# Intelligent and Energy-Efficient Data Prioritization in Green Smart Cities: Current Challenges and Future Directions

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The authors carry out an in-depth investigation of the recent approaches and trends of data prioritization (DP) for data of different natures, genres, and domains of two decades in green smart cities. They propose an energy-efficient DP framework by intelligent integration of the Internet of Things, artificial intelligence, and big data analytics.

## Abstract

The excessive use of digital devices such as cameras and smartphones in smart cities has produced huge data repositories that require automatic tools for efficient browsing, searching, and management. Data prioritization (DP) is a technique that produces a condensed form of the original data by analyzing its contents. Current DP studies are either concerned with data collected through stable capturing devices or focused on prioritization of data of a certain type such as surveillance, sports, or industry. This necessitates the need for DP tools that intelligently and cost-effectively prioritize a large variety of data for detecting abnormal events and hence effectively manage them, thereby making the current smart cities greener. In this article, we first carry out an in-depth investigation of the recent approaches and trends of DP for data of different natures, genres, and domains of two decades in green smart cities. Next, we propose an energy-efficient DP framework by intelligent integration of the Internet of Things, artificial intelligence, and big data analytics. Experimental evaluation on real-world surveillance data verifies the energy efficiency and applicability of this framework in green smart cities. Finally, this article highlights the key challenges of DP, its future requirements, and propositions for integration into green smart cities.

## Introduction

The recent advancements in data capturing devices for smart cities have produced huge repositories whose management, searching, browsing, and indexing are challenging issues. The major sources of this massive volume of data are consumer videos and surveillance networks. The important contents from such data can be extracted using data prioritization (DP), which is an effective mechanism for producing a condensed form of huge data that have numerous applications in surveillance, healthcare, entertainment, sports, and industry. Among the two main sources of data, consumer DP is difficult, tedious, and time consuming due to the diversity in its contents and issues that occur during its acquisition under uncontrolled conditions, including clutter, irregular lighting, poor-quality soundtracks, and large capturing device motion. Also, there are several other reasons that make consumer DP comparatively more challenging, such as:

- Text-features-oriented DP schemes are not suitable for consumer data due to lack of embedded text like subtitles and text captions.
- There is a lack of domain-specific knowledge for guiding DP systems.
- In special cases, consumer videos usually consist of one long shot with challenging conditions like clutter, occlusions, uneven lighting, and complicated motions of several objects and cameras.
- A mixed soundtrack is produced due to several sources of sound in the background, which makes it difficult to extract semantically important audio segments.
- There is difficulty in assessing users' satisfaction with generated summaries using DP.

People waste a lot of time browsing through such large repositories of data generated in smart cities for desired contents. Thus, it is important to explore DP frameworks that would produce semantically good summaries, satisfying the requirements of consumers, hence increasing the efficiency of smart cities.

The second major source of data is multimedia surveillance networks; they consist of smart visual sensors for continuously recording images, thus generating a huge amount of redundant visual data. Previous studies of surveillance networks have indicated that most of the captured data within a smart city are not important, and transmitting them is not feasible due to energy and bandwidth constraints. Besides, analyzing such a huge amount of data in order to find important events for decision making is a rigorous and time consuming task. Furthermore, prioritization of data captured from multiple views with significant overlapping and redundancy (e.g., multi-view videos) in smart cities is more challenging compared to data collected from a single view. Therefore, data analysis techniques need to be applied to filter and store important data for future use.

Considering these challenges, a green approach to intelligent data collection and prioritization is urgently required in smart cities to help them become greener [1]. These approaches can help in the selection of a suitable view for sensing visual data in multi-viewed surveillance that con-

