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Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures

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Abstract: Energy efficiency is a huge opportunity for both the developed and the developing world, and ICT will be the key enabler towards realising this challenge, in a huge variety of ways across the full range of industries. In the telecommunications space in particular, power consumption and the resulting energy-related pollution are becoming major operational and economical concerns. The exponential increases in network traffic and the number of connected devices both make energy efficiency an increasingly important concern for the mobile networks of the (near) future. More specifically, as 5G is being deployed at a time when energy efficiency appears as a significant matter for the network ability to take into account and to serve societal and environmental issues, this can play a major role in helping industries to achieve sustainability goals. Within this scope, energy efficiency has recently gained its own role as a performance measure and design constraint for 5G communication networks and this has identified new challenges for the future. In particular, the inclusion of AI/ML techniques will further enhance 5G's capabilities to achieve lower power consumption and, most importantly, dynamic adaption of the network elements to any sort of energy requirements, to ensure effective functioning.

Keywords: 5G; artificial intelligence (AI); energy consumption; energy efficiency; energy harvesting; energy savings; machine learning (ML); network slicing; resource allocation; smart metering

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1. Introduction

Regulation of energy consumption is one of the five pillars of the Energy Union Strategy [1] for inclusive and sustainable employment and parallel growth. The EU has early underlined the development of a sustainable integrated European climate and energy policy as a top priority and adopted an energy and climate package to guide the EU towards a competitive and secure energy economy while promoting energy savings and climate-friendly energy sources [2].

"Energy efficiency" is interpreted by the ratio of output performance, products or energy, to input of energy. "Energy savings" signifies a measure of saved energy controlled by estimating and additionally assessing utilisation when execution of an energy efficiency improvement measure, while guaranteeing normalisation for heterogeneous conditions that influence energy utilisation. Furthermore, "energy efficiency improvement" signifies an increase in energy efficiency because of mechanical, social or potentially financial changes. Improving energy efficiency all through the full energy chain [3] will benefit the climate, improve air quality and general wellbeing, lessen ozone harming substance discharges [4], improve energy security by decreasing reliance on energy imports from outside the EU, and cut energy costs for the society in general. It will also help to ease energy destitution and lead to actual competitiveness, expanded financial movement, and thus improve the general public's quality of life [5].

Early EU approaches have set the general goal of 20% saving on energy effectiveness of the Union's essential energy utilisation by 2020. The energy efficiency target has been set to 20% (reduction) and has to be achieved by the entirety of explicit public and European policies advancing energy productivity in various fields influencing both industry and consumers. This has been the main focus of related activities aiming to trigger social changes in energy utilisation by communities and companies.

Specifically, within the EU framework, energy efficiency is treated as a directive by its own right [6]. The energy efficiency's first guideline ought to be considered when setting new principles for the supply side and other policy areas; as a result, energy efficiency should be considered as a focal point towards economic, environmental and societal directives. Energy efficiency is particularly perceived as a significant component and a definite requirement in future investments, particularly those relevant to energy foundation.

The EU Member States should exploit the energy efficiency first guideline, which intends to prioritise energy planning, policy and investment decisions, regardless of whether cost-proficient, technically, financially and ecologically alternative measures could replace entirely or to some extent the conceived strategy [7]. This incorporates, specifically, the treatment of energy efficiency as an essential component and a critical element in future investment decisions, particularly those on energy infrastructure. Such proficient options incorporate measures to make energy interest and energy supply more productive, specifically through practical end-use energy investment funds, demand response initiatives and more efficient conversion, transmission and distribution of energy. Advances in energy efficiency can add to higher financial yield.

When planning energy efficiency improvement measures, efficiency gains and savings are to be taken into consideration with the inclusion of smart metering systems or "intelligent metering systems"; the latter are electronic systems that can measure energy consumption, thus providing more information than a conventional meter and are able to transmit and receive data using a form of electronic communication [8]. This provides a way towards developing new forms of electronic communications services for the support of energy management and consumption, at different levels. The establishment of modern communication systems, especially in parallel with smart grids, allow for the implementation of energy efficiency improvement measures.

Section 1 serves as a wider introduction, also correlating the essential framework of reference to international trends and/or policies, especially those promoted by the EU. Section 2 purely focuses on the innovative features promoted by the fast deployment of modern 5G infrastructures that, apart from many other operational benefits, are also able to contribute to energy efficiency. In particular, among others we also discuss potential approaches used for increasing the energy efficiency of wireless networks, following to on-going trends. Section 3 goes a step further and provides a more detailed discussion on the way how, to which extent and by which specific approach, we can have deal with energy consumption in 5G networks. Section 4 discusses opportunities for improving energy efficiency via the inclusion of artificial intelligence and machine learning techniques in 5G. Section 5 provides an overview of our approach with some concluding remarks.

