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Sûreté de Fonctionnement - Management - Cindyniques

RELIABILITY CONTRIBUTION TO SUSTAINABILITY

CONTRIBUTION DE LA FIABILITE AU DEVELOPPEMENT DURABLE

HOSSENLOPP Luc
Schneider Electric
Lattes
luc.hossenlopp@se.com

CHEVALIER Marcel
Schneider Electric
Grenoble
marcel.chevalier@se.com

ABSTRACT

Sustainability is a fast-growing business imperative. This paper aims at exploring the interactions between practices often considered in silos, to create more user value: dependability, energy efficiency and sustainability. The purpose is to benefit from the sustainability business traction to expand dependability studies. The paper is developing a series of examples, using a modern IoT (Internet of Things) architecture, where recommendations will improve existing site sustainability including increase of a low voltage circuit breaker lifetime, predictive maintenance usage to improve PV (photo-voltaic) installation energy efficiency, uninterruptable power supply replacement optimization.

KEYWORDS

Sustainability, energy efficiency, dependability, decarbonization, lifetime extension, ISO 50006, resource efficiency.

RESUME

Le développement durable est un besoin vital pour les entreprises. Le but de ce papier est d’explorer les interactions entre des pratiques souvent traitées en silos, en vue de créer plus de valeur pour l’utilisateur. Le but est de tirer parti des investissements en développement durable, pour compléter les travaux en sûreté de fonctionnement. Le papier développe une série d’exemples où les recommandations améliorent le développement durable du site tels que l’allongement de la durée de vie d’un disjoncteur basse tension, la maintenance prédictive pour améliorer l’efficacité énergétique d’installation photovoltaïques, ou encore l’optimisation du remplacement d’onduleurs.

MOTS CLES

Développement durable, efficacité énergétique, sûreté de fonctionnement, décarbonation, extension de la durée de vie, ISO 50006 ; efficacité des ressources.

I. INTRODUCTION

Sustainability business is growing fast, a concrete 2024 example being new company reports becoming mandatory to show the progress in their decarbonization journey, which is the case with CSRD (Company Sustainability Reporting Directive) in Europe (European Commission, 2023), CBAM (Carbon Border Adjustment Mechanism) being another one. This “new” business driver can be leveraged by and contributes to expanding traditional efforts made in reliability and more generally dependability studies - for instance valuating that an asset will last longer. Sustainability is also very much influenced by energy efficiency, itself very connected with dependability: additional energy consumption compared to a baseline is often the signal for maintenance requirement.

The purpose of this paper is to explore some interactions between three practices often considered in silos, to identify possible improvement actions in existing sites, and as briefly mentioned in IEC 60200-3-4: dependability, energy efficiency and sustainability. While one can contribute to the other, there are also potential oppositions. For instance, redundancy will improve dependability but will consume more energy and resources. This is what is reflected in Figure 1: complementarity (circle intersections) and trade-off, with decision optimization, typically made on a financial basis. Several examples will be taken in the energy domain that is expected to further increase its importance with process decarbonization and renewable generation at site.

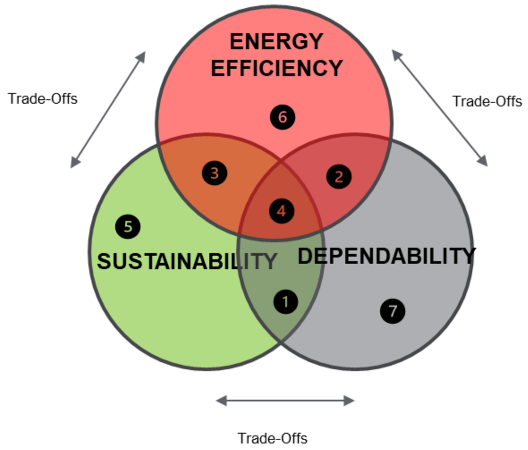


Figure 1: Sustainability enforcing practices and requesting new trade-offs.

The paper will first introduce the type of installation considered, and the selected sustainability elements. It will then discuss how internally developed ageing models used today to reduce the maintenance visits will enable us to advise on life extension and spare part management, benefits having auditable carbon equivalent. It will then move more generally to asset management, looking at energy efficiency and replacement use cases, combining the three practices.

