	8	R	1614.2	656	20	4428	3.4	443	5	1	33
F088	12655	13.4	77.2	9.4	49	4	R	1871.9	765	36	9335	4.9	570	4	1	18
F089	18105	14.3	73.4	12.3	43	7	R	2288.2	818	40	6821	4.6	654	6	1	25
F090	7770	10.4	71.3	18.3	34	9	R	959.6	851	15	10799	1.7	459	2	1	50
F091	5518	5.7	71.5	22.9	98	8	U	2092.1	540	12	4201	1.5	660	5	1	58
F092	5601	10.1	66	23.9	46	8	U	2268.2	811	20	10032	0.6	551	5	1	13
F093	16215	11.5	65.8	22.7	36	3	R	1388.4	471	40	7940	2.4	372	5	1	25
F094	12229	13.2	68.4	18.4	77	4	R	2164.1	358	32	3595	2.5	466	1	1	46
F095	17447	10.3	74.9	14.9	28	6	R	2441.1	842	43	8881	3.8	593	1	1	56
F096	7651	5.9	78.9	15.2	57	7	R	1802.6	422	29	10370	1.4	533	9	1	46
F097	16486	8.7	67.5	23.8	26	1	R	1466.2	788	44	4709	3.3	729	1	1	58
F098	10170	6.8	67.9	25.3	52	2	R	598.5	837	17	4817	2.4	399	4	1	21
F099	14966	11.4	67.7	20.9	10	5	R	995.8	899	45	5622	2.3	638	6	1	52
F100	13691	11.7	71.7	16.6	90	2	R	1526.4	418	8	9194	2.1	520	3	1	46

Annex II: List of input parameters provided by DSO

Parameter Name	Value
Percentage of Weak-Spot Repairs due to cable system (0-100)	93
Percentage of Faults due to cable system (0-100)	89
Percentage of Intrinsic Cable Faults (0-100)	92
Cost of MV cable joint (€/unit)	300
Cost of MV underground cable (€/m)	13
Cost of excavation (€/hour)	85
Number of joints replaced per weak-spot repair (units/repair)	2
Length of cable replaced per weak-spot repair (m/repair)	6
Administrative cost of a weak-spot restoration in urban areas (€/restoration)	1500
Repair cost of a weak-spot restoration in urban areas (€/restoration)	2000
Administrative cost of a weak-spot restoration in rural areas (€/restoration)	900
Repair cost of a weak-spot restoration in rural areas (€/restoration)	1600
Localization cost of a weak-spot restoration in urban areas (€/restoration)	600
Localization cost of a weak-spot restoration in rural areas (€/restoration)	500
Share of the weak-spot restoration time used for localization (%)	5
Share of the weak-spot restoration time spent in administrative matters (%)	20
Share of the weak-spot restoration time used for excavation (%)	45
Share of the weak-spot restoration time used for repair (%)	30
Number of joints replaced per fault repair (units/repair)	2
Length of cable replaced per fault repair (m/repair)	15
Administrative cost of a fault restoration in urban areas (€/restoration)	2000
Repair cost of a fault restoration in urban areas (€/restoration)	3000
Administrative cost of a fault restoration in rural areas (€/restoration)	1200
Repair cost of a fault restoration in rural areas (€/restoration)	2400
Localization cost of a fault restoration in urban areas (€/restoration)	1200
Localization cost of a fault restoration in rural areas (€/restoration)	900
Share of the fault restoration time used for localization (%)	15
Share of the fault restoration time spent in administrative matters (%)	45
Share of the fault restoration time used for excavation (%)	25

Share of the fault restoration time used for repair (%)	15
Client's rate of return (%)	5
Client's ENS cost (€/MWh)	0
Compensation for reducing SAIDI (€/minute/user)	0
Compensation for reducing SAIFI (€/interruption/user)	0
Compensation to pay to residential users due to downtime (€/min/user)	0.005
Compensation to pay to industrial users due to downtime (€/min/user)	0

Annex III: Results For the Baseline Scenario

Name	SCG Installed (YES = 1 or NO = 0)	SCG Systems Needed	Annual Faults not related to Cable System (faults/year)	Annual Weak-Spot Rest. not related to Cable System (rest./year)	New Annual Faults related to Cable System (faults/year)	New Annual Weak-Spot Rest. related to Cable System (rest./year)	Weak-spot Restoration Cost (€/rest.)	Fault Rest. Cost (€/rest.)	Annual Cable- System Weak-spot Rest. Cost (€/year)	Annual Cable-System Fault Rest. Cost (€/year)	Downtime due to Cable System Issues per Year (min/year)	Experienced Downtime for Residential Users due to Cable System Issues per Year (min- users/year)	Experienced Downtime for Industrial Users due to Cable System Issues per Year (min- users/year)	Total Experienced Downtime due to Cable System Issues per Year (min- users/year)	Interruptions due to Cable System Issues per Year (faults/year)
F001	0	0	0.33	0.49	2.67	6.51	4013.325	8578.83333	26126.74575	22905.485	122.82	78604.8	1719.48	80324.28	2.67
F002	0	0	0.231	0.35	1.869	4.65	3998.6625	7594.604167	18593.78063	14194.31519	108.402	50081.724	5094.894	55176.618	1.869
F003	0	0	0.176	0.07	1.424	0.93	5020.25	8906.4375	4668.8325	12682.767	19.936	15171.296	199.36	15370.656	1.424
F004	0	0	0.253	0.56	2.047	7.44	4087.275	8148.166667	30409.326	16679.29717	69.598	13432.414	2714.322	16146.736	2.047
F005	0	0	0.451	0.49	3.649	6.51	5119.0625	9442.645833	33325.09688	34456.21465	204.344	98902.496	2860.816	101763.312	3.649
F006	0	0	0.517	0.49	4.183	6.51	4005.0375	8717.3125	26072.79413	36464.51819	96.209	89185.743	2309.016	91494.759	4.183
F007	0	0	0.253	0.21	2.047	2.79	4068.7875	8490.291667	11351.91713	17379.62704	98.256	10906.416	2259.888	13166.304	2.047
F008	0	0	0.088	0.63	0.712	8.37	4210.95	7197.583333	35245.6515	5124.679333	34.176	18694.272	1025.28	19719.552	0.712
F009	0	0	0.308	0.42	2.492	5.58	3882	7659.770833	21661.56	19088.14892	97.188	25366.068	2040.948	27407.016	2.492
F010	0	0	0.462	0.28	3.738	3.72	4107.0375	7341.375	15278.1795	27442.05975	134.568	36333.36	4575.312	40908.672	3.738
F011	0	0	0.33	0.21	2.67	2.79	3885.1875	6780.729167	10839.67313	18104.54688	128.16	46265.76	5382.72	51648.48	2.67
F012	0	0	0.374	0.14	3.026	1.86	4062.4125	8390.416667	7556.08725	25389.40083	169.456	119974.848	8133.888	128108.736	3.026
F013	0	0	0.176	0.63	1.424	8.37	4134.45	6856.166667	34605.3465	9763.181333	31.328	16196.576	1065.152	17261.728	1.424
F014	0	0	0.286	0.42	2.314	5.58	3905.5875	8568.5625	21793.17825	19827.65363	50.908	34515.624	2087.228	36602.852	2.314
F015	0	0	0.264	0.07	2.136	0.93	4165.6875	8116.645833	3874.089375	17337.1555	126.024	124133.64	1512.288	125645.928	2.136
F016	0	0	0.341	0.49	2.759	6.51	4103.2125	8142.5	26711.91338	22465.1575	110.36	79348.84	4635.12	83983.96	2.759
F017	0	0	0.33	0.07	2.67	0.93	4117.2375	7693.0625	3829.030875	20540.47688	106.8	59060.4	2029.2	61089.6	2.67
F018	0	0	0.187	0.56	1.513	7.44	3938.1	7702.979167	29299.464	11654.60748	60.52	17369.24	2057.68	19426.92	1.513
F019	0	0	0.11	0.07	0.89	0.93	4079.625	7464.625	3794.05125	6643.51625	10.68	5286.6	256.32	5542.92	0.89
F020	0	0	0.539	0.49	4.361	6.51	4017.7875	8860.041667	26155.79663	38638.64171	156.996	122927.868	4866.876	127794.744	4.361