2. 5G—An Enabler of Energy Efficiency in Modern Networks

We are at the beginning of a new frontier in operator networks where massive transformation is driving them to become more agile, efficient, demand-driven and new business models are disrupting the operator's traditional models now more than ever. As 5G deployments continue and revenue opportunities are formalised, the optimisation of networks and the associated costs are an essential consideration for operators. 5G is part of a broader evolution of ICT platforms which encompasses several trends that will be significant for adopting a new approach to energy consumption. These flexible, agile 5G networks also help vertical industries to operate in new ways.

The progress made by mobile networks over the years is not measured only by their operational performance and the service delivered to the end customer. Networks are also judged on their ability to take into account societal and environmental issues, particularly those related to energy consumption. In this scope, the switch to 5G should further improve this performance. For many operators, energy consumption has historically been a significant consideration as it is one of the highest operating costs [9,10]. Energy is becoming even more important due to climate change and sustainability considerations [11]. The potential increase in data traffic (up to 1000 times more) and the infrastructure to cope with it in the 5G era could make 5G to, arguably, consume up to 2–3 times as much energy. This potential increase in energy, coming from a high number of base stations, retail stores and office space, maintaining legacy plus 5G networks and the increasing cost of energy supply, all call for action [12].

In 5G, the load of traffic flowing on the networks will be greater for energy consumption of the same order of magnitude, mechanically resulting in a reduction in the share of electricity consumption per bit transported. This purely implicates that 5G will be more efficient than 4G in terms of the amount of bits of information delivered for a given unit of energy consumption. Thus, 5G provides some inherent energy improvements compared to previous generations of mobile technology, and to maximise the effects, a multi-layered approach can be taken to its deployment. This includes enhanced power management at equipment level; new siting solutions such as liquid cooling, to reduce the need for air conditioning; and flexible use of resources such as spectrum. The energy efficiency of 5G networks is expected to increase 100× times from 1000 mW/Mbps/s to 10 mW/Mbps/s in future [13].

The current reality is that overall energy usage by the telecom industry needs to come down as the industry consumes between 2% and 3% of global energy currently [14]. Many national governments are mandating businesses to adhere to energy reforms (e.g., EU's 2030 climate and energy framework) with the global goal to reduce greenhouse gas emissions, since 2014, by 30% in absolute terms by 2020 and 50% by 2030 [15,16].

The rising use of technologies such as cloud computing and mobile connectivity supports new experiences in every aspect of business and personal life, but it is essential that these benefits can be delivered without any detrimental impact on the environment. National and international policies are targeting a dramatic increase in energy efficiency and a sharp shift from fossil fuels to renewable sources of energy such as solar, wind and water. This will entail a completely new approach to energy use, which must be adopted by every industry and individual [17].

The telecom industry is not exempt from these pressures and the evolution to 5G is an opportunity to deliver a cleaner, greener telecom footprint—indeed, 3GPP's 5G specification calls for a 90% reduction in energy use [18] (as compared to 2010 levels) and this factor refers to energy savings per service provided. The main focus is expected to be in mobile communication networks where the dominating energy consumption comes from the radio access network. In this context, a growing number of operators have taken a leading role in sustainability, and the use of renewables to meet or exceed these decarbonisation goals and these will expand in the 5G era [19,20]. The many solutions to enhance network energy efficiency fall into two major groups: increasing the use of alternative energy sources to reduce dependence on the main power grid; network load optimisation to reduce energy consumption.

With the increasing growth of mobile access to the Internet and its services, 5G wireless networks represent a key communication infrastructure for ubiquitous connectivity of the future. The need to support exponential growth in data traffic as well as availability of several mobile devices (smartphones, tablets, etc.) is leading to a sharp increase in the number and density of base station devices as well as in their complexity, leading to a consequent increase in power usage and consumption. Indeed, high power consumption could represent a limiting factor for the scalability and deployment of 5G wireless networks and one of the possible causes of an appearing cost–revenue gap.

Energy consumption has become a primary concern in the design and the operation of wireless communication systems. Indeed, while for more than a century communication networks have been mainly designed with the aim of optimising performance metrics such as the data-rate, throughput, latency, etc., in the last decade energy efficiency has emerged as a new prominent figure of merit, due to economic, operational and environmental concerns. The design of the next generation (5G) of wireless networks will thus necessarily have to consider energy efficiency as one of its key pillars.

