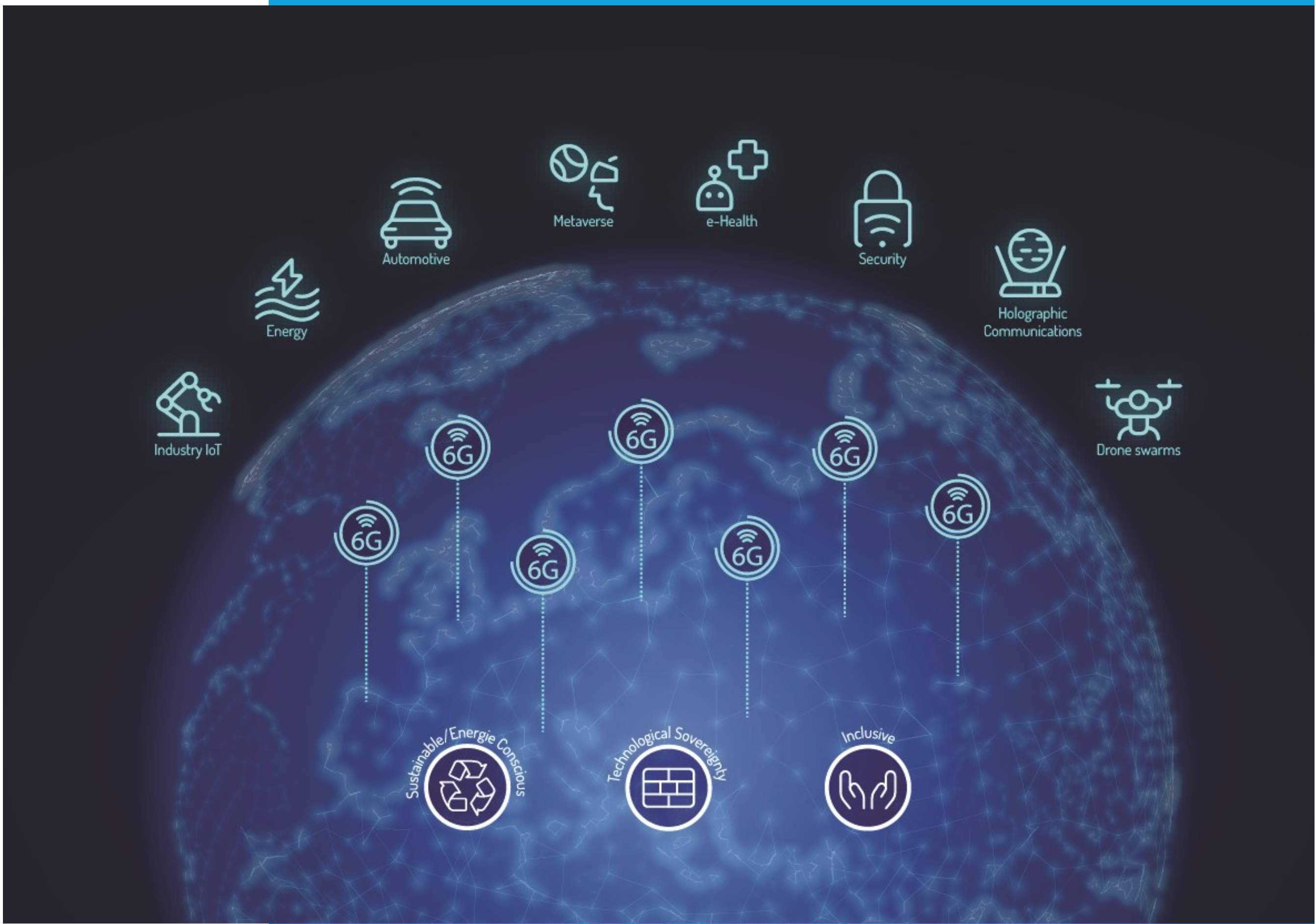
Smart Networks and Services Joint Undertaking (SNS JU)

Test Measurements and Validation Working Group



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WHITE PAPER

6G KVIS – SNS PROJECTS INITIAL SURVEY RESULTS 2025

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EXECUTIVE SUMMARY

The Test, Measurement, and Validation (TMV) Working Group (WG) of SNS JU focuses on developing and sharing related experiences and best practices for 6G networks testing, monitoring, and assessment from various perspectives. More specifically, besides its strong focus on 6G networks' technical performance, the TMV-WG, through the KVIs sub-working group, aims to set the scene for 6G networks' impact monitoring and validation from the emerging dimension of Key Value Indicators (KVIs).

Within this context, the TMV WG aims to record, report, and promote state-of-the-art and new innovative methodologies for the monitoring and evaluation of the foreseen impact of the 6G networks on Key Values, as identified by SNS-JU projects.

This work leverages the methodology and previous work of 6G-IA (published in [1]) on the definition of values and KVIs -which still progresses in the context of 6G-IA SNVC (Societal Needs and Value Creation Sub-Group)- addressing the dimension of evaluation of KVIs. To this end, various SNS JU projects provided the KVIs and information on how these can/ will be evaluated in accordance with the use cases that are addressed. To align with the SNVC methodology, the main reported KVIs were classified into categories based on the impacted Key Values (KVs).

The identified categories of KVs are the following: KV #1 – Environmental Sustainability, KV #2 – Societal Sustainability, KV #3 – Economic Sustainability & Innovation, KV #4 – Democracy, KV #5 – Cultural Connection, KV #6 – Knowledge, KV #7 – Privacy & Confidentiality, KV #8 – Simplified Life, KV#9 – Digital Inclusion, KV#10 – Personal Freedom, KV#11 – Personal Health & Protection from Harm and KV #12 – Trust. This categorisation utilised within the present whitepaper does not represent or stand for a final proposal of classification of the Key Values, rather, it is utilised as a point of reference for many of the research projects that participated in the questionnaires.

At this point it is important to clarify and take into serious consideration that the long discussions about what are the key priority values for the societies, are still ongoing and several approaches have been defined, by the time of the formation of the present research, no universal approach for the classification of the KVs has been established. For example, all recorded frameworks in the related literature contribute to the big dialogue with different starting points, e.g. some begin from the SDGs, others from Green Deal literature, etc. To this end, the utilisation of this list of categories does not aim to necessarily create definitions, promote, or provide guidelines as an ultimate way to organize the Key Values. The purpose of the current work is to establish the indicators of KVIs as viable measures of impact. In fact, in 6G4Society, the research groups are working on an ontology to propose [2], based on all the project work, which can go through a consensus process to facilitate the alignment on how all SNS projects define and generate research outcomes about these categories.

Some of the main challenges (identified by the contributing projects related to the specification and measurement of the KVIs are the following:

- The harmonisation of different understandings and definitions of the societal values themselves, which is necessary for the development of measurement and validation methodologies and the determination of the technological enablers
- The extrapolation of KPIs (to be used for the evaluation of the SNS projects) stemming from the definition of specific and quantitative KVIs, and the determination of target values as benchmarks or thresholds for the evaluation of 6G networks and systems.
- The major challenge is the determination of target values as benchmarks or thresholds for the evaluation of 6G networks and systems. In addition, given the fact that KVIs is an emerging aspect of 6G, while technical KPIs in some use cases and projects, traditional KPIs are used for the measurement of long-term impact. Such types of KPIs are directly used with the KVIs for the evaluation of the SNS projects for the determination of quantitative KVIs,
- As far as the definitions used at a project-level, the existence of definition for any specific KVI, recommends a satisfiable progress toward the determination of a general definition for KVIs, using a specific to general approach. In general, the SNS projects tend to identify concrete and relevant KVIs, they are strongly linked with their vision, scope and use cases for the measurement of the impact, contributing in parallel to the relevant research for the determination of universal definitions of KVs and KVIs.

This white paper highlights the steps that projects undertake in order to address the challenges of measuring the value of the networks and elaborate with the good practices.

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1 INTRODUCTION

EU is welcoming the use of Key Value Indicators (KVIs) as a means to assess 6G networks from the sustainability dimension. Since the early steps of 6G, the Smart Networks & Services Joint Undertaking (SNS JU) ([3],[4]) between 6G-IA and the European Commission, have launched an ambitious work programme based on a European vision of 6G. To this end, the notion of KVIs as means to assess the impact of technology advancements on various dimensions of life and environment sustainability (inherent in the SNS JU Work Program) has gained attention from international organisations. Still, significant work remains to qualify/quantify such indicators such that they can be used in a standardisation context.

By defining qualitative and quantitative KVIs, Europe will be able to design and develop networks and services that align with sustainability goals and provide value to industry and benefits to the society and the environment. In addition, the definition and validation of KVIs will show how the SNS projects contribute these goals.