F021	0	0	0.187	0.42	1.513	5.58	3999.9375	7835.4375	22319.65125	11855.01694	72.624	68121.312	3558.576	71679.888	1.513
F022	0	0	0.209	0.21	1.691	2.79	4015.875	8793.8125	11204.29125	14870.33694	23.674	15056.664	662.872	15719.536	1.691
F023	0	0	0.242	0.28	1.958	3.72	4031.175	6502	14995.971	12730.916	93.984	48495.744	1879.68	50375.424	1.958
F024	0	0	0.242	0.63	1.958	8.37	3978.2625	6880.25	33298.05713	13471.5295	93.984	47367.936	1879.68	49247.616	1.958
F025	0	0	0.418	0.21	3.382	2.79	3880.725	7445.854167	10827.22275	25181.87879	162.336	42207.36	4058.4	46265.76	3.382
F026	0	0	0.176	0.56	1.424	7.44	4155.4875	7913.354167	30916.827	11268.61633	27.056	3544.336	189.392	3733.728	1.424
F027	0	0	0.231	0.28	1.869	3.72	4205.2125	6876	15643.3905	12851.244	20.559	20353.41	164.472	20517.882	1.869
F028	0	0	0.429	0.49	3.471	6.51	4173.975	8178.625	27172.57725	28388.00738	97.188	13995.072	2818.452	16813.524	3.471
F029	0	0	0.539	0.56	4.361	7.44	3939.375	8226.791667	29308.95	35877.03846	122.108	27596.408	3052.7	30649.108	4.361
F030	0	0	0.44	0.63	3.56	8.37	4127.4375	7515.979167	34546.65188	26756.88583	99.68	58412.48	3488.8	61901.28	3.56
F031	0	0	0.099	0.21	0.801	2.79	3943.8375	7986.3125	11003.30663	6397.036313	18.423	17446.581	110.538	17557.119	0.801
F032	0	0	0.396	0.14	3.204	1.86	4121.0625	7239.020833	7665.17625	23193.82275	96.12	28932.12	1441.8	30373.92	3.204
F033	0	0	0.319	0.56	2.581	7.44	5027.9	9096.979167	37407.576	23479.30323	131.631	93589.641	1053.048	94642.689	2.581
F034	0	0	0.539	0.63	4.361	8.37	4205.2125	6794.895833	35197.62863	29632.54073	156.996	112409.136	3924.9	116334.036	4.361
F035	0	0	0.11	0.56	0.89	7.44	3880.0875	6676.958333	28867.851	5942.492917	37.38	34389.6	1308.3	35697.9	0.89
F036	0	0	0.495	0.56	4.005	7.44	3945.1125	7153.666667	29351.637	28650.435	124.155	85418.64	5711.13	91129.77	4.005
F037	0	0	0.176	0.07	1.424	0.93	4036.9125	8472.583333	3754.328625	12064.95867	55.536	28212.288	1332.864	29545.152	1.424
F038	0	0	0.253	0.56	2.047	7.44	4177.8	7577.25	31082.832	15510.63075	42.987	16764.93	1246.623	18011.553	2.047
F039	0	0	0.55	0.35	4.45	4.65	4073.25	7730.604167	18940.6125	34401.18854	222.5	58295	9790	68085	4.45
F040	0	0	0.33	0.35	2.67	4.65	4149.75	7629.666667	19296.3375	20371.21	133.5	124422	1468.5	125890.5	2.67
F041	0	0	0.143	0.56	1.157	7.44	4152.3	7248.229167	30893.112	8386.201146	57.85	40957.8	1099.15	42056.95	1.157
F042	0	0	0.11	0.14	0.89	1.86	4150.3875	7190.854167	7719.72075	6399.860208	47.17	12688.73	1132.08	13820.81	0.89
F043	0	0	0.55	0.28	4.45	3.72	3970.6125	8151.354167	14770.6785	36273.52604	182.45	109470	6568.2	116038.2	4.45
F044	0	0	0.44	0.14	3.56	1.86	4018.425	8174.020833	7474.2705	29099.51417	135.28	68451.68	2976.16	71427.84	3.56
F045	0	0	0.154	0.42	1.246	5.58	4021.6125	7481.979167	22440.59775	9322.546042	63.546	39779.796	1969.926	41749.722	1.246
F046	0	0	0.374	0.63	3.026	8.37	3991.0125	7618.6875	33404.77463	23054.14837	51.442	19496.518	2314.89	21811.408	3.026
F047	0	0	0.176	0.63	1.424	8.37	3970.6125	7580.4375	33234.02663	10794.543	19.936	7615.552	677.824	8293.376	1.424
F048	0	0	0.231	0.49	1.869	6.51	3981.45	8841.625	25919.2395	16524.99713	39.249	22136.436	784.98	22921.416	1.869

F049	0	0	0.418	0.42	3.382	5.58	4037.55	7480.916667	22529.529	25300.46017	158.954	87901.562	1907.448	89809.01	3.382
F050	0	0	0.253	0.07	2.047	0.93	3925.35	7438.416667	3650.5755	15226.43892	96.209	57629.191	3752.151	61381.342	2.047
F051	0	0	0.451	0.35	3.649	4.65	3978.9	7655.875	18501.885	27936.28787	215.291	157162.43	6674.021	163836.451	3.649
F052	0	0	0.319	0.28	2.581	3.72	3945.75	8243.4375	14678.19	21276.31219	72.268	13730.92	3396.596	17127.516	2.581
F053	0	0	0.121	0.28	0.979	3.72	3922.1625	8272.125	14590.4445	8098.410375	58.74	13510.2	2349.6	15859.8	0.979
F054	0	0	0.462	0.49	3.738	6.51	4133.175	7158.270833	26906.96925	26757.61638	56.07	54836.46	1682.1	56518.56	3.738
F055	0	0	0.275	0.56	2.225	7.44	3959.775	6829.25	29460.726	15195.08125	129.05	67880.3	4387.7	72268	2.225
F056	0	0	0.396	0.28	3.204	3.72	4013.9625	8227.5	14931.9405	26360.91	96.12	77280.48	2499.12	79779.6	3.204
F057	0	0	0.462	0.49	3.738	6.51	4139.55	7669.6875	26948.4705	28669.29188	250.446	60107.04	1753.122	61860.162	3.738
F058	0	0	0.506	0.28	4.094	3.72	3988.4625	8394.666667	14837.0805	34367.76533	241.546	180193.316	11352.662	191545.978	4.094
F059	0	0	0.187	0.07	1.513	0.93	3936.1875	6872.104167	3660.654375	10397.4936	43.877	33873.044	702.032	34575.076	1.513
F060	0	0	0.407	0.07	3.293	0.93	4165.6875	7514.5625	3874.089375	24745.45431	184.408	181273.064	922.04	182195.104	3.293
F061	0	0	0.209	0.35	1.691	4.65	4174.6125	8591.229167	19411.94813	14527.76852	37.202	26673.834	1674.09	28347.924	1.691
F062	0	0	0.209	0.56	1.691	7.44	4062.4125	6896.541667	30224.349	11662.05196	94.696	52177.496	3598.448	55775.944	1.691
F063	0	0	0.352	0.07	2.848	0.93	5219.15	9918.645833	4853.8095	28248.30333	159.488	20733.44	5263.104	25996.544	2.848
F064	0	0	0.231	0.56	1.869	7.44	3971.25	7983.833333	29546.1	14921.7845	59.808	44317.728	1794.24	46111.968	1.869
F065	0	0	0.22	0.07	1.78	0.93	4038.825	8102.479167	3756.10725	14422.41292	71.2	22712.8	925.6	23638.4	1.78
F066	0	0	0.33	0.49	2.67	6.51	4064.9625	6572.479167	26462.90588	17548.51938	138.84	14022.84	5970.12	19992.96	2.67
F067	0	0	0.539	0.63	4.361	8.37	3875.625	7553.166667	32438.98125	32939.35983	148.274	55306.202	5486.138	60792.34	4.361
F068	0	0	0.176	0.49	1.424	6.51	4148.475	8565.020833	27006.57225	12196.58967	31.328	27944.576	501.248	28445.824	1.424
F069	0	0	0.55	0.28	4.45	3.72	3964.2375	8121.958333	14746.9635	36142.71458	106.8	101673.6	4058.4	105732	4.45
F070	0	0	0.539	0.63	4.361	8.37	4100.025	8230.6875	34317.20925	35894.02819	239.855	72915.92	10073.91	82989.83	4.361
F071	0	0	0.165	0.28	1.335	3.72	4232.625	8389.708333	15745.365	11200.26063	77.43	32210.88	2864.91	35075.79	1.335
F072	0	0	0.473	0.07	3.827	0.93	4168.875	6384.0625	3877.05375	24431.80719	156.907	135881.462	6433.187	142314.649	3.827
F073	0	0	0.506	0.21	4.094	2.79	4020.975	7629.666667	11218.52025	31235.85533	151.478	17419.97	7422.422	24842.392	4.094
F074	0	0	0.407	0.35	3.293	4.65	3938.1	8869.604167	18312.165	29207.60652	118.548	31415.22	3556.44	34971.66	3.293
F075	0	0	0.22	0.28	1.78	3.72	4062.4125	8126.916667	15112.1745	14465.91167	64.08	44535.6	2563.2	47098.8	1.78
F076	0	0	0.187	0.63	1.513	8.37	4076.4375	7377.5	34119.78188	11162.1575	25.721	3806.708	1106.003	4912.711	1.513

