6G Drivers and Sustainable Development Goals

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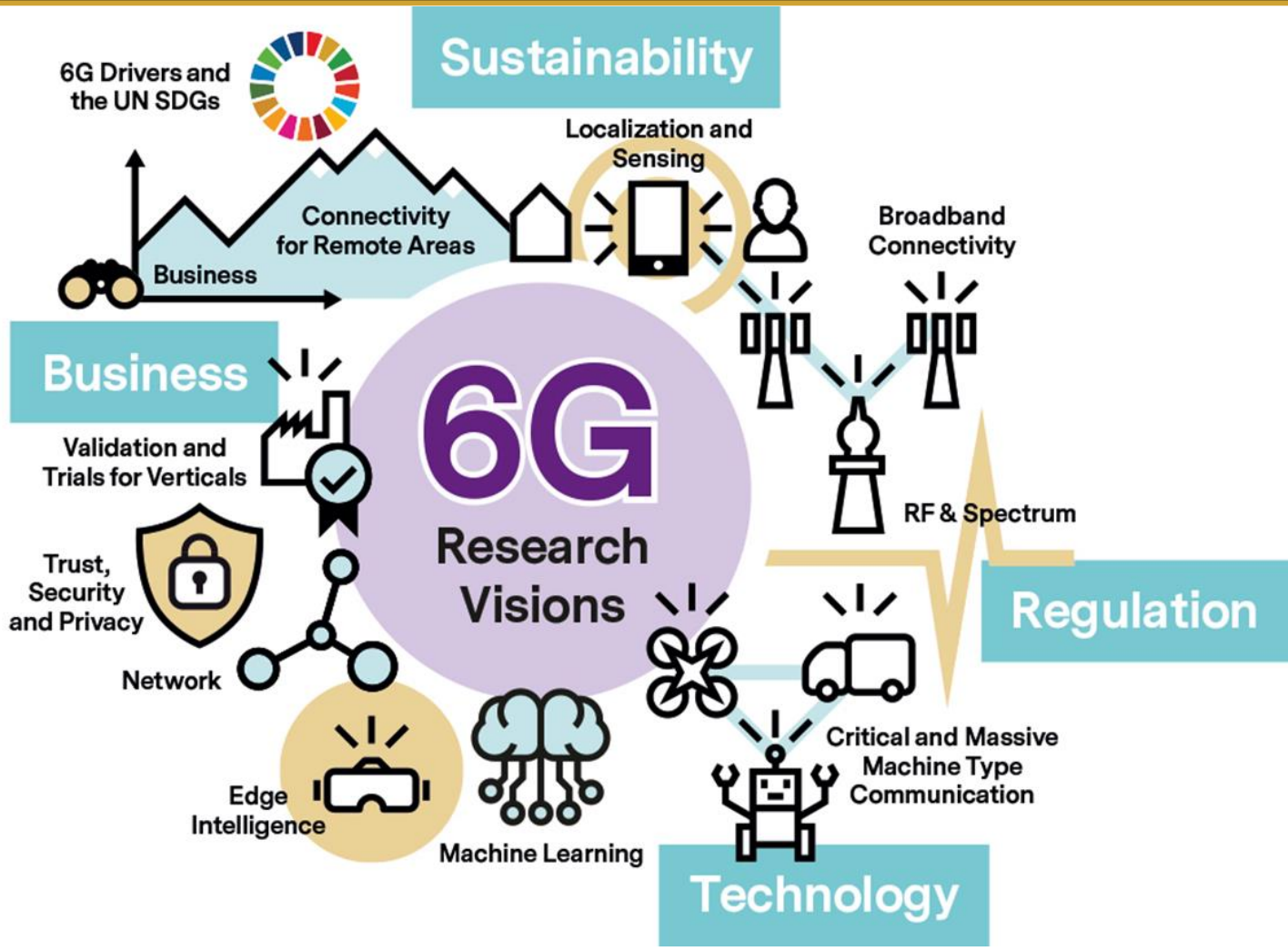
Finnish 6G Flagship's multi-disciplinary agenda (2018-2026)

- 6G Flagship's multi-disciplinary research roadmap includes technology, business, sustainability, and regulation perspectives.
- Multi-stakeholder collaboration emphasises academia, industry, and public sector interplay.
- Sustainability and UN SDGs identified as global drivers for 6G R&D.
- Contributions to ITU-R process on IMT-2030.



