# Green Future Networks

## Metering for Sustainable Networks

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# Green Future Networks
# Metering for Sustainable Networks

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# EXECUTIVE SUMMARY

The number of Mobile Network Operators (MNO) committing to net-zero emission targets by 2050 or before has significantly increased in the past couple of years. Reduction of power consumption is an essential key for MNOs to achieve those targets and reduce their operational expenses as well. To optimize the energy consumption, it is important for MNOs to have detailed understanding about where and when energy is consumed, and which factors are influencing this consumption. Therefore, an accurate metering system is a prerequisite to make sure that energy consumption can be properly monitored, measured, and optimized. It will allow all the actors involved in mobile network deployment and operation i.e. MNOs and Tower Companies, to develop precise optimization processes, predict maintenance, and control the network remotely, thereby reducing manual interventions as well. In simple terms, an interface should be established between both MNOs and network equipment suppliers including manufacturers and vendors. This interface should include valuable functions and mechanisms for the secured transfer of measured data to the MNOs' sites, to enable them to analyse the data and derive affordable measures or solutions for improvements, which could be implemented by the MNOs themselves or in cooperation with manufacturers and/or vendors. Although this White Paper focusses foremost on base station (BS) sites, identified as the most energy consuming part of mobile networks, its insights and recommendations are applicable to the rest of the mobile network including backhaul, core and Network Function Virtualization (NFV) as well.

The term "metering" is used in a generic way in this White Paper to identify not only the sensing but also the necessary infrastructure to collect, transmit and use the information obtained for a better management and improvement of the network. This includes a methodology on how to transfer the information from the measurement site to a central point using different communication channels, protocols, and interfaces to be able to perform an action or distribute information on the network status. With this information, it would be possible to plan the evolution of the network in a way to reduce the energy consumption and improve the efficiency of the network. This White Paper describes the aim of metering in different parts of mobile networks and the advantage that can be realized with the help of several use cases such as smart facilities, renewable energy use and management, new operation models, disaggregated and virtualized networks. An analysis of the requirements for metering is performed, considering the aspects which need to be monitored including energy consumption, environmental aspects, site security, etc. and how this could be implemented in the BS, site facilities, core network and in the virtual environment as well.

The most important quantity to be measured for energy saving are energy consumption, current, and voltage. Every BS equipment as well as technical site-equipment (BS site) should be enabled to measure these parameters by metering. Since various equipment with different scales of energy consumption are interworking at a BS site, the accuracy classes of power meters should be identified and harmonized. Therefore, it is recommended to follow the principles of measurement as well as the accuracy of the measurements according to the established international standards.

Furthermore, it is also important to evaluate the energy efficiency of the entire site based on Direct Current (DC) metering and energy consumption indicators at the first energy distribution layer and even at its sub-distribution layers. Once this energy consumption data is sent to the network management centre, the energy optimized running policy can be delivered to the sites.

Virtualization of network functions has become a trend in mobile networks, leveraging Commercial Off-The-Shelf (COTS) hardware, such as General-Purpose Processors (GPP) and standard Ethernet Network Interface Cards (NICs), enabling agile feature development, and service deployment. Open interfaces and methods are already available to collect resource usage for Central Process Unit (CPU), memory, storage, network interface and power, Virtual Machine (VM) status, resource utilization and to publish telemetry from the virtualized computing platform. The power and resource utilization telemetry can be used to build recommendation policies that can be subsequently applied to optimize power according to the workload demand.

The proposed recommendations for metering solutions cover a unified architecture of metering system and data collection at internal site level; different topologies of sites including site owned by one operator, site sharing scenario between different MNOs, Tower Companies and RAN sharing scenarios. For these scenarios, a possible site communication architecture is described, establishing the principles of information flow between site Network Management System (NMS) and the different actors involved. The target would be to collect the information from the equipment present on the site as well as from the whole environment i.e. power system, cooling system, energy storage system, etc. to create transparency for the MNOs about where energy is being consumed.

The technical site equipment, site control unit(s), or power unit(s) may come from different vendors and support different levels of capabilities and versions of protocols for the control and monitoring of their power consumption data. Hence, it is recommended to equip them with the Next Generation Control Unit (NG-CU) or Next Generation Data Gathering Unit (NG-DGU) which includes a higher level of intelligence. The technical site should further include an entry point which is responsible for the control and monitoring of power units, cooling systems, and building controls via their NG-CU/NG-DGU.

Common Application Programming Interfaces (APIs) are essential to permit a better and simple integration of different solutions. The standardization of a common API for the different scenarios described above is expected to enable the controlling and monitoring of Power, Energy and Environmental (PEE) data from site equipment, power unit, building control units and BSs. The intention of the recommendations set up in this White Paper is to work together with the Standard Development Organizations (SDOs) to create a uniform and more sustainable metering solution for mobile networks by updating existing standards or developing new standards for the missing parts.

The solutions presented in this White Paper shall be discussed in standardization bodies such as European Telecommunications Standards Institute (ETSI), 3rd Generation Partnership Project (3GPP), International Telecommunication Union (ITU), and others to form the basis of future work on standardizing the measured parameters, data collection methods, interfaces, and communication protocols.

# 1 INTRODUCTION

In this White Paper the 'metering' terminology is used in a generic way to identify solutions implemented in a mobile network to measure physical parameters like:

- Electrical: voltage, current, energy, power.
- Environmental: temperature, humidity, wind, solar radiation.
- Other: fuel level, battery shelter temperature.

Metering not only includes the sensing but also all the necessary "infrastructure" to collect, transmit and use the measured information. This includes the methodology to transmit the information from the measured site to a central point using different communication channels, protocols and interfaces, as well as the Network Management System (NMS) and the application platform to display or distribute the information. Sensors are integrated in different network equipment e.g. Radio Access Network (RAN), backhaul equipment, and in the equipment support e.g. site environmental sensor, power unit, cooling, solar unit, etc.

The motivation for extensively using metering is that it allows to better identify and understand the behaviour of energy intensive or underutilized parts of the network to optimize and manage them in a more energy efficient way. The objective is to reduce network associated Green House Gas (GHG) emissions for current and future mobile networks.

Metering solutions are standardized in 3GPP and ETSI for all type of network equipment, but standardization does not exist for other parts of the network such as core, Network Function Virtualization (NFV), data centre or the support equipment. Furthermore, actual solutions do not consider new types of deployments such as smart facilities, renewable energies, Tower Companies and virtualized networks, as illustrated in Section 3. It is important to have standards covering metering for support equipment as reported in the Sections 4 and 5.

Energy measurements will enable MNOs to know the status of their network energy consumption. This helps to lower operational expenditures and to derive migration plans for future network design. More precisely, having metering information from the network and support equipment will give telco actors, including MNOs, Tower Companies, vendors the option to:

- Include requirements for Energy Efficiency (EE) of telecommunication equipment and related site equipment as part of procurement decisions.
- Validate the promised energy efficiencies requested in Requests for Quotation (RFQ) by actual network performance measurements instead of tests.
- Leverage emerging renewable energy power units for MNOs having higher contribution of "renewable energy" for their networks. Metering provides necessary insights to optimize usage of renewable power.
- Save costs by optimizing the fluctuation of renewable energy prices on the energy stock exchanges. An efficient energy management will enable the parties to benefit from metering.
- Increase the contribution of locally produced renewable energy. The return of investment of on-site installations (Photovoltaic (PV) panels, windmills, etc.) can be shortened with a more

efficient on-site energy management. To do so, it is needed to forecast the site's specific energy demand according to the usage of radio network equipment.

To exploit the information gathered from equipment, the data needs to be processed and transmitted to the NMS and/or operation management centre. This White Paper presents solutions in this sense and considers different solutions for data collection and exchange.

Please notice that methodologies for measuring, collecting and managing energy consumption of user equipment (fixed and mobile) are not part of the scope of this White Paper.

# 2 MOBILE NETWORK CONSIDERED METERING

This section provides a description of a mobile network when considering the need for metering. Figure 1, from standard ETSI ES 203 228 [1] and ITU-T L.1331 [2], gives an overview of a generic mobile network. In this figure, the mobile network is divided from an architectural point of view into Base Station (BS) site, backhaul, cloud (both central and local) and NMS.

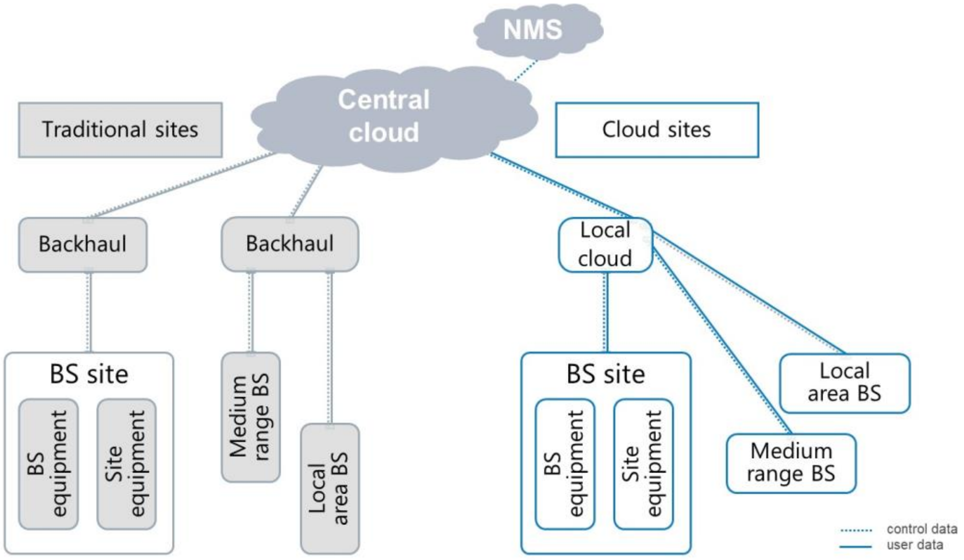



**Figure 1. Mobile Network Diagram. [2]**

A BS site can be represented as reported in Figure 2, in which it is easy to see the difference between site equipment, BS equipment and backhaul equipment. BS is also a generic term used for a network component which serves one or more cells and interfaces the user terminal (through the air interface) and a radio access network infrastructure as defined in [1] and [2].

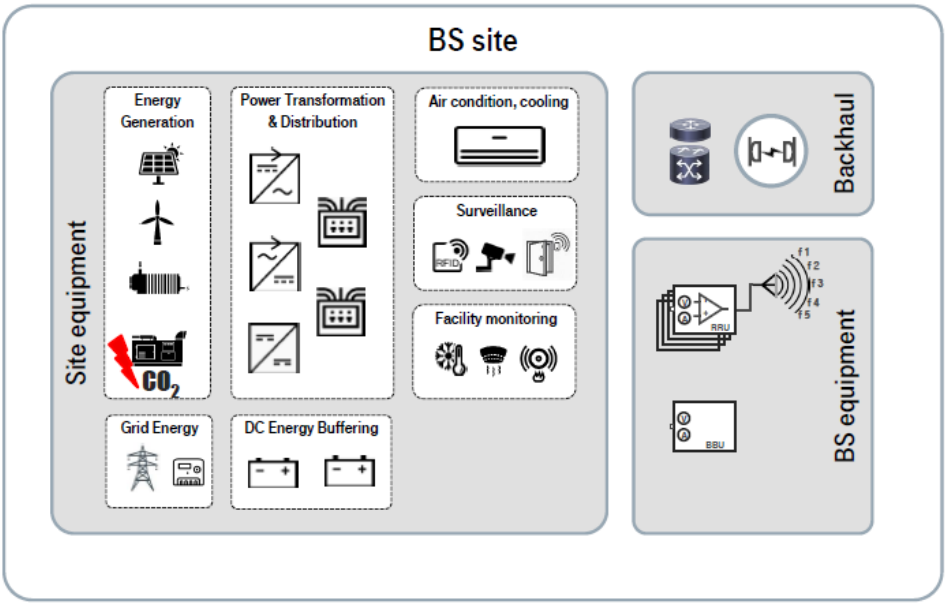



**Figure 2. Schematic Overview of a Base Station Site [2].**

Based on Figure 2, when considering metering needs in a BS site, the equipment to measure can be classified in three separate sections:

- The *BS equipment* itself in which it is necessary to perform measurements according to its intended use (e.g. traffic volume, traffic quality, energy consumption, etc.). In past years MNOs and industry have spent lots of efforts to evaluate and improve the quality of networks. Standardization bodies like 3GPP and ETSI established a widely used framework for the definition, processing and collection of these parameters.
- The *BS site equipment (support equipment)* creates the adequate conditions for the BS equipment to work. It includes air condition systems, power supply units, sensors, locks, camera, etc. Some of this equipment is passive and might not be equipped with any kind of data interface to transmit measurement values. ETSI Technical Committee on Environmental Engineering, working on power utilities and air condition systems has partially standardized the monitoring and data collection for this type of equipment [3]. The minimum parameters to be collected for this equipment are power, energy consumption, temperature and humidity.
- The backhaul is composed of transmission systems of different technologies such as microwave, fibre connection, router, etc. The metering of these types of equipment need to provide information related to their energy consumption - as the other equipment present in mobile network - to have a complete overview of mobile network energy consumption. Furthermore, the metering of these product types is covered by ETSI standard [3].

Based on Figure 1, the other part of the network that needs to be considered in order to have a global view of the energy consumption of a mobile network is the cloud, with central and local (edge), which needs to have metering capabilities as well to provide data regarding its energy consumption and environmental conditions.

Finally, the NMS is the part dedicated to the supervision and control of the network that collects and manages all the information provided by metering units present in the network.

# 3 USE CASES

This section describes four use cases, selected to illustrate the use of metering in mobile networks and to emphasize the requirements when implementing metering.

## 3.1 Use Case 1: Smart Support Equipment Facility

On one hand, the network densification is accelerating on a continuous basis and on the other hand, electricity prices are increasing as well. This makes measurement and transparency a prerequisite for energy saving. However, measuring equipment at a large number of *BS sites* is still invisible, let alone unmanageable. In addition, knowledge on the accuracy of meters and measurements, especially in case of interaction i.e. triggering actions, with various equipment – is very important. Figure 3 shows the considered position where metering needs to be deployed in the present use case.

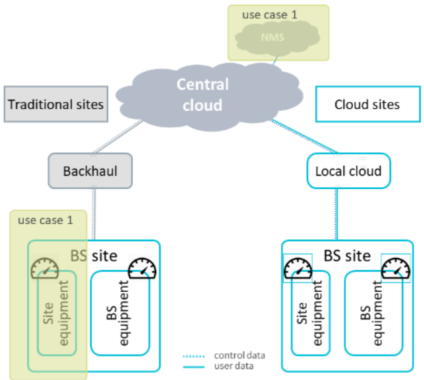



**Figure 3. Smart Support Equipment Facility Use Case. (Derived from [2] and modified)**

To have a smart facility, the traditional approach is to install external and independent meters at each active equipment. This could be realized by a central or a decentralized metering solution, in which, for different active equipment, different metering precision levels will be defined. In a centralized solution it will be hard to ensure an adequate accuracy for each measured active equipment, as the collection of measurements is concentrated at a single point. In a decentralized solution, each active equipment is accurately measured, but the data collection will require a complex architecture.

