Research Issues for Sustainable Wireless Networks: A Stakeholder Approach

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***Abstract*—Sustainability and sustainable development are topics that are increasingly addressed in the ICT sector including wireless networks. Yet, their interpretations vary a great deal depending on the person without a commonly agreed approach. This paper presents an overview of sustainability and sustainable development in the context of ICTs and wireless networks highlighting the urgency of introducing sustainability principles at all levels and stages of ICT technology development. The paper presents a way forward to adopt sustainability principles into future technology design considering the triple bottom line of economic, social and environmental sustainability perspectives. A change in mindset is urgently needed and all stakeholders need to act in their own capacity as well as collaboratively to make the wireless networks and their use truly sustainable without green-washing. New metrics need to be defined and measured to respond to growing concerns as today's metrics, such as total consumed mobile data are far from sustainable. Time to act is now as the design criteria for the future sustainable 6G are defined in the next years.**

Keywords—5G, 6G, sustainable development, sustainability, wireless communications, UN SDGs

I. Introduction

Sustainability has become a key topic in all sectors of society including the information and communication technologies (ICTs) sector. Sustainability has also become a highly controversial topic with different interpretations depending on the stakeholder and viewpoint. While there is a common agreement on the importance of sustainability in the public discussions, the development is now challenged with different interpretations leading to the use of sustainability as a marketing term rather than focusing on the contents.

For decades, sustainability has referred to the "*principle of ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations*" [1-2]. This triple bottom line of sustainability emphasizes economic, social and environmental perspectives that are interrelated and need to be considered. Sustainable development, on the other hand, is about the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [3]. There is no need to re-event these well-known definitions for sustainability that still capture the essence. What is needed is to take these principles into concrete actions. Today, the best-known and globally agreed framework for sustainable development is the Agenda 2030 of the United Nations, presenting the UN Sustainable Development Goals (UN SDGs) [4]. With its 17 goals and 169 targets, whose achievement is measured with 231 individual indicators, the UN SDGs are the key design criteria that countries are committed to achieve by 2030 [4].

The role of ICT is important in the context of sustainability and sustainable development. Sustainability needs to be considered in the use of today's ICT solutions and services as well as in the development and upcoming deployment of future solutions and services. The reductions on green-house gas (GHG) emission among other requirements to combat the climate change apply also to the ICT sector, similar to other sectors. ICTs' consumption keeps increasing and changing, which is a major sustainability challenge that needs to be addressed by the sector. Yet, the ICT sector is not thoroughly addressed in the on-going sustainability debate, but focus is more on how ICTs help other sectors to reduce their burden.

Prior work on sustainability in the context of wireless networks has particularly focused on the design of resource efficient communications algorithms and techniques, see e.g. [5]. Energy efficiency has been the major design criteria, resulting in active research on green communications in the past decades [6-9]. Energy efficiency improvements and reductions in energy consumption are important factors in introducing environmental sustainability. Yet, 5G did not have a target for energy efficiency although the metric was discussed. Resource efficiency considerations in wireless networks also consider other resources, resulting in complicated optimization problems and trade-offs [10].

Regarding future wireless systems, 6G as the next generation of mobile communication networks is already in research and development phase and has taken sustainability principles as the commonly agreed starting point [11]. A more detailed connection between 6G and the UN SDGs that are both targeted for the year 2030 was developed in [12] and detailed in [13], highlighting how communications could contribute to the achievement of the targets via the existing indicators of the UN SDG framework. Additionally, the role of ICT systems as a measurement tool for collecting sustainability related indicator data was highlighted in [12] emphasizing the role of ICTs in providing and transferring the much-needed data for sustainable development actions.

This paper aims to bring clarity into sustainability in the context of ICTs and wireless networks by discussing the key principles and topics that should be addressed particularly by the research community. The fear of green washing in the context of ICT is real and much of today's sustainability discussion is marketing without facts, which can ultimately lead consumers making choices on sustainability without actually knowing how sustainability is interpreted. The rest of this paper is organized as follows. Section II introduces key principles of sustainability. Sustainability in the context of ICTs and wireless networks is discussed in Section III. Section IV proposes a way forward emphasizing a stakeholder approach, followed by conclusions in Section V.