II. TYPE OF INSTALLATION CONSIDERED

A. Smarter products with extended durability enablement

Products are becoming smarter in the industry field, with more sensors (part of the product or connected to it) and more intelligence.

- The primary expectation is to increase the product availability, by identifying or preventing failures, and optimizing services. Product availability reduce the risk of unplanned downtime with associated wastes, whether in the supply chain or alternate solution put in place to overcome the failure consequences. Sensor data are available remotely for reducing routine maintenance and identifying urgent work to be done.
- A second expectation under development (and that will be explained in the subsequent sections) is to contribute to the product durability and reduce the site carbon footprint.

Adding electronic and software into the product is rightly challenged by the “frugal design” approach. Beyond the availability benefits highlighted in the above bullet point, directly and strictly derived from to an FMEA (Failure Mode Effect and Analysis) the above element should be considered:

- “Data has no frontiers”, meaning that the same data could be used for multiple purpose, at product or system level. This is different from solution built in silos. What is initially needed for availability is likely to be used as well for energy efficiency (as it will be shown in a further section), safety or control schemes. Trade-off should be analyzed as a system encompassing multiple practices.
- Schneider Electric Sustainability Research Institute, 2024, has made some deep analysis on microgrid and building management system, showing that benefit of digital solutions overcome their limitations.
- Nascent green software and firmware practices are also introducing new framework on the eco-design.

The new Medium Voltage Circuit Breaker shown on Figure 2, includes 5 new sensors (speed of operation, motor charging time, etc.) compared to the previous generations, to anticipate additional product failures. During the design phase of the product, accelerated ageing tests have shown that sensor lifetime is higher than the circuit breaker one. This is different from the use phase of the product that will perform condition-based monitoring, as discussed later. Failure of the sensors or associated signal processing sub-assembly is not preventing the product from working properly. Sensor health is itself checked through analytics. Thus, adding the sensors is improving the availability without requesting urgent additional maintenance.

Figure 2: New generation of Medium Voltage Circuit Breaker

B. Modern architecture, IoT complemented by services.

Modern architecture is made of three main layers, as shown on Figure 3:

- Smart products. Note that a smart product might be limited to a sensor. Increasing temporal and spatial resolution thanks to new sensor is improving the analytics accuracy (that will be discussed later in the paper).
- Analytics are distributed between the product itself and higher levels, i.e., cloud or on-premises servers, and are increasingly used by service teams.
- Service layer is made of three components: people on the field (typically for commissioning and repair), remote people permanently connected (managed services for alarm management and recommendations), and consulting experts (professional services, for deep studies).

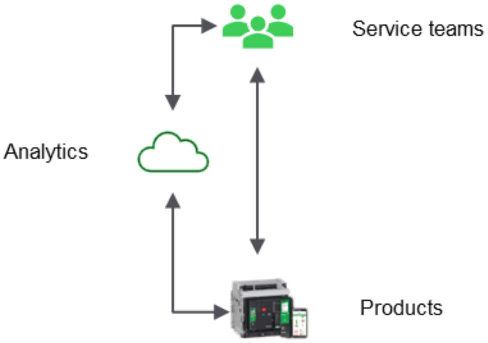


Figure 3: Schema of a modern architecture mixing IoT and Services

C. Service layer

Managed and professional services are recommending actions, generally optimizing dependability or energy efficiency, with now the need to be co-optimized with sustainability. They are eventually assembled in a roadmap for optimizing the action sequences, therefore following the true outcome if recommended actions are decided, and once they are implemented.

Environmental impact of the service layer might be rightly challenged:

- In this context, service is about people, who might be already in the site, and possibly belonging to the site owner, thus reducing the transportation costs.
- New resources are “managed services”, having remotely access to the device and analytics. One benefit is to postpone traditional preventive maintenance, reducing travel and spare part by a factor of 2 to 3, in term of cost and carbon equivalent. Safety and energy efficiency are other opportunities that can be detected.
- What is also new is the dynamic interaction between these three groups of people: a low carbon addition compensated by data sharing not done before that are improving and accelerating solutions.

Typical actions, for which expected benefits might require sophisticated analytics, include:

- Addition of simple sensors and actuators for observability and controllability improvement, possibly adding dashboards for awareness
- Maintenance (which could be corrective or preventive, or initially auditing and deep diving),
- Tuning software parameter or automation sequence,
- Replacement of a product or subsystem by a more modern technology,
- Extension, adding of a more complex type of product, for example a new automation scheme.