SNS WP 2025 and beyond, hence includes efforts into a better qualification/quantification of KVIs, leveraging the sustainability flagship project expected to start at the beginning of 2025, duly complemented with relevant R&I of WP 2025 and beyond. More specifically, based on the Strategic Plan for Horizon Europe covering the 2025-2027 period, the three main strategic orientation include (a) Green Transition, (b) Digital Transition and (c) A more resilient, competitive, inclusive, and democratic Europe. To this end, SNS pioneers on the notion of KVIs so that key values could be widely recognised, along with the indicators for measuring the real impact of projects and initiatives. High emphasis is given toward the definition of the qualitative and quantitative metrics for that could be utilised for standardisation and certification purposes. In addition, the main work related with the Green Transition strategic objective, The core focus focuses on addressing the Sustainable Development Goals SDGs 8, 9, 11 and 13, while specifically for SDG 13 (Climate Action) the work program focuses on “Sustainable 6G” and “6G for sustainability” ([5], [6] and [7]).

The SNS TMV WG, is one of the three SNS JU WGs – following up 5GPPP TMV WG activities. The WG focuses on promoting commonalities across SNS projects that have a strong interest in Testing & Monitoring (T&M) methodologies, including the development of test and measurement methods, test cases, and procedures, as well as the KPI/KVI formalization and validation to the greatest possible extent. It aims to ensure a unique European vision on how the entire lifecycle of the 6G network, ranging from R&D to actual deployed environments, can be supported.

The present white paper aims to constitute a starting point for the recording of the work on key methodologies utilised in 6G SNS projects for the definition and evaluation of KVIs, and to serve as a reference work for the mapping and analysis of the future outcomes and advancements in this.

1.1 Objectives & Motivation

> The TMV objectives are to cover all aspect of testing, validation and measurement activities:
>
> - KPI/KVI definition, sources, collection procedures, validation methodologies and analysis.
> - Testing frameworks (requirements, environment, scenarios, expectations, limitation) and tools.
> - Testing methodologies and procedures.
> - Testing lifecycle (i.e., testing execution, monitoring, evaluation and reporting).
> - Analysis of trials results and generation of insights.

The Test, Measurement, and KPIs Validation (TMV) WG is an integral WG of SNS JU focusing on Test and Measurements procedures, tools, and methodologies (definition, testing, monitoring, and analytics), and allowing experts to exchange experience and results from the various 6G measurement campaigns within the SNS JU programme. In particular, the TMV WG focuses on promoting commonalities across projects that have a strong interest in Testing & Monitoring (T&M) methodologies. The TMV WG provides a forum to share the best practices to support 6G Trial use cases. Such efforts include the development of testing and measurement methods, test cases and procedures as well as the KPI/KVI formalization and validation to the greatest possible extent, to ensure a uniform European vision of how the entire lifecycle of the 6G network, ranging from R&D to actual deployed environments, can be supported[1].

The present white paper represents an initial contribution from the SNS TMV sub-Working Group focusing on KVIs (key value indicators). Within the context of the TMV WG objectives, the present whitepaper aims to cover the main aspects of the KVIs analysis and validation methodologies, as well as the target values, when available within the 6G SNS ongoing projects. **This initial contribution facilitates the discussions on the existing definitions of key values and KVIs, the enablers, the standards followed by the EU projects, the data and results description, and maturity, in the early beginnings of the 6G era.**

Towards this scope, the white paper aims to provide a coherent analysis of the set of the KVIs investigated within the 6G SNS projects and their advancements in the long-term impact of the

[1] https://smart-networks.europa.eu/sns-ju-working-groups/

technologies associated with 6G. To this end, the core purpose of the analysis is to provide a holistic and comprehensive overview of the KVIs defined, developed, and implemented within the context of the 6G SNS projects. More specifically, the white paper aims to provide a better understanding of the Key Values that 6G can have a high impact on, explore the level at which the existing KVIs definitions and metrics, methodologies and enablers will apply to 6G and identify, at early stages, gaps and potential novel KVIs for future contributions to the standardisation of the 6G networks, systems and provided services.

The KVIs are utilized in the SNS projects as a means to indicate the impact that the 6G can have on the environment, society and EU competitiveness, by considering various vertical sectors, leveraging emerging 6G technologies, networks, solutions and applications. To this end, in the initial steps of KVIs research, alternate frameworks have been discussed, based on the research initiated within the HEXA-X project, which are still under shaping. Thus, this white paper intends to provide an analysis of the nature of the 6G KVIs identified in [1] by further elaborating on the feasibility of being measured, on the methods and tools to be used for their evaluation, and on identifying challenges, gaps and research steps to be followed on the measurement and evaluation methodologies to be used in the 6G era. The indicative list of KVIs illustrated for the defined Key Values has been drawn from ongoing EU projects and is to be adapted to the goals of all the SNS projects.

The 6G KVIs are recorded, along with the Key Values they serve, the Key Enablers,[2] and the methodological approaches used for their measurement, as well as the corresponding target values, in the cases that the research is mature, or based on the previous definitions and propositions from SDOs and organisations related with KVIs measurement.

The remainder of this paper is structured as follows:

- Section 2 provides an overview of the KVIs and the related frameworks considered within the 6G networks, taking into account the results of a dedicated questionnaire that has collected knowledge and experience gained by the SNS JU projects, focusing on the formation of a common KVIs Measurement and Evaluation Framework.
- Section 3 reports the white paper’s approach on the 6G Key Values and KVIs, building upon the three existing contexts available.

[2] Technological enablers for 6G have been ongoing for several years, building on the features and enhancements of previous generations as well as exploring technological breakthroughs that may revolutionize mobile connectivity in the coming years.

- Section 4 provides an analysis of the collected material by Key Value, utilizing the 12 Key Vales as defined in [1], along with aggregate insights on 6G networks' performance and capabilities.
- Finally, Section 5 concludes this white paper.

2 OVERVIEW OF KVIS ACTIVITIES & CURRENT TRENDS

The evolution of the 6G networks is based on technological advancements that provide higher speed, lower latency, and substantially higher capacity than 5G which, through the proliferation of a number of innovative use cases can lead to broader socioeconomic and environmental benefits and externalities. These technological achievements contribute to the form of valuable enablers and catalysts toward the dual digital and sustainable transition for ecosystems and societies. To this end, the initial developments in the 6G era emphasize not only the performance targets but also the three-dimensional sustainability (environmental, societal, and economic) leading to the maximization of long-term impact, based on well-established societal values. The latter can be safety, security, trustworthiness, inclusiveness, and sustainability, articulated through Key Value Indicators (KVIs). The initial definitions of both the Key Values and the KVIs entail the ambition for measuring the overall expected impact for technologies, systems, and applications, as well as for societies as a whole and the evident improvements in human life on a more sustainable planet. The existing proposed KVIs frameworks are fully aligned and contribute significantly to the United Nations (UN) Sustainable Development Goals (SDGs), such as the 6G Flagship [8].

Currently, several SDOs and initiatives coordinate their efforts in the emerging field of KVIs. The present section provides a comprehensive overview of these activities, highlighting the efforts and primary results of some of the main SDOs involved in both 6G networks standardisation and sustainability.

The contributions towards the formation of a unified and globally accepted framework are in progress with several initiatives working and providing contributions for the 6G sustainable vision and the specification of key values and technology enablers as well as addressing the challenges. SNS JU recognises the need for sustainable infrastructure toward the “Path to the Digital Decade” as a core enabler for building competitive advantages from the digitisation process for EU’s digital leadership [3].

SNS JU

SNS JU focuses on 6G networks research, innovation and development. SNS-JU relies on an end-to-end approach from policy and regulation to research, standardisation, and deployments, and to build further on a strong public-private cooperation for a sustainable future. SNS continues to promote the benefits of 6G for the maximisation of environmental impact and societal well-being through energy-efficient computing architectures and breakthrough innovative solutions to minimise the use of natural resources to achieve sustainable competitiveness. The sustainability pillar of the SNS defines two critical areas:

(a) **Sustainable 6G** for the maximisation of the environmental impact through the 6G system design, contributing with quantitative measures (KPIs and KVIs) for sustainability assessment. In addition, it defines benchmarking scenarios that allow to assess sustainability performance for specific 6G implementation scenarios, taking into account the contemplated 6G architectures and

(b) **6G for Sustainability**, for leveraging 6G to support sustainability in other sectors, focusing on climate action and responsible digital services. Mainly focuses on how 6G can enable the verticals/domains to be more sustainable, how to measure it and what research aspects still need to be tackled, leveraging deep knowledge of the use cases' processes with potentially conflicting requirements

More specifically, the SNS programme sets special emphasis on the KVIs' specification, within the context of supporting and contributing to the efforts for the development of 6G KPIs/KVIs, reflecting the major forward-looking strategic interests and priorities. To this end, SNS JU 2025 Work Programme provides complementary and extended opportunities to test 6G technologies through Proof of Concepts (PoCs), trials and experimentation in several verticals, targeting the compilation of the specific definitions and validation of KVIs/KPIs in the context of very advanced digital use cases with a focus on specific vertical sectors. Additionally, key partners from Hexa-X-II and 6G-IA have already submitted a contribution [9] in the IMT-2030 activities analysing the KVIs, which will be needed to measure sustainability goals, as reported in the SNS-JU 2025 Work Programme.