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II. Understanding Sustainability Principles

A. The Triple Bottom Line of Sustainability

The well-known triple bottom line of social, economic and environmental sustainability (see Figure 1) is a good starting point to consider sustainability [1-2]. The triple bottom line considers three Ps – people (social performance), planet (environmental performance) and profit (economic performance) to take a more comprehensive approach to operations beyond traditional finance-based approach.

Social sustainability emphasizes the role of humans in sustainable development and contributions to societal capital where equity and inclusiveness are important considerations. Environmental sustainability refers to doing no harm to environment and minimizing the environmental impact, which requires careful management of e.g., materials and resources at all phases of products, services or processes. Especially reduction of energy consumption and GHG emissions are key criteria of interest. Economic sustainability refers to the actual economic impact of operations that include and go beyond the profitability of operations. In fact, solving major sustainability challenges presents a major business opportunity. Understanding sustainability from these three distinct but interrelated perspectives helps to identify key aspects related to sustainability in the specific context in question, such as the development and use of ICTs and more specifically wireless networks. Additionally, the interrelations of these three perspectives need to be considered carefully – positive development in one might negatively impact the other.

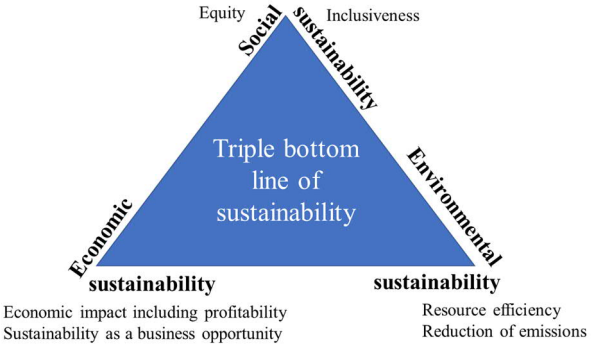

Fig. 1. Triple bottom line of sustainability.

B. UN SDG Framework

The UN SDG framework globally agreed in 2015 defines 17 distinct goals, which are detailed into 169 targets, whose achievement is monitored via 231 individual indicators [4]. The high-level goals in the UN SDG framework address major societal challenges that should be solved by 2030. These include challenges related to poverty, hunger, health, education, equality, water and sanitation, energy, work, infrastructures, cities and communities, consumption and production, climate, oceans, land, peace as well as partnerships for tackling the challenges. They steer nations' actions including research community. Figure 2 summarizes the ICT specific indicators, and which targets they address to illustrate the type of sustainability indicators related to ICTs. There are only 7 ICT indicators in the UN SDG framework, while in reality, the linkage to ICT is stronger as illustrated e.g., in [5, 12, 14]. In fact, contributions of ICTs and wireless networks can be realized towards all 17 SDGs.

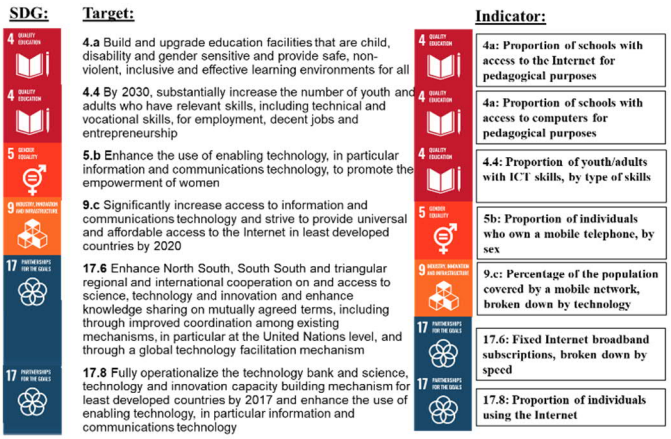

Fig. 2. ICT specific indicators in the UN SDG framework.

Similar to the holistic treatment of the three different perspectives in the triple bottom line of sustainability, also the UN SDG framework needs to be considered holistically: positive development towards one target can negatively influence the achievement of another target. There have been attempts to classify the UN SDGs into the triple bottom line of sustainability by splitting the 17 SDGs into these three perspectives [15], but this simplified approach ignores the complexity of sustainability topic, which needs to be addressed from all three interrelated perspectives in all 17 SDGs.

C. Other Frameworks

Other important frameworks to sustainability exist and require further expansion. Life cycle assessment (LCA) is a commonly used method to assess the environmental impact of a product, process or a service, considering the different stages in its life-cycle. While LCA is difficult to assess in practice, the LCA of a product, process or a service could provide important information to base our sustainable consumption decisions on. Additionally, developments in circular economy aiming at production and consumption, where different forms of sharing, leasing, reusing, repairing, refurbishing and recycling of existing materials and products are important to lengthen the products' life-cycles.