III. SUSTAINABILITY CONSIDERATIONS

Sustainability is a wide topic, so this section will only introduce the concepts which are of importance for this paper. Focus is done on two families regarding energy usage (and efficiency) and circular economy. These are parts of the sections ESRS E1 and ESRS E5 (ESRS being the European Sustainability Reporting Standard) used in the CSRD reporting, this reporting being either a quantitative numerical data (measurement, target) or qualitative. Qualitative data would typically contain recommendations and their evaluations, to become more energy-efficient, increase an asset lifetime or material efficiency (in the sense of recyclable one).

A. Product lifecycle

Life Cycle Assessment (LCA) is an important concept defined in ISO 14040 and in ISO 14025 if limited to environmental declaration verified by third party. It leads to the creation of Environmental Product Declaration (EPD) per product (Energy management Research Center, 2023). This rich declaration contains (among other data) the CO_2 emissions for each phase of the product lifetime, and this paper will focus on:

- The use phase: for an electrical product such as a circuit breaker or a transformer, this is where more than 80% of the emissions are occurring, thus an important source for energy efficiency opportunities.
- The manufacturing phase, since extending the lifetime will prevent manufacturing a new product.
- Circular economy, which promotes the reuse, the refurbishment after their end of use and the remanufacturing and recycling of parts and products after their end of life increasing the percentage of recycled material content.

Durability (an emerging terminology very much discussed in the sustainability domain, IEV 192-01-21, 2021) refers to the ability of a product to function as required, under specified conditions of use, maintenance, and repair, until the end-of-life is reached. End of life is itself triggered by the failure of non-reparable parts, or the cost of repair. Interestingly, the cost of repair for product as shown earlier is very much impacted by the safety verification cost and associated specific tools, leading to the definition of non-repairable parts. Durability extension means that the manufacturing of a new product or spare parts can be delayed, thus reducing the manufacturing energy consumption and resource depletion.

B. Sustainability accounting

There is a direct coupling between energy and carbon:

- For a site powered by the utilities only, there is an available coefficient, converting the kWh to CO_2 (IEA, 2023-2). The frequency update of this coefficient depends on the expected usage: yearly average is usually sufficient, however when generation is from renewable energy or when instantaneous carbon content is used in control optimization analytics, real-time data can be considered. Any green power purchase agreement contract, when existing, shall be integrated as well.
- When there is a local generation (renewable such as PV, or not such as back-up generator), a rule of 3 shall be applied to recompute the carbon equivalent.

There is another relationship between lifetime extension and carbon (Schneider Electric, 2022): lifetime difference / initial lifetime x carbon emission during the manufacturing phase.

Carbon is key for global warming prevention and might be valued using the carbon market or internal conventions, see Goldstandard, 2023 for the principle. This enables a new type of cost optimization that can be used for the above action decisions. This adds to the traditional Capex (Capital Expenditure : initial cost) and Opex (Operation Expenditure : operation and maintenance costs) calculation for the carbon cost.

Sustainability is well addressing non-renewable resources such as raw material. This is less mature than carbon impacted by nascent recycling. Resource scarcity is following the traditional supply-demand price mechanism, with coming resource depletion not always considered.

IV. GLOBAL AGEING FRAMEWORK – MAINTENANCE OPTIMIZATION

A. *Overview*

The Global Ageing Framework (GAF) is a methodology developed by Schneider (Marcel Chevalier et al., 2022) to evaluate the ageing of the product, relying on measured data. Its purpose is to make operation and maintenance optimization decisions during the use phase of the product. It complements the accelerated ageing methodology, described in the IEC 62506 standard, which is first used during the design phase, detecting possible failures, improving product robustness, and assessing lifetime based on idealized mission profiles. Accelerated ageing methodology results are a source for GAF validation.

In this methodology, every product is split into subsystems, each being associated to one or more degradation modes. These degradation modes are modeled based on asset usage (for instance number of operations) and environment (for instance corrosion) thanks to expert knowledge and complemented by the quantitative effect of maintenances on the ageing. They are permanently evaluated using measured data from the product and its surrounding, to compute the time before it enters a critical zone. They are represented by the orange curve of figure 4, in which the pink part represents the area where the part has reached the lifetime it was designed for. Their linearity is linked to the usage of simplified physical laws in this example.