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| Class name | 1. Cluster-based DP | 2. Visual-attention-based DP | 3. Event-based DP | 4. Multi-modality-based DP |
|---|---|---|---|---|
| Key approaches | Similar activity, *K*-means, partitioning, and spectral-based methods | Motion, texture, and multi-scale contrast saliency-based methods | General-event and deep-features-based event-assisted methods | Visual- and audio-features-based, and hybrid methods |
| Main steps | Feature extraction from input data, clustering, and important data selection | Salient contents detection from input data, followed by important data selection | Object detection and tracking in input data, abnormal events detection, and prioritization | Feature extraction from input data, their fusion, attention curve generation, and prioritization |
| Key characteristics and limitations | • Simple and concise; suitable for data such as news and documentary videos<br>• Low-level features cannot represent diverse visual contents captured in green smart cities effectively<br>• Has semantic gap problem, failing to fulfill varying users' requirements | • Use visual attention model to extract summaries closer to human perception<br>• Mainly applicable to medical and surveillance domains<br>• Computational visual attention models may not adequately represent human attention | • Detects event and then prioritizes the data; thus, the generated summaries are closer to human semantics<br>• Mainly suitable for sports and surveillance domains<br>• Computationally expensive for complex events such as goal and event detection in crowded scenes of green smart cities | • Consider multiple modalities for more effective DP<br>• Mainly suitable for entertainment and sports domains<br>• Fusion of multiple modalities is difficult, considering users' preferences and reliability of each modality in IoT-assisted green smart cities |

**Table 1.** Classification of DP methods of the last two decades (1998–2018).

sists of multiple sensors connected via Internet of Things (IoT) infrastructure. Furthermore, data of interest will be processed in real time; this will facilitate surveillance decision makers, and hence produce cost-effective services for green smart cities. To achieve these goals, we propose an energy-efficient and intelligent DP framework for a smart city. The major contributions of this work are highlighted as follows:

- We first investigate the current approaches and trends of DP for data of different natures, genres, and domains of two decades and discuss its possible applications in green smart cities.
- We propose an intelligent and energy-efficient framework of a smart city by integrating IoT, DP, artificial intelligence (AI), and big data analytics, which will enable it to prioritize data captured from different environments in a cost-effective way, and consequently contribute to greener smart cities.
- We conduct experiments on data captured by real surveillance cameras and evaluate its performance for adoptability, therefore providing a proof of concept to the research community of green smart cities.
- We highlight the key challenges of DP, followed by its future requirements with solutions and prospects for future research in green smart cities.

The rest of the article is organized as follows. In the next section we summarize the recent trends in DP for the last two decades. Then we present the details of our framework for a green smart city with experimental evaluation and discussion. Following that, we highlight the major challenges of DP and prospective requirements. Then we present future research directions for effective integration of DP to green smart cities. The final section concludes the article by presenting the key findings of this work.

## Recent Trends in Data Prioritization

In this section, we highlight the trend of DP techniques, ranging from conventional low-level features to the recent frameworks of convolutional neural networks (CNNs). Our focus is on video data because it is generated at an exponential rate and can play a vital role in improving the services of green smart cities. DP generates the representation once the pertinent contents have been identified. This can be in the form of key frames, showing the salient frames in a video or video skims. Video abstracts can be generated either manually or automatically. The former approach seems less feasible due to the current massive volume of video data generated in smart cities; thus, automatic DP methods are preferred for generating summaries, saving manpower and other constrained resources.

The existing literature uses two features for prioritization. The first feature is low-level features like color, shape, moments, motion, and visual attention models based DP whose prioritized contents are in accordance with human perception. The pioneering work on visual attention was presented by Ma *et al.* Following this work, many visual-attention-driven DP methods were presented for different domains such as surveillance, industry, medical, and agriculture [2], indicating that DP methods based on visual attention model generate semantically relevant summaries. However, such methods are comparatively expensive in terms of computation; they also ignore the active responses of users, making them less efficient in fulfilling users' preferences. To tackle this issue, electroencephalography brain signals of viewers are considered for analysis of videos during its prioritization. For instance, Mehmood *et al.* [3] combined visual attention, aural attention, and neuronal attention models through inter- and intra-modality fusion mechanism in divide-and-conquer fashion for personalized DP. Summarizing the literature of DP for two decades, four main classes can be found, as illustrated in Table 1.

The DP methods discussed so far are based on handcrafted features, which is a tedious task and lacks discriminative features for intelligent DP. In this context, rich features from CNNs can be combined with aural, visual, and neuronal attention models for efficient DP. For instance, Fei *et al.* [4] presented a memorable and rich DP method for selecting important contents using entropy and memorability scores predicted by a modified AlexNet model. Their model can produce summaries by considering the diversity of captured contents and human perception.