In both cases additional investment and space for meters, cables and data collection hardware is required. Nevertheless, adding external meters may introduce inaccurate data, therefore having a maintenance process to guarantee accurate measures is important. Equipment with on-board metering (integrated sensors) will reduce the need for additional investment and might overcome the disadvantages of external meters, as this will be linked to the life span of the active equipment.

Data interfaces with various data logging, configuration and functionality to trigger equipment specific activities (e.g. disconnecting active equipment, etc.) are implemented into an ever-increasing number of support equipment. To move from traditional facilities to smart facilities, the capabilities mentioned above should be used to manage equipment and not only to measure it. A traditional and centralized metering solution does not have intelligent management functions such as remote disconnection.

Furthermore, as the focus is on energy efficiency and active equipment measurements, other data like environmental conditions, storage conditions (i.e. battery State of Health, State of Charge, etc.) are necessary to implement an advanced management of facilities present in the network.

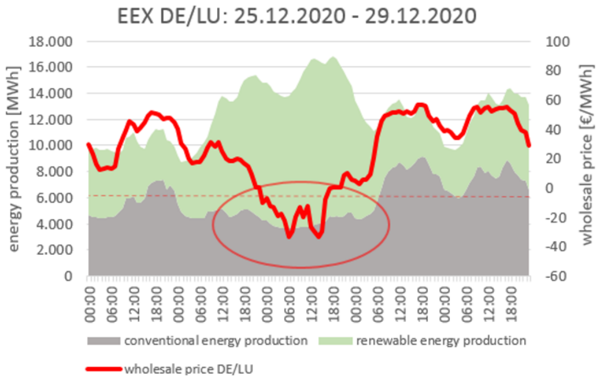
Energy Management System (EMS) in smart facilities aim to increase the efficiency of networks by measuring the varying active equipment consumption, detecting and directly addressing the most relevant abnormalities. This information could be exploited for predictive maintenance. Moreover, using and managing different energy sources such as renewable energy storage solutions can accelerate the reduction of at least part of the energy originating from fossil sources used on the site, along with the GHG emissions of the site. This is expanded in use case 2, in Section 3.2.

In summary, better verification of site functionality also enables precise Operations & Maintenance (O&M), resulting in fewer site visits, which are also a source of GHG emissions, and can help extend the lifespan of support equipment.

## 3.2 Use Case 2: Intelligent Renewable Energies Management Providing Most Cost-efficient Power to BS Sites

Following the United Nations Sustainable Development Goals (UN SDGs) and Net-Zero initiatives, national governments and companies are increasing the usage and production of renewable energies. During the last years, MNOs have been deploying renewable energy solutions and this trend is expected to continue in the coming years. Nevertheless, from a global point of view, the availability of this kind of energy as well as its prices are subject to major fluctuations.

Figure 4Figure 4 illustrates that the renewable energy availability has been strongly impacting prices at energy markets since 2019. When these fluctuating prices are mapped into energy supply contracts the MNOs can start to monetize it. This is done by buying energy only in off-peak price periods and buffer it in storage systems e.g. batteries, that will then be discharged during the high-price periods.




| Wholesale prices | December 2019 | December 2020 |
|---|---|---|
| Average [EUR/MWh] | 31,97 | 43,52 |
| Minimum [EUR/MWh] | -50,43 | -33,58 |
| Maximum [EUR/MWh] | 76,47 | 114,00 |
| Hours with negative prices | 38 | 25 |

**Figure 4. Fluctuation of Energy Production and Whole Sales Prices [4]**

MNOs will increasingly also use their site for the on-site production of renewable energy (photovoltaic, wind generators, hydrogen fuel cells, etc.), in order to reduce the overall use of grid energy and the dependencies on increasing energy prices.

To this end MNOs will have to handle the fluctuating prices of grid power, the availability of renewable energies, the storage capacity systems and the cyclic energy demand for the BS-equipment. Metering appears as the foundation for local power optimization. Figure 4 shows the metering position considered in this use case.

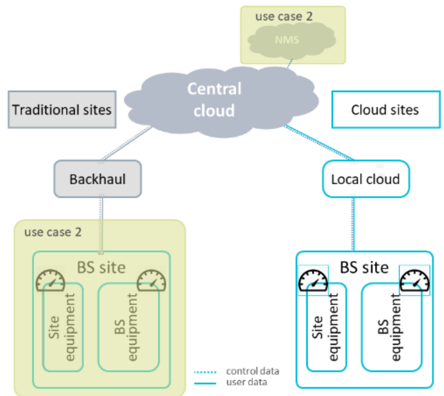



**Figure 5. Intelligent Renewable Energies Management Use Case (Derived from [2] and modified)**

Until now, the on-site renewable energy production is provided to the power distribution system and instantly consumed to reduce the grid power share. The batteries, when existing, are only discharged in case of power outages and immediately re-charged once the power is available again.

In the future, a smart BS site will predict, thanks to metering, its energy demand and production for the upcoming 24/48 hours as well.

As illustrated in Figure 6, an intelligent Energy Management System (EMS), based on site energy consumption monitoring and energy locally produced by renewable sources, will optimize the energy storage capacities. In particular, the battery will be charged when grid power prices are low and the battery will be discharged when grid power reaches the peak price level.

The key parameters to consider developing an intelligent EMS are:

**Cyclic energy demand:**

The energy efficiency of each equipment will be optimized for an overall reduction of energy consumption. This will be done either on a long term basis by considering the life cycle management based on the energy efficiency when exchanging equipment or on a short term by implementing features to save energy (e.g. switching off capacity boosters when the traffic demand is low, and re-activating them on a need basis - see [5], etc.).

Energy saving features will impact the energy consumption of each specific equipment, along with cyclic energy consumption. Forecasting the energy demand will be based on actual power metering data and AI-applications considering site specific features.

**Availability of renewable energies:**

Renewable energies produced by photovoltaic systems and wind turbines are strongly depending on local seasons and weather. Fuel cells (e.g. powered by “green” hydrogen) are limited by the availability of combustible material e.g. filling the tank. Forecasting the renewable energy production will also be based on actual metering data and AI-applications considering the implemented site-specific capabilities for production including filling levels and the local weather forecast.

**Renewable energy storage:**

Handling renewable energies implies the awareness of having periods where the production can be higher than the demand and periods where the production does not cover the demand (i.e. energy gap). To overcome this situation energy buffering capacities with sensors to measure the actual capacity (quantity of energy available in the energy storage unit) need to be installed at the sites.

**Fluctuating prices of grid power:**

The assurance of electrical energy supplies is assured by the regulations. They forecast the amount of energy produced by various sources (e.g. water, coal, gas, photovoltaic, etc.) and the related cost per MWh

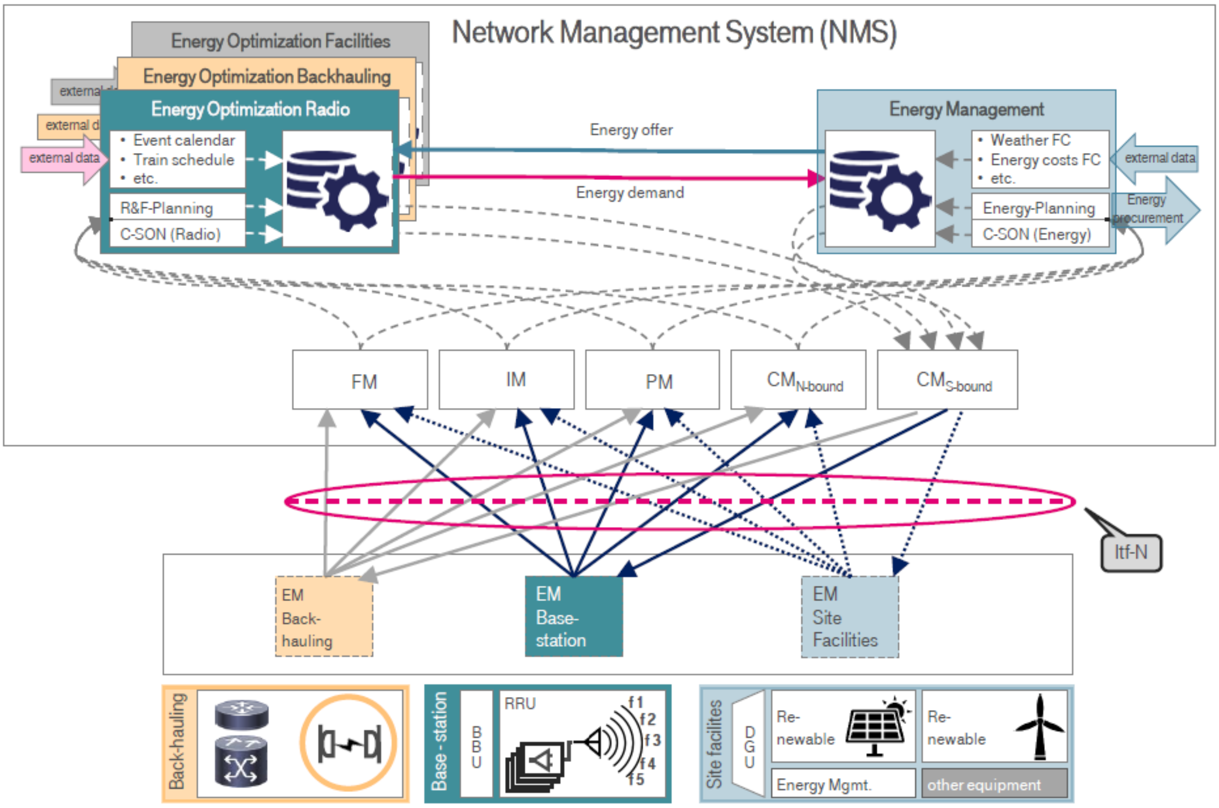



**Figure 6. Intelligent Energy Mmanagement**

## 3.3 Use Case 3: Emergence of New Operating Models

The mobile infrastructure market is growing rapidly. More and more MNOs are carving out their site infrastructure to so-called Tower Companies. Experts in [6]] explain these trends in terms of site ownership. This trend increases the information exchanges, leading to a change of paradigm in the nature of site information flow. In some regions, the split of responsibilities becomes even more granular as 'Energy Service Companies' (ESCO's) are taking over the power management at mobile sites. As shown in Figure 7, in the present case of emergent new operation models, metering systems are positioned on the BS site, especially on BS equipment.

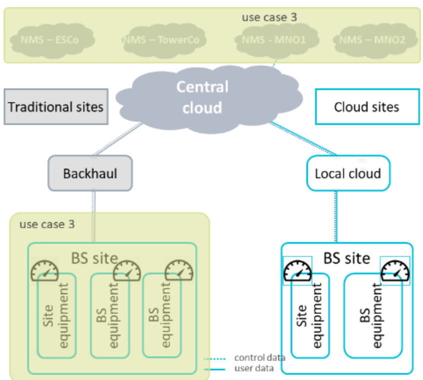



**Figure 7. Emergence of new Operation Models Use Case (Derived from [2] and modified)**

As many of the sites are shared between several MNOs, the interaction between site facilities and the BS equipment of the MNOs will reach a higher level of complexity. The exchange of information i.e. measurements, warnings & alarms, inventory & configuration data, will become key for an efficient and highly automated cooperation of different equipment at the BS site. This exchange of information may occur on various architectural levels on-site or at even higher architectural layers between the NMS, as presented in Figure 8.

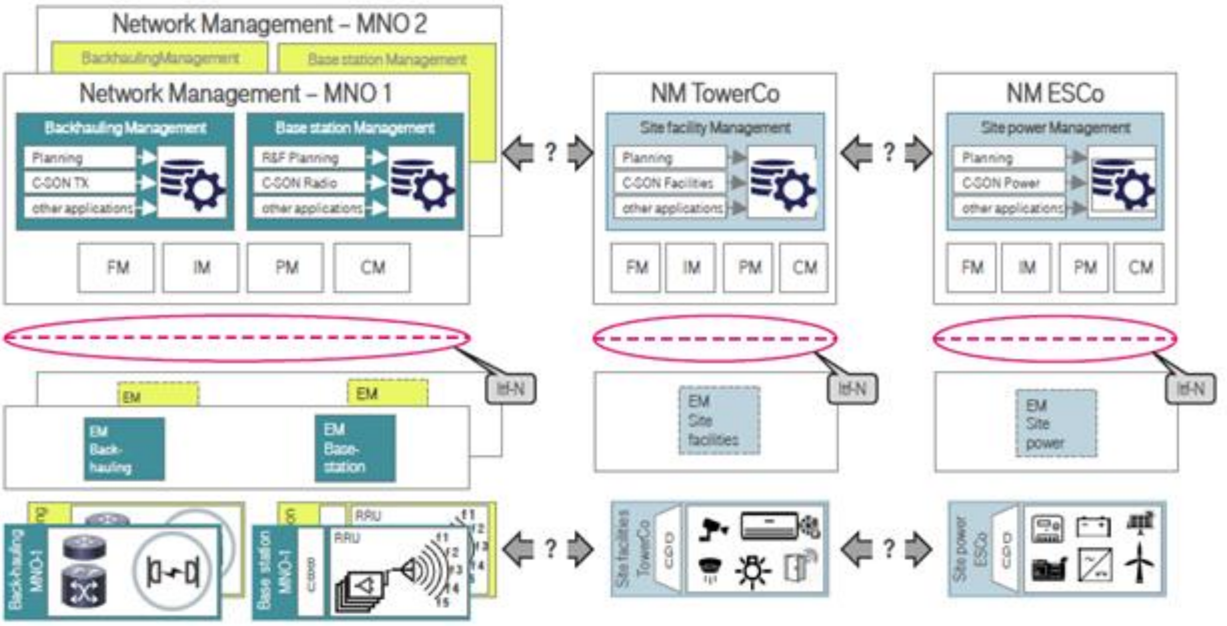



**Figure 8. Site Sharing: Interaction of Site Facilities and BS-equipment on Various Architectural Levels**

Additionally, a fair and transparent energy cost invoicing, origin of used energy, etc., based on measurements, will become of vital interest for all parties involved. The global year-to-year growth of mobile network data traffic is around 45% [7]]. To cope with this growth rate MNOs need to continuously improve the overall (radio, transmission and site equipment) joule/byte ratio in order to keep the curve of energy costs flat. ITU-T defines for BS site an indicator called Site Energy Efficiency (SEE) that measures the efficiency of sites and that can be used to control site status. [8], [9]. In this context, Figure 9**Fehler! Verweisquelle konnte nicht gefunden werden.** illustrates different types of site sharing and the role of Tower Companies.