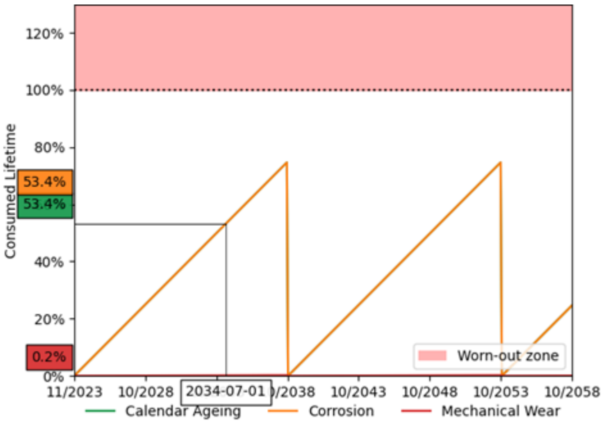


Figure 4: Asset ageing as a function of time, environment, operation, and maintenance

GAF validation is done using accelerated tests and observations made on multiple mission profiles. For instance, the ageing in a data center with regulated temperature and humidity will be very different from the case where the product is in a petrochemical installation close to the sea. Each mission profile will initialize a lifetime baseline described later in the paper. For medium voltage circuit breaker, 7 different mission profiles have been defined with lifetime ratio raising from 1 to 4.

B. *Application to maintenance extension*

Arnaud Rival, 2022, explains how this methodology enables to delay some of the traditional maintenance by one or two years, keeping the real time calculation to cope with abnormal degradation and thus urgent service need.

From a sustainability point of view, this means:

- less human intervention
- potentially less leakage of SF6 for circuit breakers using it,
- less travel from the Services people,
- less spare part usage,
- less unexpected downtime that would stop production and generate extra waste.

C. *Application to durability extension*

Extending the product lifetime and durability is one of the classical sustainability discussions. We enabled this thanks to GAF and Services teams, as shown on Figure 5:

- Call $C_{manufacturing}$ the carbon emissions generated during the manufacturing stage.
- The first step is to establish the lifetime baseline $LF_{baseline}$, using one of the validated mission profiles, depending on the product exact application. Note that there might be other conventions, that are being discussed at the time of writing

this paper. GHG (Green House Gas protocol) requires in its Category 11 (GHG Protocol, 2023) that “product Category Rule” or “Industry Recognized benchmark” are used as a baseline – meaning that there is a predefined consensus which is not the case for all products and is not always aligned with extreme usage conditions. Another option would be to compute the carbon saving following preventive, corrective, or predictive.

- The second step is to use the GAF to compute the actual lifetime with the measured data, which is not idealized as per the mission profile. We often observe that temperature for instance is above the expected one, triggering a degradation of the lifetime compared to the baseline.
- Next is to advise on possible changes to improve the raise up the lifetime. This change will be reported in the carbon savings. If this extension requests additional spare parts, the corresponding carbon footprint shall be added. Improvement capability depends on the speed of decision and implementation, i.e. ageing is often non-reversible.
- Finally, from a carbon perspective, the countermeasure, $C_{\text{countermeasure}}$ such as cooling the room where the product is located, shall be integrated into the carbon picture.
- Carbon reduction is thus $- C_{\text{countermeasure}} + C_{\text{Manufacturing}} * \Delta 2 \; / \; LF_{\text{baseline}}$