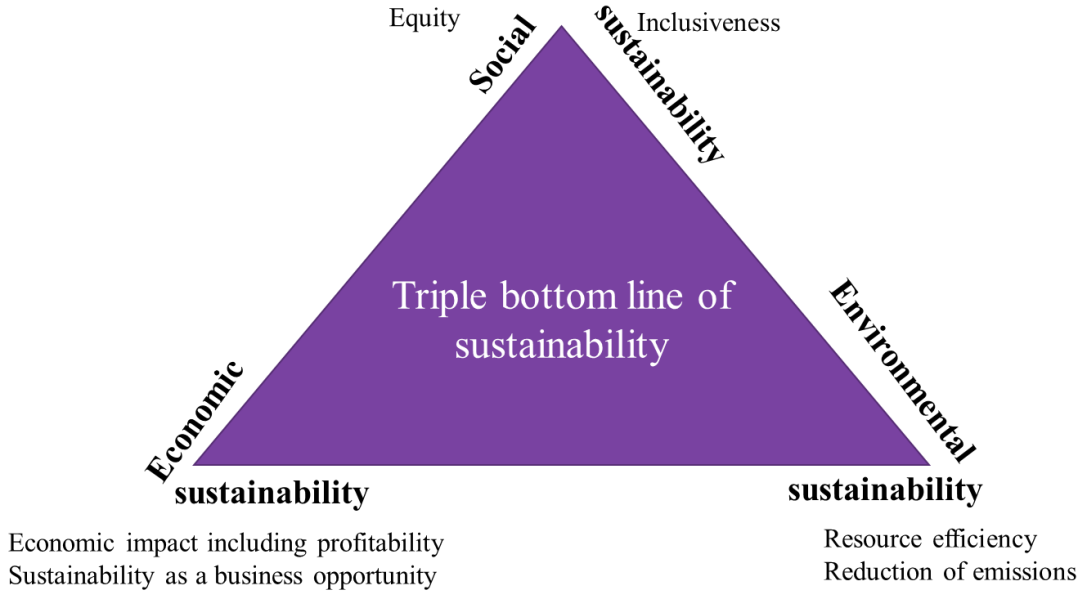
Success story: **Local 5G (private) (micro) operator concept with local licensing introduced in EuCNC 2017.**

Sustainability and sustainable development

Sustainable development[2] is the "**development that meets the needs of the present without compromising the ability of future generations to meet their own needs**".

Sustainability[1] is the "**principle of ensuring that our actions today do not limit the range of <u>economic, social, and environmental</u> options open to future generations**".

There are only 7 ICT indicators in the UN SDG framework of 169 targets and 231 indicators. In reality, the linkage to ICTs is much stronger.



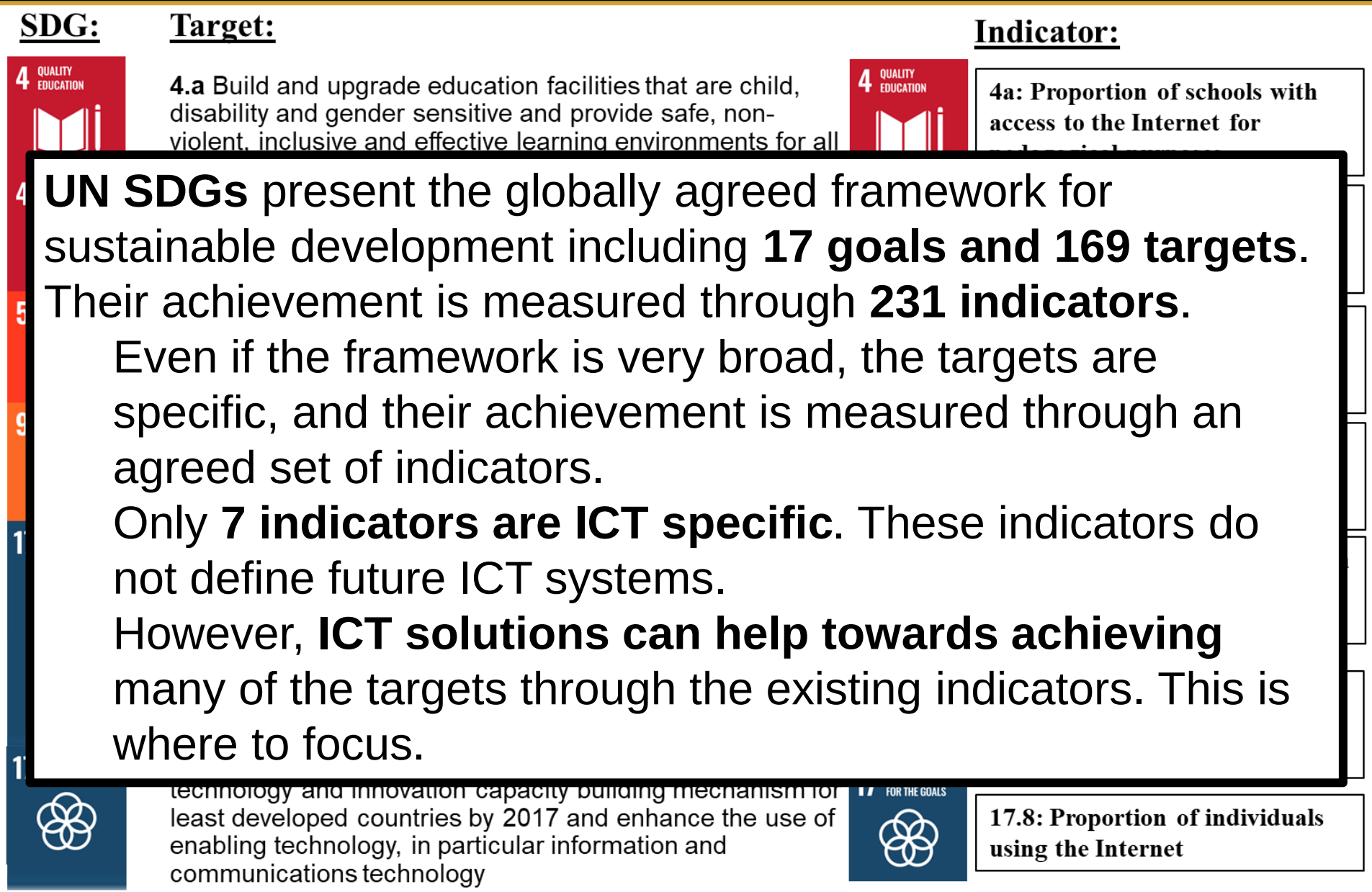
[1]J. Elkington. Cannibals with forks: The triple bottom line of 21st-century business. Capstone Publishing Ltd. 1997.
[2]World Commission on Environment and Development's Brundtland report ´Our Common Future`. 1987.