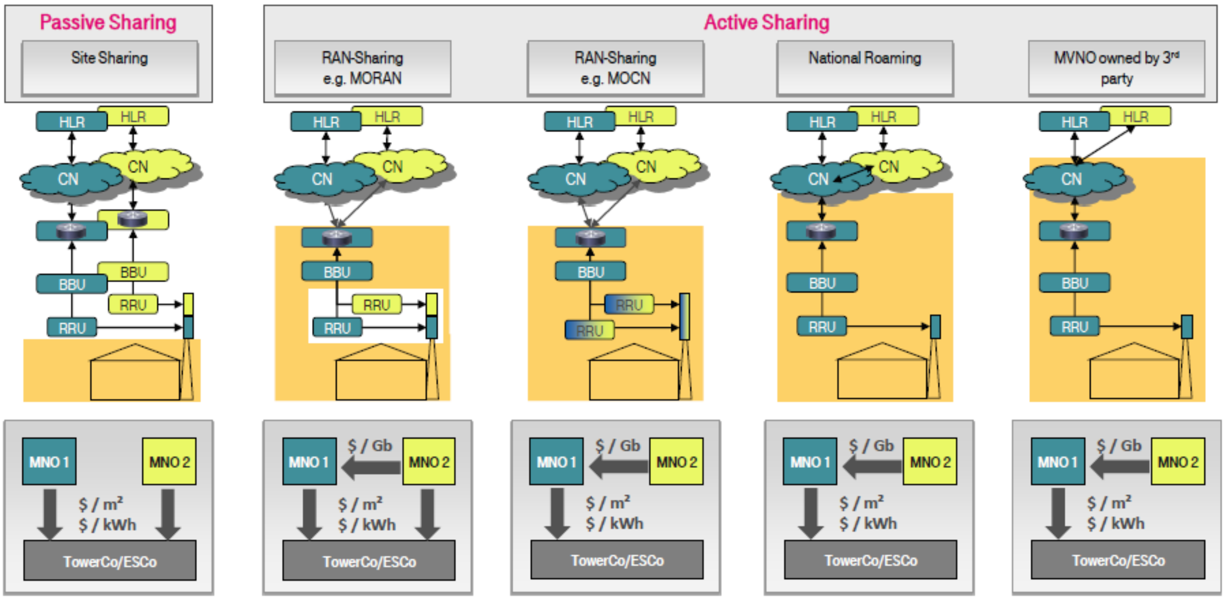



**Figure 9. Sharing Scenarios Between MNOs and Business Relationships Indicated by Simplified Key Performance Indicators (KPIs)**

The detailed understanding of the energy consumption of each component at a site enables MNOs, Tower Company & ESCO's to focus on individual energy efficiency priorities including renewable energy production and to directly benefit from these activities.

In future, the complexity of BS site tends to increase since on top of the telecommunications equipment, the energy production system is also installed as shown in Figure 10.

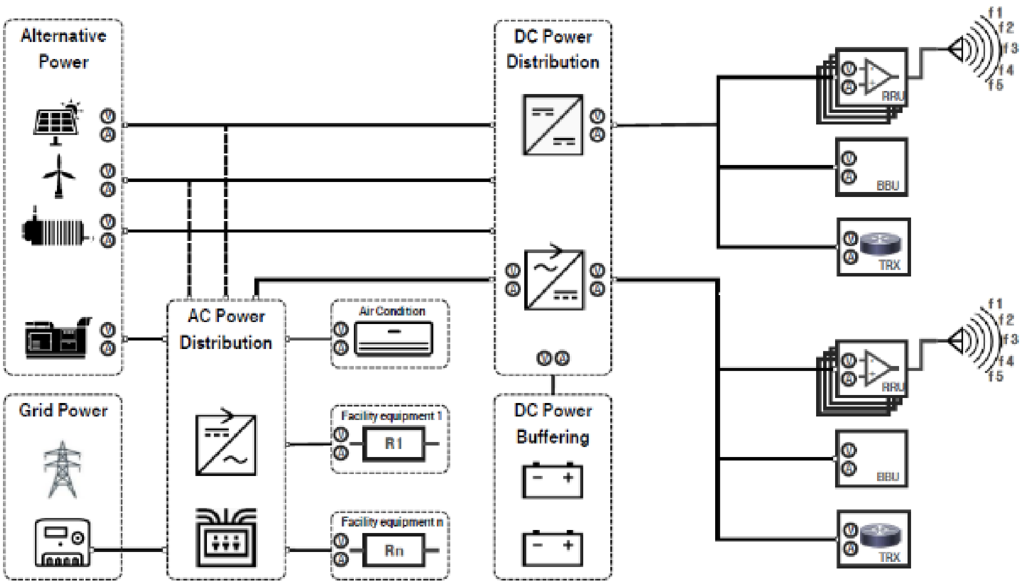



**Figure 10. Passive Site Sharing: Metering Supports Inter-working Between MNOs, Tower Company and ESCO at a Grid and/or Multiple Powered Site**

## 3.4 Use Case 4: Towards Disaggregated and Virtualized Networks

This use case describes how aggregated RAN, disaggregated RAN and virtualized network architectures impact energy consumption.

### 3.4.1 Aggregated Radio Access Network

Wireless mobile networks have experienced a rapid increase in the number of users and data traffic, mainly driven by new data services like online gaming and high definition video streaming.

As a result of the introduction of new spectrum bands, which are used by existing Long Term Evolution (LTE) and emerging 5G technologies, and the related architectural diversity, the demand for electrical power will continue to increase. Indeed, a benchmarking study from GSMA pointed out that energy cost in radio access networks are up to 20% - 40% of the annual OPEX [10]]. Hence, one of the main challenges for MNOs is decreasing their operational expenditures and becoming greener.

To this end, MNOs will need accurate data to be able to decide on optimal migration paths towards suitable architectures for BS sites. Standardized power metering, with well-defined accuracies, and the re-use of existing telecommunication management systems for energy measurements will enable MNOs to define the status of the network energy consumption and to derive insights for future network design and plan and reconfiguration of current networks.

In aggregated RAN or “current cellular systems” the BS constitutes both base band processing and radio front-end, which are located at the BS site. The following Figure 11a indicates where the energy consumption should be measured at the BS site, namely at site and BS equipment level.

As the BS equipment is the main energy consumer at a *BS sit*e (i.e. rule of thumb around 70% related to the mobile traffic and hardware components) suppliers of *BS equipment* have implemented power meters into their systems during the last decade. In 2020 3GPP explicitly took over the ETSI requirements into their standardization environment called “Power, Energy and Environmental (PEE)” parameters [11]. In a consequent step approaches and functionalities to save energy and to increase energy efficiency are defined. With this specification, MNOs can track the energy consumption of their systems and optimize it.

MNOs will focus on the conformity of the PEE-meters and measurements to international standards (see Section 4 about requirement for metering). Figure 11 (a) shows the metering position considered in this case.

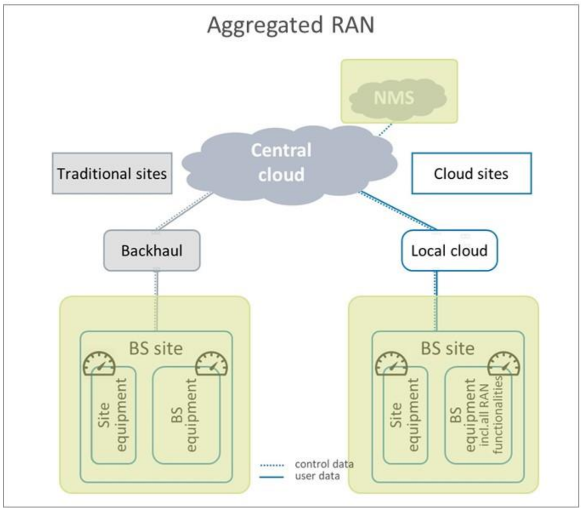



**Figure 11 (a). Overview of an Aggregated RAN with Measuring Equipment at BS Site According to ITU-T 1331 [2]]**

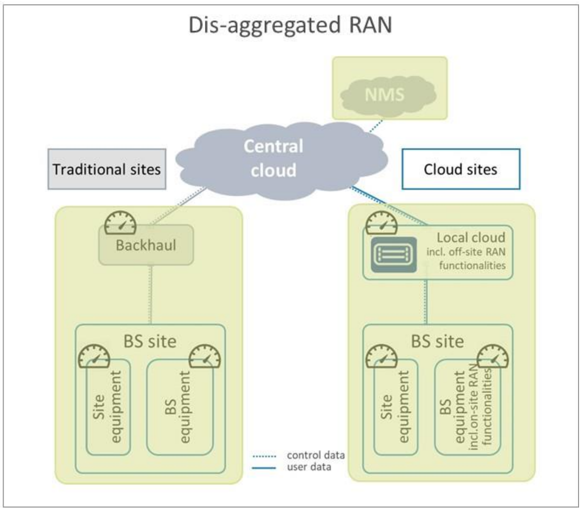



**Figure 11 (b). Overview of a "Disaggregated RAN" With Measuring Equipment not Only BS Site but also at Backhaul Site According to ITU-T 1331 [2]**

The big variety of hardware configurations across an operator's network and their different traffic profiles make it difficult to manually configure energy saving parameters. Therefore, MNOs are evaluating fully automated solutions and their impact on quality and Customer eXperience (Cx). The control over the activation and parameter settings of these features will be automated as much as possible. The Introduction of AI and automation based solutions, that leverage energy reductions up to 15%, are already available [12].

### 3.4.2 Disaggregated RAN

Looking on Distributed RAN (DRAN) network elements and embedded, proprietary hardware and software components i.e. Baseband Units (BBU), Remote Radio Unit (RRU), there are, normally, several hardware equipment generations in use.

Due to advances in software-defined radios that enable efficient and scalable implementation of RAN functionality on programmable platforms, it is possible to split the BS into a radio front-end and a back-end software implementation of base-band processing. This results in a pool of software-defined radio engines and BBUs, running on a cloud computing platform, that provides base-band processing services to radio front-ends and Remote Radio Heads (RRHs), which are deployed in the BS site.

Cloud-RAN has to cope not only with processing latency in servers but also with latency and throughput on fronthaul interfaces. A fronthaul link - an interface between RRH and BBU - is a new element that does not exist in traditional BS systems.

Figure 11 (b) illustrates how the energy consumption can be measured in a Disaggregated RAN. More details relating to different Disaggregated RAN solutions can be found in Figure 12.

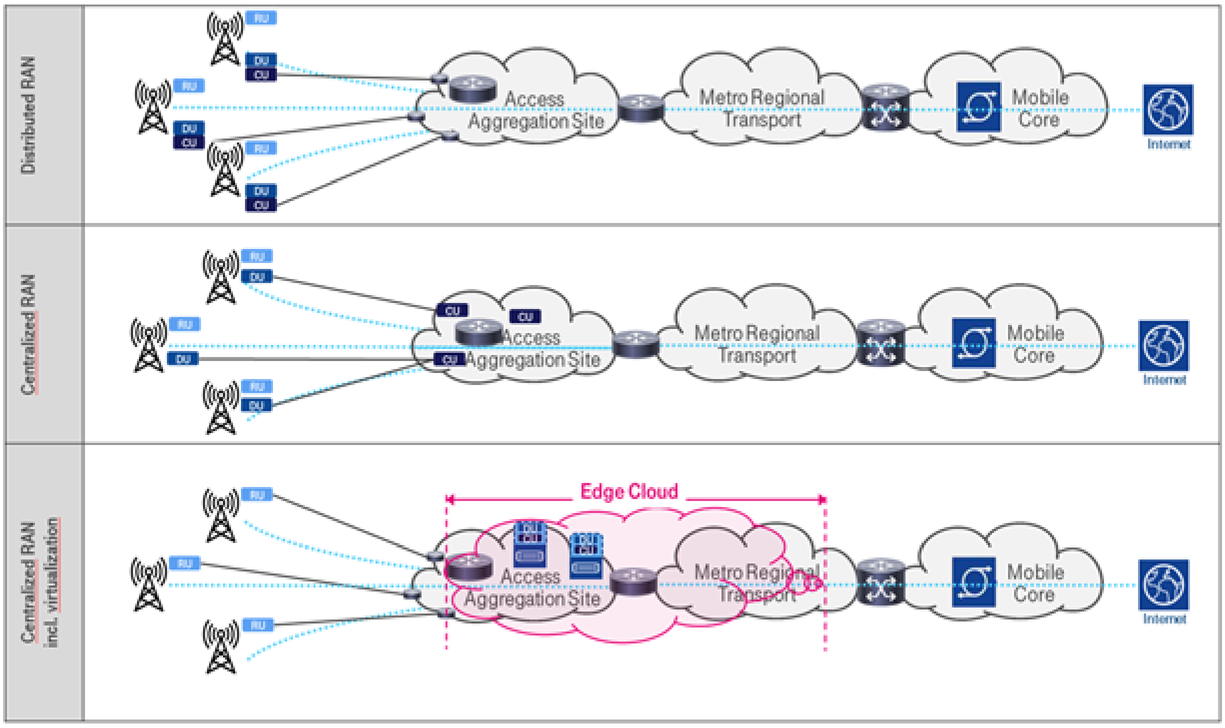



**Figure 12. Overview of Disaggregated RAN, Centralized RAN and Centralized RAN with Virtualization.**

A RRU for example could consist of several modules serving dedicated frequency bands, Radio Access Technology (RAT) combination(s) or looking on new Ultra-Wideband modules (UWB). In addition, a BBU consists of several hardware units. In recent RAN hardware developments like UWB, on-board metering capabilities are limited (i.e. as defined by ETSI ES 202 336-12 [3]). Compared to single RAN modules, UWB modules support several frequency bands and RAT combination(s) per module. Resulting energy consumption per UWB includes different RAT, whereof energy consumption per single RAT is not natively given, when applying ETSI ES 202 336-12 [3].

To gain a better understanding of energy consumption at a more granular level than at equipment unit level, it is important that energy consumption measurements are provided also at a board/card level of an equipment unit. This is beneficial for several reasons: for instance in DRAN architectures, energy consumption measurements can be determined per RAT across respective RRU and BBU together. These energy consumption measurements approach will help to provide transparency across deployed RAT also in Cloud RAN (CRAN) architectures.

MNO may request energy consumption per RAT to understand respective consumption per service. To achieve this, new methods/models are needed to obtain energy consumption not only at the lowest level per hardware component, but also for functions provided by new hardware solutions and for all Virtualized RAN approaches (e.g. Virtualized RAN (V-RAN), Open RAN (O-RAN, etc.).

Previous paragraphs show that a combination of metering and intelligent features is needed to understand energy consumption at lowest component level to gain maximum EE benefits from networks.

### 3.4.3 Network Virtualization

With the advent of 5G, network virtualization may now apply to the whole network (RAN, core). 5G network functions will be deployed as software running on off-the-shelf servers in central, regional or edge data centres. This may lead to new situations such as e.g.:

- 5G network functions running on multiple servers,
- Multiple 5G network functions running on the same server,
- 5G network functions running on servers in a data centre owned and operated, or not, by the MNO,
- 5G network functions dynamically migrated from central cloud to edge cloud and vice versa, based on MNO's policy,

The decoupling between 5G network functions and the hardware on which they run brings a new dimension regarding definition and measurement of the actual energy consumption of network functions in live networks.