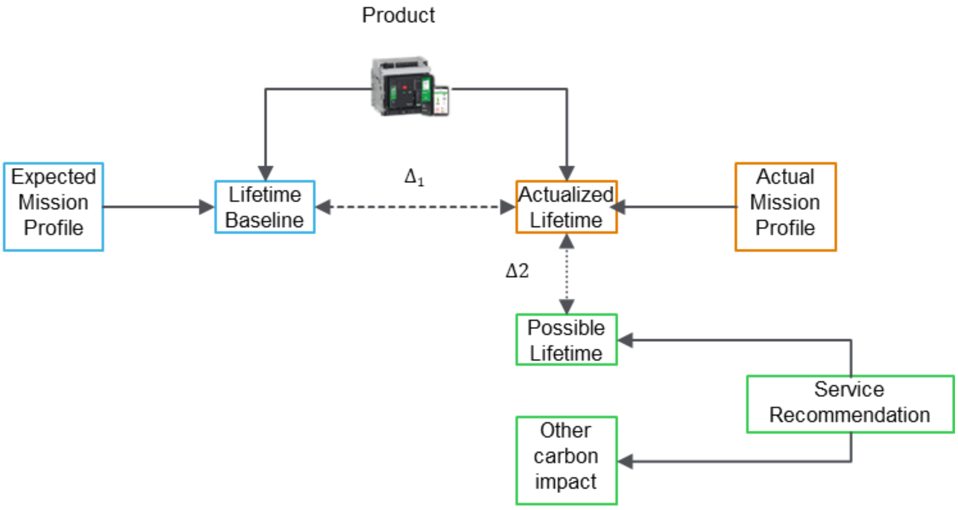


Figure 5: Computing the lifetime extension.

D. *Application to re-use*

One of the future applications of the GAF is to leverage the ageing of sub-assemblies, to identify where to reuse them. This will typically be triggered when the product is no longer needed (lack of features, lack of performance, etc.).

One classic case is to dismantle the product and fill the customer internal spare parts stock. With GAF ageing tagging, a state of health of the spare part will be attached to each spare part, thus improving the information on the spare part, potentially allowing to reallocate it for an application on a criticality basis and adjusting the stock accordingly.

Another use case will be to set up a marketplace, i.e., using the above principle for a different customer, and valuing the spare parts.

V. FROM PREDICTIVE MAINTENANCE TO ASSET PERFORMANCE MANAGEMENT

As IEA (Internal Energy Agency) puts in IEA, 2023-1, “energy efficiency is the first fuel for energy transition”, thus with a specific impact on sustainability. Predictive maintenance, when applied to asset converting energy, can support efficiency efforts: poor performance of the asset degrades the energy conversion, and this will be detailed for PV installations. Note that similar reasoning could be done for heat pump or HVAC (Heating Ventilation and Air Conditioning) for instance.

Conversely, analyzing energy efficiency reduction can be a proxy for predictive maintenance, thus acting as a virtual sensor with a low marginal cost. Detecting energy anomalies in an energy baseline comparison will then be presented.

Energy efficiency will also drive energy dissipation reduction and thus increase of asset durability. Improving an asset efficiency point is thus important and will be illustrated, fundamentally showing the need for an asset management practice mixing maintenance and operation optimization. An alternate example will illustrate replacement as another asset management action.

A. Photo-voltaic (PV) installation

PV role is growing is the energy transition, contributing to the net zero building trajectory, and is increasingly part of regional regulations (see for instance in Europe EPBD - Energy performance Building Directive - European Council of the European union, 2023). Reduction of the PV efficiency is thus a concern and was analyzed using the Schneider Electric “Intencity” building, equipped with a 900kW peak solar installation. The initial phase was analyzed through 13 months of historical data of a 3-years old installation.

It has been observed that part of the generated energy by the solar panel is not usable, for two main reasons: DC/AC inverter failure, with then time to replace them, and ground fault leakages. Impact of panel ageing and cleaning will add to that and will be measured in the next phase with permanently connected installation. Utility statistics, with users very focused on the energy production volume, show that there is an average of 8% losses (kWh analytics, 2022).

Predictive maintenance enables a 2-month anticipation windows prior to inverter failure – as shown in the example of Figure 6, where the ground losses pattern on two panel strings (through two Maximum Power Point Tacking) managed by the same inverter are compared.