ICT sector's dual role

- **Enabling role** to help different sectors of society towards environmentally and socially sustainable operations via information and communication technology (ICT) solutions and services in an economically feasible manner (handprint).
- **ICT** solutions and services' **own environmental sustainability burden** (footprint) keeps increasing and rapid changes must be done to stop this development.

- The role of ICT for **emitting and consuming less** is equally important, as is support for **absorbing and enabling more** in other sectors.
- Urgent need for **new indicators, measurement methods and requirements** for future sustainable ICT solutions and services and their use to solve major sustainability challenges.

Connecting UN SDGs to ICTs



UN SDGs present the globally agreed framework for sustainable development including **17 goals and 169 targets**. Their achievement is measured through **231 indicators**.

Even if the framework is very broad, the targets are specific, and their achievement is measured through an agreed set of indicators.

Only **7 indicators are ICT specific**. These indicators do not define future ICT systems.

However, **ICT solutions can help towards achieving** many of the targets through the existing indicators. This is where to focus.

Indicators for ICT's environmental sustainability

- Energy related indicators
  - Energy consumption
  - Energy efficiency
  - Use of renewable energy
- Climate related indicators
  - Carbon emissions (direct from energy, GHG scope 1)
  - Carbon emissions (indirect from energy, GHG scope 2)
  - Carbon emissions (other indicrect, GHG scope 3)

- Environment related indicators
  - E-waste production
  - Distribution/utilisation of recycled/refurished/reused products
  - Recycled/refurbished/reused components used in products
  - Recyclability
  - Reparability
  - Expected lifetime
  - Raw materials depletion
  - Water usage consumption
  - Waste heat recovery
  - Land use
  - Eco toxicity
  - Human toxicity
  - Eutrophication

European Commission, Joint Research Centre, Baldini, G., Cerutti, I. and Chountala, C., Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/093662, JRC136475.

Country case examples: France

Electronic communications operators:

- GHG emissions (scope 1 and 2),
- energy consumption of networks (by technology)
- mobile phones volumes (sold, collected, recycled and repackaged).

Device manufacturers:

- GHG emissions
- Use of rare earths and precious metals
- Devices volumes:
- sold by the screen size and by the screen technology or by network compatibility (mobile phone)
- sold repackaged (only for mobile phones)
- collected in order to recycle or repackage them.
- in use by year of sale
- Devices duration of use by year of commercialisation
- Electric consumption of TV and computer screen in operating and idle mode

Country-specific approaches vary a great deal.

Data Centres operators:

- GHG emissions
- Number and location of data centres
- Floor area (total, reserved to host IT equipment)
- data centres energy consumption
- IT equipment energy consumption
- maximum permissible electrical power of IT equipment
- Water consumption by types of water
- Cooling systems used
- water discharge areas and conditions

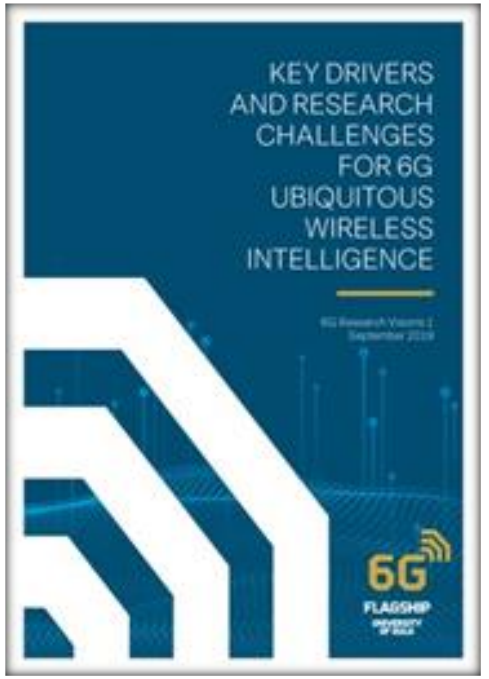
BEREC Report on Sustainability Indicators for Electronic Communications Networks and Services. (2023).