6G-IA

The 6G-IA envisions sustainability as a key target for 6G, one that should drive activities of the future network needs. The experts group highlights three areas that the 2030 network should address: i) societal, economic, and environmental values as mentioned by the UN Sustainable Development Goals and the European Green Deal; ii) strategic autonomy and technological sovereignty reflecting European values, and iii) a human-centred approach to innovation that negotiates corporate and social value. 6G-IA VSC WG also aims to identify relevant open research topics paving the way to the realization of the formulated vision and service concepts, we also formulate KPIs for the functional and, whenever possible, extra-functional properties. In addition, SNVC analyses societal acceptance and also develops KVIs, i.e. estimation of the value of the technology for the society, through studying suitable economic models for all realizations and services, validating the latter as the technology matures over time and trying to understand the value of the proposed system to the society as a whole.

HEXA-X and HEXA-X-II projects

The HEXA-X and HEXA-X-II projects are key initiatives in EU's effort to define and advance 6G technology, with their contributions being particularly relevant to the establishment of 6G KVIs, which complement traditional KPIs, by emphasizing societal, economic, and environmental impact alongside technical performance. HEXA-X has already introduced the concept of KVIs to ensure 6G aligns with EU values, such as sustainability, inclusion, and trustworthiness, while has developed a framework connecting KVIs with 6G design choices, ensuring they are embedded early in the research and development phases.

Some of the core artefacts of HEXA-X-II include the identification of core KVIs, while conducting research to define core KVIs based on stakeholder needs, including sustainability (carbon footprint reduction), security and privacy, digital inclusion, and trustworthiness) and mapping KVIs to 6G Use Cases. More specifically, Hexa-X-II moves ahead of the current state of the art of 6G research by building advanced technology readiness demonstrated with PoCs. Overall, the project aims to:

As the foundation, the project will analyse needs and develop a consolidated set of requirements in terms of Key Performance Indicators (KPIs) and KVIs for the future 6G platform, considering the key values of sustainability, inclusion, and trustworthiness (Obj. 1).

- The 6G platform will be systemized and integrated into a blueprint considering the key values, involving an evaluation of KPIs, which in turn will provide a validation of the project's developed design and content.
- The 6G system will enable breakthrough technologies and interfaces for connectivity services (Obj. 3), building on the progress of 5G-Advanced and meeting the demands of the 2030s.
- Expanding the scope of networks, the project will develop enabling technologies and interfaces for novel digital services building on new network capabilities of sensing, compute, and AI (The project will further ensure that the 6G system is realizable, implementable, and manageable in a resource-efficient manner.
- Finally, Hexa-X-II will contribute to a holistic European 6G view and will be a leading voice in the globally aligned roadmap towards 6G by impacting standardisation activities.

6G4Society project

6G4SOCIETY is an SNS JU project at work to ensure that societal, environmental, and economic values are embedded into the design, development, and adoption of 6G, bringing a sustainability perspective to technological development. Overall, the project aims to:

- Generate a better understanding and shared knowledge on the aspects influencing public acceptance of 6G technologies
- Support the conception and development of a unified EU consensus framework on a value-based, sustainable and ethics-driven approach towards 6G, and support its promotion through the 6G EU and global standard-setting process
- Empower the 6G community on how to reflect EU policy and legislation into technology solutions for future networks' development and services engaging and reaching out to public audiences to help build 6G awareness and social acceptance

Specifically, on the KVIs domain, the project aims to develop innovative sustainability indicators for larger public validation and downstream exploitation at a regulatory level.

3 KVIS – INITIAL INVESTIGATION & GROUPING

For the definition of the KVIs the first step is the definition of the set of the "key values". This focus on values aims to ensure that globally accepted sustainable development goals are in the focus of EU research. Within this context, KVIs aim to measure a broader set of multidiscipline "key values" addressing various dimensions of life on a more sustainable planet [1]. Of course, this definition process is still ongoing and has not been finalised yet for the establishment of a universal definition and common vision for KVIs.

Focusing on the dual, digital, and green 6G transition, the co-creation of a unified integrated framework approach for the harmonisation of the three aspects of sustainability and a set of broader universal values is required. Currently, some of the major KVs are directly or indirectly linked with complex aspects in terms of definition, such as value or impact, quality, experience, resilience, responsibility (social and environmental), ethics, efficiency, etc., which could be utilised as potential Key Values.

Figure 1: KPIs and KVIs Key Features

Key Performance Indicators	&	Key Value Indicators
used for monitoring and validating the performance of 6G technologies	Focus	used for monitoring and validating the impact on key societal values
monitoring operations and performance of 6G, based on technical standards and SLAs	Purpose	evaluate high-level objectives, such as digital inclusion, or environmental sustainability
network operators, telecoms, tech providers, engineers, and industry players	Stakeholders	policymakers, regulators, SDOs, end-users, and society overall
short and medium-term focus, measuring real-time results and within projects lifetime	Time Horizon	long term focus, reflecting impact of 6G technologies over decades
Quantitative and straightforward measures for technical results	Measures	multi-dimensional or qualitative, using assessments (e.g., surveys, impact analysis etc).

Research on the KVIs activities has taken place within the period July 2024 till April 2025, in which the majority of the ongoing SNS JU projects provided information on the KVs, Key Enablers, and the KVIs they utilise to measure the long-term impact of their results and outcomes. The projects that participated in the research highlighted a categorisation of the KVs based on one of the three main frameworks for defining their "key values". The three frameworks are presented in Figure 2 and are based on the results of (a) HEXA-X and HEXA-X-II project, (b) the values defined in the 6G-IA SNSWP

(2022), and (c) the values defined in the SNS Work Programme 2021-2022. Figure 2 showcases an indicative list of KVs that (some of them) could be addressed by 6G R&D activities identified by each framework.

In order to address the core objectives of the TMV WG in the area of KVIs, SNS-JU Phase I and Phase II projects were asked to provide the 6G Key Values and KVIs, that they have already identified - and which have been used to drive the projects' technical developments-, along with the key enables, the validation methodology and the target values. Depending on maturity of the work of the SNS-JU projects, the following 15 projects in total provided input for the questionnaires developed for this purpose: FIDAL, TRIALSNET, CENTRIC, 6G-SENSES, ENVELOPE, Deterministic6G, DESIRE6G, PREDICT-6G, 6GXR, 6G-PATH, SAFE-6G, ORIGAMI, PRIVATEER, 6G-EWOC, ECO-eNET. All KVIs serve as critical benchmarks, helping to validate the effectiveness of technological interventions in real-world use cases.

Figure 2: Key Values as defined and Utilised in 6G SNS projects, participated in the survey.

Note: The categorisation of the 6G-IA SNSWP is and indicative listing for the Key Values categories.

Overall, the great majority of the projects that participated in the current research utilise one of the three well-established frameworks for the definition and implementation of the KVs and KVIs. More specifically, for each one of the KVs, we have documented the KVIs utilised at a project level and the current definition used, while the tables also showcase the PoCs/UCs and vertical application where these KVIs are about to be evaluated. Additionally, for each KV, we have also collected the key technological enablers, as defined within the context of each project, the validation methodology proposed, the target values, and the existence of any relationship with already existing KPIs/ technical enablers to come in the B5G/6G era. Based on the mapping of the Key Values, in the present research the categories of the three frameworks were grouped into the ones proposed by the 6G-IA Whitepaper.

After taking into consideration the alternate frameworks defined and analysed in the previous section, the present whitepaper follows the categorisation as defined in Wikström et al. (2022)[1], as shown in the following Table **1**.

Table 1: Key Values indicative categorisation

1.	Environmental Sustainability	7.	Privacy and Confidentiality
2.	Societal Sustainability	8.	Simplified Life
3.	Economical Sustainability and Innovation	9.	Digital Inclusion
4.	Democracy	10.	Personal Freedom
5.	Cultural Connection	11.	Personal health and protection from harm
6.	Knowledge	12.	Trust

The proposed approach for the recording of the KVs and KVIs, besides the great advantage of the coherence, also manages to address some of the challenges on the KV and KVI measurement frameworks. Firstly, the variability in the use cases addressed by projects might require different sets of KVs and KVIs. In our results, the inputs from the projects were handled with flexibility in order to ensure that their frameworks are aligned within the diverse vertical applications without being overly rigid. In addition, in some KVs and KVIs the methodological approaches and specific indicators are mentioned without specific measurement formulation, depending on the maturity of each project and data availability.

Since a reliable measurement of KVIs depends on consistent data collection from the use cases, and different data sources, collection methods, and reporting formats are required, some methodologies are still in progress. In addition, given that the great majority of the projects work in emerging technologies, such as Artificial Intelligence (AI), Blockchain, Big Data and Cybersecurity, it is difficult for the projects to define the set of KVIs by the time of the initiation of this research. To this end, the TMV WG envisions the continuous update of the present database.

4 SOCIETAL KEY VALUES – KVIS CLUSTERING AMONG SNS PROJECTS

The present section focuses on the main results and research outcomes. More specifically, the following subsections provide the core information and the main insights of the ongoing 6G SNS JU projects for all the 12 Key Values (KVs). Overall, we can notice that some KVs are more mature in terms of definitions and in terms of methodologies for evaluation, while others further analysis and work is needed in the research community. For example, KVs such as KV#1, KV#2, and KV#3, which deal with the main environmental, societal, and economic principles, showcase a large set of KVIs and alternate methods for their validation. In contrast, KVs such as KV#5 Cultural Connection of KV#9 Digital Inclusion seem less mature in all examined aspects. Last but not least, we should mention that all the results provided are also subject to the nature of the verticals, use cases, proofs-of-concept (PoCs), or experiments related to each project, their vision, and research focus.

