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Citation for the original published paper (version of record):
Roger, S., Botella-Mascarell, C., Martin-Sacristan, D. et al (2024). Sustainable Mobility in B5G/6G: V2X Technology Trends and use Cases. IEEE Open Journal of Vehicular Technology, 5: 459-472.
http://dx.doi.org/10.1109/OJVT.2024.3375451

This article has been accepted for publication in IEEE Open Journal of Vehicular Technology. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/OJVT.2024.3375451

Received XX Month, XXXX; revised XX Month, XXXX; accepted XX Month, XXXX; Date of publication XX Month, XXXX; date of current version XX Month, XXXX.

Digital Object Identifier 10.1109/OJIM.2022.1234567

Sustainable mobility in B5G/6G: V2X technology trends and use cases

SANDRA ROGER(1), SENIOR MEMBER, IEEE, CARMEN BOTELLA-MASCARELL(1), SENIOR MEMBER, IEEE, DAVID MARTÍN-SACRISTÁN(2), DAVID GARCÍA-ROGER(1), JOSE F. MONSERRAT(3), SENIOR MEMBER, IEEE, AND TOMMY SVENSSON(4), SENIOR MEMBER, IEEE

[1]Computer Science Department, Universitat de València, Burjassot 46100 Spain
[2]5G Communications for Future Industry Verticals S.L (Fivecomm), Valencia 46022 Spain
[3]ITEAM Research Institute, Universitat Politècnica de València, València 46022 Spain
[4]Department of Electrical Engineering, Chalmers University of Technology, Gothenburg 41296 Sweden

CORRESPONDING AUTHOR: Carmen Botella-Mascarell (e-mail: carmen.botella@ uv.es).

This work was supported by grant PID2020-113785RB-100 funded by MCIN/AEI/10.13039/501100011033 and Grant TED2021-131003B-C21 funded by MCIN/AEI/10.13039/501100011033 and by the “European Union NextGenerationEU/PRTR”. Mobility Grant CIBEST/2022/207 and Grant CIAICO/2022/179 from Generalitat Valenciana of Spain funded also partially this work.

ABSTRACT The concept of sustainability has been recently extended to cover economic and social factors besides the traditional environmental ones. This paper reflects on the potential of mobile communication standards towards achieving sustainable mobility, with focus on vehicular communications and use cases in smart cities scenarios. In this context, intelligent transportation systems, including connected and autonomous vehicles, will be key for developing affordable and sustainable infrastructures and services. We start by identifying three current technology trends, namely, towards climate neutral; cloudification and edge computing; and big data and artificial intelligence, and then we examine their capability to enable sustainable Vehicle-to-Everything (V2X) communication systems in beyond 5G and 6G networks. In the second part of the paper, a set of selected use case categories involving connected and autonomous vehicles is presented, showcasing the potential impact of the selected technology trends. Finally, a review of the estimates of the quantitative savings that could be achieved in environmental-related parameters such as energy/fuel consumption and greenhouse gas emissions is provided.

INDEX TERMS beyond 5G, 6G, ITS, mobile communications, SDGs, Sustainability, V2X

I. INTRODUCTION

THE concept of sustainability is gaining momentum in the framework of the development of Beyond 5G (B5G) networks, and especially when paving the way for the future 6G standards. Substantial efforts are being done to envision and design future B5G/6G networks as sustainable as possible from a technological perspective (sustainable 6G). Although the traditional vision of sustainability builds around environmental factors, the concept has been recently extended to cover economic and social factors as well. From this perspective, a new task for mobile communication technology appeared, which is to support vertical sectors and role actors to achieve a sustainable society (6G for sustainable societies) [1]. B5G/6G networks are key towards enabling sustainable mobile communication deployments both from a technological perspective and from the society's point of view. In fact, mobile communication standards are at the core of the Information and Communication Technologies (ICTs), and the mobile industry became the first sector in 2016 to commit to the 17 United Nations Sustainable Development Goals (SDGs) from the 2030 Agenda [2]. This Agenda is the reference framework for addressing global challenges directly related to sustainable development and the role of ICTs can be clearly identified in a subset of at least 7 of them, although their cross-sectoral impacts can be found to some extent in all 17 SDGs. The Global System for Mobile Communications Association (GSMA) has measured the impact of the mobile industry across all SDG and it found that in 2021 the average SDG impact across the 17 SDGs reached a 53% of its potential contribution [3].

This article has been accepted for publication in IEEE Open Journal of Vehicular Technology. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/OJVT.2024.3375451

The intertwine between 6G networks and sustainability is being widely discussed from different perspectives [1], [4]. In this paper, the aim is to examine how to provide a minimum quality of life for citizens through sustainable mobility in future mega-cities, which is a challenging scenario framed in the SDG 11 "sustainable cities and communities". Note that United Nations predictions establish that, by 2050, 70% of the world's population will be concentrated in densely populated urban areas. In this context, we envision that three main pillars are needed to develop affordable and sustainable infrastructures and services: future smart cities, ICTs and Intelligent Transportation Systems (ITS).

The role of smart cities and ICTs for improving the quality of life and environmental sustainability is clear. ITS are enablers for achieving road safety and traffic efficiency, including Cooperative, Connected and Automated Mobility (CCAM) and its potential for social inclusion. In fact, the European Commission is developing a 'Sustainable and Smart Mobility Strategy'[1], framed in the European Green Deal [5], which sets intermediate milestones at 2030 and 2035, with the aim of achieving a 90% cut in emissions by 2050, thanks to the deployment of smart, competitive, safe, accessible and affordable transport systems. Alongside with this strategy, we find the aim to achieve zero fatalities in road transport by 2050 (the so called "Vision Zero")[2].

On the one hand, considering 2030 and 2050 as landmarks for sustainable mobility, B5G/6G networks need to pave the way towards safe, affordable, accessible, and sustainable transport systems, as well as improving road safety. Besides ITS, Vehicle-to-Everything (V2X) connectivity is a clear enabler to meet these targets, since it allows to add collective intelligence. For example, V2X applications allow to coordinate traffic in a more smart and dynamic manner and, thus, to reduce congestion. This way, the time spent by vehicles on the roads can be reduced, together with their acceleration and braking, improving the efficiency of traffic flows. On the other hand, in future highly dynamic urban scenarios, quantifying the environmental effect of wireless technologies and mobile communication systems remains an open question [1]. Besides, the broad range of envisioned use cases of B5G/6G networks and their impact on vertical sectors obliges to search for an additional reference framework besides the SDGs. In this context, the Doughnut economics model originally proposed by Raworth in 2012 [6], which combines the boundaries given by the planet with the concept of social boundaries, could provide a more general research approach to benchmark the performance of B5G/6G networks with respect to society and sustainability-driven Key Performance Indicators (KPIs). In parallel, novel concepts such as Key Value Indicators (KVIs) have been explored by the Hexa-X European project [7], with the aim of encompassing sustainability-related concepts such as trustworthiness and inclusiveness.