The vision is to have a connected society in which sensors cars, drones, medical and wearable devices will all use cellular networks to connect with one another, interacting with human end-users to provide a series of innovative services such as smart homes, smart cities, smart cars, tele-surgery and advanced security.

In the scope of the rapid development and evolution of 5G, the energy efficiency depends on the usage pattern and it is measured as the electrical energy spent per transmitted data volume over a period of time, that is in either Joules/bit or bits/Joule [21,22]. The energy is computed over the whole network, including potentially legacy cellular technologies, radio access and core networks as well as data centres. 5G should support a 1000-times traffic increase in a 10-year timeframe, with an energy consumption by the whole network of only half that typically consumed by today's networks. This leads to the requirement of an energy efficiency increase of ×2000 in the next 10 years timeframe. Every effort should be made to obtain the energy gain without degrading the performance, but the technology should allow native flexibility for the operator to configure trade-off between energy efficiency versus performance where justified [23].

The efficiency of an operator's network is then obtained by averaging the energy spent over a wide range of deployment and operational conditions, from busy hours in metropolitan areas down to rural areas at night times with very low traffic demand. Network traffic patterns can be analysed and representative traffic models can then be defined for all the use cases, including user densities as well as the anticipated, near-exponential rise in mobile data traffic between 2010 and 2020 and beyond.

Most of the approach useful for increasing the energy efficiency of wireless networks can be grouped under four broad categories as follows:

(i) Resource allocation: This intends to increase the energy efficiency of a wireless communication system via allocating the system radio resources in a way to maximise the energy efficiency rather than the throughput. This approach has been shown to provide substantial energy efficiency gains at the price of a moderate throughput reduction [24]. The literature is rich in contributions dealing with the design of resource allocation strategies aimed at the optimisation of the system energy efficiency and the common message is that, by accepting a moderate reduction in the data rates that could otherwise be achieved, large energy savings can be attained.

(ii) Network planning and deployment: The second technique is to deploy infrastructure nodes in order to maximise the covered area per consumed energy, rather than just the covered area. In addition, the use of base station (BS) switch-on/switch-off algorithms and antenna muting techniques to adapt to the traffic conditions, can further reduce energy consumptions [25]. The underlying concept is that, since networks have been designed to meet peak-hour traffic, energy can be saved by (partially) switching off BSs when they have no active users or simply very low traffic; however, as there are different degrees of hibernation available for a BS, attention must be paid in order to avoid unpleasant coverage holes.

(iii) Energy harvesting and transfer: The third technique is to operate communication systems by harvesting energy from the environment [26]. This applies to both renewable and clean energy sources like sun or wind energy and to the radio signals present over the air. This is of major interest in developing countries lacking a reliable and ubiquitous power grid, but it is also intriguing more broadly as it allows "drop and play" small cell deployment [27,28] (if wireless backhaul is available) rather than "plug and play".

(iv) Hardware solutions: This technique is to design the hardware for wireless communications systems explicitly accounting for its energy consumption [29] and to adopt major architectural changes, such as the cloud-based implementation of the radio access network [30]. This implicates that much of the power consumption issues would be dealt with by hardware engineers, emphasising on matters about low-loss antennas, antenna muting and adaptive sectorisation. Energy-efficient hardware solutions refer to a broad category of strategies comprising the green design of the RF chain, the use of simplified transmitter/receiver structures and, also, a novel architectural design of the network based on a cloud implementation of the radio access network (RAN) and on the use of network function virtualization.

A summarised overview of the energy consumption per network element of 5G is depicted in Figure 1.