F077	0	0	0.088	0.42	0.712	5.58	4168.875	8618.854167	23262.3225	6136.624167	24.92	15051.68	373.8	15425.48	0.712
F078	0	0	0.363	0.28	2.937	3.72	4094.2875	7775.583333	15230.7495	22836.88825	46.992	29745.936	610.896	30356.832	2.937
F079	0	0	0.484	0.42	3.916	5.58	4081.5375	7904.145833	22774.97925	30952.63508	184.052	68835.448	6073.716	74909.164	3.916
F080	0	0	0.462	0.42	3.738	5.58	4010.1375	7607.708333	22376.56725	28437.61375	175.686	169712.676	6676.068	176388.744	3.738
F081	0	0	0.297	0.56	2.403	7.44	4121.0625	7092.395833	30660.705	17043.02719	112.941	16828.209	1355.292	18183.501	2.403
F082	0	0	0.319	0.21	2.581	2.79	3983.3625	8477.541667	11113.58138	21880.53504	33.553	30097.041	167.765	30264.806	2.581
F083	0	0	0.308	0.14	2.492	1.86	3940.0125	7319.0625	7328.42325	18239.10375	99.68	78049.44	2492	80541.44	2.492
F084	0	0	0.429	0.35	3.471	4.65	4117.2375	7316.583333	19145.15438	25395.86075	194.376	105546.168	2915.64	108461.808	3.471
F085	0	0	0.374	0.56	3.026	7.44	4012.05	6978	29849.652	21115.428	169.456	102520.88	7117.152	109638.032	3.026
F086	0	0	0.11	0.14	0.89	1.86	3934.275	8228.208333	7317.7515	7323.105417	30.26	20183.42	1301.18	21484.6	0.89
F087	0	0	0.374	0.35	3.026	4.65	3960.4125	6863.25	18415.91813	20768.1945	99.858	65506.848	1997.16	67504.008	3.026
F088	0	0	0.539	0.28	4.361	3.72	4041.375	8601.145833	15033.915	37509.59698	78.498	60050.97	2825.928	62876.898	4.361
F089	0	0	0.506	0.42	4.094	5.58	4094.925	7710.770833	22849.6815	31567.89579	102.35	83722.3	4094	87816.3	4.094
F090	0	0	0.187	0.14	1.513	1.86	3970.6125	9119.645833	7385.33925	13798.02415	75.65	64378.15	1134.75	65512.9	1.513
F091	0	0	0.165	0.35	1.335	4.65	5198.75	8482.854167	24174.1875	11324.61031	77.43	41812.2	929.16	42741.36	1.335
F092	0	0	0.066	0.35	0.534	4.65	5129.2625	10548	23851.07063	5632.632	6.942	5629.962	138.84	5768.802	0.534
F093	0	0	0.264	0.35	2.136	4.65	3915.15	8107.083333	18205.4475	17316.73	53.4	25151.4	2136	27287.4	2.136
F094	0	0	0.275	0.07	2.225	0.93	3975.075	6568.229167	3696.81975	14614.3099	102.35	36641.3	3275.2	39916.5	2.225
F095	0	0	0.418	0.07	3.382	0.93	4056.0375	8440.354167	3772.114875	28545.27779	189.392	159468.064	8143.856	167611.92	3.382
F096	0	0	0.154	0.63	1.246	8.37	4017.7875	8967.708333	33628.88138	11173.76458	57.316	24187.352	1662.164	25849.516	1.246
F097	0	0	0.363	0.07	2.937	0.93	4142.7375	6962.770833	3852.745875	20449.65794	170.346	134232.648	7495.224	141727.872	2.937
F098	0	0	0.264	0.28	2.136	3.72	3932.3625	7001.020833	14628.3885	14954.1805	44.856	37544.472	762.552	38307.024	2.136
F099	0	0	0.253	0.42	2.047	5.58	4084.725	7286.125	22792.7655	14914.69787	106.444	95693.156	4789.98	100483.136	2.047
F100	0	0	0.231	0.21	1.869	2.79	4009.5	8551.208333	11186.505	15982.20838	85.974	35937.132	687.792	36624.924	1.869

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Annex IV: Results For the Full Deployment Scenario