Today, increasing number of companies is actively reporting their activities towards sustainability in the form of environmental, social, and corporate governance (ESG) approach. The ESG reporting is disclosing data for investors on the company's operations in the three areas of environmental, social and corporate governance, similar to the triple bottom line approach. Thus, the pull towards organizations' sustainability considerations also comes from outside of the company from the investor side.

Companies and organizations are increasingly reporting their green-house gas emissions in response to requirements being set to reduce their environmental impact to combat climate change. In terms of this reporting, a common approach is GHG protocol's scope 1, 2 and 3 emission system. Many organizations have started to report their emissions with this scope-based approach, where scope 1 emissions are emissions from sources that the organization controls directly. Scope 2 emissions are in direct emissions caused by the organization from the use of e.g., energy. Scope 3 emissions are caused indirectly in organization's upstream or downstream value chain. The challenge of scopes 1-3 is to evaluate the emissions due to lack of data and proven methods to quantify the impact.

Regulators and policy makers are in the key position to set targets at national, regional and international levels for the various aspects related to sustainability. For example, the European Green Deal [16] defines a framework for European Union member countries. European level activities on ICT sector role are conducted also in other bodies, such as BEREC [17]. At the national level, an example of ICT sector's environmental and climate strategy is made in Finland [18].

There are also standardization efforts on-going in multiple standardization fora to build frameworks for sustainability e.g., in ETSI, and ITU-T. Significant efforts on the environmental sustainability of the ICT sector take place in standardization bodies, whose expertise is directly relevant, and mechanisms are needed to share that knowhow in the standards bodies with other activities including regulatory activities.

III. Understanding the Complex Role of Sustainability in ICT and Wireless Networks

It is important to understand the complex connection between ICT/wireless networks and sustainable development. This role can be simplified into two distinct perspectives: a) ICT sector's enabling role to help other sectors of society to renew their operations via sustainable ICT solutions and services to meet sustainability targets (handprint), and b) ICT sector's own sustainability impact/burden (footprint), where the growth of digitalization keeps increasing the demands and resource usages and usage patterns change.

A. ICTs in an Enabling Role

Much of the discussion is dominated by the enabling role of ICTs and mobile communications in other sectors of society. However, quantifying this benefit and counting the resulting enablement effect is a challenge.

In general, we can identify three levels of preconditions related to the enabling role ICTs: 1) deployment of infrastructure and networks as foundation for digital economy; 2) access and connectivity allowing people to connect; and 3) enabling services and relevant content providing life-enhancing services for people [14]. All three preconditions need to be fulfilled – otherwise the enablement impact is not achieved.

The connection between mobile communications and UN SDGs in the enabling role is thoroughly studied by trade associations promoting the technologies [14] as well as research [5, 12]. A connection between future 6G and the UN SDGs was first established in 6G white paper work [11], which was further expanded in [12]. The enabling role of wireless networks can be captured via the existing indicators of the UN SDG framework beyond the seven ICT specific indicators [12]. The role of 6G as a measurement tool being able to sense the environment at hyper-local granularity was also presented in [12].

B. ICT Sector's Own Sustainability Burden

ICT sector's own sustainability related footprint is significant and keeps increasing. Yet today, the sector itself is talking about reducing the growth of this increase and not how to decrease the burden. Also, the regulators are not yet certain about how to regulate the emissions of ICTs. In general, carbon emission limits apply to ICTs as well, but detailed requirements are still lacking.

To estimate the environmental impact of ICT solutions and services, there is an urgent need for defining common indicators and measurement methods that the sector can use. Additionally, sustainable design criteria for future sustainable ICT solutions and services beyond traditional energy efficiency and energy consumption metrics are needed, which themselves are difficult to derive and measure.

IV. The Way Forward

Next, we discuss the way forward towards a wide-spread adoption of sustainability principles into the ICT research domain with a focus on wireless networks. Sustainability principles of ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations need to be developed specifically in the context of the ICT sector, which is the responsibility of everybody in the sector. It is of utmost importance to integrate the sustainability principles into all aspects of ICT covering the whole life-cycle of products, services and processes, which calls for a change in mindset that spans across all stakeholders in a collaborative manner.