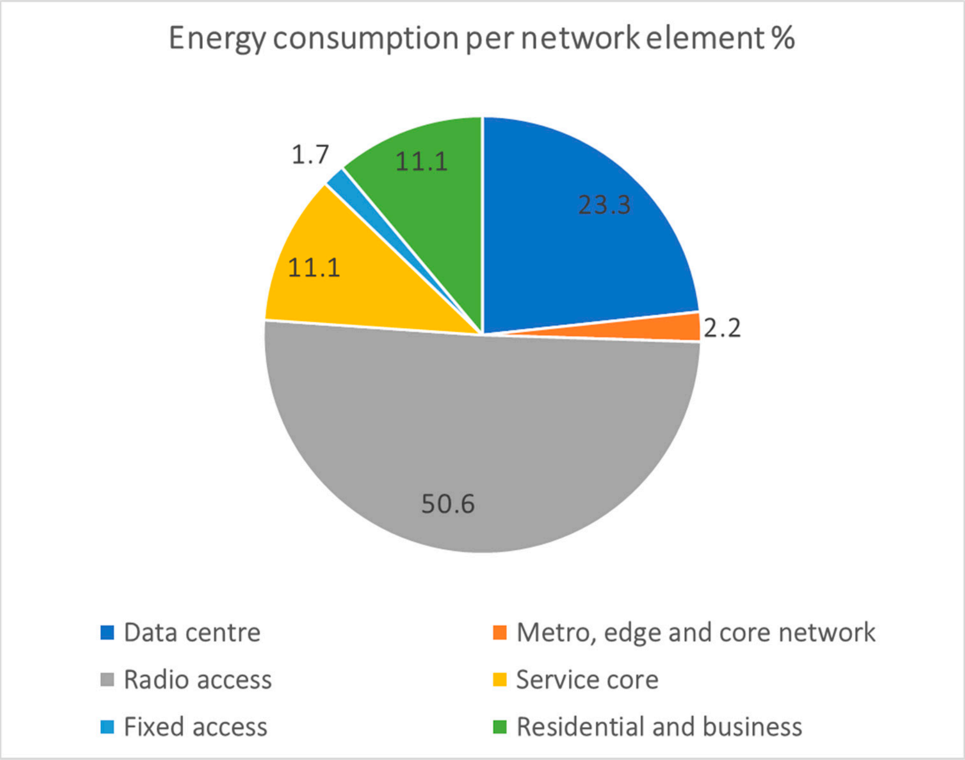

Figure 1. Energy consumption breakdown by network element, 2025.

The presented results show the split and distribution among the different elements of the 5G ecosystem and are based on the work in [31]. This presents a cohesive outlook on the landscape of its domain in the network layer and how it reflects in relation to the others. This projection is also insightful on the important aspect that the RAN layer projects and how it has the most impact on the field.

3. Concerns for Energy Consumption in 5G Networks

Energy consumption constitutes between 20% and 40% of network OPEX, and there are two opposing "views" on how this will evolve for 5G. Some stakeholders point to no overall net increase in the energy consumption of 5G networks by more efficient equipment. On the other hand, other stakeholders believe that the energy consumption of wireless networks will initially fall before picking up again. However, in the same way, 5G data traffic (and network deployments) both increase [32] and so does energy usage. In addition to the data load question, (i.e., equipment will be able to handle more bandwidth with the same or lower energy consumption), this does not address the increase in cell sites that will result to an increase of network energy consumption. It is worth highlighting that issues of power capacity at existing sites may also affect CAPEX and deployment times.

5G technology has been designed to be more energy efficient than previous generations. This is mainly achieved through low-power, small antennas and through efficient technology where transmission power is only generated when really needed. Notably, 5G uses more systematically a power saving mode where network resources are activated only when there is active traffic.

The future of telecommunications and computing infrastructure connecting billions of users and trillions of devices is requiring more efficient technology to be able to overcome exploding traffic and properly address security issues. This evolution does rely on a common global definition of 5G and associated standards, and of its service characteristics. Only then can we ensure seamless optical and wireless connectivity, interoperable ways to store and access information and computing power (cloud computing), sensing the world at large (Internet of Things) and ensuring the highest security and energy efficiency.

5G will also support greener [33] and more sustainable energy consumption [34]. 5G networks will support better management of renewable energy resources and allow families, businesses, and cities to have more insight into their energy use and a smarter way to manage it. Internet of Things (IoT)-enabled objects can allow for better monitoring and control of energy use. Combined with 5G networks, which can transmit information in real-time, energy use can be based on real-time needs in smart homes and smart cities.

Energy efficiency is one of the fundamental concerns when planning and optimising new mobile networks and many related supported techniques, ranging from smart power for base stations to artificial intelligence (AI)-enabled preventive maintenance. In this scope, 5G can act as a promoter of measures for energy savings and for an effective way of energy management, dynamically adopted to any sort of requests [35,36].

In particular, the 5G's enabling role derives from modifications to processes and behavior, which are supported by a high-capacity, ubiquitous and low-latency network [37,38]. The consideration of aspects such as virtualisation, edge computing, AI-enabled analytics and cloud allow 5G to help industries so that for the latter to incorporate appropriate procedures as an integral parts of energy efficiency programmes [39,40], by supporting the most efficient and flexible allocation of involved resources, per case [41,42]. The intelligent use of resources can help to reduce energy consumption in a variety of cases such as, among others: support for smart energy management; reduced requirement for office space and business travel; efficient just-in-time supply chains enabled by predictive analytics; and intelligent automated management of the movement of vehicles carrying people and goods.