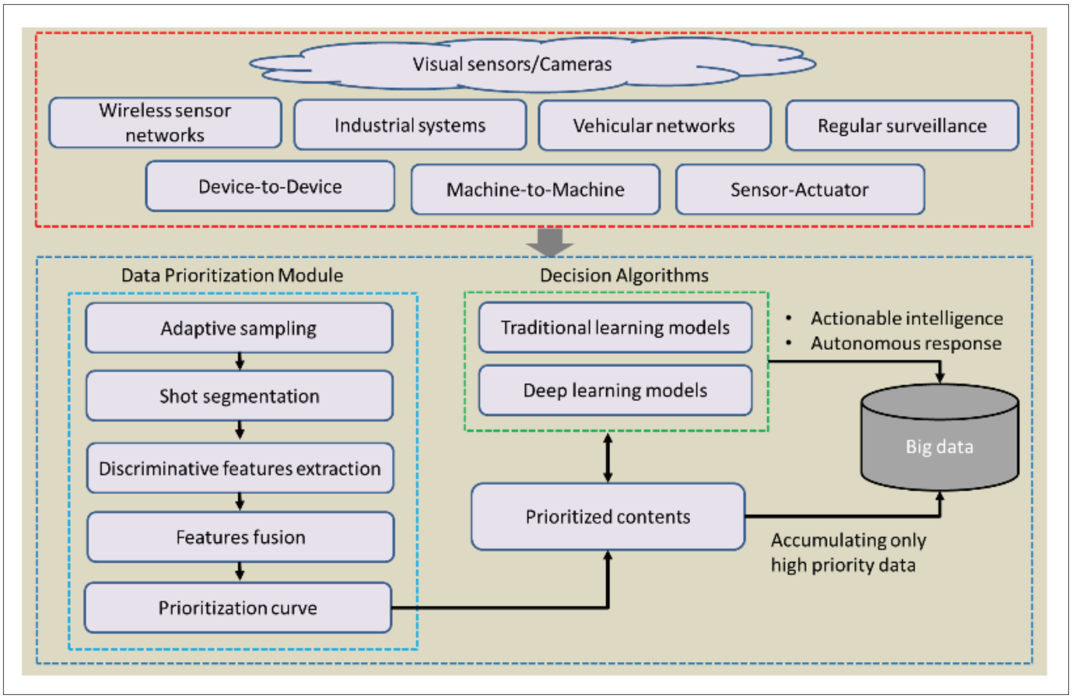


Figure 1. Overview of the proposed architecture for intelligent data prioritization.

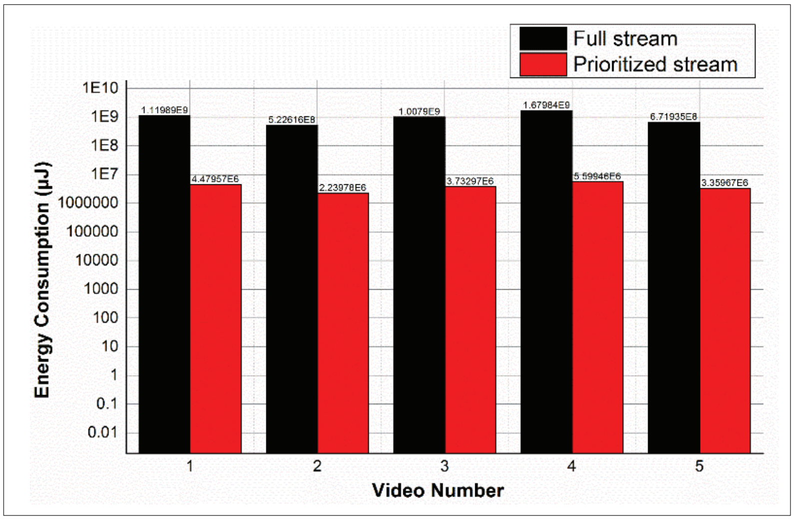


Figure 2. Energy consumption for transmission of only key frames vs. energy required for disseminating the full stream.

## Proposed Data Prioritization Framework

In smart cities, a significant number of sensing devices collect data from various sources. Visual sensors are one of the major visual data collection sources, producing a huge amount of data [5]. The energy and bandwidth constraints limit the processing of such huge-sized data; thus, only prioritized data needs to be stored for case management and analysis. Also, searching through large volumes of data for required information is time consuming and inefficient. To address these issues, we propose a data prioritization framework for autonomous collection of visual data. This framework processes multiple streams from visual sensors for intelligent selection of suitable views for prioritization in an IoT-assisted multi-viewed surveillance environment. The smart sensors are trained to prioritize data, detect important events, and autonomously inform the concerned department about the detected event. Such distributed processing of huge real-time data facilitate their efficient storage, management, retrieval, and analysis as well as minimize the energy and bandwidth requirements, thus helping smart cities become greener. The overview of our framework is presented in Fig. 1.