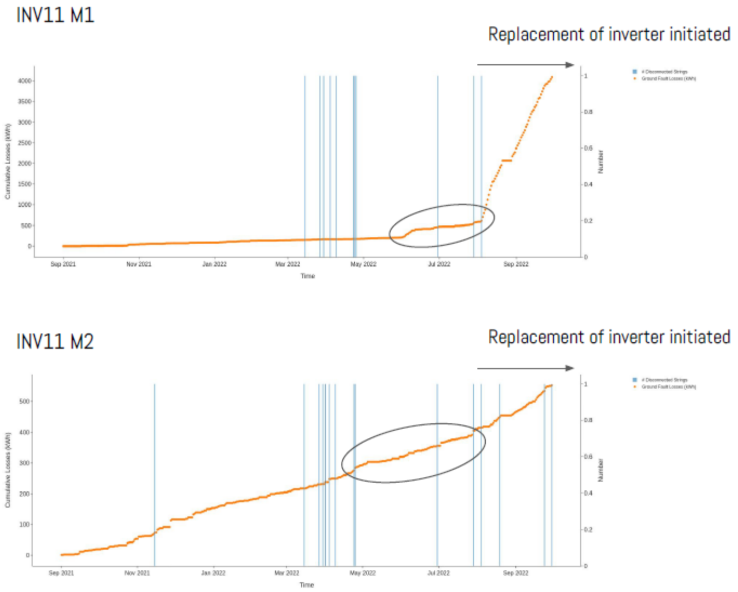


Figure 6: comparison of losses on two panels managed by the same inverter

B. Baseline analysis

Energy baseline is defined in ISO 50006 to contribute to ISO 50001, with increasing customer requirements to implement it. It is about decorrelating influence variables, such as external temperature or occupancy of a building, to compare a reference period with an actual one. The actual one is usually expected to be lower than the reference period, thanks to the application of Energy Conservation Measures (ECM). Thus, detecting increase shows some anomalies, which might be the result of poor maintenance and possibly dependability reduction. An example detected in one of our buildings was that one of the compressor maintenance’s activities was not properly finalized. Poor refrigeration maintenance will also trigger a more frequent start.

Figure 7 shows the example of a building energy consumption with a daily granularity, splitting open and closed days into two curves. The slope of the curve shows the energy need for heating and cooling, while the horizontal flat part reflects the baseline consumption. Outliers, i.e., days with a point far from the curves, show the need for further investigation, typically by Services team deep dive.

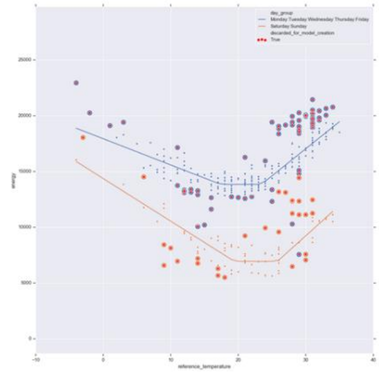
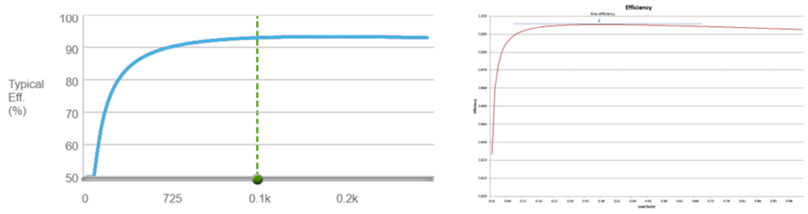


Figure 7: Building baselining.

The baseline, i.e. the horizontal flat part of the curve, shall be investigated as well: rule of thumb is that when there is no activity, then there should be no energy consumption. Coupling this with dependability makes it slightly more complex: typically, a transformer has “no-load losses”, corresponding to the energization of its core. Succession of energization and de-energization would address the extra-consumption but would also accelerate the ageing. A better solution is to add a capacitor bank. Similar situations exist for a motor, where a solution might be the addition of a variable speed drive.

C. Asset performance management integrating best efficiency point.

The best efficiency point of an asset is minimizing losses, thus asset heating, contributing to reducing its carbon footprint thanks to increased asset lifetime and energy efficiency. Figure 8 shows the evolution of a UPS (Uninterruptable Power Supply) and a transformer efficiency, as a function of their loads. Motors or pumps follow similar patterns. In this UPS case, the need is either to increase the load through site reconfiguration, or to resize the UPS.



Example of UPS energy efficiency curve

Example of transformer energy efficiency curve

Figure 8: Examples of best efficiency point curves for UPS’ and transformers

While not yet demonstrated, complementing a true asset performance management program by optimizing maintenance and energy efficiency is probably at the center of the three circles of Figure 1. This is valid until the product is young enough: remaining useful life is not reached, new technology drastically improving the energy efficiency is not yet there, and the resource sizing is still adequate.