Energy savings can be considered at three levels, that is: network level, site level and equipment level.

- For the network level, potential power efficiency mechanisms implicate for: (i) flexible cooperation between 5G and LTE spectrum and radios, to deliver the right amount of capacity for a given task, at the lowest practical power level; (ii) intelligent power management from end-to-end; (iii) hierarchical caching, where data and content that is used frequently is cached close to the user—perhaps in an edge compute node—rather than at the macro cell; and (iv) use of device-to-device (D2D) communications, which, as a 5G technique, allows for connectivity without involving base-station hardware.
- Regarding the case of the site level, we can distinguish the following mechanisms, among others: (i) renewable energy sources for on-grid and off-grid sites, including solar power (the cost of which has fallen by as much as 80% in the last ten years); (ii) smart lithium batteries; (iii) one site, one cabinet; and (iv) liquid cooling to reduce the need for air conditioning.
- As for the equipment level, our potential concerns can be about, for example: (i) efficient 5G power amplifiers; (ii) base-station automatic wake-up/sleep including shutdown on symbol, channel or carrier basis; and (iii) AI prediction to wake base stations pre-emptively.

Together, the above techniques can greatly increase the energy efficiency of cellular networks, while reducing GHG emissions. Furthermore, the device side is equally important, with new techniques to power them efficiently (the goal for 5G device manufacturers and Mobile Network Operators (MNOs) is to increase battery life to at least three days for smartphones and up to 15 years for cellular IoT devices, in order to make some emerging use cases practicable).

Since base stations account for such a high percentage of power consumption, it is imperative that they only consume power when they are actively handling data and signalling, and that MNOs implement their sites with a network-wide smart power system. Traditional (4G and earlier) mobile networks spend only about 15% to 20% of overall power consumption on actual data transfer. The rest is wasted because of heat loss in power amplifiers, equipment kept running when no data is being transmitted, and inefficient rectifiers, cooling systems and battery units [43]. New approaches need to eliminate the energy wastage or harness that wasted power for other purposes.

As operators' network energy consumption keeps increasing, reducing the energy consumption of main equipment is key to energy saving. Reducing the power consumption of main equipment of wireless sites has become the top priority for all market actors.

Two important strategies for reducing energy consumption at network level are to use the most efficient combinations of spectrum bands available and to minimise the number of radio technologies in use (through selective sunsetting or dynamic spectrum usage). The first generation of 5G roll-outs are mainly taking place in mid- and low-band spectrum, using a similar site grid to that of 4G. However, as the demand for data consumption continues to rise, some MNOs will move to augment capacity by adding millimetre-wave spectrum in dense hotspots. On a per-bit basis, spectrum in higher bands is the most energy efficient, but this requires more base stations than when using low bands. Therefore, careful network planning is important to enable MNOs to achieve the optimal balance between capacity and coverage, and to deliver this with the lowest possible power consumption.

Another network-level approach to saving energy is to "sunset" older radio technologies, which are less energy efficient than 5G. Many MNOs are currently running 2G, 3G, 4G and 5G networks in parallel. Sunsetting the legacy networks can significantly reduce total network energy consumption because older technologies, with lower energy efficiency, are removed, and the total number of antennas and base stations is reduced, together with their requirement for space and power.

Energy consumption in mobile networks is one of the major issues that operators need to deal with, as it increases significantly their electricity bills and, therefore, their Operational Expenditure (OPEX). According to techno-econometric studies during the last decade, the base stations in the radio access network and the data centers are the most power-hungry elements in mobile networks. To that end, a discrete research line towards the reduction of power consumption has been created, focusing mainly on the deactivation of underutilised components in the network [44,45].

As mentioned before, the most challenging elements of a mobile network, in energy consumption terms [46], are the base stations [47], which account for about 57% of total power usage of a typical cellular network [48]; the newest approaches reach up to 80% of the total network power usage [49]. This energy consumption is experienced at the transmission end of the BS (i.e., the power amplifier and antenna interface). Yet, with small cells, the power consumption per base station can be reduced due to shorter distances between the base stations and the users [39]. By 2025, the above energy consumption figure will be lower as 5G becomes more prevalent, but the radio access network (RAN) will still be the biggest consumer of energy. Within the base station, the largest energy consumer is the radio-frequency (RF) equipment (power amplifier plus transceivers and cables), which typically uses about 65% of total energy, followed by cooling (17.5%), digital signal processing/baseband (10%), and the AC/DC converter (7.5%) [47]. We notice that the radio operator equipment (the module of digital signal processing, the power amplifiers of transceivers, the radio frequencies, and connecting wires) and the systems of air cooling are the large-scale consumers of energy in telecommunication base stations. Emphasis must thus be laid on these components to reduce the total energy consumption of base stations.