Measuring the energy consumed by 5G network functions requires measuring the energy consumption at a more granular level than at the server, as a server may host several network functions, potentially down to the micro-service level.

Furthermore, with 5G slicing, it may happen that a customer orders a network slice from a mobile network operator and, to assess its environmental footprint, requests the MNO to provide its network slice energy consumption, based on measurements from each network function constituting the customers network slice.

Customer may need to know the energy consumed by its network slice per type of energy source. As MNOs may share 5G network functions between network slices offered to various customers, it is needed to distinguish the part of the 5G network functions energy consumption attributed to each customer's network slice.

# 4 REQUIREMENTS FOR METERING

As already mentioned in the previous section, energy consumption constitutes between 20 – 40% of mobile access network OPEX [10] which makes energy saving by intelligent methods an important target for MNOs. The ever-increasing traffic as well as the increasing prices of energy makes the knowledge about energy consumption and efficiency a key success factor impacting the migration towards green networks. For instance, major driving factors could be:

- Energy efficiency of telecommunication equipment and related site equipment will become part of procurement decisions as recurring energy consumption strongly impacts the overall network sustainability. MNOs will permanently validate the promised energy efficiencies requested in RFQs by daily network wide performance measurements as opposed to the latest static laboratory environment KPI.
- Emerging renewable power units will enable MNOs to have higher contribution of renewable energy for their networks. Nevertheless, the varying availability of the renewable energy from the grid requires accurate measurements to have an efficient energy management.
- The contribution of locally produced renewable energy will also increase. The Return-On-Investment (ROI) of the on-site installations (PV panels, windmills, etc.) can be shortened with a more efficient on-site energy management. It is essential to have forecasts of the site's energy demand according to the usage of radio network equipment.

Use of metering will provide necessary insights regarding the behaviour of energy-intensive parts of the network. This will lead to an optimization and intelligent management of the networks' energy efficiency. On top of this, customer and investor demands on sustainability will continue to increase as well as regulations request for KPIs based on those metrics.

## 4.1 General Requirements for Metering and the Collection of Data

Current, voltage and energy consumption are the most important values to be measured for energy saving activities. Therefore, every equipment on the network i.e. BS equipment, site equipment and others, shall be capable to measure these parameters. Furthermore, giving that every equipment has an intended usage, their specific performance indicators shall be monitored too i.e. traffic, active carriers, etc.

All measurements should be accurate and comparable. As various equipment with different scales of energy consumption are interworking at a BS site, the accuracy classes of power meters need to be known and harmonized. These ideas should also apply to all kind of intended use parameters like data throughput, filling level of tanks (kg, m³ or %), capacity of batteries (State of Charge (SoC), State of Health (SoH) in %), etc. The principles of measuring as well as the accuracy of the measurements should follow international standards with specified accuracy classes. For BS equipment ETSI and 3GPP are significant standardization bodies. For site equipment additional international standardization bodies like IEC, EN, IEEE, JIS, etc. play a more dominant role.

Measurement data are collected at various sites in the network (BS sites, Access Aggregation Sites, etc.) and transmitted to one or several NMSs of MNOs, Tower Companies and ESCOs (see 3.1 and 3.3). International standards for the interfaces between the NMSs and the operational handling of them will support the unobstructed exchange of measurement data for advanced AI-based optimization models. This will enable to improve energy efficiency not only at site level, but also at network level and generate considerable energy savings as well.

## 4.2 Metering for Facilities / Site Equipment

This section describes metering and networking for facilities equipment e.g. energy equipment, cooling equipment, site environmental control and monitoring for MNO and Tower Company considering use cases reported in Section 3.

In this context, Figure 13 illustrates a traditional solution used to measure the energy consumption in site sharing / Tower Company scenarios with external Alternate Current (AC) power meters #1 and #2 dedicated to any MNO (carrier) present on the site. Here, the site energy distribution is neither monitored nor remotely controlled and adding further equipment to this facility will increase the complexity. Furthermore, it involves visiting the site in case any problem arises.

Also in some sites, as no detailed monitoring is available, unauthorized (e.g. connection of active equipment unauthorized by MNOs) or incorrectly (e.g. not connected to the right distribution frame) connected devices affect site reliability and security, making site management more complex.

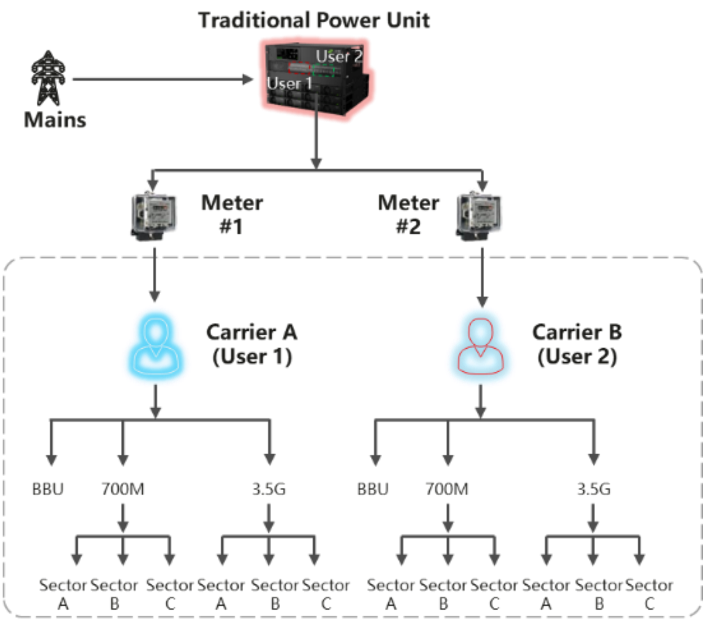



**Figure 13. Traditional Site Facilities Metering**

In future, refined power consumption management is required for the sites. In addition to the current utility energy metering, a simple AC energy consumption measurement cannot provide the detailed site energy consumption statistics and the reliable guidance needed for site energy saving management.

The energy efficiency of the entire site based on Direct Current (DC) metering and energy consumption indicators needs to be evaluated both at the first energy distribution layer and at its sub-distribution layers as well. Based on this site energy consumption data, inefficient sites and devices can be identified and energy efficiency can be visualized.

The power consumption of active equipment varies according to measurement methods. Therefore, different site configurations require different Power Distribution Units (PDUs). Similarly, each site active equipment's energy consumption needs to be measured in a differentiated manner.

DC metering function with remote power-on/off control and software-defined will be the trend. Then, more granular power metering per function or active equipment can be used to manage site energy consumption. Energy consumption data needs to be reported to the NMS so that the running policy, after energy consumption data analysis, could be delivered to sites for energy saving management.

The energy operation support system should have the capabilities below (non-exhaustive list):

1. Energy efficiency and energy consumption detailed report: The SEE report (i.e. main equipment energy consumption/total input energy consumption) is collected and reported as a function of physical parameters, site region and type. Then, it can be displayed for different time periods, regions and site types. Energy consumption and energy efficiency statistics of best-in-class regions or sites are collected and analysed.
2. Site temperature monitoring and management: Identify low-temperature sites based on site temperature analysis, preventing low-temperature air conditioners from running and reducing air conditioner power consumption.
3. The management system should analyse efficiency based on the site service traffic and display the service traffic/total energy consumption report to visualize the service traffic/total energy consumption, with reference to consumption. Furthermore, it should help users identify low-traffic and high-power-consumption sites likewise.
4. The renewable energy yield i.e. solar, wind, etc. should be monitored and the introduction of green power should be evaluated as well.
5. The site facility equipment power consumption should also be monitored (see Figure 2), including cooling, intelligent access control and camera surveillance. The management system should support remote operations, for instance remote monitoring via camera.

The metering of site equipment for MNOs is illustrated in Figure 14. The traditional solution used to measure the energy consumption in site sharing / Tower Company scenarios has the limitation described above. To remove these limitations, the power system itself should be embedded with the precise metering function for each active equipment. Based on the results from analysis, the power system can identify active equipment with abnormal energy consumption, perform precise power-on/off control, and differentiate power backup for each of them. This function is recommended as a standard function of the power system in the 5G era. Standards such as Redfish Power Distribution equipment [13]] could be leveraged. Different circuit breaker type integrated with the metering function can be developed. That is, the circuit breaker integrates the metering and disconnection functions to implement precise metering, control, and power-off of each active equipment.

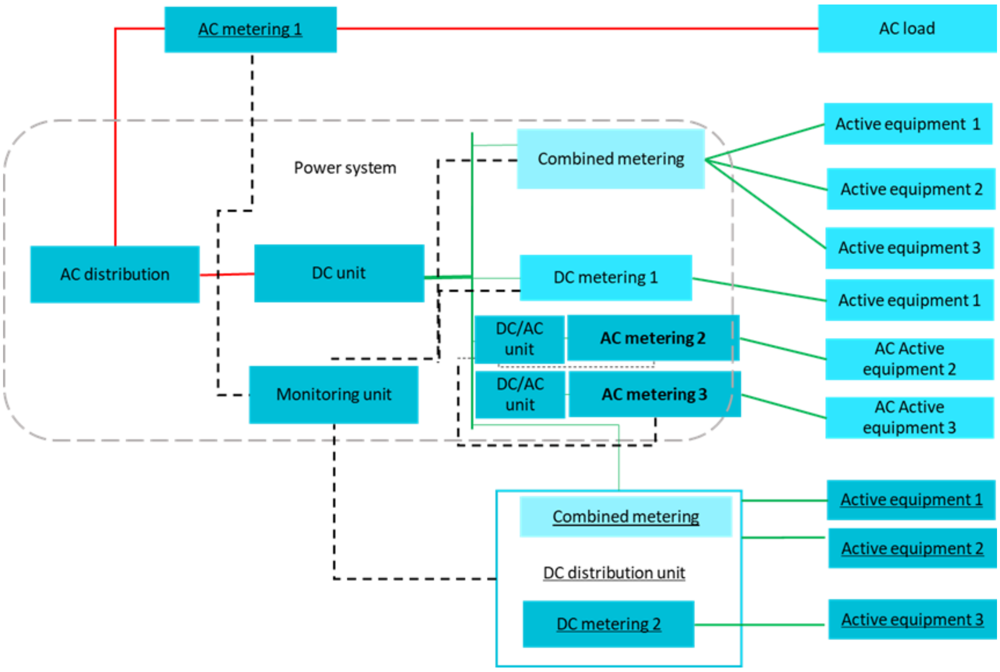



**Figure 14. Schematic Diagram of Monitoring on Facilities**

The main functionalities of these type of solutions are:

1. Software-defined metering for precise metering of each active equipment: Software-defined metering enables accurate device-level power consumption measurement. Users can identify abnormal power consumption in real time, improving power consumption efficiency.
2. Software-defined authorization and power-on/off for more intelligent management: Authorize and activate the circuit breakers by software authorization, to achieve active equipment power-on and off and independent control of circuit breakers 1, 2, and 3 etc.
3. Software-defined capacity for more flexible power distribution: With software-defined capacity, power systems can be expanded on demand without power distribution replacement and site interruption. On-demand capacity configuration is more flexible and does not waste any resources.
4. Precise consumption measurement and energy flow control: In traditional management solutions, no indicators are available to evaluate the energy efficiency of the entire site, and the energy performance is invisible. As a result, firstly, low-efficiency sites and devices cannot be identified, leading to a high energy consumption. Secondly, there is a large number of devices on the entire network and the devices running data change dynamically. Manual management cannot ensure that devices run in the optimal energy efficiency state, resulting in high power consumption.

The management system must be able to visualize and evaluate the energy efficiency of the entire site, helping MNOs identify low-efficiency sites and devices and reconstruct them. The management system must provide energy efficiency statistics (power consumption of wireless devices/total power consumption of the entire site) on the entire network and analyse to automatically identify low-efficiency areas and sites. In addition, the management system needs to analyse and evaluate the efficiency of the entire network including the site equipment, based on the service traffic of the site. This visualizes the service traffic and total energy consumption of the site, helping MNOs to identify low-traffic and high-energy sites. Based on the analysis report of the management system, they can optimize the site to minimize the energy consumption per bit. Finally, the visualization of energy efficiency indicator enables MNOs to establish an energy-saving evaluation system, which helps them not only to evaluate the effect of energy saving features but also to promote further activation of such features.

## 4.3 Support for Power Metering in Virtualized Environment.

Server power consumption for ETSI Network Function Virtualization Infrastructure (NFVI) [14]] is available from the following frameworks and interfaces:

- Collectors from open industry forums including
    - Kafka
    - Influxdb
    - VES
    - Prometheus
    - Many others

  The above frameworks/interfaces have been published as part of the CNTT & Open Platform for NFV (OPNFV) and Barometer projects now part of CNTT Anuket (with CollectD for OPNFV) [15]].
- Other open standard interfaces that monitor the underlying hardware infrastructure such as Redfish Telemetry [16]] apply to chassis and servers and provide thermal, power, memory and processor metrics and are implemented by some server vendors. An open source implementation of the Redfish telemetry API is being implemented by the Linux Foundation ODIM project [17]].

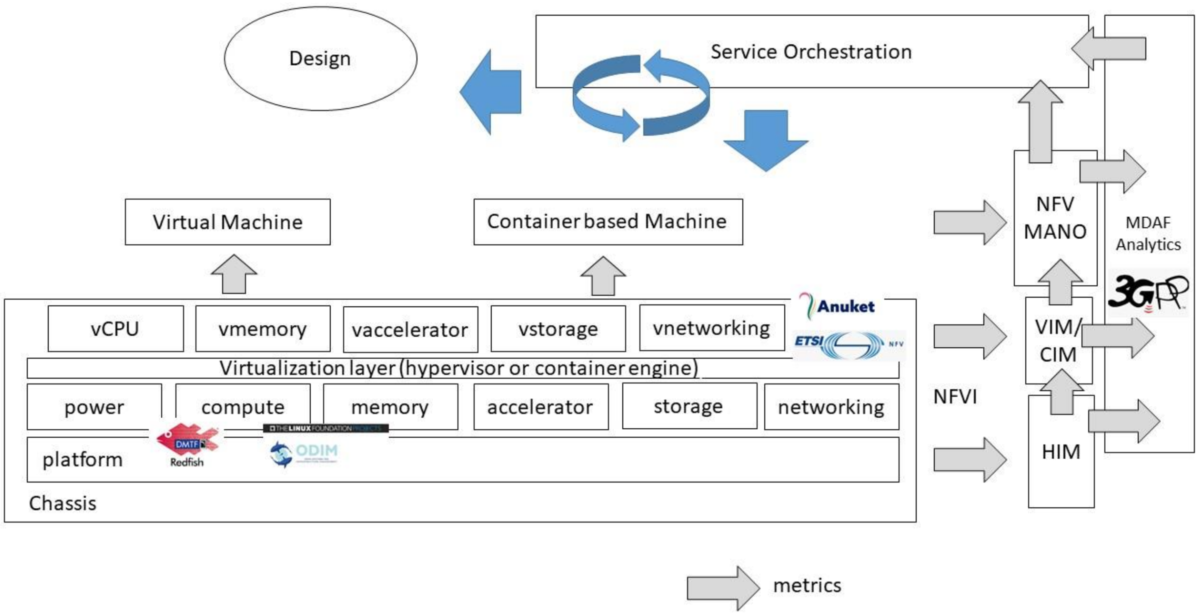



**Figure 15. Telemetry & Power Consumption Metrics for Virtualized Environment**

A platform solution as represented in Figure 15 above illustrates that collected data includes telemetry for compute/CPU, memory, storage, networking interface and power consumption, as well as Virtual Machine (VM) or container-based machine status and resource utilization. Telemetry collectors send data to Hardware Infrastructure Management (HIM), Virtualized (VIM) and Container based Infrastructure Management (CIM) and ETSI Network Functions Virtualization Management and Orchestration (NFV MANO) layers including Network Function Virtualization Orchestrator (NFVO) but also to monitoring and analytic functions such as 3GPP Management Data Analytics Function (MDAF). These metrics are processed at different levels and smart metrics issued to a Service Orchestration platform that performs some actions and completes the closed loop. This closed loop is more and more automated leading to zero touch management. Many existing standards contribute to this platform and a number of vendor products support these standards or expand with further metrics, such as HPE Integrated Lights-Out (iLO) and embedded telemetry function in Intel® Xeon® Scalable Processors.