D. Modernization, combining multi-optimizations.

Modernization is usually done when the product cannot be maintained economically, or cannot be properly sized, or if some new technology offers significant improvement, or as a combination of these different factors.

The example taken is about a 3-phases UPS installed at a customer location. The histogram of Figure 9 shows that the energy efficiency is 74%. It is used to identify what could be a better sizing, while keeping the needed operation margin. As a result, the recommendation is to update the UPS: the resizing, together with the new generation, enables to divide by more than 20 the electrical losses and CO_2 emissions. Return on investment is today based on kWh savings.

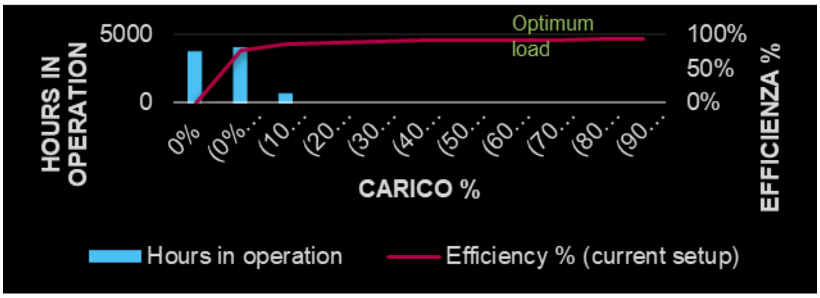


Figure 9: Current UPS load histogram (Carico = Load in Italian language)

VI. CONCLUSION

This paper is suggesting extensions the areas for Environmentally Conscious improvement discussed in T Cormenier et al., 2023-2, itself using IEC 62430 as a baseline. This is shown multiple through examples for the different sections of the proposed framework, see Figure 10:

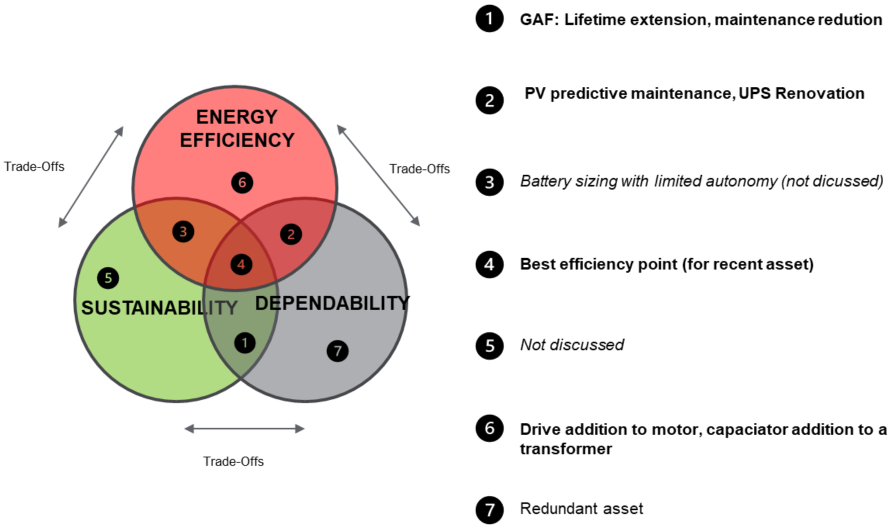


Figure 10: Examples covered in the paper

When looking at existing installations, modern digital architecture made of IoT and Services enable trackable and iterative improvements, with extra-cost (financial, consumption, material) being considered as bringing sustainability benefits and thus justified.

Sustainability will continue to drive the business and is still progressing on multiple concepts (illustration was shown on CSRD reporting) such as resource depletion / efficiency consideration, safety (T Cormenier, et al., 2023-1) or lifetime extension. New types of optimization schemes can be anticipated and will need to be auditable to prevent green washing.

A system approach is essential. This is first to encompass the different components (hardware, software, and services), the different practices and overall lifetime. This is then to apply the different discrete concepts (as illustrated in this paper) in a more systematic way is an opportunity for the future, as well as addressing time variable parameters (ageing, energy efficiency of new technologies, raw material cost). Usage of Generative AI is expected to contribute to the completeness and efficiency of this approach in the near term: this is currently used to assist teams in FMEA generation and synthesis of events that have occurred on a given asset.

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