Name	SCG Installed (YES = 1 or NO = 0)	SCG Systems Needed	Annual Faults not related to Cable System (faults/year)	Annual Weak-Spot Rest. not related to Cable System (rest./year)	New Annual Faults related to Cable System (faults/year)	New Annual Weak-Spot Rest. related to Cable System (rest./year)	Weak-spot Restoration Cost (€/rest.)	Fault Rest. Cost (€/rest.)	Annual Cable- System Weak-spot Rest. Cost (€/year)	Annual Cable-System Fault Rest. Cost (€/year)	Downtime due to Cable System Issues per Year (min/year)	Experienced Downtime for Residential Users due to Cable System Issues per Year (min- users/year)	Experienced Downtime for Industrial Users due to Cable System Issues per Year (min- users/year)	Total Experienced Downtime due to Cable System Issues per Year (min- users/year)	Interruptions due to Cable System Issues per Year (faults/year)
F001	1	2	0.33	0.49	0.2136	8.9664	3513.325	7678.83333	31501.87728	1640.1988	9.8256	6288.384	137.5584	6425.9424	0.2136
F002	1	2	0.231	0.35	0.14952	6.36948	3498.6625	6694.604167	22284.66082	1000.977215	8.67216	4006.53792	407.59152	4414.12944	0.14952
F003	1	2	0.176	0.07	0.11392	2.24008	4420.25	7706.4375	9901.71362	877.91736	1.59488	1213.70368	15.9488	1229.65248	0.11392
F004	1	2	0.253	0.56	0.16376	9.32324	3587.275	7248.166667	33445.02577	1186.959773	5.56784	1074.59312	217.14576	1291.73888	0.16376
F005	1	2	0.451	0.49	0.29192	9.86708	4519.0625	8242.645833	44589.95121	2406.193172	16.34752	7912.19968	228.86528	8141.06496	0.29192
F006	1	4	0.517	0.49	0.33464	10.35836	3505.0375	7817.3125	36306.44024	2615.985455	7.69672	7134.85944	184.72128	7319.58072	0.33464
F007	1	2	0.253	0.21	0.16376	4.67324	3568.7875	7590.291667	16677.8005	1242.986163	7.86048	872.51328	180.79104	1053.30432	0.16376
F008	1	2	0.088	0.63	0.05696	9.02504	3710.95	6297.583333	33491.47219	358.7103467	2.73408	1495.54176	82.0224	1577.56416	0.05696
F009	1	4	0.308	0.42	0.19936	7.87264	3382	6759.770833	26625.26848	1347.627913	7.77504	2029.28544	163.27584	2192.56128	0.19936
F010	1	4	0.462	0.28	0.29904	7.15896	3607.0375	6441.375	25822.63718	1926.22878	10.76544	2906.6688	366.02496	3272.69376	0.29904
F011	1	4	0.33	0.21	0.2136	5.2464	3385.1875	5880.729167	17760.0477	1256.12375	10.2528	3701.2608	430.6176	4131.8784	0.2136
F012	1	2	0.374	0.14	0.24208	4.64392	3562.4125	7490.416667	16543.55866	1813.280067	13.55648	9597.98784	650.71104	10248.69888	0.24208
F013	1	3	0.176	0.63	0.11392	9.68008	3634.45	5956.166667	35181.76676	678.5265067	2.50624	1295.72608	85.21216	1380.93824	0.11392
F014	1	2	0.286	0.42	0.18512	7.70888	3405.5875	7668.5625	26253.26537	1419.60429	4.07264	2761.24992	166.97824	2928.22816	0.18512
F015	1	1	0.264	0.07	0.17088	2.89512	3665.6875	7216.645833	10612.6052	1233.18044	10.08192	9930.6912	120.98304	10051.67424	0.17088
F016	1	4	0.341	0.49	0.22072	9.04828	3603.2125	7242.5	32602.8756	1598.5646	8.8288	6347.9072	370.8096	6718.7168	0.22072
F017	1	4	0.33	0.07	0.2136	3.3864	3617.2375	6793.0625	12249.41307	1450.99815	8.544	4724.832	162.336	4887.168	0.2136
F018	1	4	0.187	0.56	0.12104	8.83196	3438.1	6802.979167	30365.16168	823.4325983	4.8416	1389.5392	164.6144	1554.1536	0.12104
F019	1	3	0.11	0.07	0.0712	1.7488	3579.625	6564.625	6260.0482	467.4013	0.8544	422.928	20.5056	443.4336	0.0712
F020	1	3	0.539	0.49	0.34888	10.52212	3517.7875	7960.041667	37014.58221	2777.099337	12.55968	9834.22944	389.35008	10223.57952	0.34888

F021	1	2	0.187	0.42	0.12104	6.97196	3499.9375	6935.4375	24401.42425	839.465355	5.80992	5449.70496	284.68608	5734.39104	0.12104
F022	1	2	0.209	0.21	0.13528	4.34572	3515.875	7893.8125	15279.00831	1067.874955	1.89392	1204.53312	53.02976	1257.56288	0.13528
F023	1	2	0.242	0.28	0.15664	5.52136	3531.175	5602	19496.8884	877.49728	7.51872	3879.65952	150.3744	4030.03392	0.15664
F024	1	3	0.242	0.63	0.15664	10.17136	3478.2625	5980.25	35378.66006	936.74636	7.51872	3789.43488	150.3744	3939.80928	0.15664
F025	1	2	0.418	0.21	0.27056	5.90144	3380.725	6545.854167	19951.14574	1771.046303	12.98688	3376.5888	324.672	3701.2608	0.27056
F026	1	3	0.176	0.56	0.11392	8.75008	3655.4875	7013.354167	31985.80806	798.9613067	2.16448	283.54688	15.15136	298.69824	0.11392
F027	1	3	0.231	0.28	0.14952	5.43948	3705.2125	5976	20154.42929	893.53152	1.64472	1628.2728	13.15776	1641.43056	0.14952
F028	1	3	0.429	0.49	0.27768	9.70332	3673.975	7278.625	35649.7551	2021.12859	7.77504	1119.60576	225.47616	1345.08192	0.27768
F029	1	2	0.539	0.56	0.34888	11.45212	3439.375	7326.791667	39388.13523	2556.171077	9.76864	2207.71264	244.216	2451.92864	0.34888
F030	1	4	0.44	0.63	0.2848	11.6452	3627.4375	6615.979167	42242.23518	1884.230867	7.9744	4672.9984	279.104	4952.1024	0.2848
F031	1	3	0.099	0.21	0.06408	3.52692	3443.8375	7086.3125	12146.13936	454.090905	1.47384	1395.72648	8.84304	1404.56952	0.06408
F032	1	4	0.396	0.14	0.25632	4.80768	3621.0625	6339.020833	17408.90976	1624.81782	7.6896	2314.5696	115.344	2429.9136	0.25632
F033	1	2	0.319	0.56	0.20648	9.81452	4427.9	7896.979167	43457.71311	1630.568258	10.53048	7487.17128	84.24384	7571.41512	0.20648
F034	1	2	0.539	0.63	0.34888	12.38212	3705.2125	5894.895833	45878.3858	2056.611258	12.55968	8992.73088	313.992	9306.72288	0.34888
F035	1	3	0.11	0.56	0.0712	8.2588	3380.0875	5776.958333	27915.46665	411.3194333	2.9904	2751.168	104.664	2855.832	0.0712
F036	1	4	0.495	0.56	0.3204	11.1246	3445.1125	6253.666667	38325.49852	2003.6748	9.9324	6833.4912	456.8904	7290.3816	0.3204
F037	1	3	0.176	0.07	0.11392	2.24008	3536.9125	7572.583333	7922.966953	862.6686933	4.44288	2256.98304	106.62912	2363.61216	0.11392
F038	1	2	0.253	0.56	0.16376	9.32324	3677.8	6677.25	34289.01207	1093.46646	3.43896	1341.1944	99.72984	1440.92424	0.16376
F039	1	4	0.55	0.35	0.356	8.744	3573.25	6830.604167	31244.498	2431.695083	17.8	4663.6	783.2	5446.8	0.356
F040	1	3	0.33	0.35	0.2136	7.1064	3649.75	6729.666667	25936.5834	1437.4568	10.68	9953.76	117.48	10071.24	0.2136
F041	1	2	0.143	0.56	0.09256	8.50444	3652.3	6348.229167	31060.76621	587.5920917	4.628	3276.624	87.932	3364.556	0.09256
F042	1	4	0.11	0.14	0.0712	2.6788	3650.3875	6290.854167	9778.658035	447.9088167	3.7736	1015.0984	90.5664	1105.6648	0.0712
F043	1	3	0.55	0.28	0.356	7.814	3470.6125	7251.354167	27119.36608	2581.482083	14.596	8757.6	525.456	9283.056	0.356
F044	1	2	0.44	0.14	0.2848	5.1352	3518.425	7274.020833	18067.81606	2071.641133	10.8224	5476.1344	238.0928	5714.2272	0.2848
F045	1	3	0.154	0.42	0.09968	6.72632	3521.6125	6581.979167	23687.49259	656.0916833	5.08368	3182.38368	157.59408	3339.97776	0.09968
F046	1	2	0.374	0.63	0.24208	11.15392	3491.0125	6718.6875	38938.47414	1626.45987	4.11536	1559.72144	185.1912	1744.91264	0.24208
F047	1	3	0.176	0.63	0.11392	9.68008	3470.6125	6680.4375	33595.80665	761.03544	1.59488	609.24416	54.22592	663.47008	0.11392
F048	1	3	0.231	0.49	0.14952	8.22948	3481.45	7941.625	28650.52315	1187.43177	3.13992	1770.91488	62.7984	1833.71328	0.14952