The proposed system was experimentally tested on a Core i5-3570 CPU @ 3.40 GHz with MATLAB R2018a for energy consumption to highlight its performance for data prioritization in green smart cities. The energy consumption is evaluated for five videos collected from a real surveillance environment. The experimental specification is similar to the report by Irgan *et al.* [6], where 88.48 μJ energy was required for a packet transmission of which a frame consists of 4219 packets. To this end, the total consumed energy can be represented by $E_t = N \times e_p$, where $e_p$ is the energy required for transmitting one data packet and $N$ refers to the total number of packets in a given frame. The experimental results are presented in Fig. 2, showing the reduction in energy consumption. Furthermore, the proposed system enables the surveillance analyst to analyze only the important prioritized data, thereby improving the decision making process and reducing the analyst's efforts. These features make this system more suitable for energy-efficient data sensing and processing in green IoT environments.

Recent studies verify that both academia and industry have shown significant interest in green smart cities, with focus on their different aspects such as DP, security, interoperability, and communication [1, 7, 8]. Table 2 presents a summary of recent projects from different regions of the world such as Asia, Europe, and North America related to the development of green smart cities.

| Project name and country | Funding | Duration | Goals | Main partners |
|---|---|---|---|---|
| REPLICATE from Spain | European Commission | 2016~2021 | Increasing resource and energy efficiency, improving the sustainability of urban transport, and reducing greenhouse gas emissions in urban areas | 38 partners including 7 public organizations, 24 multi-sectoral companies, and 5 universities |
| Smart Seoul from the Republic of Korea | Korean government | 2015~2019 | Intelligent data prioritization and autonomous response generation, abnormal events detection, smart building energy management, exchange of information via different devices and communication sources. | National Research Foundation of Korea, Seoul metropolitan government, universities, and other regional agencies |
| Greener Busan from the Republic of Korea | Korean government | 2014~2020 | Smart missing-child prevention service, smart parking, drones, streetlight and energy management. | Busan government, Cisco, ETRI, KETI, SK Telecom, and KT |
| Fujisawa Sustainable Smart Town from Japan | Japanese energy and government bodies | 2014~2020 | Reduction in energy costs, bicycle sharing, and smart healthcare. | 19 companies and 1 association including Fujisawa SST Management Company and Panasonic Corporation |
| Green Vision from the United States | State and federal funding | 2007~2022 | A total of 10 main goals including energy reduction by 50 percent, zero-emission lighting, and 100 percent energy from renewable sources | Different universities, private companies, and regional agencies |

**Table 2.** Summary of the latest worldwide projects and initiatives for green smart cities.

## Current Major Challenges and Requirements

Both academia and industry have shown interest by investing significant funding and researching in different aspects of green smart cities. For instance, a green approach for minimizing the amount of data was exploited in [9]. Similarly, a mechanism to integrate big data analytics with electric vehicles in green smart cities is presented in [10]. To integrate cloud computing and sensors for big data in green cities, Zhu *et al.* [11] proposed three sensor-cloud services for sensing, transmitting, and sharing, respectively. An IoT-assisted smart metering system for smart cities was presented in [12]. To cover the energy management aspect of IoT-assisted smart cities, Ejaz *et al*. [13] presented an efficient optimization and scheduling framework. The green industrial networking aspect was investigated in [14]. Last but not the least, a perspective of fifth generation (5G) technologies with soft and green themes was explored in [15]. Intelligent and cost-effective DP is one of the preferred embodiments of smart cities, which can play a vital role in making the current smart cities greener. To date, attempts have been made to deal with data of different domains such as surveillance, sports, consumer, broadcasting platforms, and news. Despite the accepted performance for prioritization, there are still issues and challenges that limit the effectiveness of DP methods for generating summaries that could fully satisfy the requirements of users and green smart cities. After an extensive literature review, we found several key features, their applications and advantages, major research challenges, and requirements of future green smart cities, which are presented in Table 3.