In this paper, we consider an expanded concept of sustainability, and focus on the potential of mobile communication standards towards achieving sustainable mobility, with special focus on vehicular communications and use cases in smart cities scenarios. The concept of connected sustainable mobility is two-fold in this article: on the one hand, it aims to enable sustainable traffic systems, and on the other hand, it builds towards sustainable vehicular communication. The contributions of this work are the following:

- We identify three current technology trends with a large potential to support sustainable V2X communication systems in B5G/6G networks, namely, towards climate neutral infrastructure and vehicular user equipment; cloudification and edge computing; and big data and Artificial Intelligence (AI). These trends have been selected after analyzing the state of the art due to their ability to integrate isolated technology components into a common umbrella. Moreover, the densification of access points and infrastructure envisioned in future smart cities ensures their plausibility.
- A set of selected V2X use case categories is examined, where B5G/6G V2X communications could contribute towards achieving sustainable mobility. For each of them, we discuss the potential impact of the selected technology trends. Tentative estimates of quantitative savings in energy/fuel consumption or greenhouse gas emissions are retrieved from the literature.

Figure 1 represents our expanded sustainability concept, combining the visual framework for sustainable development provided by the Doughnut model [6], its link with the SDGs, and the impact of the selected V2X technology trends towards sustainable mobility presented in section II. As shown in Figure 1, these trends have a cross-sectoral impact in all SDGs. Basic elements of an ITS are included as well.

II. Technology trends towards sustainable V2X communications in B5G/6G

The sustainability perspective has been mainly addressed from the energy efficiency point of view. One of the references paving the way was the work from S. Buzzi et al. [8], which presented a vision on how wireless networks, in general, should have increased their energy efficiency by 2020. The authors classified the approaches to follow under four main groups: i) Resource allocation focusing more on maximizing energy efficiency than throughput; ii) Network planning and deployment to maximize the covered area per consumed energy; iii) Energy harvesting and transfer by exploiting renewable and clean energy sources; and iv) Hardware solutions accounting for their energy consumption.

In the context of future 6G standards, we can point out the work done in [1], [4]. On the one hand, in [1], the focus is on sustainability as a whole. Chapter 6 deals with sustainability of 6G networks, and technology enablers are presented from the point of view of different system layers: deployment

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[1] https://transport.ec.europa.eu/transport-themes/mobility-strategy_en

[2] https://road-safety.transport.ec.europa.eu/index_en

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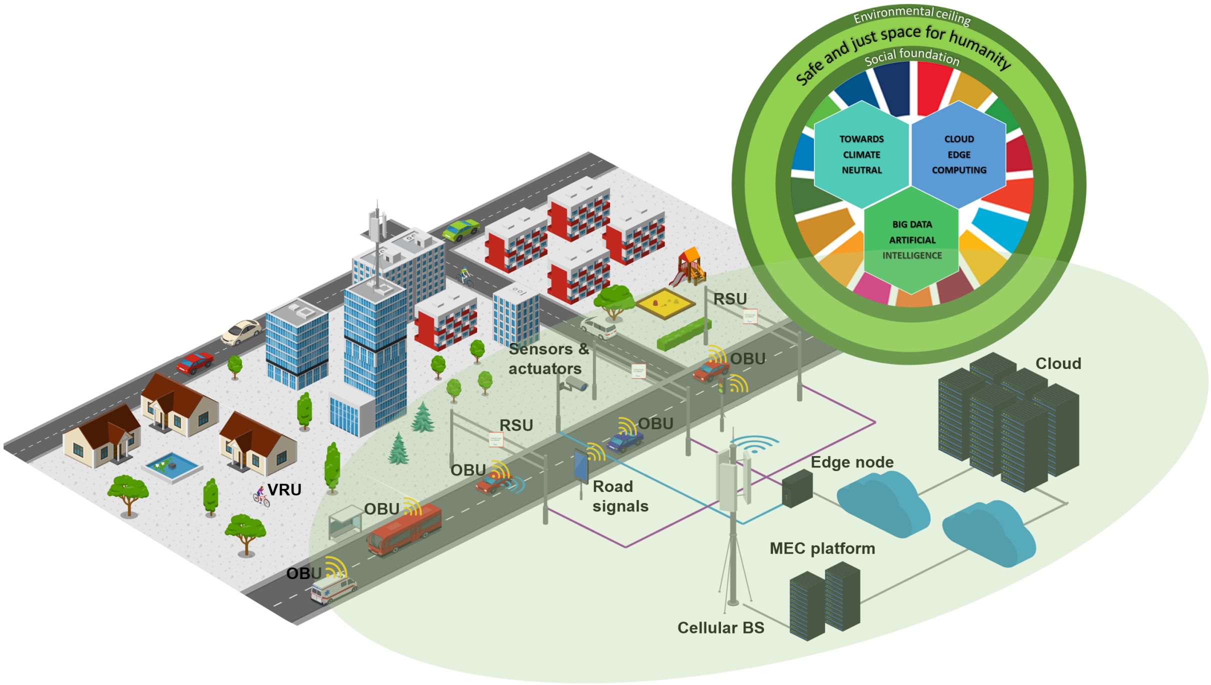

FIGURE 1. **Typical ITS system in a smart city context. Doughnut model [6] (in green), SDGs from United Nations (wheel of colors) and cross-sectoral impact of technology trends.**

layer, network/management level, service/application layer and cross-layer. On the other hand, in [4], the contribution is two-fold, but focused on the energy point of view. First, energy models are provided for 6G techniques related to computing and learning models. Second, the cases of how to achieve energy-efficient network planning, radio resource management and service provisioning are discussed. The particular case of AI and obtaining energy-efficient training and distributed computation is also presented. If we look into the particular case of V2X, we can highlight recent surveys such as [9], [10]. The potential of cellular-based V2X communications (C-V2X) to achieve road safety and traffic efficiency is reflected on [9]. It presents an extensive classification by type of application, but there is no discussion related to sustainability. Reference [10] also considers C-V2X and elaborates a classification by application, but it includes the environmental impact of each application. This impact is measured through the estimation of benefits in different environmental-related parameters. From the survey, it is clear that there is not a common framework to evaluate the impact of C-V2X applications from the point of view of sustainability. Besides, the road type considered are freeways, arterials or networks, so they are framed in the context of inter-urban, suburban or even rural areas.

In this contribution, we adopt a novel point of view and narrow the scope to the case of future smart cities with a large population density. After analyzing the state of the art, we extract three current technology trends as the main drivers towards achieving sustainable V2X communication systems, namely, i) Towards climate neutral infrastructure and vehicular user equipment; ii) Cloudification and edge computing; and iii) Big data and AI. These trends have been selected due to their capability to encompass individual technology components and the large transformative impact that they could generate in the communication systems. Actually, they can be seen as an update of the four groups proposed in [8]. Note that achieving sustainable solutions in some use cases might require a combination of the three trends, while others might be resolved with just one of them. For each one of the technologies, an effort has been made to synthesize the potential impact into two main enablers.