Towards sustainable 6G development

Sustainability should drive 6G R&D globally

- World's first 6G Summit organized by Finnish 6G Flagship gathered major telecom players for joint 6G vision building in 2019, leading to the world's first 6G White Paper[1].
- Consensus that 6G R&D is driven by sustainability and United Nations' Sustainable Development Goals (UN SDGs).
- Our follow-up work[2] connected 6G with the UN SDGs.

WE ARE FAR AWAY FROM THIS BEING A REALITY.



[1] **M. Latva-aho & K. Leppänen (eds.) (2019). Key drivers and research challenges for 6G ubiquitous wireless intelligence. (6G Research Visions, No. 1). University of Oulu, Finland. http://urn.fi/urn:isbn:9789526223544**

[2] **M. Matinmikko-Blue, et al. (eds.). (2020). White Paper on 6G Drivers and the UN SDGs. (6G Research Visions, No. 2). University of Oulu. http://urn.fi/urn:isbn:9789526226699**

White Paper on 6G Drivers and the UN SDGs by Finnish 6G Flagship

HIGHLIGHTS:

- We identify megatrends influencing the sustainable development of 6G.
- We develop a novel linkage between 6G and the UN SDGs that are both targeted for 2030.
- We envisage three-fold role of 6G as:
  1) a provider of services to help support activities towards reaching the UN SDGs,
  2) a measuring tool for reporting of indicators;
  3) a reinforcer of developing 6G in line with the UN SDG.

https://www.6gchannel.com/portfolio-posts/6g-white-paper-6g-drivers-un-sdgs/

Linking 6G and UN SDGs via existing indicators

UN Targets	UN Indicators	6G can
4.2 By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education	**4.2.1** Proportion of children under 5 years of age who are developmentally on track in health, learning and psycho-social well-being, by sex **4.2.2** Participation rate in organized learning (one year before the official primary entry age), by sex	**Increase access to remote learning and developmental activities** to children under 5 years. **Enable improved socialization** through virtual interactions. **Improve remote access to pediatrics** in locations with poor connectivity. **Facilitate remote and virtual training** of local pediatricians. **Help improve and develop the knowledge and skills** of local medical community. **Deliver prosthetic technologies** to support handicapped children. **Permit family and experts to monitor** the cognitive development of children with Brain-Computer Interfaces. **Help coordinate virtual meetings** for preschoolers.

https://www.6gflagship.com/white-paper-on-6g-drivers-and-the-un-sdgs/

Key stakeholders in sustainable 6G development

Users

Inclusion of a variety of users into human-centric 6G development.

Governmental, regulatory and standardization organizations

Lead in pro-active manner with long-term visions of the role of ICT/6G in achieving UN SDGs and formulate policies.
Develop new indicators to complement pure technical performance indicators.

Research and educational organizations

Conduct unbiased research and facilitate stakeholder interactions.

6G

ICT industry

Flexible approaches to serving different challenge areas.
Develop cost and consumption optimized solutions.
Develop services matching the varying level of skills of people.

Verticals

Early engagement in 6G development to transform their operations towards UN SDGs.

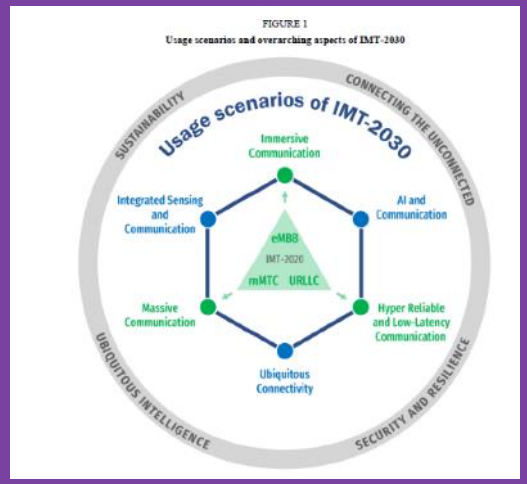
Global IMT-2030 framework at ITU-R

Sustainability is included in ”Motivation and societal considerations”, ”User and application trends”, ”Usage scenarios”, and ”Capability” of ITU-R framework for IMT-2030.

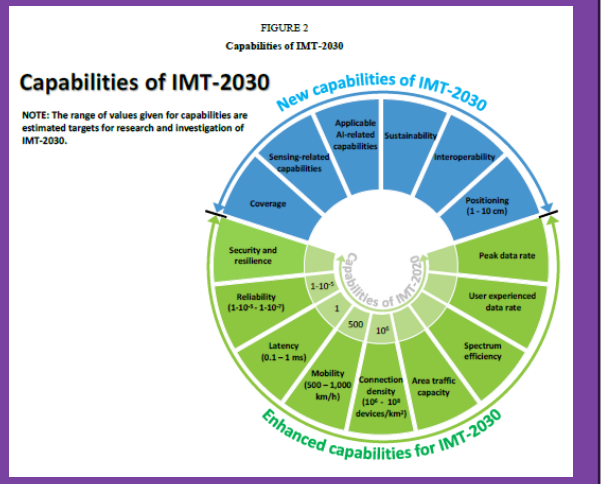
Trends and drivers

- Motivation and societal considerations
- User and application trends

Usage scenarios



Capabilities



[Recommendation ITU-R M.2160-0 (11/2023) - Framework and overall objectives of the future development of IMT for 2030 and beyond]