Energy efficiency is a vital requirement of all business units owing to increasing equipment loads with the evolution of new technologies, and the growing price of electricity and fuel [40]. To decrease energy consumption in mobile phone and radio access networks automated network management software tool can be used, that continuously "adapt" network activity to changes in the network traffic. This means networks can be switched off during quiet periods, thus saving energy. They also found ways to evaluate energy consumption in both busy and quiet times, giving mobile operators data on how to use their networks more efficiently.

Network load optimisation is essential to ensure a reduction in total energy consumption. This is a prescient requirement for 5G era networks. Improving energy efficiency to consume less energy can be achieved through a multitude of solutions, including smart building, virtualising the core, and enhancing RAN efficiency through modernisation of legacy equipment and implementation of low-powered solutions.

While existing core networks enjoy the benefits of having well-established energy management systems (including remote management systems), the critical elements for access network infrastructure such as power systems, batteries, air conditioners, free cooling and generators (gen-sets) often do not come with holistic, well-developed energy management systems.

Remote monitoring and automation of management functions for the main site infrastructure elements allow operators to identify CAPEX and OPEX reduction opportunities and develop energy efficiency strategies. Further energy efficiency gains will also come from network automation and using shared network infrastructure.

4. Applying AI/ML Techniques for Improving Energy Efficiency

Today's mobile phone networks are designed to offer consumers flawless coverage during peak hours. However, optimising energy consumption to deal with increasing demand has not been widely applied in modern infrastructures. Radio network solutions that improve energy efficiency are not only good for the environment (as they start cutting energy costs and also reduce CO_2 emissions and electro smog (electromagnetic radiation)), but they also make commercial sense for operators while supporting sustainable, profitable business.

As mobile communication enters the 5G era, especially with the rapid deployment of small cells, new technologies, features, services and applications emerge one after another. The traditional telecom network operation and management mode do not meet the increasing requirements for network evolution, service development, user experience and operation analysis. Furthermore, the traditional mode is not able to effectively improve network operation efficiency and control the operating costs. The industry has realised that the 5G era requires a highly intelligent, automated network, followed by an intelligent autonomous network. Intelligent autonomy is an essential enabler for innovative business models of mobile communications and will become the essential element of mobile communications networks in the post-5G era. The introduction of artificial intelligence (AI)—and/or machine learning (ML) [44] as this can be conceived as a subfield of AI—into mobile networks [45] will be same an inevitable requirement for network design, deployment, operation, assurance and optimisation in the 5G and post-5G eras [46].

Reducing unnecessary power consumption is a key measure of energy saving but is faced with many challenges. The network traffic volume varies greatly during peak and off-peak hours. The equipment keeps running and the power consumption is not dynamically adjusted based on the traffic volume. As a result, a waste of resources is caused. The capability of "zero bits, zero watts" needs to be constructed. However, in a typical network, the features of different scenarios vary greatly. How to automatically identify different scenarios and formulate appropriate energy saving policies becomes the key to energy saving.

In traditional energy saving mode, a large amount of data needs to be manually analysed including common parameter data, network inventory data, feature adaptation data, site co-coverage data and multi-frequency and multi-RAT network identification data. Therefore, unified shutdown parameters need to be manually set. However, these parameters are not differentiated and cannot automatically match different scenarios to adapt to the traffic volume of a single site. During peak hours, services are affected and KPIs are affected due to inappropriate parameter settings. During off-peak hours, the power saving effect cannot be maximised due to inappropriate parameter settings. To deal with the above issue, AI technology can be used to achieve intelligent energy saving in different scenarios, sites and time. This also enables multi-network collaboration in energy saving. This approach maximises the network energy saving effect and achieves the optimal balance between power consumption and KPIs while ensuring stable KPIs. In principle, four phases can be identified: (i) Evaluation and design; (ii) function verification; (iii) energy saving implementation; and (iv) effect optimisation.

- In the evaluation and design phase, the system automatically sorts out mainstream scenarios on the live network based on big data analysis, analyses energy saving scenarios based on service models and base station configurations, evaluates energy saving effects in different feature combinations, network environments and scenarios, and automatically estimates energy saving effects and designs solutions.
- During function verification and solution implementation, the network management system automatically monitors and analyses power consumption in all scenarios, provides accurate power consumption reports, and verifies the deployment and effect based on automatic energy saving policies and parameter design. The energy saving policy can be customised for each site, enabling customers to quickly and efficiently start network-wide energy saving.
- In the effect optimisation phase, the system automatically adjusts threshold parameters, monitoring items, and power consumption based on the traffic model, energy saving effect, and KPI trend analysis in all scenarios and the respective AI algorithm. In this way, the energy saving effect and KPIs are balanced.