Figure 1 shows a typical system with communication, computation and storage nodes to support an ITS. Pedestrians and Vulnerable Road Users (VRU) are as well part of the system, and they could participate either passively (sensed) or actively through user equipment with Internet-of-Things (IoT) capabilities. The figure includes On-Board Units (OBU) in the vehicles providing wireless communication to Road-Side Units (RSU) and/or cellular Base Stations (BSs). The former are typically part of vehicular-dedicated networks while the latter provide access to Mobile Network Operator (MNO) networks. In addition to the vehicles, other elements such as cameras or road signals can be connected wirelessly or via wires to the abovementioned system. Edge compute-and-storage nodes and cloud nodes are part of the system. In the case of the MNO networks, the edge nodes are part of Multiaccess Edge Computing (MEC) platforms. The first trend selected in this section is focused on the radio part of the system, i.e., the communication between OBUs and RSUs/BSs, the second refers to the presence itself of

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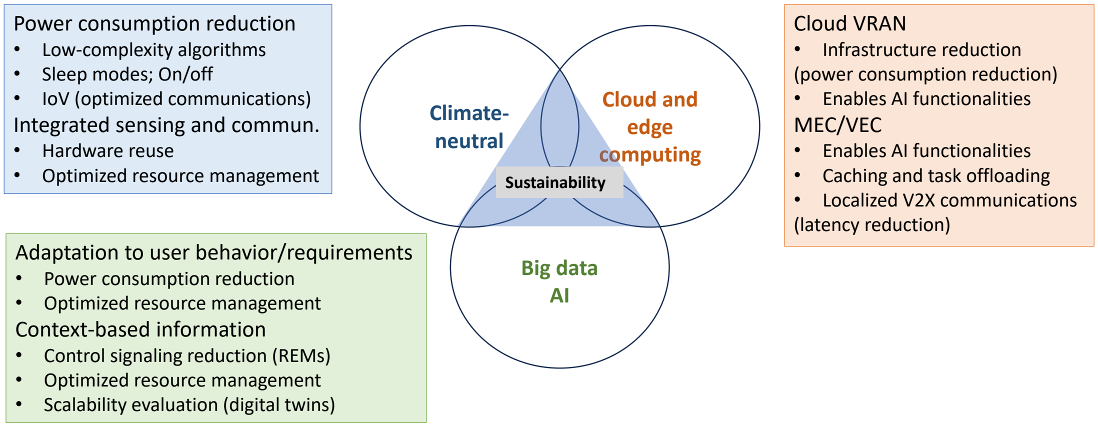

FIGURE 2. **Summary of the selected technology components and relation to each of the three technology trends towards sustainability.**

edge and cloud nodes, while the third one is more pervasive and has implications on the whole system. Figure 2 presents a visual summary of the selected technology components to be described throughout this section, highlighting in different colors their connection to the corresponding technology trend.

A. Towards climate neutral infrastructure and vehicular user equipment

The term climate neutral is a broad concept that includes aspects related to achieving no net emissions of greenhouse gases, reduced resource and material usage or increase KVIs [5]. Reducing the power consumption at infrastructure and user equipment, with the special case of vehicular users, has been in the focus of most of the efforts long so far, before 5G and 6G, and it is still considered the default path towards climate-neutrality [11]. From a different perspective, there is an emerging trend to implement different functionalities of communication systems on the same hardware architecture, spectral resources, and signal processing framework. In the following, we review first the capabilities of more traditional approaches focused on reducing power consumption, such as those based on diversity or multi-antenna, and second, we discuss the potential of the more disruptive approach based on integrated sensing and communication (ISAC) within the same system.

1) Power consumption reduction at BS and UE

Focusing on C-V2X, reduction of power consumption at BSs can be addressed considering two different processing types [7]. On the one hand, aspects such as control signaling, backhaul infrastructure, and some part of the consumption of baseband processors are independent of the network traffic. On the other hand, basic elements of transceiver chains (power amplifiers, etc.) and processes in digital communication systems (channel coding, Multiple-Input Multiple-Output (MIMO) schemes, etc.) have been shown to experience a linear power consumption increase with the traffic over a certain fixed consumption. For the traffic-dependent power consumption term, important research efforts have been dedicated to the development of low-complexity algorithms, able to reduce the computational cost and thus the power consumption. Examples are the low-complexity receivers for V2X developed in [12], the low-complexity and fast-processing algorithms for vehicular massive MIMO in [13], or the low-complexity, scalable resource allocation algorithm in a centralized framework proposed in [14], among many others. Another complementary solution is to deactivate system components when identified as unused, considering BS switch-on/off algorithms and antenna muting techniques able to adapt to the traffic conditions [8]. Further energy-saving benefits could come from more sophisticated sleep modes involving substantial changes in the air interface of 6G systems related to, e.g., the duty cycle and frame structure [7].

When focusing on the vehicular user equipment, similar aspects apply regarding the reduction of control signaling [15], etc. However, implementing advanced multi-antenna schemes enabling diversity and identifying optimal antenna locations in the vehicle are specific solutions for enabling realistic and energy-efficient C-V2X systems in the vehicle side [16], [17]. In general, trade-offs between energy-efficient solutions and important metrics for V2X such as latency and reliability should be carefully considered [11].

Recently, the concept of the Internet of Vehicles (IoV) and its potential in smart cities is being explored. In this scenario comprising a dense deployment of access nodes, communication efficiency could be increased by optimizing the transmission rates, and smartly selecting the communication channel and time slots, for instance, through joint optimizations of resource allocation and communication links selection [18].

2) Resource reuse and optimization through ISAC

Although research on environment sensing and wireless communications have traditionally followed independent paths by adopting different spectral and signaling resources, there is growing interest towards what is known as integrated

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sensing and communication (ISAC) [19]. ISAC is a key element of B5G communications, where wireless sensing capabilities are provided by the same system and infrastructure used for communication according to the definition in [20]. Such an integrated framework is expected to boost the spectral, energy, hardware, and cost efficiencies, thus contributing to greener and sustainable future networks.

ISAC enables both communication-assisted sensing and sensing-assisted communication. While in the former the communication system includes sensing services (using dedicated waveforms, for example), in the latter the sensing information is used to improve the communication services (e.g., the resource allocation, beamforming, etc. could be improved if the location of the receiver is known). Some examples of ISAC use cases identified in [20] for communication assisted sensing include the use of wireless communications signals for:

- Positioning and hence environment real-time monitoring such as creating dynamic 3D maps, pedestrian flow statistics, intrusion detection, etc.
- Object detection through leveraging wireless signals for environmental sensing and extracting information about physical objects. For example, to locate and avoid physical obstacles, pedestrians, or other vehicles in connected and autonomous vehicles.
- Air pollution monitoring: to estimate humidity or Particulate Matter (PM) concentration, for example.
- Vital signs monitoring: respiration rate, heartbeat, etc. can be used for health care monitoring or driver state detection.

Some examples of ISAC use cases identified in [20] for sensing assisted communication include the use of wireless sensing signals for:

- Beam selection in beam management for communications, where sensing the location and environment of a receiver can help to detect and determine the optimal direction (beam) for communication.
- Beam prediction in beam management for communications, e.g., based on the location, velocity, and trajectory of a receiver the system can predict and optimize the beams for more efficient communication.
- Communications channel estimation, based on the knowledge of the sensed environment.

It is worth noting that, in a broad sense, ISAC sensing can be based on non-radio-frequency sensors such as cameras, accelerometers, gyroscopes, etc. These sensors are very useful in some cases but have some deficiencies that can be overcome with the use of wireless sensing. We refer here to the interference problems of traditional radars [21], or rain and fog issues of cameras and lidars [22].