The telemetry from such platform can be used to build power recommendation policies that subsequently can be applied to optimize power for the workload demand.

**Table 1. Examples of platform power optimization use cases.**

| Platform power use cases | Reports/Insights from collected Platform Telemetry | Automated actions |
|---|---|---|
| Energy Efficiency/OPEX savings | Application shows low load | Scale up/down power via feature activation or scaling power |
| Energy Efficiency/Service Level Agreement (SLA) | Network Slice energy efficiency below SLA | Either update the slice with more energy efficient components, or switch traffic to more energy efficient network slice |
| Improved Performance in same Power Envelope | Platform/Application | Deploy new workloads to nodes benefiting from Optimized (higher or lower) frequency cores |
| Power Aware Workload Placement | Platform shows high load | Back-off, scale up or down, scale out or in deploy based on power consumption |

Examples of power metrics

- Per core utilization, Busy %.
- Per core C-state Residency
- Per core temperature
- CPU package temperature
- CPU Watts (Package Watts)
- Intelligent Platform Management Interface (IPMI) Metrics, including fan speeds, temperature and Power Supply unit (PSU) power
- Memory/Data random access memory (DRAM) power

Examples of Load Indication Metrics

- Application Processor Utilization as measured by the operating system
- Application load/busyness measurement, as measured by networking applications using Data Plane Development Kit (DPDK)
- Network interface receives rate
- Network interface transmits rate
- Network interface packets drops

# 5 ARCHITECTURES AND PROTOCOLS RECOMMENDATIONS FOR METERING SOLUTIONS

This section describes architecture and protocol recommendations for metering. The focus in this section is on BS site use cases presented in Section 3. The target is to collect information from equipment present in these sites as well as from the whole environment i.e. power system, cooling system, energy storage system, etc. The objective is to allow MNOs to improve the energy performance of the BS and the overall site electricity consumption.

The architecture and protocol recommendation described for BS can be extended also to fixed sites, like core and data centre, using similar architecture.

## 5.1 Existing Standardized Solutions

Different standard organizations have defined specifications for network measurements, including ETSI, 3GPP and ITU-T for instance.

As far as 3GPP is concerned, the initiation, management and termination of measurement jobs from an Operations Support System (OSS) can be done via either Representational State Transfer (REST) / HTTP / Yet Another Markup Language (YAML) or Yet Another Next Generation data modeling language (YANG) / NETCONF APIs.

The reporting of performance measurements to the OSS system can be done either via Extensible Mark-up Language (XML) or Abstract Syntax Notation 1 (ASN.1) or Google Protocol Buffer (GPB) files transferred via Secure File Transfer Protocol (S-FTP) protocol in case of file-based reporting, or via Web sockets using either ASN.1 or GPB format in case of streaming.

Operations of Control / configuration are also made possible using either REST / HTTP / JavaScript Object Notation (JSON) or Network Configuration Protocol (NETCONF) / YANG APIs.

A number of PEE measurements are already defined in 3GPP [18]] (in accordance with ETSI [3]) and valid for 5G PNF (Physical Network Function), these are:

- Power (Average, Minimum, Maximum),
- Energy Consumption,
- Temperature (Average, Minimum, Maximum),
- Voltage,
- Current,
- Humidity.

To collect those measurements, the measurement system can be configured via Operation, Administration and Maintenance (OA&M), for example with the following parameters:

- Start time,
- Stop time,
- Granularity period,
- Reporting period,
- Reporting method, which can be:
    - File-based, where files can be sent out from every 5 minutes to 24 hours,
    - Streaming.

3GPP [19]] also defines the EE KPI for Next Generation RAN (NG-RAN), in accordance with ETSI [1] and ITU-T [2], as the ratio between the Data Volume (DV) divided by the energy consumption of the considered next generation Node-B (gNB) network elements, being physical (PNF) or Virtualized Network Function (VNF). For VNF, the estimated energy consumption is the sum of the estimated energy consumption of the VNFC (VNF Components) considering only virtual compute as mentioned in Release 17 [19]].

Accuracy of sensors is defined in ETSI standard ES 202 336-12 [3]. Also, on top of the collection of the measurements, 3GPP [5]] defines the following network function parameters:

- Site identification
- Site latitude
- Site longitude
- Site description
- Equipment type
- Environment type
- Power interface

which can be accessible from an OSS system.

These different standards in terms of architecture i.e. equipment, measurement system and OA&M, protocols and measurement could apply for existing networks and 5G deployments but may also apply for future networks.

## 5.2 Recommendations for Potential new Solutions

This section describes different new architectures related to the use cases described in Section 3. The aim is to propose a unified solution for multiple operation models as well as source and type of data.

### 5.2.1 Data Collection Unified Architecture

It is expected that a unified architecture is to be standardized by relevant Standard Development Organizations (SDOs) in the near future. Such an architecture should be generic enough to be applicable to the different use cases identified in this White Paper, where we find use cases such as:

- Multiple operation models implying different types of stakeholders;
- Multiple types of PEE data to be wholly or partially controlled and monitored by these stakeholders;
- Multiple sources of PEE data in the telecom site, which include: BS(s) with embedded sensor, BS(s) with external sensor, power units, site equipment such as e.g. cooling system(s), site control unit(s);
- Multiple PEE devices with different capabilities with respect to PEE data collection.

It is expected that when applicable, PEE data shall be collected via the OA&M channel which is also used to collect other OA&M performance measurements such as e.g. data traffic volume measurements.

For future standardization, as in existing 3GPP TS 28.532 [19], it is expected that PEE data be collected using latest communication APIs and protocols such as RESTful HTTP-based on YAML or JSON payload.

Following sections present the unified architecture principles to be applied for 'site-internal' (local) communications or communications between the site(s) and external Network Management System(s).

### 5.2.2 Site Internal Communication Architecture

On a technical site, site equipment, site control unit(s) and power unit(s) may come from different vendors and support different levels of capabilities and versions of protocols for the control and monitoring of their PEE data. Therefore, they should be equipped with Next Generation Control Unit (NG-CU) or Next Generation Data Gathering Unit (NG-DGU) to be able to collect the relevant information. These next generation units should include a higher level of intelligence as described below:

- NG-CU: site equipment, power unit(s), site control unit(s) are each connected to one NG-CU, as presented in Figure 16, NG-CU monitors and controls the connected equipment through sensor and actuator (see ETSI [3]), via serial, digital, or analogue interface. This functional unit is used for several functions:
    - To collect PEE data from one equipment via serial / digital / analogue interface / protocol and forwards it to external NMS(s) via the Entry Point NG-DGU,
    - To receive commands from external NMS via the Entry Point next generation data control unit (NG-DCU) and forwards them to the equipment as serial / digital / analogue commands,
    - To act as a mediation between serial / digital / analogue interface / protocol and latest technologies communication protocols;

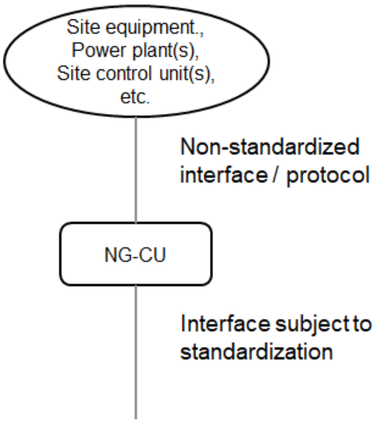



**Figure 16. NG-CU Based Architecture**

- NG-DGU: site equipment, power unit(s), site control unit(s) from same vendor are connected to a NG-DGU, as presented in Figure 17. This functional unit performs several functions:
  - collects PEE data from several equipment via serial / digital / analogue interface / protocol and forwards it to external NMS(s) via the Entry Point NG-DGU,
  - receives commands from external NMS via the Entry Point NG-DCU and forwards them to the equipment as serial / digital / analogue commands,
  - acts as a mediation between serial / digital / analogue interface / protocol and latest technologies communication protocols,
  - supports latest technologies communication protocols e.g. REST / HTTP / YAML.

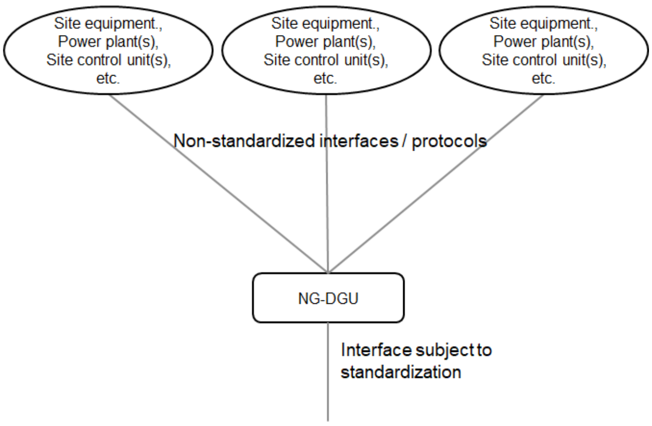



**Figure 17. NG-DGU Based Architecture**

In addition to these improvements, it is expected to also include a new functionality called Entry Point in the standardized solutions, Figure 18, which is supposed to be the input/output point between the site and the external NMS(s).

- Entry Point: is responsible in the telecom site for the control and monitoring of the following type of on-site equipment:
  - Power units (e.g. rectifiers, batteries, solar panels, solar regulators, generators, fuel cells) via their NG-CU / NG-DGU,
  - Cooling systems via their NG-CU / NG-DGU,
  - Building controls via their NG-CU / NG-DGU.

Collection links of sensor, NG-CU, NG-DGU internal to the site can be wired or wireless.

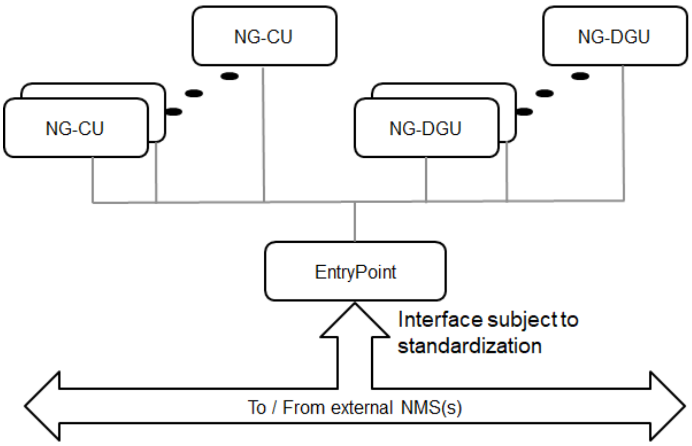



**Figure 18. Entry Point**

### 5.2.3 Communication with Network Management System(s)

The overall architecture including how the Entry point communicates with NMS(s) is illustrated below according to three scenarios. Please notice that this list of scenarios is not exhaustive.
In other parts of this document, it is assumed that BSs are all Type-1 BSs, i.e. BSs with embedded sensors (see [3]).

**Scenario #1: Site and network equipment owned by the MNO**

In this scenario, the following actors are involved:

- MNO: owns and operates the BS site and site equipment but also controls and monitors site equipment and on-site BSs related PEE data. The MNO owns the following elements:
  - Telecom site
  - Site equipment (incl. cooling systems), equipped with NG-CU or NG-DGU
  - Site control unit(s), equipped with NG-CU or NG-DGU
  - Power unit(s), equipped with NG-CU or NG-DGU
  - BS(s) with embedded sensor.

As observed in Figure 19, the following principles apply:

- The OA&M channel used by the MNO to collect BSs' performance measurements (as well as to collect alarms, provision configuration parameters, etc.) serves also to collect and monitor PEE data via same API and protocol;
- All collected data is sent in-band via the OA&M channel to MNO's NMSs via latest technologies telecom protocol;
- Entry Point collects PEE data from / to all site NG-CUs / NG-DGUs;
- BSs send their PEE data, as well as any other BS performance measurements, directly via the OA&M channel.

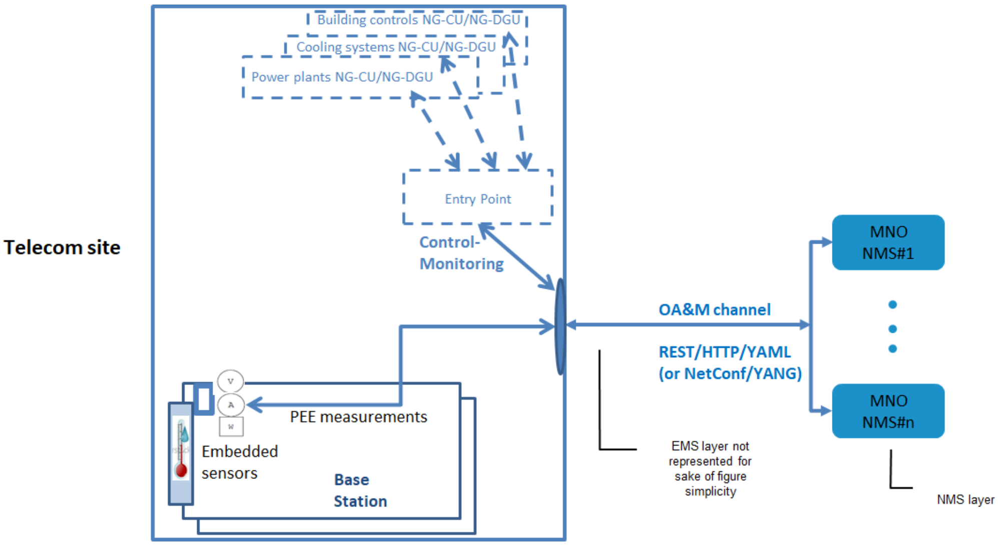



**Figure 19. Architecture for Scenario #1**

In this scenario, it is expected that the Entry Point is deployed and managed by the MNO.