A. General Principles

The role of wireless technologies for emitting less is equally important, as is support for absorbing more in other sectors of society. This dual role cannot be compensated for by simply emphasizing the ICT sectors' enabling role. The sustainability burden created by the use of ICTs keeps increasing and should be minimized, which is an open topic and currently avoided. Future technology design for ICTs and particularly wireless networks including beyond 5G and 6G requires brand new design principles that take sustainability at the center. 6G will combine communication service with other services, like imaging, sensoring, and locationing, providing a powerful measurement tool with hyper-local granularity [12]. This can be used to collect sustainability related data and steer decisions towards sustainability. New mechanisms are needed to reduce the GHG emissions and resulting footprint through sharing and optimizing the use of all potential resources in wireless networks. In particular, the optimization of the collection, processing, storage and transfer of data between different locations of network elements needs to be a major design criteria for future wireless networks.

Significant improvements in energy efficiency and reduction in the total energy consumption for beyond 5G and 6G in all levels are urgently needed. This requires defining and adoption of new measures, measurement methodologies and techniques for assessing the sustainability impact of the use of ICT services from end to end in the network. Sharing of data and methods on the impact of the wireless communications sector between sectors and stakeholders is needed to develop sustainable solutions. At the same time, the use and optimization of existing ICT solutions and services must take place. All ICT solutions and services should follow the principles of preserving resources. It is important to act now and not wait until future technologies.

The life-cycle approaches adopted often ignore the prior steps of R&D of ICT solutions and services, which in fact include a number of decisions that lock the emissions of the future systems. Future work should consider the development of new technology in addition to considering existing networks. Also, the service provisioning and usage aspects in the context of electronic communications networks and services need further work.

B. *Introducing a Stakeholder Perspective*

Stakeholder engagement is key to success for realizing sustainable ICTs, and the inclusion of relevant stakeholders are needed, including e.g., the academic domain and standards bodies. Different stakeholders have different roles in sustainable development. For example, an external study conducted for BEREC on the environmental impact of electronic communications networks [17] interviewed a number of mobile network operators, but they represent only one stakeholder group within the complex ICT sector. The process should not be left only in the hands of operators, which corresponds to self-evaluation. Inputs from all relevant stakeholders need to be included.

It is important to define, who should act and how. Figure 3 illustrates a subset of stakeholders in the context of wireless networks. Users are in charge of choosing solutions that are sustainable. Users ultimately decide which ICT solutions and services they use. Their sustainability requirements need to be incorporated into the R&D process early on. Users need real-life unbiased data to base the decisions on without marketing and green-washing. Mobile network operators operate the communications infrastructure and play a key role in the emissions of the infrastructure. Mobile network operators' should disclose data on sustainability to different stakeholders including customers as well as developers and R&D organizations in order to facilitate the development of sustainable solutions.

Research community including academia trains the future talents and needs to incorporate sustainability into education, training and research activities. Also being the source of unbiased research results that are used in decision making to make societal impact is critical. Service and application providers including developers need to design sustainable solutions to solve the major sustainability challenges.

Regulators and policy makers are in the key role of defining the rules and conditions that the ICT solutions and service must fulfil which should be based on sustainability. These rules do not exist yet. They should not be too different in the different countries to avoid market fragmentation but best practices need to be shared. Global agreements are needed. One country is too small a market for defining different sustainability criteria that the equipment must fulfil. Technology vendors develop the infrastructure that needs to incorporate sustainability principles and minimize resource consumption.

From the possible activities for regulators to address the environmental sustainability of the ICT sector, approaches of building awareness, developing codes of conduct, supporting environmentally friendly design and recycling programmes, encouraging research, and incentivizing sustainability solutions are needed and even more. Activities in the regulatory fora need to be closely linked to other on-going initiatives in standardization bodies, academic research and ICT sector's own initiatives to develop a common understanding of the sustainability problem and requirements to build common assessment methodologies with the same agreed indicators in order to develop sustainable solutions. Additionally, the role of different associations to bring stakeholders together is important, see e.g., the recent work on environmental sustainability of 6G [19].

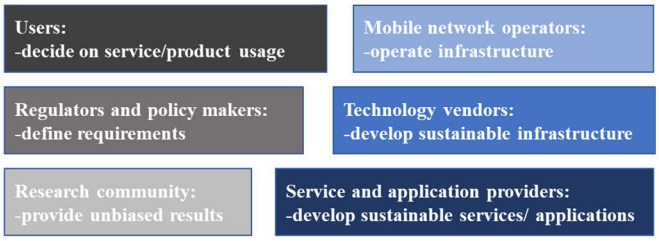

Fig. 3. Stakeholders and their roles in sustainable ICT.