F049	1	3	0.418	0.42	0.27056	8.69144	3537.55	6580.916667	30746.40357	1780.532813	12.71632	7032.12496	152.59584	7184.7208	0.27056
F050	1	4	0.253	0.07	0.16376	2.81324	3425.35	6538.416667	9636.331634	1070.731113	7.69672	4610.33528	300.17208	4910.50736	0.16376
F051	1	3	0.451	0.35	0.29192	8.00708	3478.9	6755.875	27855.83061	1972.17503	17.22328	12572.9944	533.92168	13106.91608	0.29192
F052	1	3	0.319	0.28	0.20648	6.09452	3445.75	7343.4375	21000.19229	1516.272975	5.78144	1098.4736	271.72768	1370.20128	0.20648
F053	1	3	0.121	0.28	0.07832	4.62068	3422.1625	7372.125	15812.71782	577.38483	4.6992	1080.816	187.968	1268.784	0.07832
F054	1	2	0.462	0.49	0.29904	9.94896	3633.175	6258.270833	36146.31275	1871.47331	4.4856	4386.9168	134.568	4521.4848	0.29904
F055	1	3	0.275	0.56	0.178	9.487	3459.775	5929.25	32822.88543	1055.4065	10.324	5430.424	351.016	5781.44	0.178
F056	1	2	0.396	0.28	0.25632	6.66768	3513.9625	7327.5	23429.97748	1878.1848	7.6896	6182.4384	199.9296	6382.368	0.25632
F057	1	3	0.462	0.49	0.29904	9.94896	3639.55	6769.6875	36209.73737	2024.40735	20.03568	4808.5632	140.24976	4948.81296	0.29904
F058	1	2	0.506	0.28	0.32752	7.48648	3488.4625	7494.666667	26116.30474	2454.653227	19.32368	14415.46528	908.21296	15323.67824	0.32752
F059	1	4	0.187	0.07	0.12104	2.32196	3436.1875	5972.104167	7978.689928	722.8634883	3.51016	2709.84352	56.16256	2766.00608	0.12104
F060	1	2	0.407	0.07	0.26344	3.95956	3665.6875	6614.5625	14514.5096	1742.540345	14.75264	14501.84512	73.7632	14575.60832	0.26344
F061	1	3	0.209	0.35	0.13528	6.20572	3674.6125	7691.229167	22803.61628	1040.469482	2.97616	2133.90672	133.9272	2267.83392	0.13528
F062	1	4	0.209	0.56	0.13528	8.99572	3562.4125	5996.541667	32046.46537	811.2121567	7.57568	4174.19968	287.87584	4462.07552	0.13528
F063	1	2	0.352	0.07	0.22784	3.55016	4619.15	8718.645833	16398.72156	1986.456267	12.75904	1658.6752	421.04832	2079.72352	0.22784
F064	1	4	0.231	0.56	0.14952	9.15948	3471.25	7083.833333	31794.84495	1059.17476	4.78464	3545.41824	143.5392	3688.95744	0.14952
F065	1	3	0.22	0.07	0.1424	2.5676	3538.825	7202.479167	9086.28707	1025.633033	5.696	1817.024	74.048	1891.072	0.1424
F066	1	2	0.33	0.49	0.2136	8.9664	3564.9625	5672.479167	31964.87976	1211.64155	11.1072	1121.8272	477.6096	1599.4368	0.2136
F067	1	2	0.539	0.63	0.34888	12.38212	3375.625	6653.166667	41797.39383	2321.156787	11.86192	4424.49616	438.89104	4863.3872	0.34888
F068	1	2	0.176	0.49	0.11392	7.82008	3648.475	7665.020833	28531.36638	873.1991733	2.50624	2235.56608	40.09984	2275.66592	0.11392
F069	1	3	0.55	0.28	0.356	7.814	3464.2375	7221.958333	27069.55183	2571.017167	8.544	8133.888	324.672	8458.56	0.356
F070	1	2	0.539	0.63	0.34888	12.38212	3600.025	7330.6875	44575.94155	2557.530255	19.1884	5833.2736	805.9128	6639.1864	0.34888
F071	1	2	0.165	0.28	0.1068	4.9482	3732.625	7489.708333	18469.77503	799.90085	6.1944	2576.8704	229.1928	2806.0632	0.1068
F072	1	2	0.473	0.07	0.30616	4.45084	3668.875	5484.0625	16329.57561	1679.000575	12.55256	10870.51696	514.65496	11385.17192	0.30616
F073	1	3	0.506	0.21	0.32752	6.55648	3520.975	6729.666667	23085.20217	2204.100427	12.11824	1393.5976	593.79376	1987.39136	0.32752
F074	1	4	0.407	0.35	0.26344	7.67956	3438.1	7969.604167	26403.09524	2099.512522	9.48384	2513.2176	284.5152	2797.7328	0.26344
F075	1	2	0.22	0.28	0.1424	5.3576	3562.4125	7226.916667	19085.98121	1029.112933	5.1264	3562.848	205.056	3767.904	0.1424
F076	1	2	0.187	0.63	0.12104	9.76196	3576.4375	6477.5	34913.03982	784.0366	2.05768	304.53664	88.48024	393.01688	0.12104