In addition, energy efficiency is one of the more mature ones, as it has a history of standards and cost-savings practices behind it, whereas democracy is less mature due to diverse definitions and goals, and the fact that it's mostly matured as a concept in the policy and social science realm and still being translated into implications for technology design and development.

Moreover, another reason for this might be perhaps a bias in the approach utilised for the classification of KVIs into categories, e.g. Democracy might not be a key value for action, but an underlying value of society that is broken down into other key features, like personal safety and digital inclusivity, and trust. In the same way, "Sustainability" is too large to address, and it broken down into 3 pillars. As a result, the variations of KVIs within each could be due to maturity or the need to revisit how key values are classified.

The KVs are defined by the 6G SNS projects towards the achievement of long-term impact and sustainable competitiveness, through the successful transition and the development of innovative, sustainable, and resilient practices. Despite this "bigger picture", due to the heterogeneity of the 6G projects, there is a large variation in the definitions of the Key Values and the analytics used, either for the networks or the 6G applications and end solutions.

These aspects lead to a better understanding and extended sets of KVIs, while the other more emerging and still under discussion KVs showcase limited information. For example, KVs such as KV#1, KV#2, and KV#3, which deal with the main environmental, societal, and economic principles, showcase a large set of KVIs and alternate methods for their validation. In contrast, KVs such as KV#5 Cultural Connection of KV#9 Digital Inclusion seems less mature in all examined aspects. Some KVs and deriving KVIs are widely addressed by SNS JU projects, while others are not so much in the focus of the SNS JU projects that contributed to this study/ white paper.

Last but not least, we should mention that all the results provided are also subject to the nature of the verticals, use cases, proofs-of-concept, or experiments related to each project, their vision, and research focus.

The Key Values are defined by the 6G SNS projects towards the achievement of long-term impact and sustainable competitiveness, through the successful transition and the development of innovative, sustainable, and resilient practices. Despite this “bigger picture”, due to the heterogeneity of the 6G projects, there is a large variation in the definitions of the Key Values and the analytics used, either for the networks or the 6G applications and end solutions.

Overall, the great majority of the projects that participated in the current research utilise one of the three well-established frameworks for the definition and implementation of the KVs and KVIs. More specifically, for each one of the KVs, we have documented the KVIs utilised at a project level and the current definition used, while the tables also showcase the PoCs/UCs and vertical application where these KVIs are about to be evaluated. Additionally, for each KV, we have also collected the key technological enablers, as defined within the context of each project, the validation methodology proposed, the target values, and the existence of any relationship with already existing KPIs used in the 5G/B5G/6G era and defined by SDOs.

4.1 KV #1 – Environmental Sustainability

According to United Nations' definition, environmental sustainability can be defined as responsible management and "use of natural resources to meet current needs without compromising the ability of future generations to meet their own"[10]. Further, it emphasizes "targeting the minimisation of environmental impact" [2]. Accordingly environmental sustainability targets maintaining ecological balance with a minimal or zero depletion of natural resources, thereby ensuring long-term environmental quality. In the development and deployment of 6G, environmental sustainability involves promoting efficient resource utilization, reduction in energy emission, reduction of carbon footprint, and mitigating other negative environmental impacts and rebound effects. These initiatives aim to harmonize technological advancement with ecological preservation, ensuring that innovations contribute positively to the environment.

Table 2 below provides a summary of environmental KVIs across several 6G-related projects, evaluating their technological impact, validation methods, and expected performance outcomes. The analysis of KVIs across multiple 6G projects highlights the broad scope of environmental sustainability including the following main KVIs:

- Energy efficiency improvements
- Water conservation
- Quality environment
- Waste reduction
- Contribution to climate resilience
- Reduction of Carbon footprint

Among different 6G projects, 6G-PATH project mainly focuses on sustainable smart farming, healthcare and sustainable smart cities verticals. The specific use cases such under the smart farming vertical of 6G-PATH, demonstrate how advanced 6G features optimize irrigation practices, align with soil moisture levels and climate conditions, optimize efficient energy consumption and water conservation by supporting long-term environmental sustainability. Further, the project explores waste reduction in healthcare through innovative wound care solutions. Climate resilience is another critical focus, with 6G-PATH exploring how advanced connectivity solutions can support adaptation strategies against extreme weather events and changing environmental conditions.

The CENTRIC project emphasizes energy efficiency in digital networks, leveraging AI, machine learning, and predictive control to optimize energy usage. Environmental KVIs in this project measure improvements in spectral efficiency, reduction in radiation through dynamic beamforming, and enhanced network performance via data compression techniques. The project showcases laboratory and multi-domain proof-of-concepts, demonstrating the potential of AI-driven automation in minimizing energy waste. ORIGAMI, another 6G project focuses on energy efficiency and sustainable RAN virtualization, introducing a Compute Continuum Layer (CCL) for optimizing resource allocation. The project's environmental KVIs measure the impact of AI-driven automation on energy consumption in network infrastructure.

Moreover, 6GXR and ENVELOPE are two projects that contribute to environmental sustainability by exploring how to reduce without adding new sources of emissions and developing new ways to measure travel-related carbon emissions through holographic meetings, digital twins, and VR-based collaboration. The project also emphasizes energy measurement frameworks, smart metering, and intelligent control systems to optimize energy usage and improve sustainability. Various KVIs quantify reductions in greenhouse gas emissions, enhanced resource allocation, and real-time monitoring capabilities. Other projects, such as DESIRE6G, DETERMINISTIC6G and FIDAL, introduce environmental KVIs related to the expansion of protected natural habitats, exoskeleton energy optimization, and reducing greenhouse gas emissions using AR/VR technologies. These findings indicate that 6G technologies play a crucial role in enhancing sustainability, reducing energy consumption, and improving regulatory compliance across different industries, ultimately contributing to a more resource-efficient and environmentally friendly future.

Regarding enablers, targets, and KPI-related aspects, environmental KVIs vary in how well-defined they are numerically. Some projects, such as 6GXR, define numerical targets through specific metrics like RMSE, MSE, or energy consumption reduction percentages, while others, like 6G-PATH, focus more on qualitative improvements. There is a general similarity in environmental KVIs between projects, especially in energy efficiency and carbon footprint reduction. However, projects approach measurements differently, with some relying on AI-driven predictive models and others emphasizing direct resource monitoring.

A significant difference emerges in the methodologies and standardization of target values. While CENTRIC and ORIGAMI employ AI-based optimizations for network efficiency, 6GXR and 6G-PATH apply practical monitoring solutions for sustainability. Differences also arise in compliance-related KVIs, where some projects address regulatory adherence explicitly, while others implicitly contribute to meeting environmental standards. These discrepancies highlight the need for a standardized methodology in evaluating the effectiveness of environmental KVIs across projects. However, a notable gap persists in the broader definition of environmental sustainability within these projects. The vast majority of initiatives focus heavily on energy efficiency and reductions, with limited attention given to other critical aspects such as e-waste management, lifecycle impacts of network infrastructure, sustainable materials usage, or the carbon footprint of supply chains. Addressing these underexplored dimensions would offer a more comprehensive and holistic approach to environmental sustainability in future 6G developments.

Table 2: Environmental Sustainability Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
6GPATH	Increased water conservation in agriculture	How do advanced features of 6G minimize water wastage?	UC-Farming – Water Saving UC-Farming – Smart Vineyards	Precision irrigation systems, water management platforms	Survey after field trials/ Qualitative Methodology	% increase compared to current (>10%) The KVI is related to KPIs on water conservation
6GPATH	Increased energy efficiency in agriculture	How do advanced features of 6G contribute to lower energy consumption?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	Energy-efficient machinery, renewable energy sources	Survey after field trials/ Qualitative Methodology	% increase compared to current (>10%) The KVI is related to KPIs on Energy Efficiency
6GPATH	Increased soil health maintenance	How do advanced features of 6G contribute to ensuring optimal soil health and fertility and long-term soil conservation through timely monitoring and interventions?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	Soil monitoring systems, nutrient management tools	Survey after field trials/ Qualitative Methodology	% increase in soil health indicators (target >5%) The KVI is related to KPIs on soil health indicators
6GPATH	Increased contribution to climate resilience	How do advanced features of 6G contribute to developing adaptive strategies to mitigate the impact of climate change on cultivation, such as drought resistance testing and phenological monitoring, to enhance and ensure continued productivity in changing environmental conditions?	UC-Farming – Water Saving	Climate monitoring tools, drought-resistant crop development	Survey after field trials/ Qualitative Methodology	Increase in resilience strategies (qualitative improvement)
6GPATH	Waste reduction	How does this service contribute to reduced waste generated through packaging and disposal compared to traditional wound care products?	UC-HEALTH - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	The amount of packaging used can be compared in the current solution and in the 3D hydrogel patch.
6GPATH	Environmental regulatory compliance	How does the project ensure compliance with regulations governing water usage and conservation practices in agricultural settings?	UC-FARM-1 – Water Saving	In progress of definition of enablers	Survey after field trials	Qualitative
6GPATH	Environmental regulatory compliance	How does the project engage with policies on environmental protection and counteracting the effects of climate change?	UC-FARM-1 – Water Saving	In progress of definition of enablers	Survey after field trials	Qualitative