By using the historical data of a large number of cells on the network, such as time, load information, neighbour relationships, and other external factors including weather data and specific events as input, the system performs AI modelling on the cell, cell cluster, or area level. In this way, the system can predict a load of a cell, cell cluster, or area in a coming period, and determines the optimal energy saving time for different energy saving functions (such as carrier shutdown, channel shutdown, and symbol shutdown) in a cell within the range.

In the prediction modelling, the system monitors the network KPIs and provides feedback for prediction modelling according to the changes of the KPIs, achieving iterative prediction modelling and optimal energy saving and system performance.

AI/ML is already used extensively in the cloud world to reduce energy consumption, by turning elements on and off pre-emptively rather than waiting for traffic levels to change before reacting [48,49]. AI-based decisions are helped by the emergence of new ways to capture data, from passive infrastructure and power supplies as well as the base stations' in-built sensors [50]. Many tower operators are installing IoT sensors on their infrastructure to monitor energy usage and quality of service, in real time. A typical cell tower deployment can include eight to ten sensors for equipment such as HVAC (heating, ventilation and air conditioning) and off-grid power units. In 5G networks, MNOs are starting to adopt AI/ML techniques to support network automation in an intelligent, proactive way. For instance, self-organising networks (SON) increasingly include AI capabilities to help them make near real-time decisions about changes to handover, spectrum usage as well as power functionality and locations. AI-based rules will be used to achieve the complex tasks of allocating resources in the most power-efficient way and deciding when elements can be shut down.

Machine learning techniques are being used to let the system learn intelligently from data and optimise the overall operation of the network. For example, virtualisation technology improves energy efficiency and resource utilisation and can result in up to 50% of energy-saving [51]. To achieve energy efficient virtualisation and network optimisation, ML can further improve energy efficiency through load sharing and consolidation [52]. Likewise, energy consumption in the data centres, which consume most of the energy, can be minimised by intelligent resource allocation and management through ML learning approaches [44].

The presented points are also summarised, through process automation percentage, in Figure 2. These projects are derived from the ITU-T technical report [53], and showcase the exponential impact of process automation and AI in the 5G wireless network energy consumption.