Self-assessment of own operations and reporting on emissions and actions to achieving environmental targets by the ICT companies themselves is an important starting point. Detailed data and actions on energy efficiency and energy consumption among other environmental sustainability-related metrics should be made available to the research community to allow researchers to develop new methods to assess and reduce resource efficiently and consumption based on real data, which today is a true bottleneck.

C. *Special Role of the Research Community*

The research community plays a fundamental role in develops sustainable ICT solutions and services to solve major sustainability challenges including sustainable ICT infrastructure. Already now efforts are on-going in the research domain to link the research contributions to the achievement of UN SDGs in funding applications, reporting of results, publication statistics as university evaluations. New research is needed to develop methods and metrics to assess ICT solutions and services' sustainability impact including e.g., energy efficiency, energy consumption, and GHG emissions from different ICT services used and in different locations of the networks. Skills related to sustainability are emphasized as key future skills needed by employees. Therefore, it is of utmost importance that sustainability principles incorporated into on-going-education and training activities.

Regarding the achievement of societal impact, understanding of relevant sustainability related regulations is important for the research community to steer activities towards real-world developments. Regulations should be a basic knowledge component of researchers since they define the rules and conditions under which to operate. The research community also needs to help decision makers by providing unbiased data and research results. Contributing research findings to relevant fora needs to be an important part of research activities to become an active player in societal dialogues. There, the role of openness and availability of research results via open publications and understandable material is important.

For example, regulators highlight the newness of the topic of environmental sustainability to regulators at both European and national levels [17]. While it might be a new topic in regulation, academia and industry have addressed the environmental sustainability of ICT already for decade(s). This expertise exists to help the regulators in the introduction of sustainability principles into the regulation of electronic communications and services, when the relevant stakeholders are properly invited to contribute to the process.

Academic stakeholders play an important role in the sustainability topic, not only in the ICT sector, balancing the self-interests of stakeholders towards the common good. There is a need to develop mechanisms that allow the voices

from the academic stakeholders to be heard in the process. For example, EU-funded and national-level funded research projects address sustainability topics and can significantly contribute to regulatory activities, when there are mechanisms in place for the information exchange.

Finally, many national and EU level research initiatives address the sustainability of ICT and especially the environmental sustainability perspective. There is a need to bring the expert community of researchers and other experts to the table. A linkage between national-level and EU funded research projects needs to be established by creating mechanisms for information sharing, requirements collection and joint development of best practices. The research community should be invited to provide unbiased research results and encourage the industry and operators to share their data and methodologies with the research community, to tackle the environmental sustainability of the ICT sector as a joint effort.

To follow the general goal of incorporating sustainability into every aspect of ICTs, we can identify the following high-level research challenges for the research community to address:

- What sustainable ICT solutions and service could solve major sustainability challenges locally, nationally and globally?
- What are the new sustainable ICT design and usage criteria?
- How to assess ICTs' sustainability impact through enablement effect in other sectors of society?
- How to assess ICTs' own sustainability burden?
- How to quantify different content distribution methods, technologies and network deployments in terms of GHG emissions?

V. Conclusions

The concepts of sustainability and sustainable development are commonly used in the context of ICTs and wireless communication networks, but their interpretations are very different depending on the stakeholder and viewpoint. In general, sustainability is about ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations, and sustainable development presents the actions needed to achieve this. Sustainability should be incorporated into every aspect of ICT including the development of sustainable solutions that could solve major sustainability challenges and assessing ICTs' enablement effect in other sectors as well as ICTs' own sustainability burden. This requires finding a common understanding of how sustainability should be addressed in ICTs. Academia, industry and the public sector need to act jointly. Future work is needed to define new metrics that take sustainability at the heart. Models and measurement tools need to be developed in close collaboration between stakeholders. Access to real-life data needs to be granted to developers of sustainable solutions as well as decision makers for impact assessment. What are then the new design criteria and measures for existing and future wireless networks? There the major upcoming example is 6G. High-level consensus exists about sustainability being the major driver for 6G. However, the details are yet missing and the requirements including the indicators will be defined in the coming years. Therefore, the time to act is now.

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