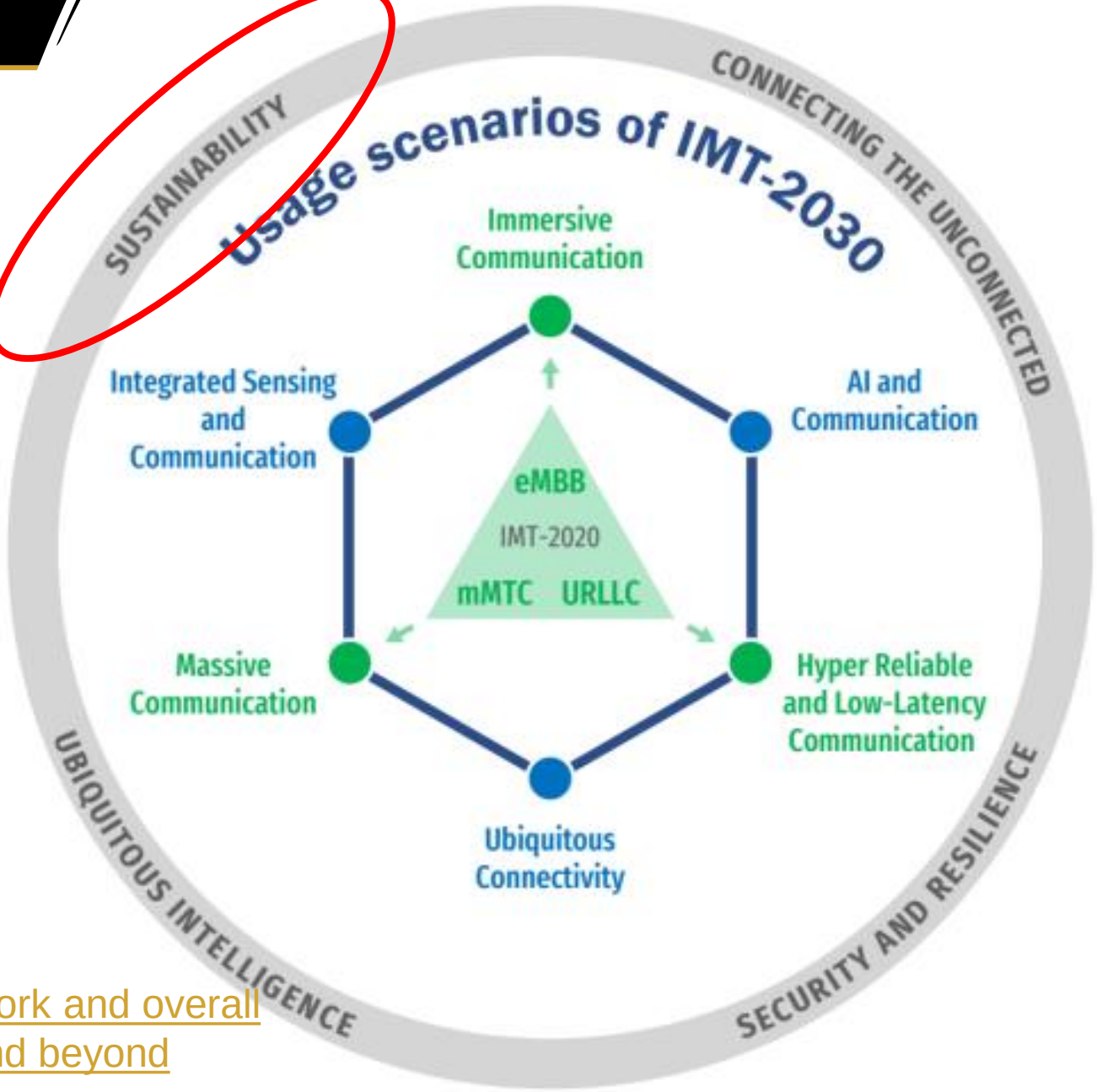
Global IMT-2030 framework

Recommendation ITU-R M.2160-0 (11/2023). Framework and overall objectives of the future development of IMT for 2030 and beyond.

- 6 usage scenarios
- 4 overarching design principles

FIGURE 1

Usage scenarios and overarching aspects of IMT-2030



[Recommendation ITU-R M.2160-0 (11/2023) - Framework and overall objectives of the future development of IMT for 2030 and beyond]