In the last decade, ISAC in vehicular scenarios has considered the use of generic higher frequency systems in the millimeter wave (mmWave) band and beyond, see e.g. [23], [24]. Nevertheless, the challenge today is to consider specific vehicular communication technologies to integrate natively ISAC in them, the technologies that will be in fact on board of the vehicles [25]. The 5G-Automotive Association (5GAA) has identified C-V2X use cases and their requirements in [26] and [27]. Some of those use cases, such as infrastructure-assisted environment perception, infrastructure-based tele-operated driving, High-Definition (HD) map collecting and sharing, and tele-operated driving support, can broadly benefit from ISAC.

B. Cloudification and edge computing

In contrast to traditional hardware-centric wireless networks, the advances towards network virtualization made it possible, in the last years, to remove the need for specialized hardware and enable the deployment of software to be independent of the hardware used, shifting the processing load to computation units. Through what is known as network slicing, a network architecture enables the multiplexing of virtualized and independent logical networks on the same physical network infrastructure. Each network slice corresponds to an isolated end-to-end network aimed at fulfilling the requirements of a specific application. The new envisioned programmable network paradigm promises to increase flexibility and profitability, simplifying design and management through, for instance, automated service orchestration. As the following step after virtualization, network cloudification is a clear trend in future 6G network design, alongside MEC and Software Defined Networking (SDN). Cloudification refers to the broader trend of migrating computing resources, including storage and processing power, to a centralized cloud infrastructure, whereas MEC offers a solution to bring computation closer to the network edge.

Focusing on achieving sustainable V2X communications, the Radio Access Network (RAN) architecture can indeed take advantage of cloudification and MEC to reduce the deployment costs of BSs and improve spectrum efficiency through smart resource sharing. Besides, cloudification provides a scalable and flexible platform for the future challenge of managing and processing the massive amounts of data generated by V2X applications. In the following, the potential of these network trends for enabling sustainable V2X communications is discussed.

1) Cloud vehicular radio access network

The authors in [28] proposed a novel C-VRAN to reduce the number of BSs through centralized processing and, thus, simplify operation management. The proposal integrates a cloud RAN architecture with a data compression function and the cellular vehicular network. Specifically, the architecture is composed of Remote Radio Heads (RRH) with limited physical layer capabilities, a Base Band Unit (BBU) pool, which performs a centralized baseband processing in the cloud and assigns scheduling tasks, an optical-fiber-based fronthaul to connect the RRH and BBU and, finally, a compression/decompression module, where data compression functions are applied to reduce the workload of the fronthaul link. In [29] a framework is proposed to optimize virtualized radio access networks (vRAN) by determining the number and location of Cloud computing Units (CUs), function split for each BS, and association and routing for Distributed Units (DUs) with the goal of minimizing network costs while considering centralization factors, revealing substantial trade-offs between centralization and cost influenced by traffic and network parameters. Finally, [30] is an example of a vehicular-cloud MAC framework that aims at improving connection quality between vehicles and base stations on scenarios with coexisting LTE-Advanced and IEEE 802.16 technologies to analyze reliability metrics.

The C-VRAN architecture creates several environmental advantages. On the one hand, there are benefits regarded to a reduced power consumption, overlapping with the towards climate neutral trend, both at the BS and the vehicular user. The number of BSs is reduced, so the power consumption of supporting equipment, such as onboard air conditioners, can be greatly reduced. In addition, the deployment of smaller cells reduces the distance between RRH and users, lowering the power consumption and emissions. An important additional outcome is that the battery lifetime of vehicular equipment is extended. On the other hand, the centralized processing approach improves spectrum efficiency through smart resource sharing and dynamic scheduling, while paving the way to the introduction of AI functionalities in the RAN. Note that big data and AI stand for the third technology trend presented in this paper and that C-VRAN architecture could be fundamental towards managing and processing the massive amounts of data collected by onboard sensors from smart vehicles.

2) MEC and Vehicular Edge Computing (VEC)

MEC brings decentralized, application-oriented capabilities closer to the RAN, paving the way towards connected vehicles and autonomous driving [31]. In addition, MEC can be exploited to implement AI-based applications at distributed edge devices, pushing the network intelligence at the edge through the concept of edge-AI [18], [32], [33]. MEC is likely to become an essential component of B5G networks, although its deployment in 5G Non-Standalone Networks (NSA) may scale badly with the growth of adoption of V2X services. A challenge for 5G Standalone (SA) networks is then to achieve a dense deployment of MEC nodes without significantly increasing the computation power of the network.

One promising technique to alleviate the densification of MEC nodes is Vehicular Edge Computing (VEC). This technique uses RSUs to act as edge servers for caching and task offloading purposes [34]. Caching of popular content files consumed by the users at the edge of the wireless network enables a fast access to those contents by any vehicular user without consuming infrastructure resources again; thus, increasing the climate-neutrality of the communication. In vehicular networks, caching presents some peculiarities. Specifically, the RSU should be designed with caching in mind, and therefore its storage capabilities should consider this technology. Concerning the type of contents that can be cached, we can consider infotainment data such as popular videos, communication protocol parameters useful in a geographical area [34], or HD maps for driving assistance [35].

Edge computing strategies such as MEC and VEC can enable localized V2X communications, e.g., those requiring the transmission of the same message to a set of vehicular users in proximity. The potential benefits of localized V2X communications are two-fold in the context of sustainability. On the one hand, localization of functions has been explored by researchers and standardization organizations, such as Third Generation Partnership Project (3GPP) and European Telecommunications Standards Institute (ETSI), as a candidate for latency reduction. The latency reduction can be achieved either by deploying local multicast and broadcast dedicated servers very close to the users, or by deploying localized V2X servers handling the termination of V2X packets at the application layer of the RSU [36]. Note that communication latency can be also reduced through vehicular caching, since it takes the data much closer to the users on the road. On the other hand, the exchange of control information can be significantly reduced in localized multicast communications by assigning Radio Network Temporary Identifiers (RNTI) statically to different geographical regions (geo-RNTI), as proposed in [37]. Pre-configuration of geo-RNTIs per area and per service eliminates the communication with application servers to obtain service identifiers, and it also removes the step of adquiring control signaling to map those service identifiers with the radio identifiers.

Reliable localized communications based on the above strategies could reduce in practice the number of retransmissions and control signaling, with a direct impact on reducing energy consumption. Besides, both the latency reduction and the reduced exchange of control information achieved through localized communications are drivers for managing and processing the massive volume of data related to V2X applications in future autonomous driving networks. However, the main challenges ahead are related to the coordination of the different V2X servers in order to achieve a proper and faster forwarding of data packets, with reduced latencies.

C. Big data and AI

The data volume required, generated, collected, and transmitted by mobile users, with the special case of connected and autonomous vehicles, is experiencing an exponential escalation. An optimized use of such a large amount of data, widely known as big data, can be crucial towards achieving sustainable vehicular systems and, particularly, sustainable communications. For instance, the monitoring of actual fuel consumption statistics of connected and autonomous vehicles can provide regulatory bodies with a better indication of real-world fuel consumption, and in turn, real-world emissions, to better assess in which areas the zero emissions target is more critical to be achieved, and act accordingly.