F077	1	3	0.088	0.42	0.05696	6.23504	3668.875	7718.854167	22875.58238	439.6659333	1.9936	1204.1344	29.904	1234.0384	0.05696
F078	1	4	0.363	0.28	0.23496	6.42204	3594.2875	6875.583333	23082.6581	1615.48706	3.75936	2379.67488	48.87168	2428.54656	0.23496
F079	1	3	0.484	0.42	0.31328	9.18272	3581.5375	7004.145833	32888.25603	2194.258807	14.72416	5506.83584	485.89728	5092.73312	0.31328
F080	1	3	0.462	0.42	0.29904	9.01896	3510.1375	6707.708333	31657.78971	2005.8731	14.05488	13577.01408	534.08544	14111.09952	0.29904
F081	1	3	0.297	0.56	0.19224	9.65076	3621.0625	6192.395833	34946.00513	1190.426175	9.03528	1346.25672	108.42336	1454.68008	0.19224
F082	1	4	0.319	0.21	0.20648	5.16452	3483.3625	7577.541667	17989.8953	1564.610803	2.68424	2407.76328	13.4212	2421.18448	0.20648
F083	1	4	0.308	0.14	0.19936	4.15264	3440.0125	6419.0625	14285.13351	1279.7043	7.9744	6243.9552	199.36	6443.3152	0.19936
F084	1	2	0.429	0.35	0.27768	7.84332	3617.2375	6416.583333	28371.15123	1781.75686	15.55008	8443.69344	233.2512	8676.94464	0.27768
F085	1	4	0.374	0.56	0.24208	10.22392	3512.05	6078	35906.91824	1471.36224	13.55648	8201.6704	569.37216	8771.04256	0.24208
F086	1	3	0.11	0.14	0.0712	2.6788	3434.275	7328.208333	9199.73587	521.7684333	2.4208	1614.6736	104.0944	1718.768	0.0712
F087	1	4	0.374	0.35	0.24208	7.43392	3460.4125	5963.25	25724.42969	1443.58356	7.98864	5240.54784	159.7728	5400.32064	0.24208
F088	1	3	0.539	0.28	0.34888	7.73212	3541.375	7701.145833	27382.33647	2686.775758	6.27984	4804.0776	226.07424	5030.15184	0.34888
F089	1	4	0.506	0.42	0.32752	9.34648	3594.925	6810.770833	33599.89461	2230.663663	8.188	6697.784	327.52	7025.304	0.32752
F090	1	2	0.187	0.14	0.12104	3.25196	3470.6125	8219.645833	11286.29303	994.9059317	6.052	5150.252	90.78	5241.032	0.12104
F091	1	1	0.165	0.35	0.1068	5.8782	4598.75	7282.854167	27032.37225	777.808825	6.1944	3344.976	74.3328	3419.3088	0.1068
F092	1	1	0.066	0.35	0.04272	5.14128	4529.2625	9348	23286.20671	399.34656	0.55536	450.39696	11.1072	461.50416	0.04272
F093	1	3	0.264	0.35	0.17088	6.61512	3415.15	7207.083333	22591.62707	1231.5464	4.272	2012.112	170.88	2182.992	0.17088
F094	1	3	0.275	0.07	0.178	2.977	3475.075	5668.229167	10345.29828	1008.944792	8.188	2931.304	262.016	3193.32	0.178
F095	1	4	0.418	0.07	0.27056	4.04144	3556.0375	7540.354167	14371.51219	2040.118223	15.15136	12757.44512	651.50848	13408.9536	0.27056
F096	1	2	0.154	0.63	0.09968	9.51632	3517.7875	8067.708333	33476.39154	804.1891667	4.58528	1934.98816	132.97312	2067.96128	0.09968
F097	1	3	0.363	0.07	0.23496	3.63204	3642.7375	6062.770833	13230.56831	1424.508635	13.62768	10738.61184	599.61792	11338.22976	0.23496
F098	1	2	0.264	0.28	0.17088	5.68512	3432.3625	6101.020833	19513.3927	1042.54244	3.58848	3003.55776	61.00416	3064.56192	0.17088
F099	1	3	0.253	0.42	0.16376	7.46324	3584.725	6386.125	26753.66301	1045.79183	8.51552	7655.45248	383.1984	8038.65088	0.16376
F100	1	3	0.231	0.21	0.14952	4.50948	3509.5	7651.208333	15826.02006	1144.00867	6.87792	2874.97056	55.02336	2929.99392	0.14952

Feeder Name	Experienced Interruptions for Residential Users due to Cable System Issues per Year (int-users/year)	Experienced Interruptions for Industrial Users due to Cable System Issues per Year (int-users/year)	Total Experienced Interruptions due to Cable System Issues per Year (int-users/year)	Contribution to SAIDI Reduction (min/year)	Contribution to SAIFI Reduction (int/year)	Contribution to SAIDI Reduction Compensation (€ /year)	Contribution to SAIFI Reduction Compensation (€ /year)	Downtime Reduction Experienced By Residential Users (min-users/year)	Downtime Reduction Experienced By Industrial Users (min-users/year)	Contribution to Downtime Compensation Reduction to Pay to Residential Users (€ /year)	Contribution to Downtime Compensation Reduction to Pay to Industrial Users (€ /year)	Energy Not Supplied Reduction (MWh/year)	Contribution to Energy Not Supplied Cost Reduction (€ /year)	Contribution to Annual Cable-System Weak-spot Restoration Cost Reduction (€ /year)	Contribution to Annual Cable-System Fault Restoration Cost Reduction (€ /year)	New Income (€ /year)
F001	136.704	2.9904	139.6944	1.240550246	0.026968484	0	0	72316.416	1581.9216	361.58208	0	2.354426648	0	-5375.13153	21265.2862	16251.73675
F002	69.07824	7.02744	76.10568	0.852162846	0.014692463	0	0	46075.18608	4687.30248	230.3759304	0	2.316059318	0	-3690.880196	13193.33797	9732.833707
F003	86.69312	1.1392	87.83232	0.237388634	0.016956331	0	0	13957.59232	183.4112	69.7879616	0	0.599754624	0	-5232.88112	11804.84964	6641.756482
F004	31.60568	6.38664	37.99232	0.249374626	0.007334548	0	0	12357.82088	2497.17624	61.7891044	0	1.216466323	0	-3035.699771	15492.33739	12518.42673
F005	141.28928	4.08688	145.37616	1.571660546	0.028065367	0	0	90990.29632	2631.95072	454.9514816	0	7.307736505	0	-11264.85434	32050.02147	21240.11862
F006	310.21128	8.03136	318.24264	1.413070192	0.061437834	0	0	82050.88356	2124.29472	410.2544178	0	1.144168739	0	-10233.64611	33848.53273	24025.14104
F007	18.17736	3.76648	21.94384	0.203344016	0.004236334	0	0	10033.90272	2079.09696	50.1695136	0	2.835406144	0	-5325.883371	16136.64088	10860.92702
F008	31.15712	1.7088	32.86592	0.304554178	0.006344879	0	0	17198.73024	943.2576	85.9936512	0	1.27455063	0	1754.179312	4765.968987	6606.14195
F009	52.03296	4.18656	56.21952	0.423281484	0.010853371	0	0	23336.78256	1877.67216	116.6839128	0	2.618011469	0	-4963.70848	17740.521	12893.49644
F010	80.7408	10.16736	90.90816	0.631804768	0.017550132	0	0	33426.6912	4209.28704	167.133456	0	1.290641688	0	-10544.45768	25515.83097	15138.50675
F011	77.1096	8.9712	86.0808	0.797673313	0.016618194	0	0	42564.4992	4952.1024	212.822496	0	2.202506496	0	-6920.374575	16848.42313	10140.87105
F012	171.39264	11.61984	183.01248	1.978546511	0.035331188	0	0	110376.8602	7483.17696	551.8843008	0	4.598776007	0	-8987.471407	23576.12077	15140.53366
F013	58.89664	3.87328	62.76992	0.266594869	0.0121117949	0	0	14900.84992	979.93984	74.5042496	0	0.386884092	0	-576.420256	9084.654827	8582.73882
F014	125.51136	7.58992	133.10128	0.565304501	0.025695659	0	0	31754.37408	1920.24976	158.7718704	0	1.664606753	0	-4460.087117	18408.04934	14106.73409
F015	168.3168	2.05056	170.36736	1.940510228	0.032890004	0	0	114202.9488	1391.30496	571.014744	0	1.803672291	0	-6738.51582	16103.97506	9936.473984
F016	158.69768	9.27024	167.96792	1.297071349	0.032426784	0	0	73000.9328	4264.3104	365.004664	0	1.703355099	0	-5890.962225	20866.5929	15340.63534
F017	118.1208	4.0584	122.1792	0.943484564	0.023587114	0	0	54335.568	1866.864	271.67784	0	2.9345792	0	-8420.382195	19089.47873	10940.77437
F018	34.73848	4.11536	38.85384	0.300034689	0.007500867	0	0	15979.7008	1893.0656	79.898504	0	1.837294403	0	-1065.697676	10831.17488	9845.375709
F019	35.244	1.7088	36.9528	0.085606379	0.007133865	0	0	4863.672	235.8144	24.31836	0	0.108228984	0	-2465.99695	6176.11495	3734.43636
F020	273.17304	10.81528	283.98832	1.973697132	0.05482492	0	0	113093.6386	4477.52592	565.4681928	0	4.80082255	0	-10858.78558	35861.54237	25568.22498
F021	113.53552	5.93096	119.46648	1.107043881	0.023063414	0	0	62671.60704	3273.88992	313.3580352	0	1.776697744	0	-2081.773003	11015.55158	9247.136615