CENTRIC	Energy efficiency improvements	Model predictive control at the digital twin allows the proactive allocation of resources, anticipating changes in connectivity and traffic requirements that may cause a spike in usages of energy and spectral resources.	Multi-domain environments and Laboratory PoCs	Model predictive control	In progress of definition of the target values	The KVI is related to KPIs on Reduction in energy and spectral requirements
CENTRIC	Energy efficiency improvements	CSI compression will reduce the amount of information that needs to be transmitted between the UE and gNB. The smaller CSI payload will lead to decreased energy consumption at both the UE and gNB	Multi-domain environments and Laboratory PoCs	AIML-enabled CSI compression	In progress of definition of the target values	The KVI is related to KPIs on Compression ratio
CENTRIC	Energy efficiency improvements	AIML based MIMO precoding will reduce unnecessary radiation and hence, energy consumption. This will result in increased energy efficiency.	Multi-domain environments and Laboratory PoCs	AIML based MIMO precoding	In progress of definition of the target values	The KVI is related to KPIs on Bit rate
CENTRIC	Energy efficiency improvements	dynamic adjustment of beam directions and power will result in reduced radiation and energy consumption.	Multi-domain environments and Laboratory PoCs	AIML aided Beam management	In progress of definition of the target values	The KVI is related to KPIs on Beamforming gain
CENTRIC	Energy efficiency improvements	AI enabled JSAC can dynamically adjust resource usage for sensing and communication according to real-time channel environment conditions. This will lead to more efficient operation and hence, energy savings. Also, AI will enable energy-efficient sensing operations by intelligently optimizing energy usage while collecting information.	Multi-domain environments and Laboratory PoCs	Joint sensing and communication	In progress of definition of the target values	The KVI is related to KPIs on Bit rate
CENTRIC	Energy efficiency improvements	The ability to adapt symbol modulation to channel conditions will result in enhanced spectral efficiency and minimized retransmission.	Multi-domain environments and Laboratory PoCs	ML-enabled symbol modulation	In progress of definition of the target values	The KVI is related to KPIs on Spectral efficiency
CENTRIC	Energy Efficiency improvements	DCI compression techniques will reduce the bandwidth needed to transmit the same control data	Multi-domain environments and Laboratory PoCs	DCI compression	In progress of definition of the target values	The KVI is related to KPIs on Compression ratio
CENTRIC	Energy Efficiency improvements	The ability to extract abstract semantic concepts from complex use-cases reduces the amount of data that needs to be transmitted for control purposes. This implicitly reduces transmit power.	Multi-domain environments and Laboratory PoCs	Task-oriented cognitive wireless scheduling	In progress of definition of the target values	The KVI is related to KPIs on Control-Plane bitrate and Task success rate
CENTRIC	Energy Efficiency improvements	Smart subband selection strategies will minimize the collision rate, and with it, the energy wasted in unnecessary transmissions.	Multi-domain environments and Laboratory PoCs	ML-based sub-band selection	In progress of definition of the target values	The KVI is related to KPIs on Collision rate. Geometric mean of

						network bitrate and SINR statistics
CENTRIC	Energy Efficiency improvements	The ability to predict confidence in point predictions will necessarily improve control algorithms in multiple fields, among them, radio resource allocation	Multi-domain environments and Laboratory PoCs	Probabilistic Time Series Conformal Risk Prediction	In progress of definition of the target values	The KVI is related to KPIs on HARQ energy efficiency and Throughput Delay
CENTRIC	Energy Efficiency improvements	Smart clustering of cell-free access points will optimize the transmit power needed to achieve a target capacity, while minimizing unnecessary radiation and energy waste	Multi-domain environments and Laboratory PoCs	EMF reduction via AI-enabled cell-free networking	In progress of definition of the target values	The KVI is related to KPIs on Transmit power, SAR and Data rate
ORIGAMI	Energy efficiency	ORIGAMI's CCL (Compute Continuum Layer) will allow multiplexing a heterogeneous computing fabric comprised of energy-hungry yet powerful resources and energy-light yet capped resources	Demonstration of sustainable RAN virtualization techniques	Integrating NI solutions into vRAN servers will enhance the ratio of bits transmitted per unit of energy consumed	To be identified	100% higher than today's vRANs The KVI is related to KPI on Energy efficiency (bits-per-joule) and 35% less energy consumption The KVI is related to KPI on Network energy consumption (KWh)
ORIGAMI	Reduced Energy Consumption	Use of a dynamic, automated, AI-driven optimization of the usage of RAN resources		Use of Compute- and Fairness-Aware Radio Resource Allocation Algorithms	To be identified	25% lower signaling overhead compared to network core without SCP. The KVI is related to KPI on Control-plane efficiency (%)
6GXR	Reduce travel and associated emissions.	Holographic meeting instead of travel, smartphones. In-cloud processing for reducing overall energy consumption Live validations digitally signed by digital video processing	Real-Time Holographic Communications (UC1, UC2, UC3)			
DESIRE6G	Increased area of protected and surveyed natural habitats and climate preserves	The AR/VR demo UC of the project could be extended to rescue operations	Linked to the AR/VR UC of the project, but the KVI evaluation is not directly achieved by the project UC demo implementation	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	Not identified so far	Not identified so far

DETERMINISTIC6G	Number of exhausted batteries	6G network would enable the feasibility of occupational exoskeletons with offloaded control. This would in turn enable the delocalization of part of the exoskeleton's hardware, which would lead to a reduction in the exoskeleton's power consumption.	Exoskeleton in industrial context	1. Network coverage in the entire relevant environment 2. Network capabilities enabling exoskeleton's offloaded control	Theoretical KVI: No validation within project	Theoretical KVI: No defined target value within project The KVI is related to KPI on Percentage reduction of power consumption (with respect to "standard" exoskeleton use case, i.e. exoskeleton with onboard controller)
6GXR	Measures the reduction of the carbon footprint associated to travels by eliminating the physical meetings within local and global communities, asset logistics and other transportation through the adoption of collaborative DT environments.	VR telepresence and remote control Standardized platform to DT implementation Remote collaboration with enhanced and real time information from 3rd party software Visualization of the information enhancing discussions and decision-making processes	Collaborative 3D DT-like Environment (UC4)			
6GXR	Resources (material, energy, equipment, supply chain, personal, etc.) optimization due to the decentralized location of the people and assets. Then, the optimal allocation of the resources can be selected according to the restrictions in place or organizational decisions.	Decentralization of the knowhow allowing to access global talent Optimization of the energetical resources consumptions Global vision of the complete environment resource consumption	Collaborative 3D DT-like Environment (UC4)			
6GXR	Allowing stakeholders to monitor energy usage patterns promptly and make informed decisions to optimize energy efficiency.	Advanced Metering Infrastructure (AMI) and IoT devices	Energy Measurement Framework for Energy Sustainability (UC5)	External energy meter, IoT sensors, Data analytics	Carlo-Gavazzi, energy analyzer, Victron Energy's Venus GX PV hybrid's system controller, Netio PowerBOX 4KF	"Internally 4096samples/s @50Hz,
6GXR	Measures the framework's capability to facilitate sharing of energy data with relevant stakeholders.	Secure data sharing platforms, secure data sharing APIs	Energy Measurement Framework for Energy Sustainability (UC5)	Victron Energy's central controller, MQTT-broker bridge	MQTT broker deployed for data exchange over 5GTN edge server	1sample/s @1Hz
6GXR	Improved energy efficiency by providing accurate and real-time energy measurements and energy balancing as a whole system.	Smart metering and intelligent control and monitoring system using Message Queuing Telemetry Transport (MQTT)	Energy Measurement Framework for Energy Sustainability (UC5)	Victron Energy's central controller, MQTT-broker bridge	In addition to distributed monitoring MQTT solution enable sending control commands to system controllers. For example,	1sample/s @1Hz