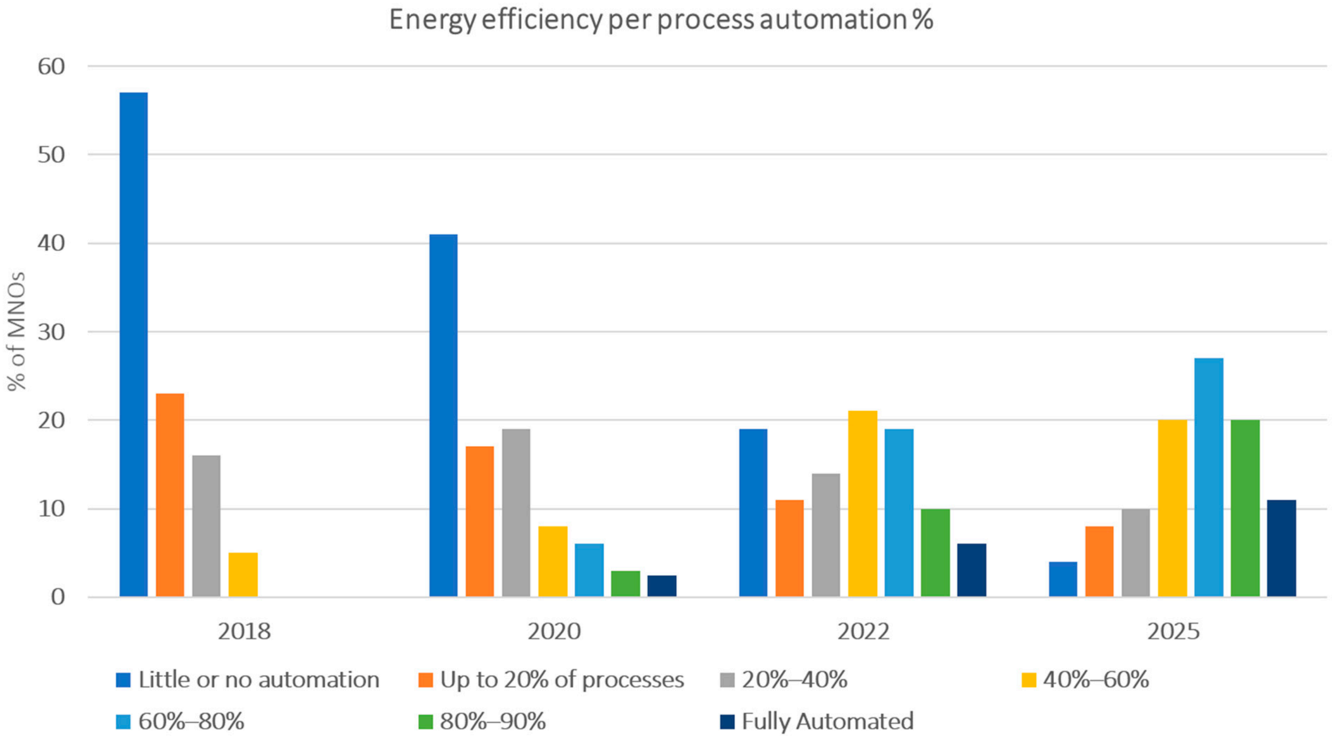

Figure 2. Energy efficiency for AI process automation in 5G networks.

In Figure 2, it can be clearly depicted that AI and automation in general will steadily increase their influence on the energy footprint of 5G networks, and they are expected to play a pivotal role.

Based on the presented report, the combination of cloud infrastructure and AI in 5G networks will enable MNOs to move towards fully intelligent power systems, with a more complete view of the network than just the 5G RAN and core alone. A cloud-based system can coordinate base stations, power supplies, edge infrastructure, backhaul units and other equipment across multiple layers and domains, so that power supplies become intelligent and efficiencies are made throughout the network.

Over time, full AI-based intelligent energy is expected to rise, in which different levels of power are automatically made available depending on the time of day or application. In this scenario, power availability (PAV) levels can potentially be identified for different applications using the MNO's network, according to their criticality. Those with the highest levels of criticality, such as telemedicine, can be assigned the highest level of network battery availability (smart batteries will have a higher threshold before they power down).

The existing literature highlights the promising potential of ML applications in the energy efficiency of the network. Although the existing works [54–57] managed to achieve important results in different network parts (e.g., data centers or RAN), a holistic solution that minimises the power consumption across all network parts and domains is still missing. In this scope, it is also important to consider the slice-based network management concept that generates a set of challenges related to scalability, security, automation in management of heterogeneous resources (e.g., communication, computational and storage), as well as to energy efficiency without sacrificing performance. The concept of energy slicing could guarantee the required energy supply in different network parts (e.g., core, access) and resources (e.g., MEC, communication) in order to satisfy various levels of service level agreements (SLAs). This can be an interesting consideration that may affect multiple implementations in future efforts. Finally, it should be underlined that use of AI by the increased network complexity should be further promoted, as it makes it hard for classical approaches to obtain efficient and optimised solutions. AI is not commonly used only for tuning a threshold; it is also used to manage and orchestrate heterogeneous networks to make them cooperate.

5. Conclusions

Climate change is threatening to disrupt every aspect of everyday life, and this calls for a suitable measure application across the entirety of the technology and telecommunication domain. Modern ICTs need to play an important role in this reform, to enable industries and citizens to achieve the required sustainability targets. The convergence of different technology domains, advanced connectivity, cloud computing, AI and the IoT can offer a wider platform of facilities with unprecedented potential to make all industries, cities and communities more energy efficient. In this scope, the presented work has investigated these sectors and analysed their background, potential benefits, shortcomings and future innovations that can drive environmental awareness across all the vertical industries. As 5G owns the predominant role in modern communication innovation, the paper began to present an overview of its impact in the energy domain and various techniques on energy efficiency. Furthermore, a set of concerns regarding this emerging technology were introduced along with their interrelation with the entire telco ecosystem. Last but not least, the role of AI and ML was underlined and analysed in detail not only in relation to 5G but also to energy efficiency across its different layers.

In 5G this can permit significant energy reduction and, consequently, it affects numerous industries to adopt new practices and processes towards reducing energy consumption. As technology evolves very rapidly, 5G also promotes the option of including suitable AI/ML mechanisms that will further support the scope for reduction of energy consumption within the underlying networks. In this scope we have also identified further potential evolutionary trends that can affect future development towards establishing "smart" communications networks, being able to promote cognitive solutions towards achieving the aim of realising significantly lower energy consumption, by adopting their modules to the appearing needs in a dynamic way.

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