Benefiting from the data availability, AI-assisted V2X communication systems are being proposed for future 6G deployments, focusing on their capability to achieve, for example, both safer transport systems and optimized transport routes to minimize traffic congestion [38]. In general, big data and AI-assisted V2X systems are seen as the technological trends that will pave the way to an enhanced deployment of automated vehicles, providing important societal benefits, especially in urban environments.

Focusing on achieving sustainable V2X communications, substantial development of AI-assisted V2X systems is needed to properly manage and process the foreseen large amount of big data related to vehicular systems. In the following, the benefits in terms of sustainability of two main directions exploiting AI-assisted V2X are discussed.

1) Adaptation to user behavior and requirements

Currently, different machine-learning methods are being used to model the behavior of 5G networks, with the general aim of predicting user requirements in highly changing complex environments [39]. Enhanced AI techniques open the door to the possibility of minimizing the network power consumption by considering inputs such as the temporal evolution of the user behaviors and requirements, having a more global view of the different types of needs for users coexisting in a certain area (vehicles, pedestrians, etc.). Thanks to this, traffic loads can be predicted, and energy-related parameters can be optimized. For example, unused resources could be identified to smartly decrease power consumption of BSs located in roads where little density of vehicular users is expected according to the AI predictions. At the physical layer, AI also shows potential for decreasing the power consumption in large systems, such as in the case of massive MIMO deployments in mmWave, for instance, by optimizing resource allocation and beamforming [40]. We further foresee advanced AI-based multi-antenna V2X algorithms allowing dynamic configurations, e.g., transmit antenna selection, depending on vehicular user requirements. This application of a diversity-based scheme has been proposed for traditional architectures in [17], where the criterion was the specific vehicular application.

2) Exploitation of context-based information

In V2X communications, wireless channel quality is critical for safety and reliability. However, it varies significantly as vehicles move from one location to another, especially in urban areas and congested traffic scenarios. In the case of connected and autonomous vehicles, big data can be collected both from the vehicle's sensors and from the infrastructure. This massive amount of data gives rise to the context-based information concept [41]. In general, context-based information can include, for instance, information about the position of the vehicles, their speed, information about the scenario and relevant conditions such as the existence or lack of communication blockages/obstacles and their type, etc. This information can be exchanged through Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I) communications. A particular use case of context-based information is the generation of Radio Environment Maps (REMs), which collect estimates of long-term channel values, together with location information [42]. Several techniques have been proposed to reconstruct REMs from a set of measurements, such as spatial interpolation or machine/deep learning based techniques [43], [44]. The availability of REMs is envisaged to enhance aspects of V2X communication such as reducing the signaling overhead of channel estimation, and thus, the power consumption related to communications, as shown in preliminary studies such as [45], [46]. In addition, in the particular case of smart cities where the mobility pattern of vehicles can be estimated through big data techniques, REMs allow the implementation of advanced schemes based on predictive Quality of Service (QoS), which could contribute to optimizing the resource allocation stage due to the capability of identifying coverage holes beforehand, for example [47].

Recently, an extended version of the context-based information based on AI techniques is being considered in future 6G deployments, that is, the digital twin concept [48]. In a digital twin, a digital replica of a real-world system is created gathering data and models of the real elements, while providing interfaces to access such data and models. Focusing on the V2X case, a trustable real-time digital twin could be created thanks to the high reliability and low latency of B5G communications [7]. From the sustainability point of view, the application of AI over the digital twin could provide benefits ranging from a decreased power consumption of the communication systems (through optimized mobility patterns in urban areas, especially in congested traffic situations, and optimized communication signaling schemes) to an enhanced efficiency of the vehicle energy consumption. One of the advantages of building a digital twin in V2X scenarios is the possibility of evaluating the scalability of use-cases without actually implementing them, which is a capability that largely contributes to optimizing system parameters.

III. Selected V2X use case categories

In this section, a set of V2X use case categories is identified and presented. These categories are also a thematic way to group the use cases already identified by the 3GPP and the 5GAA in recent years. Note that even in the case of electrical mobility, the pool of possible use cases remains the same, i.e., 3GPP and 5GAA. Use cases have been grouped from the point of view of their relevance towards enabling sustainable mobility through V2X communications in the smart city framework. Note that, under the ITS framework and CCAM, a different grouping of use cases could be obtained. In our case, for the sake of generality, use cases are defined according to 3GPP and the 5GAA. Estimates of quantitative savings in terms of environmental-related parameters such as energy/fuel consumption and greenhouse gas emissions are retrieved from the literature for each category. Note that vehicles are responsible for a significant portion of air pollution by emitting Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), and PM. For example, in the EU, passenger cars and vans cause 14.5% of CO_2 emissions [49], while lorries, buses and coaches cause the 6% of CO_2 emissions [50]. Therefore, reducing the vehicle emissions could have a great potential impact on the global pollution reduction. The performance requirements for each use case are mentioned in the context of current 5G standards and we pay special attention to the link between each specific use case category and the technological enablers that will be required for their successful implementation and enhancement in B5G/6G.

A. Green driving

To promote sustainable mobility and transportation, it is essential to consider the environmental impact of driving, particularly in critical or highly polluted areas. One strategy for reducing pollution is to implement traffic management measures that limit emissions during periods of high pollution. For example, hybrid vehicles can be programmed to operate in electric mode during these periods (Figure 3), reducing their emissions output. Additionally, speed limits can be temporarily reduced, which can lead to significant reductions in fuel consumption and emissions. Infrastructure-based vehicular communications are a key enabler for this traffic management. Using this kind of communication, vehicles and/or intelligent on-road signals can receive the decisions made by traffic management systems, which can be run on edge or cloud systems. Although this use case does not require either a very small latency or a high data rate, it requires the connectivity of the vehicles and infrastructure to a cloud where effective traffic management decisions, probably based on AI, are made based on the collection of pollution data gathered by on-road sensors.

B. Vehicle platooning

A vehicle platoon is a group of autonomous vehicles that travel together in a coordinated manner having short and constant inter-vehicle distances. Figure 4 illustrates this concept showing a platoon of trucks. Platoons are however not restricted to trucks, also passenger cars could benefit from such feature, and platoons of public transportation vehicles can be envisioned in smart cities, too. Platooning increases the energy efficiency thanks to the reduction of the air resistance that all the members of the platoon experience with regard to isolated driving, except for the first one, the platoon leader. Vehicle platooning is already supported by 5G since Rel-16, assuming a decentralized approach where member vehicles autonomously cooperate to realize the platoon-related procedures. More advanced scenarios may be envisaged in B5G/6G networks, e.g., Platooning-as-a-Service (PaaS). This is a real-time centralized paradigm where the control of the parameters of the vehicles (speed, acceleration, etc.) is itself managed at the MEC by the network [51].