					VENUS-GX can be controlled by means of MQTT-commands.	
6GXR	The electricity prices to calculate the cost of operating the system.	Renewable energy sources, such as solar or wind, reducing the reliance on expensive fossil fuels and decreasing monthly energy bills for consumers	Energy Measurement Framework for Energy Sustainability (UC5)	ELSPOT hourly day-ahead electricity market prices in Finland	ELSPOT APIs from power retailers services or Nordpool and other market exchange platforms. Needed to calculate cost/savings related KPI	Available during the previous day at 14:00 to next day's hours
6GXR	It quantifies the level of precision achieved in measuring E2E energy measurement framework, expressed as a percentage of accuracy.	Root Mean Squared Error (RMSE) and Mean Squared Error (MSE) are commonly used metrics to quantify the accuracy of measurement models ML/DL algorithms can minimize these error metrics, ensuring higher accuracy in energy measurements within the E2E framework	Energy Measurement Framework for Energy Sustainability (UC5)	Energy weather forecast	"Areal data from FMI's open data service to be applied to generate	Energy weather forecast
6GXR	Assesses the reduction in greenhouse gas emissions achieved through the use case, promoting a more sustainable and environmentally friendly energy system.	The amount of carbon dioxide (CO_2) emissions produced because of energy consumption based on indirect emissions estimates from TSO	Energy Measurement Framework for Energy Sustainability (UC5)	Fingrid's estimate for gCO_2 for consumed kWh	To be used to generate cumulative emission counter for power intake (from the grid) as an avoided CO_2 KPI.	Original data 1/3 min, to be processed to match system boundary meter readings
6G-SENSES	KVI 1: Optimisation of EMF for given coverage. KVI 2: Optimisation of Energy Footprint for given services	Stakeholder: Providers & Users Effect on: State of Being KVI 1 description: Low EMF. KV2 description: Lower Energy Consumption	UC #1 – Storyline #1: Exploiting sensing information to improve communication services, &, UC#1 - Storyline #2: Enabling Active Sensing with Wi-Fi system and Wi-Fi sensing standardization design.	ISAC enabling coverage optimisation and energy minimisation at RAN	Validation via measurement of Energy Consumption of technology elements	Not identified so far, related KPIs are the following: KPI 1: Energy Consumption and KPI2: EMF exposure
6G-SENSES	KVI 1: Optimisation of Energy Footprint for given services	Stakeholder: Providers & Users Effect on: State of Being KV1 description: Lower Energy Consumption. KV2 description: Lower Energy Resources utilisation	UC #3: Network DT - Storyline #2- EE	AI/ML and sensing plane, combined with O-RAN enabling Energy Efficient coverage optimisation	Validation via measurement of Energy Efficient network planning enabled by 6G-SENSES technology solution	Not identified so far, related KPIs are the following: KPI1: Coverage and KPI2: Energy Consumption
FIDAL	To reduce footprint on energy, resources, and emissions. Improve	Improved device/App/Service energy efficiency.	All Use Cases	"Objective Measure for Assessment:	field trial results that show minimal change from the lab trials.	"Objective Measure for Assessment:

	sustainability in other parts of society and industry.			Energy consumption and efficiency for same task, per person in use case activity. Comparison Lab Trial vs Field Trial.	Related KPIs: Measure on Resource Utilization (MRU); Energy saving; average Throughput Data rate HMD/edge; E2E Latency; User Connectivity; Average Throughput and Data rate HMD/edge	Energy consumption and efficiency for same task, per person in use case activity. Comparison Lab Trial vs Field Trial.
FIDAL	Increases lifespan of products and services	Keeping technology and related services in action longer reduces e-waste and resources mined. Improved durability of technology or service via ability to refurbish, repair, and upgrade in ways that are acceptable to users/consumers.	UC1: Internet of Senses / Haptic sensing, UC2: Digital Twin for first responders, UC3: City security event/incident.	"Key components (e.g. RAM) and features (security) are able to be replaced and upgraded. Users find acceptable cost and process of replacements and upgrades. Preparation of materials that support training those who could do maintenance along with ability to provide access as needed to key components that could need such maintenance. "	"Suggested Objective Measure for Assessment Demonstrated ability to refurbish, repair, and/or upgrade without requiring new devices or infrastructure. Suggested Subjective Measure for Assessment Stakeholders are able to have the expertise and training necessary to conduct the maintenance activities."	Increased over current average of similar
FIDAL	Greater understanding of environmental challenges	The ability to better understand the environmental footprints being produced by the innovation. Increased number of environmental factors monitored for.	UC6a: AR for improving Law Enforcement Agents (LEA) situational awareness, UC7: Smart village engagement services	Inclusion of additional environmental impact monitoring techniques that previously did not exist.	"Suggested Objective Measure for Assessment/Enabler: List of the number and variety of new data points related to environmental monitoring made available for analysis."	increase over currently monitored for by the tools and services involved in the use case
ENVELOPE	Resource Usage Optimization	Efficiency in resource allocation in cloud and edge computing environments to minimize idle processing power and unnecessary storage. Measurement unit: resource utilization percentage or efficiency rate	IT-UC1: Advanced In-Service Reporting for Automated Driving Vehicles IT-UC2: Dynamic Collaborative Mapping for Automated Driving	Dynamic management and orchestration of network and computing resources	Measurements in trials/experiments/simulations	Less energy consumption than baseline

ENVELOPE	Waste Reduction	The amount of electronic waste generated due to hardware upgrades or obsolescence by the ENVELOPE use case compared to baseline. A reduction in hardware devices required by the ENVELOPE use case compared to baseline (for instance having a more efficient architecture with less hardware nodes) would mean a reduction in hardware waste	Dt-UC3: Periodic vehicle data collection for improving digital twin	More efficient/lightweight architecture with less HW on the vehicle and with more software functionalities in the cloud, in line with the software defined vehicle concept.	Assessment by expert.	Less waste than baseline.
ENVELOPE	Carbon Footprint Reduction	The total CO_2 emissions generated by the operation of the ENVELOPE use case compared with state of the art or baseline	Dt-UC4: Vehicle testing with mixed reality	Tests and validation of new features and functionalities in the virtual environment. Reduction of the testing time on the test track as well as in the real world.	Measurements in trials/experiments/simulations	Less footprint than baseline.
ENVELOPE	Energy Consumption	The amount of energy consumed (kWh) by the ENVELOPE use case compared with the baseline.	Dt-UC5: Tele-operated driving aided by DT	Safe teleoperation of the automated driving systems could reduce the deployment of safety drivers in case of emergency situations.	Measurements in trials/experiments/simulations.	Less energy consumption than baseline.
ENVELOPE	Travel Time Emissions	Assesses the reduction of average travel time spent by citizens. Rerouting with more optimal paths can be achieved due to the information sharing	Gr-UC6: CCAM use case	Highly available and resilient service.	Assessment by expert.	Less average travel time due to reduction of waiting times in traffic lights.
ECO-eNET	Optimisation of Energy Footprint for given services	Stakeholders addressed: Providers & Users. Low Energy Consumption/ Low Energy Resources utilization	Energy and Latency AI-optimised confluent mesh	AI/ML and transport network sensing along with O-RAN enabling energy efficient network operation.	Measurements in trials/experiments/simulations.	Less energy consumption than baseline.
6G-EWOC	Environmental footprint of urban transport of persons and goods	Precise positioning / localization	Photonics for connected mobility	Crowdsourced Simultaneous Localization and Mapping (SLAM) data fusion for safe and efficient Advanced Driver Assistance Systems (ADAS) driving	Measurements in trials/experiments/simulations.	Range precision better than 0.5 m and accuracy better than 60%. Incremental reconstruction of scenes from multiple ego-poses and discrimination of dynamic elements with range precision better than 0.5 m and ACC, better than 60%.

6G-EWOC	Energy efficiency improvements	Provisioning of traffic flows achieving 50% reduction of the energy consumption	Photonics for connected mobility	AI-assisted network management and orchestration of packet optical infrastructure	Measurements in trials/experiments/simulations.	50% reduction of the energy consumption Provisioning of traffic flows achieving 50% reduction of the energy consumption

4.2 KV #2 – Societal Sustainability

The 6G projects have defined social sustainability in various unique aspects including the wellbeing, inclusivity, efficiency, ethical responsibility, and many other dimensions which ensures the delivery of social benefit through technological advancements. Table 3 below is a summary of societal sustainability related KVIs across several 6G-related projects, evaluating their technological impact, validation methods, and expected performance outcomes. The analysis of societal KVIs across multiple 6G projects highlights the broad scope of social sustainability including the following main KVIs.

- Social Inclusivity
- Improved health and well-being
- Workplace safety and diversity
- Improved accessibility
- Bridging digital divide

According to the UN, sustainability is inherently societal, defined as "people-centred, gender-sensitive, based on human rights, with a particular focus on the poorest, most vulnerable, and those furthest behind" [11]. Societal sustainability is rooted in the principle of no person or place left behind, as highlighted in the European Green Deal. This concept is closely tied to values such as justice, improved quality of life, equity, affordability, accessibility, and inclusion—key factors in closing the digital divide, building solidarity, and fostering long-term societal resilience. The EU strategy on 6G also emphasizes safety considerations, such as privacy and protection from external threats.

Although treated separately within this document, societal sustainability often encompasses elements like trust, safety, digital inclusivity, personal freedom, and cultural connection. These factors ensure that technological advancements, such as 6G, contribute positively to social resilience.

According to the 6GXR project, a strong emphasis is placed on inclusivity by ensuring equal opportunities for accessing holographic communication and aims to foster a more democratic and accessible digital environment. Further, 6GXR also enhances remote collaboration by creating immersive digital twin environments that enable teamwork across different locations. This approach reduces regional disparities and strengthens workforce productivity, particularly in rural and underserved areas. Ethical responsibility is another social KVI focus, as the project introduces mechanisms within its digital twin environments to ensure compliance with corporate, social, and governmental ethical guidelines.