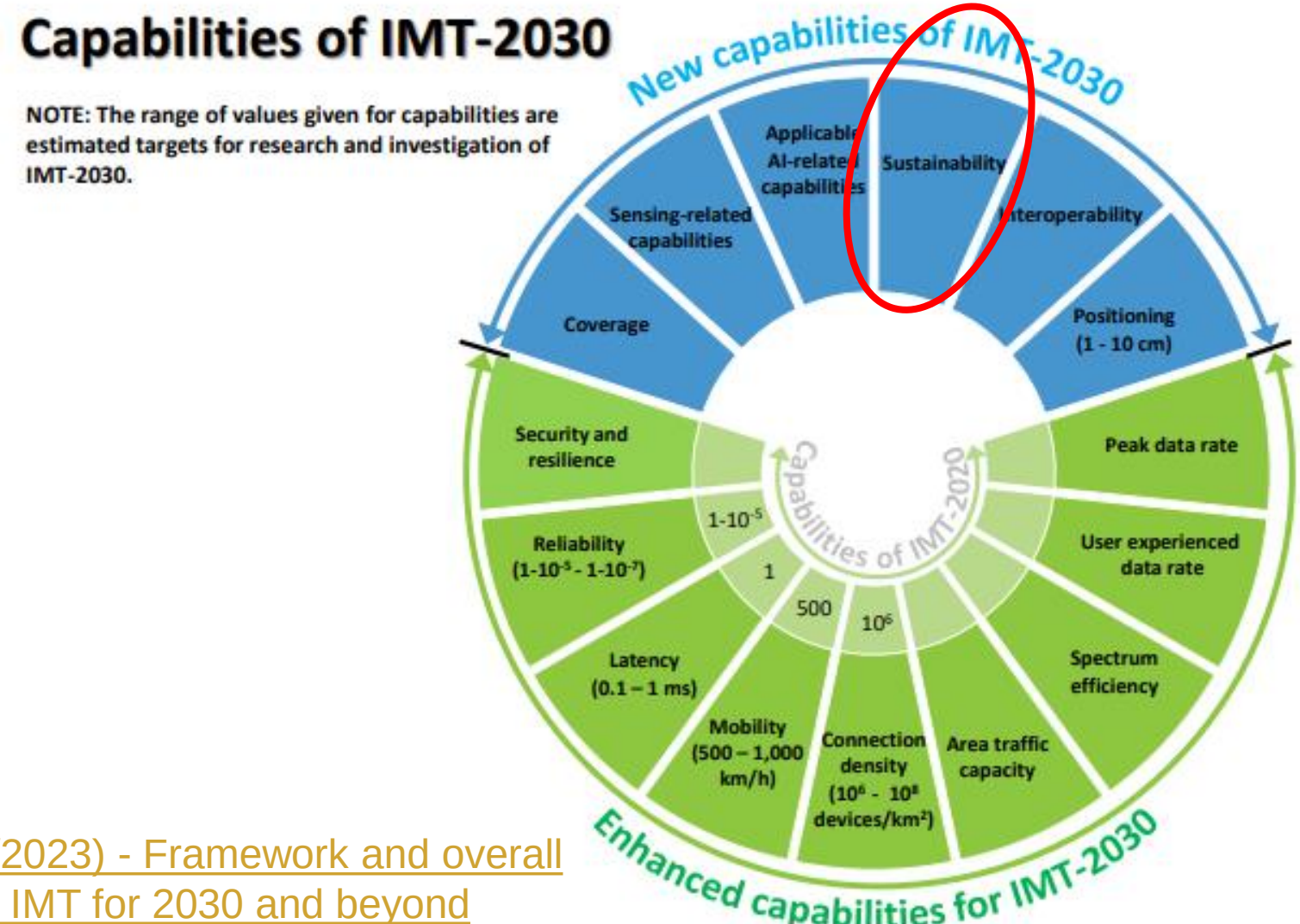
Global IMT-2030 framework

Recommendation ITU-R M.2160-0 (11/2023). Framework and overall objectives of the future development of IMT for 2030 and beyond.

- 15 capabilities (indicators)
- Requirements will be defined in 2024-2025.

FIGURE 2

Capabilities of IMT-2030



Recommendation ITU-R M.2160-0 (11/2023) - Framework and overall objectives of the future development of IMT for 2030 and beyond

2.1 Motivation and societal considerations / IMT-2030

- **Sustainability** refers to the **principle of ensuring that today's actions do not limit the range of economic, social and environmental options to future generations**. IMT-2030 is envisaged to be built on energy efficiency, low power consumption technologies, reducing greenhouse gas emissions and appropriate use of resources under the applicable model of circular economy, in order to address climate change and contribute towards the achievement of current and future sustainable development goals.

Recommendation ITU-R M.2160-0 (11/2023) - Framework and overall objectives of the future development of IMT for 2030 and beyond

2.2 User and application trends / IMT-2030

- **Sustainability** is a foundational aspiration of future IMT systems.
  - IMT-2030 is expected to help address the need for increased environmental, social, and economic sustainability, and also support the goals of the Paris Agreement of the United Nations Framework Convention on Climate Change.
  - IMT-2030 implementations are expected to be designed to achieve the least possible environmental impact and to use resources efficiently by minimizing power consumption, using energy efficiently and reducing greenhouse gas emissions.
  - Leveraging circular economy principles helps retain and recover value from resources and extend lifetime through such important considerations as reusing, repairing, repurposing or recycling.
  - Moreover, IMT-2030 may allow for efficient deployments and operation, thereby improving both environmental sustainability and the affordability necessary to support social sustainability.
  - Beyond its own environmental impact, IMT-2030 is expected to contribute towards empowering other industries/sectors to reduce their environmental impacts by promoting digital transformation.