FIGURE 3. **Example of green driving scenario where hybrid vehicles approaching a hospital are requested to switch to electrical mode to reduce NO_x emissions and particles.**

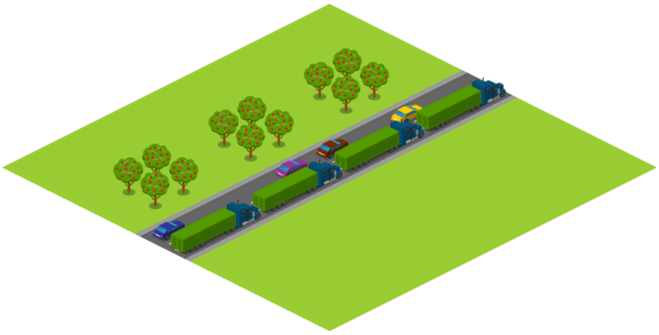

FIGURE 4. **Illustration of truck platooning.**

PaaS, and high-density platooning, i.e., platooning with very short inter-vehicle distances, enable significant energy/fuel savings but they also set stringent requirements for the V2X communication [24], e.g., end-to-end latency of less than 10 ms and message reliability higher than 99.99%. These requirements could be relaxed to 25 ms latency and 90% reliability for a less efficient lower-density platooning. The SARTRE project reported in [52] fuel consumption reductions from 1% to 8% for the leading truck and from 8% to 16% for the following trucks in platoons with trucks spaced 5 meters. Truck platoons with 5G communication could reduce the inter-vehicle distance to less than 1 meter for high-density platooning. The Partners for Advanced Transit and Highways (PATH) program conducted in California in the 1990s gathered some predictions in [53], where for 1-meter spaced platoons, fuel consumption reductions between 11% and 27% were expected. The Greenhouse Gas Equivalencies Calculator developed by the United States Environmental Protection Agency[3] is a useful tool to convert greenhouse

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[3] https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

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gases emission numbers into different types of equivalent units. Using this calculator and considering that the amount of CO_2 emitted per gallon of motor gasoline burned is 8.8910^{-3} metric tons, the fuel consumption reductions estimated for 1-meter spaced platoons could save approximately 0.32 and 0.79 metric tons of CO_2 emissions per full-tank truck, respectively.

The technology trends discussed in the first part of the paper will also play a fundamental role in this use case. In fact, localized V2X communications are a key enabler for platooning. This communication is needed for the basic management of the platoon since the leader and the rest of the members must exchange messages concerning their speed, heading, intention (braking, acceleration), change of leader, etc. This communication is also needed to join and leave the platoon, and to inform the close vehicles about the presence of the platoon, so that they can join it, for example. In order to achieve the highest reliability with the lowest delay, context-based information can be exploited as well in this use case to reduce the interference between transmissions and increase the system capacity. Such context information could reside in MEC servers to be conveniently shared among different vehicles in the zone.

C. Smart routing

Traffic congestion not only causes delays and frustration for drivers, but also has negative impacts on energy consumption and pollution due to the start and stop patterns of the vehicles involved. Such patterns require more energy to accelerate and decelerate, leading to increased fuel consumption and emissions when compared to a fluid traffic. However, smart routing approaches can help address not only these environmental concerns but also safety concerns in smart city applications. For instance, emergency vehicles can be dispatched more efficiently by utilizing data generated by vehicular ad-hoc networks and IoT sensors, such as those tracking pedestrian activity. With the help of AI-based real-time routing algorithms [54], emergency vehicles can be directed to their destination using the safest and most efficient route possible, minimizing response times and maximizing the safety of both the emergency responders and other drivers on the road. Smart routing of the vehicles via the selection of the best route could also lead to energy-efficient driving thanks to the avoidance of congested zones. In addition, the selection of routes can produce a load balance between the roads, reducing the general congestion. Figure 5 shows an example where a vehicle is routed towards a destination selecting the path that avoids a traffic jam. Smart routing has been considered, for example, in [55] where 17% reduction of CO emissions and 5.5% reduction of fuel consumption (equivalent to a saving of 0.006 metric tons of CO_2 emissions per full tank[3]) were obtained for passenger cars. In [56] a Dutch motorway is considered to estimate a 6% potential reduction of CO_2 emission reduction when a congestion is avoided thanks to connectivity.

FIGURE 5. **Example of smart routing where a vehicle is routed towards a destination avoiding a traffic jam.**

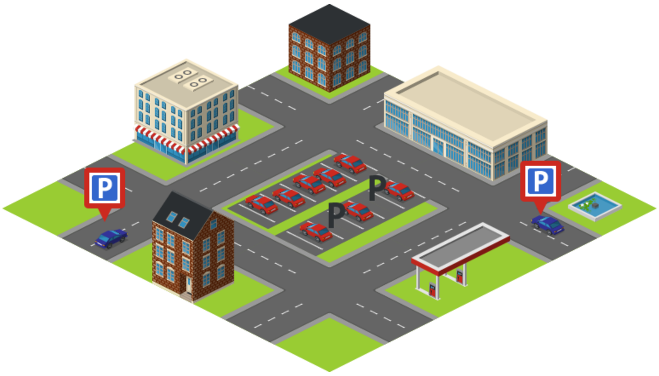

FIGURE 6. **Illustration of smart parking where two vehicles are notified about the availability of parking spots in a parking lot.**

AI and cloudification are two key technology trends that will enable the full potential of smart routing in B5G/6G networks. In order to make optimal routing decisions, smart routing algorithms require a comprehensive view of the driving situation, which can only be achieved by integrating data from a range of sources, including vehicles and roadside sensors. Cloud nodes and edge computing technologies can facilitate this integration by providing a centralized platform for data processing and analysis. With the help of AI-based algorithms, these nodes can analyze the data in real-time to identify traffic patterns, detect road hazards, and make routing decisions that minimize congestion and maximize safety. By leveraging the power of AI and cloudification, smart routing approaches can transform the way we think about transportation and mobility, enabling more efficient, sustainable, and safe transportation systems for all.

D. Smart parking

According to [57], drivers seeking parking spots represent a significant portion of a city's traffic (more than a 30%). Therefore, an optimization of that search could represent a key contribution to sustainability. Presence sensors could indicate the occupation status of parking spaces while an application would inform the vehicles of that situation. Thanks to this use case, energy consumption could be reduced. This reduction would be similar to that estimated in [58], [59] for full-autonomous vehicles which was higher than 4%. Figure 6 shows an example where two connected

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and autonomous vehicles are notified of the availability of parking spaces.

This use case requires both V2I and V2V communication since the vehicles need to access an application running typically in the cloud. Note also, that Peer-to-Peer (P2P) network based smart parking systems exist, and because of complexity of big data they require computation at the edge [60]. Hence, AI and cloudification are the key technology trends enabling this use case.

E. Speed harmonization

Speed harmonization is a broad term that includes any mechanism used to shape the speed of vehicles according to the current recommended speed at a certain location to optimize traffic flow, minimize emissions, and ensure a smooth and safe ride, always according to the most up-to-date driving conditions. Since speed harmonization reduces the need for frequent acceleration and deceleration, it promotes an overall journey with more environmentally friendly driving patterns.