**Scenario #2: site owned by Tower Company with one or more MNOs on the site**

This scenario includes architecture such as Passive RAN sharing, Tower Company and MNOs. Therefore, the following actors are involved:

- Tower Company owns and operates site and site equipment, controls and monitors site equipment related PEE data;
- MNO owns and operates on-site BS, controls and monitors its BS including related PEE data.

For any given BS site owned by a Tower Company, on-site BSs equipment may be owned by different MNOs. Currently, Tower Companies owning BS sites do not use the OA&M channel of the BS(s) located on site to communicate site equipment related PEE data to / from the NMS(s). It uses a different communication channel. It is recommended that the OA&M communication channel between the site Entry Point and the Tower Company NMS uses same latest technologies APIs and communication protocols.

As represented in Figure 20,

- The telecom site belongs to Tower Company
- Two Type 1 BSs (equipped with embedded sensor) are deployed on site. Please notice that there can be more than two MNOs present on the site.
  - One belongs to MNO#1
  - Another one belongs to MNO#2.

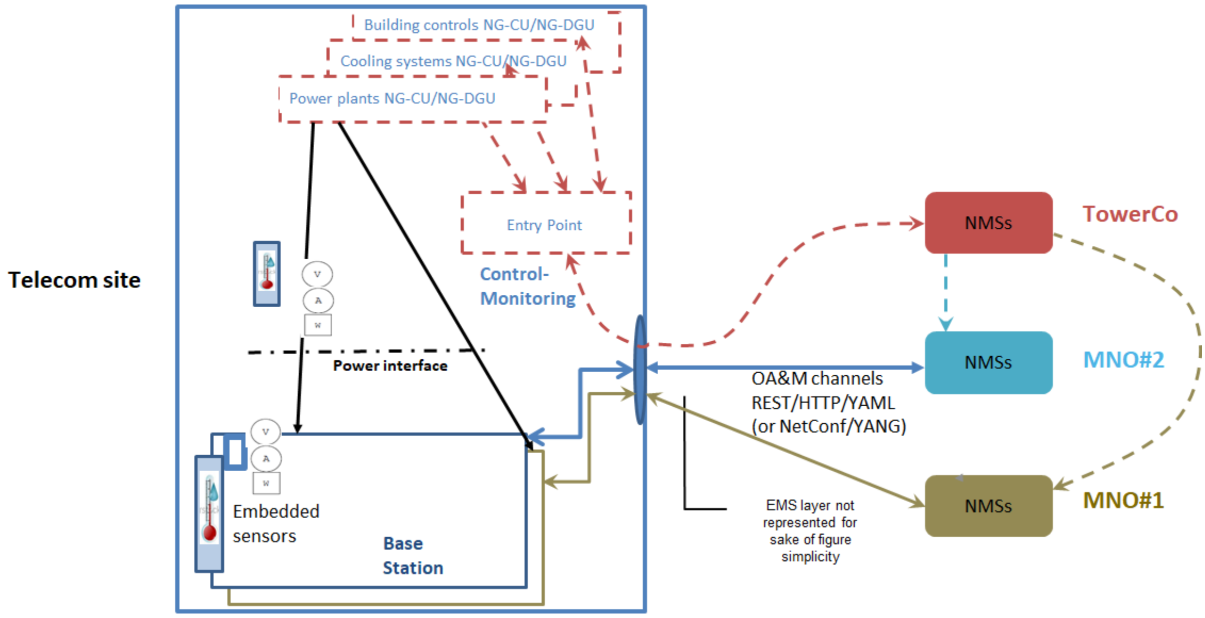



**Figure 20. Architecture for Scenario #2**

In this scenario, the following principles apply:

- Tower Company collects all site related PEE data as well as per BS PEE data
- MNO#1 and MNO#2 collect their own BS related PEE data
- Tower Company provides MNO#1 and MNO#2 with (part or all of) their BS PEE data. In this way, Tower Company can monitor all the site and optimize the site utilization increasing the efficiency at site level and as consequence of all the network.

In this scenario, it is possible to consider one single Entry Point deployed and managed on site by the Tower Company, as a separate unit. This Entry Point should enable the communication between Tower Company NMS and all on-site NG-CUs / NG-DGUs.

### Scenario #3: Active RAN sharing

In this scenario, the following roles are involved as defined in 3GPP [20]]:

- Master Operator (MOP): owns and operates site and site equipment, controls and monitors site equipment related PEE data, owns and operates on-site BSs, controls and monitors BSs related PEE data;
- Participating Operator (POP): Participating MNOs are service providers who share, alongside other Participating MNOs, the RAN facilities provided by the Master Operator.

As presented in Figure 21,

- The technical site belongs to the Master Operator.
- Two BSs are deployed on site and are owned by the Master Operator.
- Both BSs are managed by the MOP. The Master Operator is the only one to have a direct NMS connection to the site and shared BS(s)
- Master Operator provides Participating MNOs with (part or all of) its BS(s) PEE data as well as site related PEE data, based on their RAN sharing agreement.

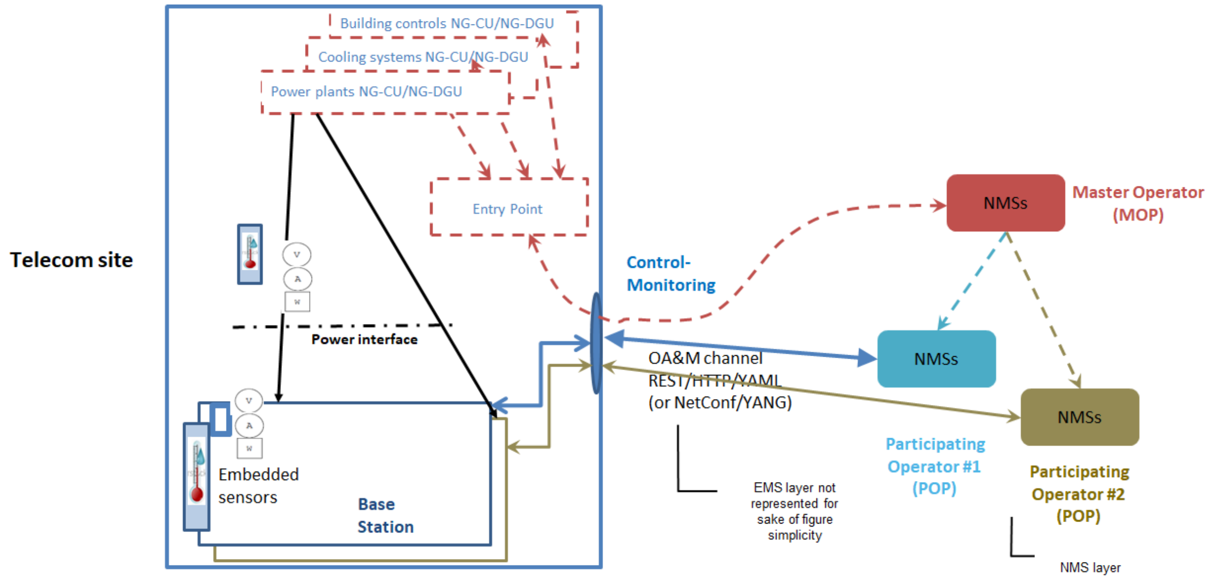



**Figure 21. Architecture for Scenario #3**

In this scenario, two options exist regarding Entry Point:

- one single Entry Point is deployed and managed on site by the Master Operator, as a separate unit, for instance when the Master Operator is different from any Participating Operator, or
- one single Entry Point is deployed and managed on site by the Master Operator, as part of a BS equipment, for instance when the Master Operator is also a Participating Operator.

This Entry Point should enable the communication between Master Operator NMS and all on-site NG-CUs / NG-DGUs. Note that NG-CU, NG-DGU and Entry Point may be co-located.

### 5.2.4 Common API

Nowadays, communications from BS PEE and site data PEE use different communication protocols and channels. The standardization of a common API for all the scenarios described above is expected to control and monitor PEE data from site equipment, power units, building control units and BSs.

This API should serve in all interactions between:

- NMS(s) and Entry Point(s),
- Entry Point and NG-CU(s) / NG-DGU(s).

Through this API,

- NMS:
  - May request to collect PEE data from site equipment, power units, building control units and BSs.

    - May assign values to configurable parameters related to site, site equipment, power units, building control units and BSs.
    - May configure threshold values related to PEE data so as to receive alarms when these threshold values are crossed by site equipment, power units, building control units and BSs.
    - May subscribe to receiving notifications such as alarms, event notifications (e.g. configuration changes related to site, site equipment, power units, building control units and BSs, NG-CU(s), NG-DGU(s)), etc.
- NG-CU, NG-DGU, Entry Point:
    - May send PEE data from site equipment, power units, building control units and BSs to NMS(s).
    - May issue alarms if configured threshold has been crossed to NMS(s) which subscribed to such alarms.
    - May issue event notifications to NMS(s) which are subscribed to such event notifications.

### 5.2.5 Common Protocol

It is expected that the API mentioned in Section 5.2.4 be supported by state of the art communication protocols. A secured RESTful HyperText Transfer Protocol (HTTP)-based communication is recommended, with payload in JSON / YAML.

**Integration of PEE data into BS OA&M channel**

As described in Section 5.2.3, in some scenarios, it is expected that BSs are capable to embed the Entry Point in order that PEE data from site equipment, power unit(s), building control unit(s) are carried from the Entry Point to NMS(s) over the NMS channel of BS(s).

As site equipment, power unit(s) and building control unit(s) are external to BSs, this PEE data should be transported through the BSs NMS channel as 'encrypted' data, i.e. it is not considered by BSs as their proper OA&M data. Instead, this PEE data is meaningful only for NG-CU, NG-DGU, Entry Point and NMS side.

It would be desirable that vendors of site equipment, power unit(s) and building control unit(s) NG-CU / NG-DGU provide MNO / Master Operator (depending on scenario – see Section 5.2.2) with a 'PEE data Description File', i.e. file providing the data model supported by their NG-CU / NG-DGU. The overall procedure could be as follows:

1) Vendor of site equipment, power unit(s) and building control unit(s) NG-CU / NG-DGU provide MNO / Tower Company / Master Operator (depending on scenario – see Section 5.2.2) with a 'PEE data Description File', i.e. file providing the data model supported by their NG-CU / NG-DGU.
2) MNO / Tower Company / Master Operator 'integrate' the PEE data Description File into its NMS(s). So, it is capable to control and monitor this equipment.
3) Related site equipment and/or power unit(s) and/or building control unit(s) together with their NG-CU(s) / NG-DGU(s) are installed on site. Some sort of plug-and-connect procedure is

automatically triggered at the NMS(s) so that all new equipment and/or power unit(s) and/or building control unit(s) and their NG-CU(s) / NG-DGU(s) are recognized by NMS(s).

4) NMS(s) can now request PEE data to be collected on this equipment and/or power unit(s) and/or building control unit(s).
5) When NG-CU(s) / NG-DGU(s) send their PEE data and/or alarms and/or event notifications to NMS(s), NMS(s) can check against PEE data Description Files if the received data is compliant to the data schema provided by the vendors. If received data is not compliant, it should be discarded. If received data is compliant, it should be appropriately treated by the NMS(s).

# 6 CONCLUSION

This White Paper proposes that optimizing the energy performance of future networks requires an interface to exist or to be established by both MNOs and network equipment suppliers (including manufacturers and vendors). This interface should be designed in a way that it can improve the metering of future networks and, consequently provide options to manage the energy consumption of a network. This metering should provide the measurement of energy consumption of different parts of the network, for example network domains (e.g. mobile access, fixed access, core, transport, and data centre) and sub-domains as well as equipment (e.g. BSs, cooling systems, aggregation, backbone, international connectivity, network DC, operator site, renewable energy, battery/storage, xHaul, central office, etc.) of modern networks. This interface also includes valuable functions and mechanisms for the secured transfer of measured data to the MNO sites. This way, MNOs will be able to analyse the data and extract relevant measures or derive solutions for improvements. These solutions can be directly implemented by MNOs or in cooperation with manufacturers and/or vendors. This interface could also be expanded to support commands and control to improve energy efficiency dynamically. Such dynamic control is out of scope of the present document.

Furthermore, this White Paper is based on diligent but not yet exhaustively selected use cases, among them smart facilities, renewable energy management, the emergence of new operations models such as Tower Company and ESCOs, and finally, disaggregated and virtualized networks. Each of these use cases explore key aspects of the architecture, infrastructure, methods, processes, and solutions, from smart facilities via strategies for cost-efficient renewable energies procurement, dynamic buffering, etc. to disaggregated RAN and virtualized networks.

Additional strengths of the White Paper lay in the extensive analysis and illustration of relevant parameters, data collection unified architecture and common protocols, as well as gaps and recommendations for potential new solutions. Section 5 is entirely dedicated to recommendations for metering solutions associated to BS sites. These include existing standardized solutions e.g. from 3GPP metrics and on OSS-system, PEE measurement solutions defined by 3GPP in alignment with ETSI and valid for 5G Physical Network Function (PNF), accuracy of sensors defined in ETSI etc. just to name a few. Furthermore, Section 5 also recommends potential new solutions such as a generic unified architecture for data collection with a site internal communication architecture ideally equipped with higher level intelligent Next Generation Control Unit or Data Gathering Unit. This includes the so-called Entry Point, as an interface between the site and the external NMS(s), with a set of common APIs, and common protocols including a secured Restful HTTP based communication protocol with payloads in JSON /YAML.

Future work is recommended to standardize measured parameters, accuracy, data collection, and interfaces, in order to standardize the monitoring of the entire network. ETSI and 3GPP specifications for network data analytic function (NWDAF), MDAF and OA&M interfaces have specified interfaces for energy measurement collection, but further work is needed to define the appropriate interface specification and define concrete and more granular measurement parameters. Future work in O-RAN could also specify appropriate extensions to provide common open interfaces enabling energy monitoring and analytics in the near real-time RIC and other entities in the RAN and enable automated energy saving actions. Convergence in energy measurement metrics, collection interfaces, analytics interfaces and energy policy enforcement interfaces in 5G core and O-RAN can accelerate implementing the use cases defined in this document.

The present White Paper does not explore metering aspects related to the so-called rebound effect [21]which states that the more we optimize the network, the more we use it and consequently the energy consumption increases. This is more a social issue than a technical issue and thus not in the scope of the metering part of the NGMN Green Future Networks project.

In summary this White Paper’s recommendations are:

- To identify and understand the behaviour of energy intensive or under-utilized parts of the network in order to optimize and manage them in an energy efficient way it is recommended to deploy metering. Metering with more granular measurements will enable to check the energy performance of equipment in real time condition as well as to improve and promote the use of renewable energy source in a more optimized way.
- It is recommended to deploy metering at the network and technical sites to measure the energy consumption and other relevant parameters such as temperature and humidity of the active equipment e.g. radio, backhauling and core equipment.
- Standardized metering shall be defined with generic unified architecture for data collection, site internal communication architecture ideally equipped with higher level intelligent Next Generation Control Unit or Data Gathering Unit. In addition, measurement parameters with given accuracy as well as data collection and interfaces, including virtualized and NFV environments should be standardized.