The project, CENTRIC addresses health and environmental sustainability by optimizing network infrastructure to minimize electromagnetic field (EMF) exposure. By deploying AI-driven clustering of cell-free access points, the project reduces unnecessary radiation while maintaining network efficiency. This KVI ensures public health by mitigating concerns about prolonged EMF exposure in urban and residential areas. DESIRE6G is another main 6G project focuses on improving emergency response and operational efficiency as social KVIs, particularly in critical missions. By leveraging AR/VR applications, the project explores the potential for faster detection, localization, and management of emergencies. The technology enhances situational awareness and decision-making, although its evaluation remains largely theoretical rather than directly validated within the project's use cases.

DETERMINISTIC6G project has a strong emphasis on workplace safety and diversity. By integrating occupational exoskeletons with network-connected sensors, the project aims to reduce the physical strain on workers and lower the occurrence of work-related injuries. This approach not only enhances worker well-being but also improves job accessibility for individuals with physical limitations. Additionally, by incorporating extended reality tools for remote support, the project creates opportunities for less experienced workers and individuals with disabilities to participate more actively in industrial environments.

Based on Table 3, it can be observed that the validation of these social KVIs vary across projects. The projects including CENTRIC, establish direct links between KVIs and measurable KPIs, such as transmit power and SAR levels while some other projects including DESIRE6G and DETERMINISTIC6G, propose theoretical frameworks without direct validation within the project's scope. While numerical targets are defined in some cases, several projects still lack clear benchmarks or standardized validation methods, making cross-comparison challenging. This variation underscores the need for a unified framework to assess and validate social KVIs consistently across 6G research initiatives. Despite these differences, all projects reflect a shared commitment to developing 6G technologies that contribute to a more inclusive, ethical, and sustainable society.

Table 3: Societal Sustainability Key Value: Definitions, Description and Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
6GXR	Equal opportunities for accessing holographic communication for everyone with a smartphone. A more inclusive and democratic society.	Smartphones, Low-cost XR capture and display gadgets, Software Development Kits (SDKs) for integrating holographic comms in third-party XR products	Real-Time Holographic Communications (UC1, UC2, UC3)	The definition of enablers is in progress	The validation method is in progress	The determination of Target Values is in progress
CENTRIC	EMF aware networks	Smart clustering of cell-free access points will optimize the transmit power needed to achieve a target capacity, while minimizing unnecessary radiation and energy waste	Multi-domain environments and Laboratory PoCs	EMF reduction via AI-enabled cell-free networking	-	The KVI is related to KPIs on transmit power, SAR and data rate
DESIRE6G	Reduced emergency response times due to critical event detection and localization	The AR/VR demo UC of the project could be extended to rescue operations	Linked to the AR/VR UC of the project, but the KVI evaluation is not directly achieved by the project UC demo implementation	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	The validation method is in progress	The determination of Target Values is in progress
DESIRE6G	Increased operational efficiency in critical missions	The AR/VR demo UC of the project could be extended to rescue operations	Linked to the AR/VR UC of the project, but the KVI evaluation is not directly achieved by the project UC demo implementation	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	The validation method is in progress	The determination of Target Values is in progress
DETERMINISTIC6G	Cost of care of work-related injuries	6G network would enable: (i) the feasibility of the integration of a occupational exoskeleton in a network able to connect exoskeletons and a series of environmental, task-related, and user-status sensors; (ii) the offloading of the control algorithms of the exoskeletons. This, in turn, would enable (i) the instant-by-instant optimization of the exoskeleton's assistive strategies mainly in terms of adaptation to user and context needs, and (ii) the delocalization of part of the exoskeleton's hardware, which would lead to a reduction in the exoskeleton's weight and	Exoskeleton in industrial context	1. Network coverage in the entire relevant environment 2. Network capabilities enabling exoskeleton's offloaded control 3. Availability of highly detailed digital twin (human+exoskeleton)	Theoretical KVI approach: No validation within project	Theoretical KVI: No defined target value within project. The KVI is related to KPIs on Percentage reduction of weight and encumbrance (with respect to "standard" exoskeleton use

		encumbrance, in its power consumption and, thus, in its cost. Therefore, the acceptability and the spread of occupational exoskeletons would be boosted, and thus, exoskeletons capable of reducing the physical load of workers performing demanding activities, they have the potential to reduce the number/severity of work-related injuries, as well as the cost to treat them.				case, i.e. exoskeleton with onboard controller), number of sold exoskeletons/number of companies adopting exoskeletons
DETERMINISTIC6G	Diversity among factory personnel	Remote support and overlay in Extended Reality (XR) device may allow for less skilled workers or workers with disabilities to perform tasks on the factory floor.	Extended Reality in industrial context	Dependable mobile communication between XR devices and production system	Theoretical KVI: No validation within project	Theoretical KVI: No defined target value within project
6GXR	Remote collaboration enhances societal and team productivity/efficiency. Real collaboration around of a common asset, machine, manufacturing place or environment is enabled thanks to a collaborative 3D DT environment. Key outcome is extracted due to the capabilities of bridge regional disparities and provide equal opportunities regardless of the geographical location. Traditional example of gaps covered is the disparity between industrial and rural locations.	Digital presence Rural and industrial equality Telepresence	Collaborative 3D DT-like Environment (UC4)	The definition of enablers is in progress	The validation method is in progress	The determination of Target Values is in progress
6GXR	Measures productivity and efficiency in remote teamwork. Reduction of regional disparities of rural area.	VR telepresence and remote control	Collaborative 3D DT-like Environment (UC4)	The definition of enablers is in progress	The validation method is in progress	The determination of Target Values is in progress
6GXR	Ensure the adherence to ethical practices in place in both manufacturing and sociological practices. Having a 3D DT environment helps in the guidance and implementation of corporative, social, or governmental ethical guidelines.	Proof of ethical compliance and channel to introduce potential ethical limitations Register potential deviations of the ethical politics and ensure corrective actions Modules and SDKs to enable ethical assurance standardized	Collaborative 3D DT-like Environment (UC4)	The definition of enablers is in progress	The validation method is in progress	The determination of Target Values is in progress

ENVELOPE	Less Stressful Mobility	Assesses the decrease in stress levels of citizens when using ENVELOPE mobility solutions compared to baseline	Dt-UC3: Periodic vehicle data collection for improving digital twin	Autonomous vehicles (AVs) can decrease stress levels as users do not need to drive and can relax during travel	Assessment by expert	"Less stress than baseline, since the vehicle operation is remotely monitored
ENVELOPE	Trust In CCAM	Evaluates the level of public trust and willingness to adopt CCAM technologies	Dt-UC4: Vehicle testing with mixed reality Dt-UC5: Tele-operated driving aided by DT Gr-UC6: CCAM use case	"1) Innovative features that increase system reliability and performance by using advanced and efficient testing methodologies like mixed-reality testing, applicable for CCAM, ADAS, and AV, 2) Advanced remote monitoring, predictive maintenance and safe teleoperation are innovative features that increase system reliability, and user trust in CCAM, 3) Quality on Demand, Traffic Influence, service continuity in cross-domains"	1) Assessment by expert 2) Assessment by expert 3) Questionnaires, interviews or focus groups	"1) A more efficient and safer approach to testing the CCAM, ADAS, and AV system, which leads to a certifiable system and higher user trust in the new technology, 2) More trust than baseline, 3) Successful pilot demonstration, positive feedback in the majority of questionnaire responses"
ENVELOPE	Increase Users	More users can be served with the ENVELOPE use case compared with the baseline: Gr-UC6 achieves accurate local situation awareness and provides traffic information notifications to a wide range of users. The current baseline is zero	Gr-UC6: CCAM use case	Ubiquitous and resilient 5G service, network slicing for network KPIs assurance	Questionnaires, interviews or focus groups	Successful pilot demonstration, positive feedback in the majority of questionnaire responses

4.3 KV #3 – Economical Sustainability & Innovation

This section of the paper discusses a summary of economical sustainability and innovation KVIs across several 6G-related projects, evaluating their technological impact, validation methods, and expected performance outcomes. Economic sustainability in the context of 6G practice is often understood in terms of cost efficiency, affordability, and market growth. However, it extends beyond these metrics to include the broader economic impact of digital infrastructure on empowering people, businesses and administrations. This includes job creation, decent work, business opportunities, supply chain diversity, increased skills, economic well-being, and technological advancements that support new ways to fulfil ambitions. A key debate surrounding economic sustainability in 6G is whether the focus should be solely on industry competitiveness and cost savings, or if it should also prioritize fostering sustainable, circular economies. The latter would aim to distribute benefits more equitably across societies and stimulate growth in areas outside of 6G through its use.

Based on the summary of Table 4 below, the economic and innovation KVIs identified by different 6G projects primarily focus on cost efficiency, operational improvements, revenue growth, and technological advancements that drive productivity and sustainability. The projects address various aspects of economic impact, such as reductions in operational and capital expenditures, increased efficiency, and enhanced revenue opportunities. The findings reveal that while some projects have numerically defined targets for their KVIs, others remain in the process of defining them or rely on qualitative assessments.