"Group start" is a speed harmonization approach, which consists of forming opportunistic platooning groups that move when green lights are on, thus producing a beneficial impact on reducing the reaction time and making traffic more fluid. Another promising approach is "Continuous traffic flow via green lights coordination", where a sequence of multiple traffic lights is coordinated according to the live conditions of the traffic to allow a seamless and continuous flow of traffic through multiple intersections along a preferential direction. For instance, Figure 7 shows a scenario where two traffic lights are coordinated to stay green until all the vehicles belonging to a platoon (cars in blue) traverse the road. In the literature, [56] reported a reduction from 3% to 7% in CO_2 emissions due to the reduction of deceleration and acceleration of passenger cars on motorways or roads between intersections. In synthetic scenarios, it has been shown that even the presence of just one vehicle following the optimum speed rules may improve the energy efficiency by 15%, with up to a 73% reduction of emissions of NO_x [61].

In this use case, like vehicle platooning, AI and cloudification are the main technology enablers. Localized V2X communications would enable a fast communication among vehicles whose speeds should be harmonized and with the infrastructure. C-VRAN is a must for achieving highly reliable communications and matching the reduced delays that are fundamental via edge computing [57]. Huge data rates could be needed to achieve an accurate knowledge of the traffic conditions leading to optimal decisions usually based on advanced AI algorithms.

F. Coordinated maneuvers

The coordination of complex maneuvers among vehicles could make the traffic flow more fluid by avoiding stops and delays. A recent World Bank report on 5G Enabled Transport [62] presents the case of the smart intersections where autonomous vehicles using V2I can coordinate their trajectories. In the example shown in Figure 8, a smart intersection without traffic lights is enabled thanks to the coordination of vehicle maneuvers. As shown, in this kind of intersections, inefficient queues of vehicles can be avoided. Reference [56] reported a CO_2 reduction for passenger cars between 7% and 45% depending on the car speed and the number of avoided stops per kilometer. A similar result is presented in [58], where a smart intersection allowed an energy consumption reduction between 13% and 44%.

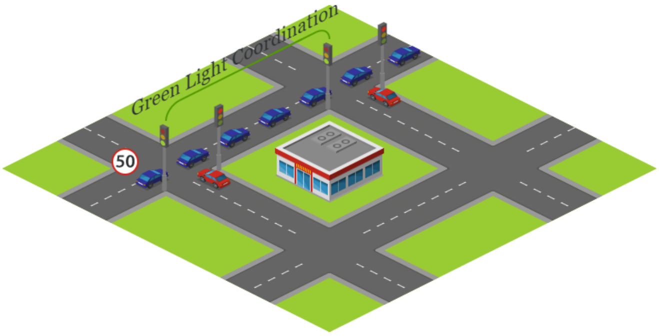

FIGURE 7. **Speed harmonization through green lights coordination.**

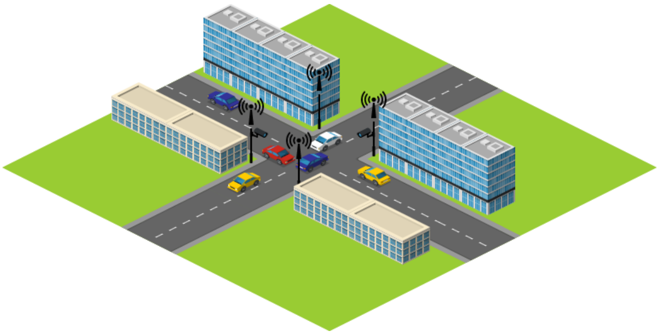

FIGURE 8. **Smart intersection without traffic lights enabled by coordinated maneuvers.**

Smart intersections can be implemented based on localized V2I communication, with the trajectory decisions based on the massive exchange of information among vehicles and RSUs (e.g., proposals like [63]), and with the decisions taken most possibly at a centralized infrastructure element. Cooperative collision avoidance is one of the new functionalities taking advantage of this scenario. As a key safety application, low delay in the transmission of data is critical to avoid accidents. Given the extremely short latency needed, this infrastructure-based case requires ultra-reliable low-latency communications, because the decision process of the most advanced AI-based proposals (e.g., [64]) would imply too high latencies unless implemented at the edge. Context information such as video from cameras can be used to make optimal decisions, usually based on AI algorithms. Thus, cloudification and AI are the technology trends enabling this use case.

TABLE 1. **Summary of average fuel, energy or greenhouse gas savings for each use case.**

Use case category	Metric	Assumption	Value, reference
vehicle platooning	fuel consumption reductions	leading truck	
		5 m truck platooning	from 1% to 8%, [52]
	fuel consumption reductions	followers	
		5 m truck platooning	from 8% to 16%, [52]
	fuel consumption reductions	1 m platooning	from 11% to 27%, [53]
	saved metric tons of CO_2 emissions per full tank	1 m platooning	0.32 for 11%, EPA calculator
			0.79 for 27%, EPA calculator
smart routing	Fuel consumption reduction	passenger cars	5.5%, [55]
	saved metric tons of CO_2 emissions per full tank		0.006 for 5.5%, EPA calculator
	reduction of CO emissions	passenger cars	17%, [55]
	reduction of CO_2 emissions	motorway	6%, [56]
smart parking	energy consumption reduction	full autonomous vehicles	above 4%, [58], [59]
speed harmonization	energy efficiency improvement	synthetic scenario, one vehicle	15%, [61]
	reduction of NO_x emissons	synthetic scenario, one vehicle	73%, [61]
	reduction of CO_2 emissions	passengers cars, motorways	
		roads to intersections	from 3% to 7%, [56]
smart intersection	energy consumption reduction	single intersection	from 13% to 44%, [58]
	reduction of CO_2 emissions	passenger cars	from 7% to 45%, [56]

IV. Discussion

Table 1 summarizes the estimated average savings per vehicle for each of the categories described above, as retrieved from the literature. According to the available data for each one, fuel, energy or greenhouse gas saving percentages are displayed. For some use cases, a range of potential savings is shown. The smart intersection use case presents the widest range of improvement, and shows also the maximum potential energy and CO_2 saving per vehicle. Concerning the fuel consumption savings, high-density vehicle platooning (with inter-vehicle distances lower than 1 meter) exhibits the highest percentage. Although the smart routing and smart parking use cases show the lowest average savings, a wide adoption of these services in future densely populated urban areas is expected, due to their relatively low-cost implementation. Then, a significant global impact on fuel/energy savings might be achieved due to the large number of benefited vehicles in urban areas.

These reductions in fuel/energy consumption or greenhouse gas emissions come from different benchmarks. Besides, as mentioned before, some of the use cases could be combined, as it is the case of speed harmonization and smart intersection. Note that, currently, there is a lack of standardized methodologies to evaluate the impact of C-V2X applications, or of ICTs in general, from the point of view of sustainability. Savings are usually given in fuel/energy or greenhouse emission savings, or time travel, which is related to the former ones. It is possible to build models to quantify the impact, but with the unavailability of data and the need for assumptions, results are uncertain to some extent. Moved by the need to quantify the impact of ICTs, the International Telecommunications Union (ITU) recently published the recommendation [65], which could be followed by MNOs and industry to assess the impact in terms of greenhouse emissions. This is a very important step towards obtaining a common framework and solid results.