F022	86.03808	3.78784	89.82592	0.242776832	0.017341202	0	0	13852.13088	609.84224	69.2606544	0	0.443950631	0	-4074.717055	13802.46198	9797.005582
F023	80.82624	3.1328	83.95904	0.778011887	0.016208581	0	0	44616.08448	1729.3056	223.0804224	0	2.435006394	0	-4500.917398	11853.41872	7575.581744
F024	78.94656	3.1328	82.07936	0.76059371	0.015845702	0	0	43578.50112	1729.3056	217.8925056	0	1.885231322	0	-2080.602937	12534.78314	10672.07271
F025	70.3456	6.764	77.1096	0.714541107	0.014886273	0	0	38830.7712	3733.728	194.153856	0	5.375821574	0	-9123.922994	23410.83249	14481.06335
F026	14.92352	0.79744	15.72096	0.057664721	0.003034985	0	0	3260.78912	174.24064	16.3039456	0	0.514632176	0	-1068.981064	10469.65503	9416.977908
F027	148.0248	1.19616	149.22096	0.316883806	0.028807619	0	0	18725.1372	151.31424	93.625686	0	0.213920507	0	-4511.03879	11957.71248	7540.299376
F028	39.98592	8.05272	48.03864	0.259672683	0.009274024	0	0	12875.46624	2592.97584	64.3773312	0	2.943325622	0	-8477.177847	26366.87879	17954.07827
F029	78.84688	8.722	87.56888	0.473353243	0.016905473	0	0	25388.69536	2808.484	126.9434768	0	1.8313188	0	-10079.18523	33320.86738	23368.62563
F030	166.8928	9.968	176.8608	0.956020373	0.034143585	0	0	53739.4816	3209.696	268.697408	0	1.974727253	0	-7695.5833	24872.65497	17445.76907
F031	60.68376	0.38448	61.06824	0.271156969	0.011789433	0	0	16050.85452	101.69496	80.2542726	0	0.345932356	0	-1142.832731	5942.945408	4880.36695
F032	77.15232	3.8448	80.99712	0.469103164	0.015636772	0	0	26617.5504	1326.456	133.087752	0	3.2940324	0	-9743.73351	21569.00493	11958.35917
F033	146.80728	1.65184	148.45912	1.461687688	0.028660543	0	0	86102.46972	968.80416	430.5123486	0	3.102998991	0	-6050.137108	21848.73497	16229.11021
F034	249.79808	8.722	258.52008	1.79669481	0.049908189	0	0	103416.4051	3610.908	517.0820256	0	1.400310122	0	-10680.75718	27575.92947	17412.25432
F035	65.504	2.492	67.996	0.551328174	0.013126861	0	0	31638.432	1203.636	158.19216	0	0.312142936	0	952.384355	5531.173483	6641.749998
F036	220.4352	14.7384	235.1736	1.407433202	0.045401071	0	0	78585.1488	5254.2396	392.925744	0	1.713148629	0	-8973.861518	26646.7602	18065.82443
F037	57.87136	2.73408	60.60544	0.456303444	0.011700088	0	0	25955.30496	1226.23488	129.7765248	0	1.456664851	0	-4168.638328	11202.28997	7163.42817
F038	63.8664	4.74904	68.61544	0.278175372	0.013246446	0	0	15423.7356	1146.89316	77.118678	0	1.222561743	0	-3206.180072	14417.16429	11288.1029
F039	93.272	15.664	108.936	1.051523443	0.021030469	0	0	53631.4	9006.8	268.157	0	2.954503333	0	-12303.8855	31969.49346	19933.76496
F040	199.0752	2.3496	201.4248	1.944287465	0.038885749	0	0	114468.24	1351.02	572.3412	0	3.5894145	0	-6640.2459	18933.7532	12865.8485
F041	65.53248	1.75864	67.29112	0.649539089	0.012990782	0	0	37681.176	1011.218	188.40588	0	0.700490223	0	-167.654212	7798.609054	7819.360722
F042	19.1528	1.7088	20.8616	0.213452386	0.004027404	0	0	11673.6316	1041.5136	58.368158	0	0.576376519	0	-2058.937285	5951.951392	3951.382265
F043	213.6	12.816	226.416	1.792125837	0.043710386	0	0	100712.4	6042.744	503.562	0	6.781861113	0	-12348.68758	33692.04396	21846.91838
F044	144.1088	6.2656	150.3744	1.103151183	0.029030294	0	0	62975.5456	2738.0672	314.877728	0	4.331954197	0	-10593.54556	27027.87303	16749.2052
F045	62.39968	3.09008	65.48976	0.644794175	0.012643023	0	0	36597.41232	1812.33192	182.9870616	0	2.328943954	0	-1246.894841	8666.454358	7602.546579
F046	91.74832	10.8936	102.64192	0.336861377	0.019815375	0	0	17936.79656	2129.6988	89.6839828	0	1.218897613	0	-5533.699519	21427.68851	15983.67297
F047	43.51744	3.87328	47.39072	0.128085177	0.009148941	0	0	7006.30784	623.59808	35.0315392	0	0.186192937	0	-361.780024	10033.50756	9706.759075
F048	84.32928	2.9904	87.31968	0.354004645	0.016857364	0	0	20365.52112	722.1816	101.8276056	0	1.469699738	0	-2731.283646	15337.56536	12708.10931
F049	149.61968	3.24672	152.8664	1.387035022	0.029511383	0	0	80869.43704	1754.85216	404.3471852	0	4.945027149	0	-8216.874572	23519.92735	15707.39997