Recommendation ITU-R M.2160-0 (11/2023) - Framework and overall objectives of the future development of IMT for 2030 and beyond

4. Capabilities / IMT-2030

- Sustainability, or more specifically **environmental sustainability,** refers to the ability of both the network and devices to minimize greenhouse gas emissions and other environmental impacts throughout their life cycle. Important factors include improving energy efficiency, minimizing energy consumption and the use of resources, for example by optimizing for equipment longevity, repair, reuse and recycling.
- **Energy efficiency** is a quantifiable metric of sustainability. It refers to the quantity of information bits transmitted or received, per unit of energy consumption (in bit/Joule). Energy efficiency is expected to be improved appropriately with the capacity increase in order to minimize overall power consumption.

Recommendation ITU-R M.2160-0 (11/2023) - Framework and overall objectives of the future development of IMT for 2030 and beyond

6G Outlook of EU-US Trade and Technology Council

- EU - US Trade and Technology Council (TTC) held a ministerial meeting in Luleå, Sweden, 30-31 May 2023 and published a Joint Statement EU-US TTC in Sweden (europa.eu).
- Annex to the joint statement is 6G Outlook, where sustainability is included as follows:

6G technologies must also be an **enabler for sustainability, considering environmental, social, and economic perspectives**. A **reduced carbon footprint** and **energy efficiency** will be important design goals for 6G networks. More broadly, 6G should allow for **reduced energy consumption across all sectors** of the economy and society. Ideally, 6G technologies will **generate less pollution** and **reduce other environmental** impacts to better contribute to **long-term social sustainability** while **maintaining economic feasibility**.

Example: Environmental Sustainability of 6G through ”6R”

Reduce

- **End-to-end energy consumption** needs to be reduced and **energy efficiency** needs to be improved.
- End-to-end visibility and transparency on **supply chains' resource use** for circular economy.
- Measurement and **reduction of CO2 and other emissions** over the product/service lifecycle.
- Assessment, evaluation and monitoring of **human exposure to EMF.**

Reuse

- The **reuse of resources** (incl. infrastructure, spectrum) needs to increase.
- **Open source** paradigm expands to increasing the reuse of SW and data.
- Introduction of new generation mobile communication technology needs to reuse existing infrastructure.
- **Modular structure** of devices would allow reuse of components.

Recycle

- Higher level of **recycling of materials/devices/components** is needed.
- Redefining waste.

Recover

- Parallel use of different generations of **component technologies** to optimize resource use and minimize sustainability burden.

Redesign

- **User experience** needs to be at the center and rethought including different types of users.
- De-centralized (zones/communities) could emerge.
- New network architecture needs to accommodate variety of different needs for communications, computing and other services.
- The different roles of users and non-users needs to be addressed.

Remanufacture

- Increasing use of “as a service (aaS)” business models.
- Considering remanufacturing as a convenient business opportunity for developing countries.

M. Matinmikko-Blue, S. Yrjölä, P. Ahokangas, K. Ojutkangas & E. Rossi. (2021). 6G and the UN SDGs - Where is the connection? Wireless Personal Communications. https://doi.org/10.1007/s11277-021-09058-y

Sustainability considerations for 6G

- 6G combines communication with other services, like imaging, sensoring, and locationing, providing a **measurement tool** with hyper-local granularity.
- New mechanisms are needed to reduce the carbon footprint through **sharing and optimizing the use of all potential resources**.
- **Optimization of the collection, processing, storage and transfer of data** between different network locations is critical.
- Technologies for significant improvement of **energy efficiency** and **reduction of total energy consumption** for 6G are needed including new end to end measures, measurement methodologies and techniques.
- **Sharing of data and methods** on the impact of the wireless communications sector **between sectors and stakeholders** is needed to develop sustainable solutions.
- The challenge of **connecting the unconnected** needs to be solved with affordable solutions to support social sustainability.

Case example: Sustainable spectrum management for 6G

Principle I: Exclusive spectrum licenses should come with obligations on social sustainability (e.g. coverage)

Principle II: Rapid access to spectrum to solve major sustainability challenges needs to be ensured with new sharing-based spectrum access models

Principle III: The most environmentally sustainable transmission solution must always be selected

Principle IV: Proper metrics and measurement methods need to be defined and developed for sustainable spectrum access

Principle V: Proper mix of spectrum management models is needed to allow a variety of stakeholders to deploy wireless systems

Principle VI: The role of spectrum sharing as the enabler needs to be acknowledged and developed

Principle VII: Proper stakeholder management needs to be incorporated into spectrum decision making

M. Matinmikko-Blue. (2022). Sustainable Spectrum Management for 6G. Invited paper at 25th International Symposium on Wireless Personal Multimedia Communications (WPMC). Herning, Denmark, 30 October-2 November 2022.

Sustainable spectrum management principles I-II for 6G

Principle I: Exclusive spectrum licenses should come with obligations on sustainability.

- If exclusive licenses are awarded in the 6G era, they need to come with the “use-it-or-lose-it” principle.
- Also, obligations on social sustainability goals need to be introduced in 6G spectrum awards including requirements to connect the remote and rural areas, schools, healthcare centers, etc.
- Clear limits for GHG emissions also need to be defined.
- The resulting challenge is to define these sustainability requirements in a measurable manner so that their achievement can be monitored.