## Recommendations for Future Research

Considering the major challenges encountered by the DP community outlined in Table 3, extensive work is required from DP industry and academia in the following areas to contribute to greener smart cities:

### Fog-Computing-Assisted DP

Fog computing is a new paradigm for extending cloud computing to the edge of the network, providing high mobility, low latency, and vast geographical coverage of large numbers of nodes. It has several potential applications in IoT-based systems, real-time computing systems, energy-aware computing, latency sensitivity, and mobile applications .However, it is still new and needs strong groundwork for adoption in the DP community of green smart cities in terms of practical feasibility, cost effectiveness, efficiency, and ease of deployment as an alternative to current ubiquitous cloud systems. In addition, mobile cloud-assisted architectures can also be investigated for DP.

### Solving DP as a Multi-Objective Optimization Problem

To cover all important contents in the collected data with minimal redundancy and computational efficiency, DP should be considered as a multi-objective optimization problem. Using this approach, important events can be detected more effectively while considering the processing and power constraints of IoT devices in green smart cities.

### Benchmarking Datasets

To make DP in green smart cities an interesting and attractive topic to researchers, it is important to collect specific large DP datasets with ground-truth just like other communities (e.g., ImageNet for image classification). Such datasets can be used for benchmarking as well as hosting different competitions in an attempt to improve the performance of DP for green smart cities.

### Lightweight Convolutional Neural Networks for DP

Recently, CNNs have achieved state-of-the-art performance in data classification and other computer vision tasks. However, their major concerns are high memory and computational requirements. Therefore, energy-friendly and computationally efficient CNN architectures need to be explored for DP, which can further help the current smart cities be greener.

| Feature | Applications and advantages | Research challenges | Major requirements |
|---|---|---|---|
| 1. Data prioritization | Smart surveillance, intelligent transportation, healthcare, disaster management, and real-time observation of the ongoing activities in smart cities, helping them become more green | • Diversity of data captured in smart cities<br>• Overlapping and redundancy in captured data from multiple views<br>• Real-time prioritization of data and events detection<br>•Complexity and lack of end-to-end deep-learning-based DP architectures and standard evaluation tools | •Energy-efficient and intelligent prioritization for data of different domains<br>•Considering both inter- and intra-view correlation in DP for multi-view data<br>•Minimization of semantic gap (e.g., by integration of deep learning and big data)<br>•Personalized DP and intelligent multi-modality information fusion for DP |
| 2. Security and privacy | Healthcare, smart schools, smart surveillance, intelligent transportation, logistics, smart meters, and protection of user's data in the network and deployment of attack-free services | • User's anonymization in smart city network for different services<br>• Lack of standard security solutions with no compromise on data integrity<br>• Secure integration of edge and cloud services and their deployment<br>• On-time detection of indoor and outdoor security threats | • Cost-effective and strong encryption tools<br>• Intelligent identification of black holes in the IoT environment that serve as weak entry points for malicious users<br>• Energy-efficient data de-identification mechanisms for ensuring users' privacy |
| 3.Data dissemination | Smart surveillance, intelligent transportation, smart industry, improved and on-time transmission of required data to concerned parties/devices and large variety of applications in green smart cities subject to low-cost communication | • Reliable data transmission<br>• Energy efficiency<br>• Secure data dissemination<br>• Prolonging the battery life of IoT devices | • Intelligent spectrum sensing algorithms for reliable and cost-effective data transmission and dissemination solutions<br>• Identification of communication points, leading to data breaches<br>• Improvement in IoT devices and wireless technologies for extending the battery lifetime and ensuring low-cost communication |
| 4. Data reconstruction | Healthcare, improvement in event detection, and decision making | • Quality assurance of reconstructed data<br>• Computational complexity | • Intelligent reconstruction schemes<br>• Cost-effective solutions for reconstruction |
| 5. Big data | Healthcare, intelligent transportation, actionable intelligence, improved performance by processing the filtered data provided by "data prioritization" feature | • Lack of intelligent tools for processing the gigantic volume of data<br>• Ensuring user's privacy during data acquisition and its cost-effective indexing<br>•Fast retrieval algorithms for desired contents extraction | • Edge and cloud assisted big data processing centers<br>• AI-assisted intelligent tools for extraction of actionable intelligence<br>• Awareness of public about careful utilization of IoT networks in smart cities |

**Table 3.** Main features of green smart cities, their challenges, requirements, and future research propositions.

### Universal DP Evaluation and Personalization

The current DP community heavily relies on subjective evaluation mechanisms. Thus, further research is required to devise a universal evaluation mechanism that can automatically measure the performance of DP methods from different perspectives. Another research direction is to explore personalized data prioritization for smartphones by considering their constrained resources as they are integral components of green smart cities.