There are other factors that are going to change the implementation of V2X use cases. First, the majority of the enablers that have been discussed in the first part of the paper require a centralized implementation. Distributed implementations remain an open question, but they could be feasible in a smart city infrastructure with cloudification and edge computing capabilities. Then, work needs to be done in this area to assess the benefits of distributed deployments with respect to centralized ones, both in terms of cost and impact in terms of sustainability related KPIs. Second, the growing penetration of Electric Vehicles (EV) is currently one of the most effective solutions towards sustainable mobility, due to its clear reduction in carbon emissions [66]. EVs can certainly benefit from a reduced electricity consumption by exploiting V2X. As an example, when EVs are used for public transportation, traffic signals can give priority to public vehicles through V2X applications, which could make them a more efficient and convenient transport option for citizens, motivating their increased usage.

There is an on-going discussion in the telecommunications community regarding whether the path towards B5G/6G is going to be sustainable as well on costs and business models. In the case of the technology enablers presented in this paper, their implementation affects other aspects of the network, and even if they pose a real benefit in terms of sustainability, they have as well an economic impact that needs to be traded-off. This is the case, for example, of the schemes affecting the power consumption at the infrastructure (on/off schemes and C-VRAN). On-off schemes are not yet fully implemented in current networks, while C-

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VRAN depends on a massive deployment of RRHs, which might not be economically feasible. In this line, although our work considers a smart city context, addressing sustainable mobility in rural or suburban areas will need a different solution, since the deployment of V2X seems unlikely due to the above mentioned cost-benefit trade-off. This confirms that achieving sustainable mobility is not only a technical problem, but a goal to be achieved through a combination of policy, regulation and public and private investments.

V. Conclusion

Driven by the growing interest of the mobile networks research and industrial communities to start addressing the Sustainable Development Goals in all technological components, advances and vertical applications, this paper has highlighted three promising technology trends towards achieving sustainable V2X communication systems in B5G/6G networks: i) Reduction of power consumption at infrastructure and user equipment; ii) Cloudification and edge computing; and iii) Big data and AI. For each selected trend, some illustrative related technology components have been described, remarking their potential to enhance the sustainability of V2X communications.

A set of use case categories for sustainable mobility have been also discussed, including how some key B5G/6G technology enablers could contribute to their successful implementation. For each use case category, some estimations have been retrieved from the literature to quantify their impact in terms of environment-related performance indicators, such as fuel/energy savings or greenhouse gas emissions. In this sense, one potential topic that could need further study is the integration of renewable energy sources and energy storage systems for the V2X network infrastructure to reduce reliance on fossil fuels. Another factor that might require deeper examination is the role of standardization and interoperability for factoring sustainability-related requirements in the specifications. These could become critical aspects when considering the broad context of addressing the impact of socio-economic factors on the adoption and deployment of V2X for sustainable mobility while also ensuring the economic feasibility of implementing sustainable V2X communications in different geographical regions, stakeholders, and contexts. As a final remark, reaching a good synergy between V2X use cases and sustainable communication enablers seems a promising direction to achieve sustainable mobility, especially in future densely populated urban areas.

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This article has been accepted for publication in IEEE Open Journal of Vehicular Technology. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/OJVT.2024.3375451

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Sandra Roger(Senior Member, IEEE) received the Ph.D. degree in telecommunications engineering from the Universitat Politècnica de València (UPV), Spain, in 2012. During her doctorate studies, she performed two research stays at the Institute of Telecommunications, Vienna University of Technology, Austria. From July 2012 to December 2018, she was a Senior Researcher with the iTEAM Research Institute, UPV, where she worked in the European projects METIS and METIS-II on 5G design. In January 2019, she joined the Computer Science Department of the Universitat de València as a Senior Researcher ("Ramon y Cajal" Fellow). Dr. Roger has authored/coauthored around 60 papers in renowned conferences and journals. Her main research interests are in the field of signal processing for communications, vehicular communications, and wireless system design.

Carmen Botella-Mascarell(Senior Member, IEEE) received her M.Sc. and Ph.D. degrees in Telecommunications Engineering from Universitat Politècnica de València, Spain, in 2003 and 2008, respectively. In 2009 and 2010, she was a postdoctoral researcher in the Communications Systems and Information Theory group, Chalmers University of Technology, Sweden. In 2011, she joins the Computer Science Department of the Universitat de València where she is currently an Associate Professor. Dr Botella-Mascarell has authored/coauthored 80 technical papers in international conferences and journals. Her research interests include the general areas of coordination and cooperation in wireless systems, with special focus on physical-layer solutions for 5G and 6G.

David Martín-Sacristán(Member, IEEE) received the Ph.D. degree in Telecommunications Engineering from the Universitat Politècnica de València (UPV), Spain, in 2016. From 2006 to 2020, he was a Researcher with the ITEAM Research Institute, UPV. He is Chief Technology Officer at Fivecomm and Adjunct Professor at the Universitat de València since 2020. His research interests are focused on modeling and simulation of communication networks, beyond 5G, IoT, and vehicular communications.

David García-Roger(Member, IEEE) received the Ph.D. degree in telecommunications from the Universitat Politècnica de València (UPV), Spain, in 2007. He has been a researcher with ITEAM at UPV since 2012, and Adjunct Professor at the Universitat de València (UV) since 2020. He has participated as a Researcher in European projects ALPHA, METIS-II, and 5G-CARMEN. He has published about 40 papers. His research interests include all topics related to the evaluation of 6G candidate technologies.

Jose F. Monserrat(Senior Member, IEEE) is full professor and Vice President of the Universitat Politècnica de València, the first technical university in Spain. His research focuses on the design of future beyond 5G wireless systems and their performance assessment. He has been involved in several European Projects, like METIS/METIS-II where he led the simulation activities, or currently 5G-CARMEN and 5G-SMART. He co-edited the Wiley book "Mobile and wireless communications for IMT-Advanced and beyond" and the Cambridge book "5G Mobile and Wireless Communications Technology". Jose Monserrat is senior member of the IEEE and has published more than 60 journal papers. Currently, his research team consists of 5 Postdoctoral fellows, 8 PhD students and 2 Master students. Jose F. Monserrat has served as advisor of the European Parliament and the World Bank Group in the vehicular 5G communications topic.

Tommy Svensson(Senior Member, IEEE) received the Ph.D. degree in information theory from Chalmers, in 2003. He is currently a Full Professor of communication systems with the Chalmers University of Technology, Gothenburg, Sweden, where he is leading the wireless systems research on air interface and wireless backhaul networking technologies for future wireless systems. He was with Ericsson AB in core networks, radio access networks, and microwave transmission products. He was involved in the European WINNER and ARTIST4G Projects, which made important contributions to the 3GPP LTE Standards, the EU FP7 METIS, and the EU H2020 5GPPP mmMAGIC and 5GCar projects toward 5G; recently the Hexa-X, RISE-6G, and SEMANTIC projects and currently the Hexa-X-II, ROBUST-6G and ECO-eNET projects towards 6G. He is currently active in the WiTECH antenna systems excellence center at Chalmers targeting cm/mm-wave and (sub)-THz solutions for 6G access, backhaul/fronthaul, and V2X scenarios. He has coauthored six books. His research interests include mobile communication systems, cooperative/context-aided/secure communications, mm-wave/sub-THz communications, C-V2X, JCAS, satellite networks, and sustainability. He has served as a Coordinator for the Communication Engineering Master's Program at Chalmers.