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AC | Alternate Current |
| API | Application Programming Interface |
| APP | Application for smartphone |
| ASN.1 | Abstract Syntax Notation 1 |
| ATS | Automatic Transfer Switch |
| BBU | Base Band Unit |
| BS | Base Station |
| CAN | Controller area Network |
| CIM | Container based Infrastructure Management |
| CM | Configuration Management |
| CNTT | Cloud iNfrastructure Telco Taskforce |
| COTS | Commercial Off-The-Shelf |
| CPU | Central Process Unit |
| CRAN | Cloud RAN |
| CU | Control Unit |
| Cx | Customer Experience |
| DC | Direct Current |
| DCU | Data Control Unit |
| DG | Diesel Generator |
| DGU | Data Gathering Unit |
| DOD | Deep of Discharge |
| DPDK | Data Plane Development Kit |
| DRAM | Dynamic Random Access Memory |
| DRAN | Distribute RAN |
| EE | Energy Efficiency / Environmental Engineering |
| EHS | Environmental Health safety |
| EM | Element Management |
| EMS | Element Management System / Energy Management System |
| ESCO | Energy Service Company |
| FPGA | Field Programmable Gate Array |
| FTP | File Transfer Protocol |
| GHG | Green House Gas |
| gNB | Next Generation NodeB |
| GPB | Google Protocol Buffer |
| 3GPP | 3rd Generation Partnership Project |
| GPS | Global Positioning System |
| GSM | Global Mobile System |
| HIM | Hardware Infrastructure Management |
| HTTP | HyperText Transfer Protocol |

| | |
|---|---|
| IM | Inventory Management |
| IPMI | Intelligent Platform Management Interface |
| JSON | JavaScript Object Notation |
| KPI | Key Performance Indicator |
| LTE | Long Term Evolution |
| MDAF | Management Data Analytic Function |
| MNO | Mobile Network Operator |
| MOP | Master Operator |
| NETCONF | Network Configuration Protocol |
| NFV | Network Function Virtualization |
| NFVI | Network Function Virtualization Infrastructure |
| NFV MANO | Network Functions Virtualization Management and Orchestration |
| NFVO | Network Function Virtualization Orchestrator |
| NG-CU | Next Generation CU |
| NG-DGU | Next Generation DGU |
| NG-RAN | Next Generation RAN |
| NIC | Network Interface Card |
| NMS | Network Management System |
| NOC | Network Operation Centre |
| NWDAF | Network Analytic Data Function |
| OA&M | Operation, Administration and Maintenance |
| OPNFV | Open Platform for NFV |
| O-RAN | Open RAN |
| OSS | Operations Support System |
| PA | Power Amplifier |
| PEE | Power, Energy, Environmental |
| PM | Performance Management |
| PNF | Physical Network Function |
| POP | Participating Operator |
| PSU | Power Supply unit |
| RAN | Radio Access Network |
| RAT | Radio Access Technology |
| REST | Representational State Transfer |
| ROI | Return on investment |
| RRH | Radio Remote Head |
| RRU | Radio Remote Unit |
| RU | Radio Unit |
| SDO | Standards Development Organization |
| SEE | Site Energy Efficiency |
| S-FTP | Secure File Transfer Protocol |
| SLA | Service Level Agreement |

| | |
|---|---|
| SOC | State of Charge |
| SOH | State of Health |
| SON | Self-Organizing Network |
| UN SDG | United Nations Sustainable Development Goals |
| UWB | Ultra Wide Band |
| VIM | Virtual Infrastructure Management |
| VM | Virtual Machine |
| VNF | Virtualized Network Function |
| V-RAN | Virtualized RAN |
| XML | Extensible Mark-up Language |
| YAML | Yet Another Markup Language |
| YANG | Yet Another Next Generation (data modelling language) |

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[22] fuel cells

# ANNEX A: ENERGY ARCHITECTURE USED IN BS SITES

This annex contains short description on possible energy architecture utilized on BS sites. In this case with active equipment, all active equipment present on site e.g. radio equipment back hauling and other type of active equipment is considered.

## A.1 Architecture Scenario No. 1: On-site Grid, Good Grid

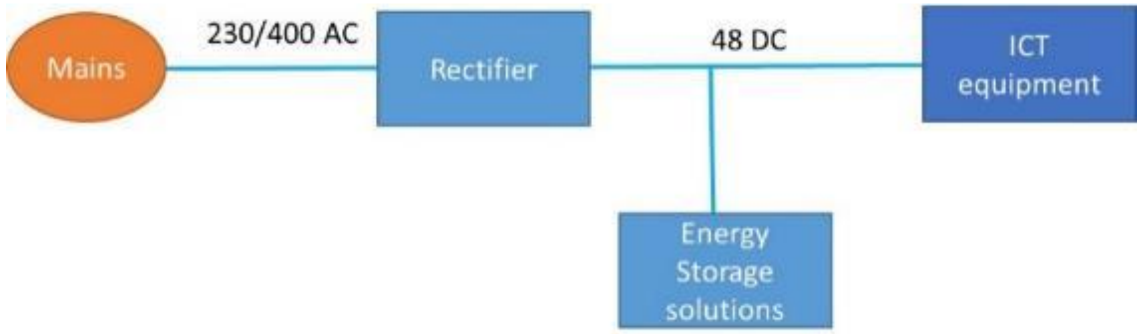


**Figure 22. Main Powering.**

This case is characterized by the presence of a good quality grid (Mains) on the site with no long interruption of mains. The backup is provided by the energy storage solutions. This scenario is also applicable at sites of lower importance for network coverage or service.
Site powering strategies are described below

- When grid is available, the rectifiers supply active equipment and charge the energy storage solutions
- If grid is missing, the energy storage solutions supply active equipment for a certain duration (depending on battery autonomy)

## A.2 Architecture Scenario No.2: On-site Grid, Bad Grid

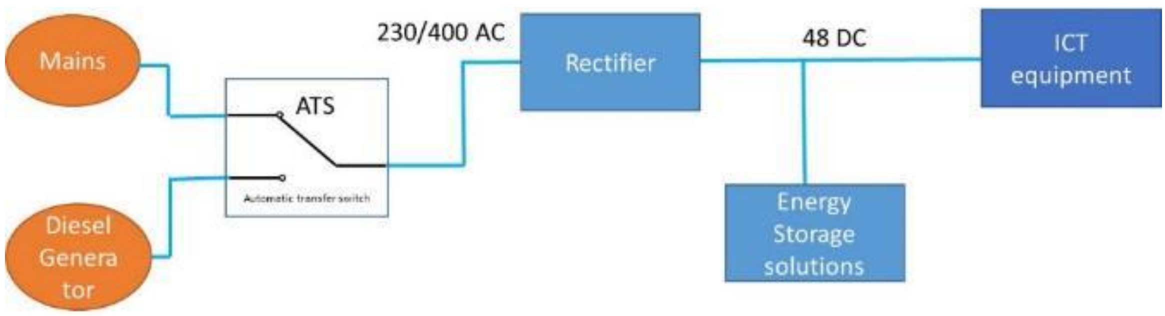


**Figure 23. Main and Generator Powering.**

This case is characterized by the presence of bad grid on site with possible long interruption of mains. The backup iss provided by the energy storage solutions and diesel generator. This scenario is also applicable at sites of higher importance for network coverage or service.

Site powering strategies are described below

- When grid is available, rectifiers supply active equipment and charge energy storage solutions; Diesel generator or other type of generator are on standby
- If grid is missing, the energy storage solutions supply equipment while the Diesel generator starts and the Automatic Transfer Switches (ATS) from mains to Diesel generator

## A.3 Architecture Scenario No.3: Off-grid Site: Pure Solar

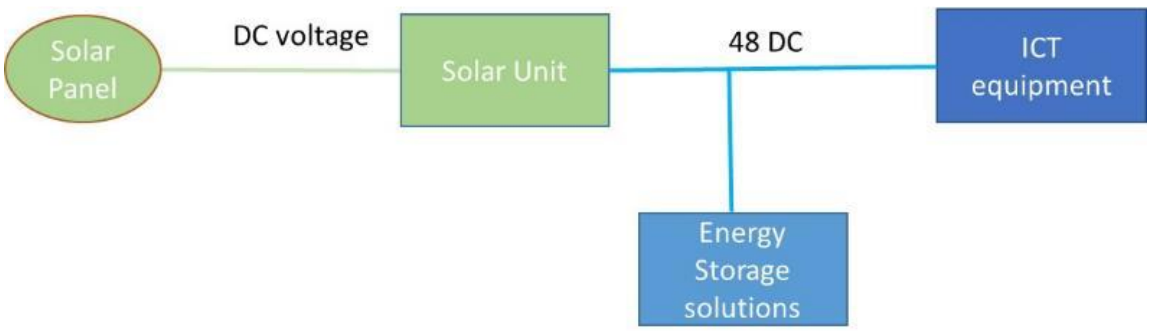


**Figure 24. Pure Solar and Battery Powering.**

This case is characterized by the absence of grid on the site, this topology is called off grid site. The backup is provides by the energy storage solutions. in this case the site is free of Green House Gas (GHG) emissions during normal working conditions.
Site powering strategies are described below

- The solar unit powers active equipment and charges the energy storage solutions when solar irradiation is sufficient
- When solar irradiation is low (nights and cloudy days), the energy storage solutions power active equipment (energy storage solutions autonomy is usually designed for 4 days to consider raining days).

## A.4 Architecture Scenario No 4: On-grid Site + Solar

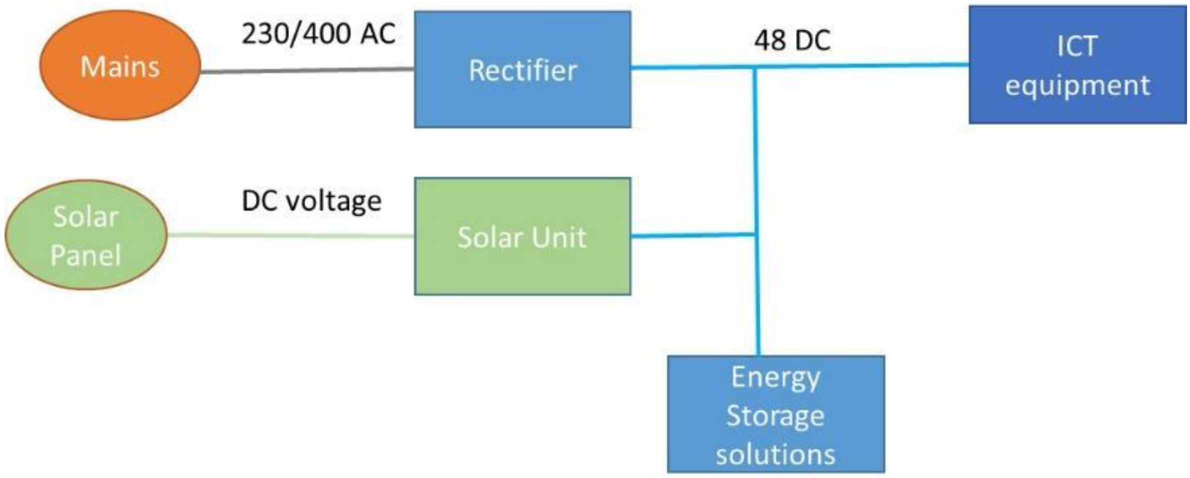


**Figure 25. Solar and Main Hybrid System.**

This case is characterized by the presence of grid on the site and the parallel use of renewable solar energy produced locally.
This site reduces the GHG emission of the site during normal operations. Energy storage solution is used to provide backup functionality.

Site powering strategies are described below

- The solar supply unit powers active equipment and charges energy storage solutions when solar irradiation is sufficient
- When solar irradiation is becoming low (morning and evening), energy storage solutions contribute to power active equipment.
- During no sun the mains powers the active equipment.

## A.5 Architecture Scenario No.5: Off-grid Site: Solar + Genset

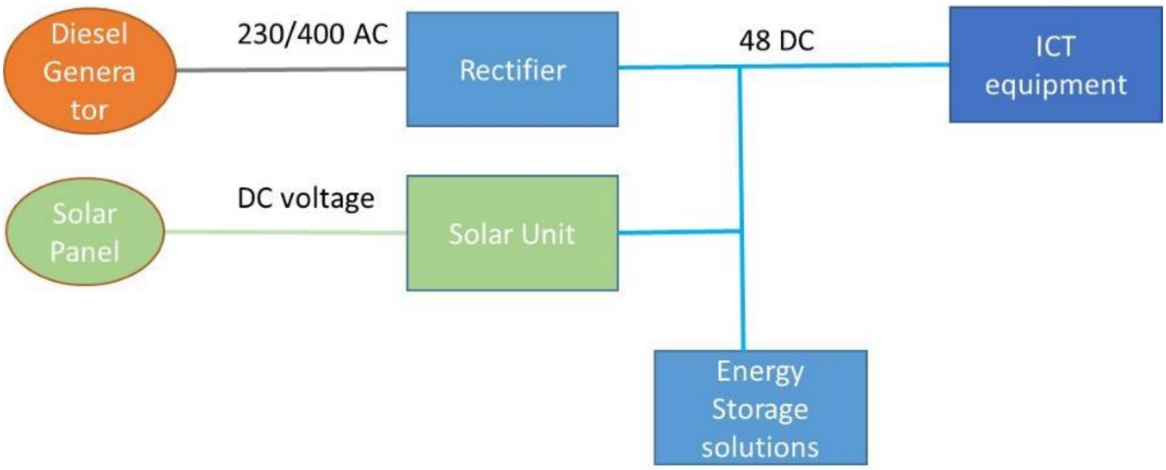


**Figure 26. Solar and Generator Hybrid.**

This case is characterized by the absence of grid on the site, this topology is called off grid site. The backup is provided by energy storage solutions and diesel generator. In this case the site is partially free of GHG emissions during normal working conditions.

Site powering strategies are described below

- The solar unit powers active equipment and charges the energy storage solutions;
- When solar irradiation is low, the energy storage solutions power active equipment until their state of charge remains above a pre-defined threshold (energy storage solutions autonomy is usually 2 days). Below this value, the Diesel generator or other type of generator starts to power active equipment and charge the energy storage solutions.