## Conclusion

In this article, we investigate the performance of state-of-the-art data prioritization schemes in the last two decades. We covered DP methods that use clustering, visual attention models, important events, and multi-modalities for prioritization and analyze CNNs for data summarization in smart cities. We also consider DP methods from different domains such as surveillance, industry, sports, and medical, which can be collected for different smart services of green smart cities. Following the knowledge gained from reviewed literature, we propose an energy-efficient framework for a green smart city by intelligent integration of IoT, DP, AI, and big data analytics. We conduct experiments on surveillance data captured from real scenarios, and verify the energy efficiency and applicability of our framework for deployment in green smart cities. Finally, we overview the strengths and weaknesses of DP methods, and highlight the major challenges and recommendations for future research in order to advance the pertinent smart services and make them greener from different perspectives in smart cities.

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### References

[1] J. Wu *et al.*, "Big Data Meet Green Challenges: Big Data Toward Green Applications," *IEEE Systems J.*, vol. 10, 2016, pp. 888–900.
[2] I. Mehmood *et al.*, "Saliency-Directed Prioritization of Visual Data In Wireless Surveillance Networks," *Info. Fusion*, vol. 24, 2015, pp. 16–30.
[3] I. Mehmood *et al.*, "Divide-and-Conquer Based Summarization Framework for Extracting Affective Video Content," *Neurocomputing*, vol. 174, 2016, pp. 393–403.
[4] M. Fei, W. Jiang, and W. Mao, "Memorable and Rich Video Summarization," *J. Visual Commun. and Image Representation*, vol. 42, 2017, pp. 207–17.
[5] M. Lopez-Martin *et al.*, "Network Traffic Classifier with Convolutional and Recurrent Neural Networks for Internet of Things," *IEEE Access*, vol. 5, 2017, pp. 18042–50.
[6] K. Irgan, C. Ünsalan, and S. Baydere, "Low-Cost Prioritization of Image Blocks in Wireless Sensor Networks for Border Surveillance," *J. Network and Computer Applications*, vol. 38, 2014, pp. 54–64.
[7] S. Egea *et al.*, "Intelligent IoT Traffic Classification Using Novel Search Strategy for Fast-Based-Correlation Feature Selection in Industrial Environments," *IEEE Internet of Things J.*, vol. 5, 2018, pp. 1616–24.
[8] F. Gonzlez-Landero *et al.*, "PriorityNet App: A Mobile Application for Establishing Priorities in the Context of 5G Ultra-Dense Networks," *IEEE Access*, vol. 6, 2018, pp. 14,141–50.

[9] L. Kong *et al.*, "Embracing Big Data with Compressive Sensing: A Green Approach in Industrial Wireless Networks," *IEEE Commun. Mag.*, vol. 54, 2016, pp. 53–59.
[10] B. Li *et al.*, "Big Data Analytics for Electric Vehicle Integration in Green Smart Cities," *IEEE Commun. Mag.*, vol. 55, 2017, pp. 19–25.
[11] C. Zhu *et al.*, "Toward Big Data In Green City," *IEEE Commun. Mag.*, vol. 55, 2017, pp. 14–18.
[12] J. Lloret *et al.*, "An Integrated IoT Architecture for Smart Metering," *IEEE Commun. Mag.*, vol. 54, 2016, pp. 50–57.
[13] W. Ejaz *et al.*, "Efficient Energy Management for the Internet of Things in Smart Cities," *IEEE Commun. Mag.*, vol. 55, 2017, pp. 84–91.
[14] E. Ahmed *et al.*, "Green Industrial Networking: Recent Advances, Taxonomy, and Open Research Challenges," *IEEE Commun. Mag.*, vol. 54, 2016, pp. 38–45.
[15] I. Chih-Lin *et al.*, "Toward Green and Soft: A 5G Perspective," *IEEE Commun. Mag.*, vol. 52, 2014, pp. 66–73.

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