Principle II: Rapid access to spectrum to solve major sustainability challenges needs to be ensured with new sharing-based spectrum access models.

- New local licensing and sharing-based spectrum access mechanisms need to be included into 6G spectrum discussions right from the beginning instead of being a restriction potentially posed afterwards.
- These access models need to include obligations to share it when not using it.
- The challenge is to find the spectrum bands and develop the mechanisms for realizing this. On the other hand, finding bands for local access via vertical spectrum sharing while potential incumbent spectrum users might make it easier to gain access to spectrum

M. Matinmikko-Blue. (2022). Sustainable Spectrum Management for 6G. Invited paper at 25th International Symposium on Wireless Personal Multimedia Communications (WPMC). Herning, Denmark, 30 October-2 November 2022.

Sustainable spectrum management principles III-IV for 6G

Principle III: The most sustainable transmission solution must always be selected.

- Different technology combinations operating in different spectrum bands that have different propagation characteristics are better suited for different types of usage.
- The principle to choose the transmission resource combinations needs to be based on sustainability criteria. Defining the criteria is an open challenge. The selection of the transmission technique needs to be based on this criteria and the resulting solution could also be fiber.

Principle IV: Proper metrics and measurement methods need to be developed for sustainable spectrum access.

- Specific sustainability-based design criteria need to be defined for 6G including metrics to quantify emissions and resource consumption and their measurement methods.
- Different components' contributions need to be quantified and their development needs to aim at minimizing the GHG emissions, overall energy consumption and other sustainability metrics.

M. Matinmikko-Blue. (2022). Sustainable Spectrum Management for 6G. Invited paper at 25th International Symposium on Wireless Personal Multimedia Communications (WPMC). Herning, Denmark, 30 October-2 November 2022.

Sustainable spectrum management principles V-VI for 6G

Principle V: Proper mix of spectrum management models is needed to allow a variety of stakeholders to deploy wireless systems.

- Different spectrum access methods need to be included into 6G spectrum discussions and technology development from early on.
- The balance between spectrum management models needs to be ensured by a proper mix where spectrum is made available for a variety of stakeholders to deploy 6G systems, especially to solve major sustainability challenges in different sectors of society.
- The balance needs to consider the different propagation and deployment characteristics of the different spectrum bands, resulting in economically sustainable operations.

Principle VI: The role of spectrum sharing as the enabler needs to be acknowledged and developed.

- Spectrum sharing, where two or more radio systems operate in the same frequency band, needs to be incorporated into 6G spectrum discussions from the beginning using the proper terms of vertical and horizontal spectrum sharing.
- Vertical spectrum sharing will play an important role in 6G to gain access to new spectrum while protecting the incumbent spectrum users.
- Horizontal spectrum sharing will play an important role in 6G, allowing different stakeholders to deploy local 6G networks.
- Specific requirements for spectrum sharing need to be defined together with techniques to fulfill the requirements to allow the potential emergence of a number of local 6G systems.

M. Matinmikko-Blue. (2022). Sustainable Spectrum Management for 6G. Invited paper at 25th International Symposium on Wireless Personal Multimedia Communications (WPMC). Herning, Denmark, 30 October-2 November 2022.

Sustainable spectrum management principles VII for 6G

Principle VII: Proper stakeholder management needs to be incorporated into spectrum decision making

- 6G spectrum decision making will not only be about awarding spectrum to MNOs like prior generations.
- Realizing proper stakeholder management in the future 6G ecosystem needs to consider new stakeholders including local operators.
- What future 6G ecosystem will look like, is yet an open question. Today's strong stakeholders need to be complemented with other stakeholder voices, including end users. Currently, participation in the spectrum decision making processes requires a lot of resources.
- The regulatory processes need to be reformed to include hearing of relevant stakeholders' perspectives beyond the currently dominant stakeholders, who defend the status quo.
- The role of the research community needs to be acknowledged.

M. Matinmikko-Blue. (2022). Sustainable Spectrum Management for 6G. Invited paper at 25th International Symposium on Wireless Personal Multimedia Communications (WPMC). Herning, Denmark, 30 October-2 November 2022.

Conclusions

- **Sustainability** is a key driver 6G R&D but is still not taken seriously. It is our shared responsibility to **translate sustainability into visible design criteria and solutions** ensuring that our actions today do not limit the range of **economic, social, and environmental** options open to future generations.
  - Economic, social and environmental sustainability perspectives.
  - Footprint and handprint effects.
  - Life cycle of equipment and services.
  - End-to-end approach.
- **Access to real-life data** needs to be granted to developers of sustainable solutions as well as researchers, decision makers and end users (consumers and verticals) for informed decision making that puts sustainability in the center.
- As a specific topic, of **sustainable spectrum management** is a new area. Different service, technology, spectrum, device, and network combinations have a different sustainability footprint. End users want to know the impact of their decisions.
- **Spectrum sharing** needs to be incorporated into 6G spectrum discussions from the beginning of the technology development phase and not a restriction posed afterwards.

Thank you!

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