## A.6 Architecture Scenario No.6: Off-grid Site: Hybrid Diesel Generator or Other Type of Generator, Fuel Cells and Energy Storage Solutions (HGB)

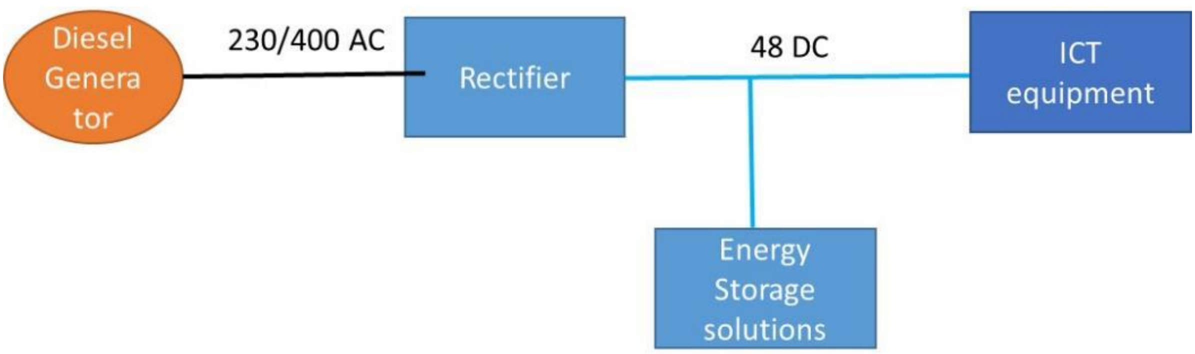


**Figure 27. Diesel Hybrid Powering.**

This case is characterized by the absence of grid on the site, this topology is called off grid site. It is assumed that the site cannot be powered by solar.

- the Diesel generator and the energy storage solutions are working alternatively.
- HGB reduces fuel consumption by decreasing Diesel generator or other type of generator usage reducing the GHG emissions compared to a solution without energy storage.

Site powering strategies are described below

- The hybrid Diesel generator or other type of generator solution is based on alternate energy supply by Diesel generator or other type of generator and energy storage solutions.
- Energy storage solutions store the energy produced by the Diesel generator or other type of generator.
- When the energy storage solution is full energy charged, the Diesel generator goes in stand by and the active equipment is powered by the energy storage solution
- Note that in case of hydrogen fuel cells, 48V DC power can be provided directly [22] as some type of Diesel generator.

# ANNEX B. SENSOR REQUIREMENT

This annex contains requirements on sensors applicable to the different cases described in Annex A.

The annex reports:

- Quantity to be measured
- additional requirement for sensor.

A description of possible architecture of BS site powering feeding is reported in Annex A.
Table 2 contains a list of the parameters that are requested to be monitored at BS site with 2 different levels of importance. Table 3 contains requirements for the sensor.

**Table 1 Monitored quantity**

| Importance | 1 | | 2 | |
|---|---|---|---|---|
| | **Parameter** | **Unit** | **Parameter** | **Unit** |
| Main Energy Delivery Point | Voltage (single, three) | V | Power Factor | - |
| | Current (single, three) | A | Reactive Power | VAr or kVAr |
| | Active Power | W or kW | Apparent Power | VA or kVA |
| | Active Energy Power | Wh or kWh | Active Energy Index Counter | Wh or kWh |
| Tenant Energy (if exists) for site sharing | | | Voltage (single, three) | V |
| | | | Current (single, three) | A |
| | | | Active Power | W or kW |
| | | | Active Energy Power | Wh or kWh |
| Energy utilized for - Air Conditioning (or ventilation) | Voltage (single, three) | V | | |
| | Current (single, three) | A | | |
| | Active Power | W or kW | | |
| | Active Energy Power | Wh or kWh | | |
| DC Energy Measurement - Total 48V power station output | Voltage | V | | |
| | Current | A | | |
| | Power | W or kW | | |
| | Energy Power | Wh or kWh | | |
| | Voltage | V | Internal Impedance | Ohm |

<table>
<tr><th>Importance</th><th colspan="2">1</th><th colspan="2">2</th></tr>
<tr><th></th><th>Parameter</th><th>Unit</th><th>Parameter</th><th>Unit</th></tr>
<tr><td rowspan="4">energy storage solutions Measurement - Branches or Blocs<br>for lead Acid</td><td>Current</td><td>A</td><td>Depth Of Discharge (DOD)</td><td>%</td></tr>
<tr><td>Temperature</td><td>°C or °K</td><td rowspan="3">State Of Health (SOH)</td><td rowspan="3">Year</td></tr>
<tr><td>Capacity</td><td>Ah or kWh</td></tr>
<tr><td>State Of Charge (SOC)</td><td>%</td></tr>
<tr><td rowspan="6">energy storage solutions Measurement - Branches or Blocs<br>for lithium batteries technology</td><td>Voltage</td><td>V</td><td></td><td></td></tr>
<tr><td>Current</td><td>A</td><td></td><td></td></tr>
<tr><td>Temperature</td><td>°C or °K</td><td></td><td></td></tr>
<tr><td>Remaining Battery Capacity Percent</td><td>H</td><td></td><td></td></tr>
<tr><td>Capacity</td><td>Ah or kWh</td><td></td><td></td></tr>
<tr><td>State Of Health (SOH)</td><td>%</td><td></td><td></td></tr>
<tr><td rowspan="4">Photovoltaic Panels Energy Measurement (if applicable)</td><td>Voltage</td><td>V</td><td>Real Consumed Energy (By BS site equipment)</td><td>Wh or kWh</td></tr>
<tr><td>Current</td><td>A</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Power produced</td><td>W or kW</td></tr>
<tr><td>Produced Energy</td><td>Wh or kWh</td></tr>
<tr><td rowspan="5">Local fuel Generator Energy Measurement (if applicable)</td><td>Voltage (single, three)</td><td>V</td><td>Operating Time Counter</td><td>Hour</td></tr>
<tr><td>Current (single, three)</td><td>A</td><td rowspan="4">Fuel Consumption</td><td rowspan="4">Litre</td></tr>
<tr><td>Active Power</td><td>W or kW</td></tr>
<tr><td>Produced Energy</td><td>Wh or kWh</td></tr>
<tr><td>Operating Status</td><td>Off/On</td></tr>
<tr><td>Fuel Tank Measurement (if applicable)</td><td>Fuel Quantity necessary put an equivalent measure for not diesel generator (DG)</td><td>Litre</td><td>Water Presence in Fuel Tank Probe (only for DG)</td><td>Yes/No</td></tr>
</table>

| Importance | 1 | | 2 | |
|---|---|---|---|---|
| | **Parameter** | **Unit** | **Parameter** | **Unit** |
| | High Level Tank Probe | % | | |
| | Low Level Tank Probe | % | | |
| environment Measurement - outdoor cabinet or Indoor site (room/ shelter) | Internal Site or Cabinet Temperature | °C or °K | Others Internal Site or Cabinet Temperature (several probes) | °C or °K |
| | Internal Site or Cabinet Humidity | % | | |
| | External Site or Cabinet Temperature | °C or °K | | |
| | Ventilation Operating Status | Off/On | | |
| | | | | |
| Intrusion and Access information | Opening / Closing Contacts of Entry Points | | Triggering of Motion Detector | |
| | | | Camera Surveillance Internal and/or External | |
| Miscellaneous | Fire and Smoke Detector status | Yes/No | Water Presence in Site Probe | Yes/No |

**Table 3. Requirements for sensor.**

| Sensor type | requirement | Note |
|---|---|---|
| AC and DC electricity meter | | |
| AC and DC Meter | wireless connection with site controller | realize easy installation, fast deployment and avoid wrong connection cable wiring |
| AC meter | protective box for Environmental Health safety (EHS) protection | Necessary void electricity shock |
| AC meter used in outdoor scenario | IP 65 protection | Protect from dust and raining |
| AC meter | Integrate surge protection | Protect from lighting |

| | | |
|---|---|---|
| AC meter | Level 1 accuracy | |
| DC meter | Precision ±0.5%. Current precision of DC meter should be ±1% FS | |
| Environment sensors | | |
| Temperature and humidity sensor, fuel level sensor, smoke sensor, electronic lock, infrared sensor, and door status sensor | wireless connection with site controller | realize easy installation, fast deployment and avoid wrong connection cable wiring |
| Temperature and humidity sensor, fuel level sensor, smoke sensor, electronic lock, infrared sensor, and door status sensor | Built in battery | no need power supply cable to realize easy installation, fast deployment and avoid wrong connection cable wiring. |
| Intelligent Access Control and Camera Management | | |
| Remote camera | Need be supported | |
| Electronic look | Need be supported | |

# ANNEX C. DETAILED ON BOARD SOLUTION FOR FACILITIES EQUIPMENT

This annex describes management functionality that can be embedded in site facility equipment for an intelligent monitoring of sites.

## C.1 Site Controller

1) Site controller needs support for wireless connection of wireless sensors to realize easy installation, fast deployment and to avoid wrong wiring.
2) Site controller needs to support GE, RS485, controller area network (CAN) port to connect power, battery and other intelligent devices.

## C.2 Branch Measurement

1. The management system supports energy consumption measurement by active equipment (for example, displays the energy consumption of 5G Radio Remote Unit (RRUs) or non-5G active equipment).
2. The management system supports remote configuration of load route information to avoid slow local configuration delivery and configuration errors.
3. The management system supports loads to bind operators to measure the active equipment energy consumption of each operator, so that the site owner can charge electricity fees based on the actual energy consumption of different operators present on the site .

## C.3 O&M Service Management

### C.3.1 Site Fault Locating and Risk Management

Root cause analysis for site breakdown: The management system provides an overview of the number of broken-down sites on the entire network and a list of these sites. The list displays the site ID, site name, subnet or region, site level, site power supply type, breakdown cause, repair suggestions, risk triggering time, and breakdown duration. For sites that break down, the root cause of the breakdown can be further analysed in one-click mode. The key alarms and key device running sequence diagram before the breakdown can be displayed in detail to help network operations centre (NOC) engineers efficiently analyse the root cause of the breakdown and provide guidance for site maintenance engineers to quickly and accurately recover power supply, improving power availability. The site breakdown list can be exported as a CSV or EXCEL file. Users can query historical breakdown site statistics (including the site breakdown cause, occurrence time, and proportion) and root cause analysis sequence diagram by region or site.

Site risk forecast management: The management system provides an overview of the number of sites with breakdown risks on the entire network and a list of sites at risk. The list displays the site ID, site name, subnet or region, site level, site power supply type, risk level, risk cause, risk triggering time, risk countdown, and handling suggestions. For each site with breakdown risks, one-click analysis can be performed to display the caus of the risk, forecast the running duration of key components such as the Diesel generator (DG) and battery after the risks occur, and forecast the site breakdown time, efficiently and accurately guiding site maintenance engineers to quickly eliminate risks and prevent site breakdown. Users can query the list of historical risky sites and export the list to a CSV or EXCEL file.

### C.3.2 Site Capacity Expansion Analysis

The management system analyses the power supply and battery configurations of a site. It analyses the rectifier, battery string, and DC load data to determine whether the rectifier and battery configurations are insufficient and provide recommended power supply and battery capacity.
During site load capacity expansion, the planned load power information can be imported in batches. Then the management system determines whether the power supply and battery configurations are insufficient and provides the capacity to be added.

### C.3.3 Precise Backup for Active Equipment

The management system allows users to remotely set the power backup time for different active equipment (for example, 4 hours for 700 MHz active equipment, 2 hours for 1.8 GHz active equipment, and 1 hour for 2.1 GHz active equipment). The management system delivers backup policies to the power system for execution, implementing differentiated backup policies for different active equipment. When the mains fail, the secondary active equipment is disconnected first to ensure that the primary active equipment works for a longer time.

### C.3.3.1 Visualized Battery Management

The management system provides efficient and visualized management for batteries, including:

1) Centralized status management: Displays the status of network-wide batteries on one page. The displayed information includes the battery status (normal or with alarms), battery type, and equalized or float charge status. The displayed status information can be set on a configurable filter template.
2) Remote battery test: Remotely sets battery test parameters for battery strings of the switch mode power supply, starts a battery test, and generates test reports. Parameters for the short test, standard test, power-off automatic test, and scheduled test can be configured. Standard tests and short tests can be conducted remotely.
3) Battery SOH management: Automatically detects and reports the battery SOH (healthy, sub healthy, or abnormal). Displays battery information such as the remaining battery capacity, discharge capacity, and number of cycles.
4) Battery risk analysis: Analyses battery performance based on daily discharge data and real-time data to identify aged batteries. Sets three levels of risks based on the power backup time, midpoint voltage imbalance, inter-group bias current, and accumulated number of charge/discharge cycles, and provides risk details.

## C.3.3.2 Lithium Battery IoT Management

Lithium batteries will be connected to the management system through IoT networking to implement simplified networking without controllers. The management system can obtain battery alarms, SOC/SOH, charge and discharge status, and installation status through lithium battery IoT management to implement visualized battery management.

## C.3.3.3 Intelligent Battery Hybrid Use Management

1) The management system will support hybrid use management of lithium batteries and lead-acid batteries and allows users to view the intelligent hybrid use status (discharge mode, cycle mode, and preferential charging status of lithium batteries) of each site by filtering.
2) The management system will allow users to view and set battery discharge parameters (discharge mode, cycle mode, and preferential charge) in the hybrid use scenario.
3) The management system will allow users to export the intelligent hybrid use support status, license activation status, and configuration parameters to an Excel file.

## C.3.4 Asset Management

The management system manages energy assets in a centralized manner. The asset information includes the site name, device name, bar code, model, manufacturer, manufacturing date, and serial number. Users can query the information by site name, device name, device model, and bar code. The query result can be exported to an Excel file.

## C.3.5 Site Security Management

## C.3.5.1 Intelligent Access Control and Camera Management

1) A complete set of management software, electronic lock, and camera solutions will be provided.
2) The electronic lock will support unlocking using the application for smartphone (APP). The unlocking records are automatically uploaded to the management system.
3) The management system will support remote camera operations and remote photo viewing. Cameras should support sensor-triggered snapshot taking. Associated alarms should be configured in the management system. When an associated alarm is triggered, the camera automatically takes snapshots and uploads intruder photos.

## C.3.5.2 Lithium Battery Software Lock Management

1) Users can view the availability and usage of lithium battery software locks at each site and the timeout duration of battery identity authentication.
2) Users can filter and query all batteries, batteries with intelligent software lock enabled, or batteries with intelligent software lock disabled.
3) Users can view and set intelligent software lock parameters.
4) Users can export the intelligent lock support status, license activation status, and configuration parameters to an Excel file.

## C.3.5.3 Lithium Battery Global Positioning System (GPS) Tracking

The management system will support real-time reporting of battery location information. The map on the management system can display battery location information in real time and track stolen batteries based on the location information.

## C.3.5.4 Electronic Lock for Fence, Cabinet and Shelter

1) Electronic lock will support unlocking by APP to realize convenient and secure unlocking.
2) Vendor should provide APP and web management system solution so that users can manage an electronic lock through APP and computer.
3) Unlocking needs authority by supervisor account of the management system. Authorization can be approved for specified site and time.
4) Electronic management system support creating temporary account which only have 0.5- or 1-day validity for temporary site visitors to increase site security.
5) Electronic lock will have built-in battery that is free of power cables. It can be easily deployed, doesn't need wiring. The battery should support 11,000 times unlock and lock in 5 years.
6) Electronic support reporting unlock & lock information includes username and time to management system for unlock tracing
7) Electronic lock will meet IP 65 dustproof and waterproof protection. Electronic lock should meet IK09 standard (EN/IEC62262) to ensure high reliability.