F050	98.09224	6.38664	104.47888	0.947990308	0.020170007	0	0	53018.85572	3451.97892	265.0942786	0	3.551260194	0	-5985.756134	14155.7078	8435.045948
F051	213.1016	9.04952	222.15112	2.530335156	0.042887037	0	0	144589.4356	6140.09932	722.947178	0	2.318712775	0	-9353.945612	25964.11285	17333.11441
F052	39.2312	9.70456	48.93576	0.264522062	0.009447217	0	0	12632.4464	3124.86832	63.162232	0	2.732265183	0	-6322.00229	19760.03921	13501.19915
F053	18.0136	3.1328	21.1464	0.244943108	0.004082385	0	0	12429.384	2161.632	62.14692	0	1.903947452	0	-1222.273321	7521.025545	6360.899145
F054	292.46112	8.9712	301.43232	0.872888167	0.058192544	0	0	50449.5432	1547.532	252.247716	0	1.98986823	0	-9239.343498	24886.14307	15899.04728
F055	93.628	6.052	99.68	1.116126844	0.019243566	0	0	62449.876	4036.684	312.24938	0	2.52589565	0	-3362.159425	14139.67475	11089.76471
F056	206.08128	6.66432	212.7456	1.232138058	0.041071269	0	0	71098.0416	2299.1904	355.490208	0	2.921003496	0	-8498.036982	24482.7252	16340.17843
F057	71.7696	2.09328	73.86288	0.955385335	0.014259483	0	0	55298.4768	1612.87224	276.492384	0	8.605441435	0	-9261.266868	26644.88453	17660.11004
F058	244.32992	15.39344	259.72336	2.958288703	0.050140486	0	0	165777.8507	10444.44904	828.8892536	0	6.322595375	0	-11279.22424	31913.11211	21462.77712
F059	93.44288	1.93664	95.37952	0.533986972	0.018413344	0	0	31163.20048	645.86944	155.8160024	0	1.637884533	0	-4318.035552	9674.630116	5512.410566
F060	258.96152	1.3172	260.27872	2.813871236	0.050247701	0	0	166771.2189	848.2768	833.8560944	0	3.289334671	0	-10640.42022	23002.91397	13196.34984
F061	96.99576	6.0876	103.08336	0.437813126	0.019900597	0	0	24539.92728	1540.1628	122.6996364	0	1.09243177	0	-3391.668159	13487.29904	10218.33052
F062	74.53928	5.14064	79.67992	0.861419001	0.015382482	0	0	48003.29632	3310.57216	240.0164816	0	1.92216466	0	-1822.116374	10850.8398	9268.739909
F063	29.6192	7.51872	37.13792	0.401497767	0.007169603	0	0	19074.7648	4842.05568	95.373824	0	4.619272209	0	-11544.91206	26261.84707	14812.30883
F064	110.79432	4.4856	115.27992	0.712165901	0.022255184	0	0	40772.30976	1650.7008	203.8615488	0	0.551976006	0	-2248.74495	13862.60974	11817.72634
F065	45.4256	1.8512	47.2768	0.365077943	0.009126949	0	0	20895.776	851.552	104.47888	0	1.742515573	0	-5330.17982	13396.77988	8171.078943
F066	21.5736	9.1848	30.7584	0.308776766	0.005938015	0	0	12901.0128	5492.5104	64.505064	0	3.347876688	0	-5501.973885	16336.87783	10899.409
F067	130.13224	12.90856	143.0408	0.938893599	0.027614518	0	0	50881.70584	5047.24696	254.4085292	0	5.591303806	0	-9358.412575	30618.20305	21514.199
F068	101.61664	1.82272	103.43936	0.43932512	0.019969324	0	0	25709.00992	461.14816	128.5450496	0	0.772423168	0	-1524.794128	11323.39049	9927.141415
F069	338.912	13.528	352.44	1.632954053	0.068039752	0	0	93539.712	3733.728	467.69856	0	2.0355368	0	-12322.58833	33571.69742	21716.80765
F070	106.05952	14.65296	120.71248	1.281717732	0.023303959	0	0	67082.6464	9267.9972	335.413232	0	9.080798368	0	-10258.7323	33336.49793	23413.17886
F071	44.4288	3.9516	48.3804	0.541720136	0.009340002	0	0	29634.0096	2635.7172	148.170048	0	0.877622592	0	-2724.410025	10400.35978	7824.119798
F072	265.13456	12.55256	277.68712	2.197946534	0.053608452	0	0	125010.945	5918.53204	625.0547252	0	1.570576307	0	-12452.52186	22752.80661	10925.33948
F073	37.6648	16.04848	53.71328	0.383672726	0.010369533	0	0	16026.3724	6828.62824	80.131862	0	3.105632252	0	-11866.68192	29031.75491	17245.20485
F074	69.8116	7.9032	77.7148	0.540111924	0.015003109	0	0	28902.0024	3271.9248	144.510012	0	1.191525948	0	-8090.930236	27108.094	19161.67378
F075	98.968	5.696	104.664	0.727406806	0.020205745	0	0	40972.752	2358.144	204.86376	0	2.38074288	0	-3973.80671	13436.79873	9667.855783
F076	17.91392	5.20472	23.11864	0.075873258	0.004463133	0	0	3502.17136	1017.52276	17.5108568	0	0.318626604	0	-793.2579425	10378.1209	9602.373814
F077	34.40384	0.8544	35.25824	0.238235351	0.006806724	0	0	13847.5456	343.896	69.237728	0	0.437626765	0	386.74012	5696.958233	6152.936081

F078	148.72968	3.05448	151.78416	0.468839253	0.029302453	0	0	27366.26112	562.02432	136.8313056	0	0.420149206	0	-7851.908597	21221.40119	13506.3239
F079	117.16672	10.33824	127.50496	1.156917707	0.02461527	0	0	63328.61216	5587.81872	316.6430608	0	4.380793434	0	-10113.27678	28758.37628	18961.74256
F080	288.87264	11.36352	300.23616	2.724196217	0.057961622	0	0	156135.6619	6141.98256	780.6783096	0	5.75864742	0	-9281.222457	26431.74065	17931.1965
F081	28.64376	2.30688	30.95064	0.280830985	0.005975127	0	0	15481.95228	1246.86864	77.4097614	0	3.158041183	0	-4285.300133	15852.60101	11644.71064
F082	185.21256	1.0324	186.24496	0.467417978	0.035955229	0	0	27689.27772	154.3438	138.4463886	0	0.703087457	0	-6876.313924	20315.92424	13578.0567
F083	156.09888	4.984	161.08288	1.243904125	0.031097603	0	0	71805.4848	2292.64	359.027424	0	0.95373824	0	-6956.710258	16959.39945	10361.71662
F084	150.78024	4.1652	154.94544	1.675113958	0.029912749	0	0	97102.47456	2682.3888	485.5123728	0	1.998379656	0	-9225.996854	23614.10389	14873.61941
F085	146.4584	10.16736	156.62576	1.693279885	0.030237141	0	0	94319.2096	6547.77984	471.596048	0	2.778908944	0	-6057.266236	19644.06576	14058.39557
F086	47.4904	3.0616	50.552	0.331814064	0.009759237	0	0	18568.7464	1197.0856	92.843732	0	0.446865559	0	-1881.98437	6801.336983	5012.196345
F087	158.80448	4.8416	163.64608	1.042550443	0.031592438	0	0	60266.30016	1837.3872	301.3315008	0	2.471592015	0	-7308.511567	19324.61094	12317.43087
F088	266.8932	12.55968	279.45288	0.971088085	0.053949338	0	0	55246.8924	2599.85376	276.234462	0	2.253086228	0	-12348.42147	34822.82122	22750.63422
F089	267.91136	13.1008	281.01216	1.356259061	0.054250362	0	0	77024.516	3766.48	385.12258	0	3.591024807	0	-10750.21311	29337.23213	18972.14159
F090	103.00504	1.8156	104.82064	1.011799224	0.020235984	0	0	59227.898	1043.97	296.13949	0	1.113104013	0	-3900.953776	12803.11821	9198.303929
F091	57.672	1.2816	58.9536	0.660109305	0.011381195	0	0	38467.224	854.8272	192.33612	0	2.483866646	0	-2858.18475	10546.80149	7880.952858
F092	34.64592	0.8544	35.50032	0.089094963	0.006853459	0	0	5179.56504	127.7328	25.8978252	0	0.241436281	0	564.863919	5233.28544	5824.047184
F093	80.48448	6.8352	87.31968	0.421434102	0.016857364	0	0	23139.288	1965.12	115.69644	0	1.13682192	0	-4386.179568	16085.1836	11814.70047
F094	63.724	5.696	69.42	0.616481391	0.013401769	0	0	33709.996	3013.184	168.54998	0	3.396266403	0	-6648.478525	13605.3651	7125.436559
F095	227.81152	11.63408	239.4456	2.588644537	0.046225795	0	0	146710.6189	7492.34752	733.5530944	0	7.088980438	0	-10599.39732	26505.15957	16639.31534
F096	42.06496	2.89072	44.95568	0.399227026	0.008678848	0	0	22252.36384	1529.19088	111.2618192	0	1.584206598	0	152.489833	10369.57542	10633.32707
F097	185.14848	10.33824	195.48672	2.188884189	0.037739383	0	0	123494.0362	6895.60608	617.4701808	0	3.829673346	0	-9377.822435	19025.1493	10264.79705
F098	143.02656	2.90496	145.93152	0.591624202	0.028172581	0	0	34540.91424	701.54784	172.7045712	0	0.411643512	0	-4885.004196	13911.63806	9199.338435
F099	147.22024	7.3692	154.58944	1.551889156	0.029844022	0	0	88037.70352	4406.7816	440.1885176	0	1.62528634	0	-3960.897509	13868.90604	10348.19705
F100	62.49936	1.19616	63.69552	0.565645387	0.012296639	0	0	33062.16144	632.76864	165.3108072	0	2.012204275	0	-4639.51506	14838.19971	10363.99545