For cost-related KVIs, 6GPATH emphasizes operational cost savings in agriculture and healthcare verticals, with enablers such as automation technologies, IoT sensors, and predictive analytics tools. It defines target values in terms of percentage reductions in operational costs and resource utilization. Similarly, CENTRIC focuses on cost reductions through AI-driven optimization techniques, such as in-context learning and AIML-based CSI compression, but without predefined numerical targets. ORIGAMI and 6GXR also contribute to cost savings, particularly in network infrastructure and travel expenses, though there is a difference in impact measuring methodologies.

Most of the projects address productivity and efficiency KVIs through various technical enablers. 6GPATH highlights real-time monitoring, predictive analytics, and automated field operations to enhance agricultural productivity, with targets such as percentage increases in yield and resource efficiency. DESIRE6G explores increased industrial productivity through xURLLC services, but its validation remains theoretical. 6GXR focuses on digital twin environments to improve collaboration and industrial processes, demonstrating potential economic benefits without defining specific measurement targets.

Revenue growth and economic development KVIs are primarily addressed by 6GPATH and PREDICT6G. The former links revenue growth to improved product quality and new business opportunities, while the latter considers the economic impact of transitioning to 6G. However, numerical targets for revenue-related KVIs are generally lacking across projects.

A significant difference between projects lies in the level of standardization and validation methodologies. While some projects establish clear KPIs linked to KVIs, others remain in the early stages of defining their validation methods. Additionally, cross-project alignment on economic KVIs is limited, as different projects prioritize distinct use cases, making direct comparisons challenging. Standardized methodologies and common benchmarking approaches would enhance consistency and enable more comprehensive evaluations of 6G's economic impact.

Table 4: Economic Sustainability Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
6GPATH	Increased cost savings in agricultural activities	How do advanced features of 6G save operational costs in agricultural activities through efficient crop management practices (ex, water saving/pesticide saving)?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	Automation technologies, IoT sensors, predictive maintenance tools	Survey after field trials/ Qualitative Methodology	% decrease in operational costs (target >10%)
6GPATH	Operational cost savings	How does the 6G-facilitated 3D hydrogel patch service contribute to reducing transportation costs for patients and healthcare systems, hospital admission costs, the overall cost of medical equipment and maintenance?	UC-HEALTH - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	"Number of kilometres driven and hospitalisation days
6GPATH	Time savings	How does the 6G facilitate 3D hydrogel patches service contribute to saving cost	UC-HEALTH - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	Comparison of time-related metrics[3]
6GPATH	Increased profits	How do advanced features of 6G contribute to increasing the profits from agriculture through efficient crop management practices (ex, water saving/pesticide saving)?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	AI-driven decision-making tools, real-time data analytics, yield prediction systems	Survey after field trials/ Qualitative Methodology	% increase in profits (target >10%)
6GPATH	Increased productivity in agricultural activities	How do advanced features of 6G increase the agriculture production/yield and quality resulting from timely interventions based on real-time data monitoring?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	Real-time monitoring and tracking, predictive analytics, automated field operations	Survey after field trials/ Qualitative Methodology	% increase in productivity (target >10%)
6GPATH	Increased operational efficiency in agricultural activities	How do advanced features of 6G help to increase operational efficiency through automation and real-time monitoring to streamline the farming process?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	Real-time monitoring and tracking, predictive analytics, automated field operations	Survey after field trials/ Qualitative Methodology	% increase in productivity (target >10%)
6GPATH	Resource Utilization Optimization	How do advanced features of 6G contribute to optimal resource utilization by reducing water consumption through precise irrigation scheduling	UC-Farming– Water Saving	Precision irrigation systems, AI-based resource management platforms	Survey after field trials/ Qualitative Methodology	% increase in resource efficiency (target >10%)

[3] a) time for patients to travel and wait for the wound expert compared to employing the system, b) time of hospitalisation, especially when the complications are not detected at the right time. c) if we compare a situation when the connectivity quality is low and it takes 10 minutes to get the model sent to the headquarters, the solution also saves time due to the employment of 6G connectivity d) compare time to compute and accurate estimation of the wound characteristics. Compare minutes for applying the state-of-the-art patch to bioprinting the hydrogel patch

		enabled by real-time soil moisture monitoring, and decreasing fertilizer usage due to targeted application based on accurate soil nutrient data, reducing waste and costs?	UC-Farming – Smart Vineyards	In progress of definition of enablers		
		How does the 6G facilitated 3D hydrogel patches service contribute to the efficient use of medical staff and equipment through remote monitoring and consultations?	UC-HEALTH - 3D hydrogel patches		Survey after field trials/ Qualitative Methodology	compare: time for doctors to check a patient, allocated days of hospitalisation, hours of driving for the medical service transportation of the patient
6GPATH	Revenue Growth	How do advanced features of 6G contribute to increasing the revenue through market expansion (due to enhanced product quality), premium pricing (through improved quality of wine) and the creation of new revenue opportunities (through value-added services such as agritourism, eco-certifications, or data-driven advisory services)?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	Market expansion strategies enabled by 6G, premium pricing models, digital marketing tools	Survey after field trials/ Qualitative Methodology	% increase in revenue from new opportunities (target >10%)
6GPATH	Operational Efficiency	How does the 6G facilitated 3D hydrogel patches service contribute to operational efficiency through streamlined operations, reducing the time and resources needed per patient?	UC-HEALTH - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	compare time that personnel (ambulance car driver, doctor, sister) allocates per patient in both systems (state of the art centralised and 6G-path decentralised).
6GPATH	Economic Development	How does the 6G facilitated 3D hydrogel patches service contribute to enhancing the economic stability of remote areas by providing essential services locally?	UC-HEALTH - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	"a) number of sick days for the patient (objective KVI)
CENTRIC	OPEX reductions	In-context learning is a data-efficient, "universal", form of meta-learning that does not require explicit optimization, e.g., gradient descent, at run time. Via in-context learning, the network can quickly adapt to changing conditions, reducing sample and computational complexity.	Multi-domain environments and Laboratory PoCs	In-context learning	In progress of definition of the target values	The KVI is related to KPIs on Reduction in # of pilots and computational complexity
CENTRIC	CAPEX reductions	CSI compression will result in reduced bandwidth requirement for CSI feedback translating to minimized need for spectrum licenses.	Multi-domain environments and Laboratory PoCs	AIML-enabled CSI compression	In progress of definition of the target values	The KVI is related to KPIs on Spectral efficiency

CENTRIC	CAPEX reductions	AIML based MIMO precoding will enhance spectral efficiency translating to reduction in capital investments for acquiring more spectrum.	Multi-domain environments and Laboratory PoCs	AIML based MIMO precoding	In progress of definition of the target values	The KVI is related to KPIs on Spectral efficiency
CENTRIC	CAPEX reductions	JSAC will reduce the need for separate networks and devices to perform communication and sensing tasks translating to CAPEX reductions via elimination of the investment required to deploy and maintain separate communication and sensing systems	Multi-domain environments and Laboratory PoCs	Joint sensing and communication	In progress of definition of the target values	The KVI is related to KPIs on Spectral efficiency
CENTRIC	CAPEX reductions	the developed neural receiver will improve the system's spectral efficiency, translating to reduction in capital investments for acquiring more spectrum	Multi-domain environments and Laboratory PoCs	Multi-user MIMO Neural Receiver	In progress of definition of the target values	The KVI is related to KPIs on Block error rate
CENTRIC	CAPEX reductions	AIML optimised beam management will lead to improved coverage in specific areas translating to a reduction in the need for additional gNBs or infrastructure to cover the same area.	Multi-domain environments and Laboratory PoCs	AIML aided Beam management	In progress of definition of the target values	The KVI is related to KPIs on Spectral efficiency
CENTRIC	OPEX reductions	DCI compression will increase network capacity and help the network serve more users in the same bandwidth. Operating margins will thus grow	Multi-domain environments and Laboratory PoCs	DCI compression	In progress of definition of the target values	The KVI is related to KPIs on PDCCH coding rate
CENTRIC	CAPEX reductions	The ability to automatically produce protocols to solve a concrete use-case will reduce development efforts significantly.	Multi-domain environments and Laboratory PoCs	Emerging multiple-access protocols for specialized services	In progress of definition of the target values	The KVI is related to KPIs on Protocol performance (e.g., task success rate).
ORIGAMI	Reduced CAPEX	Compute-aware virtualized RAN solutions that can build reliable RAN systems that improve cost and energy-efficiency	PoC of inter-MNO handover, with results aligned with the CAMARA Project	RAN components deployed as a containerized network function (CNF)	In progress of definition of identifying methodology	**10x higher than today's vRANs** and 50% reduction. The KVI is related to KPIs on Cost efficiency (bps-per-$) and Network CAPEX ($) respectively
ORIGAMI	Cost efficiency	A system that discovers and monitors available resources from different providers can select the most cost efficient and higher performance components maintained by each provider.	PoC demonstrating an AI-aided NI solution that exploits ORIGAMI's CCL to improve cost-efficiency	Utilization of radio resource quota optimization solutions for multi-MNO configuration	In progress of definition of identifying methodology	35% less energy consumption and 30% reduction. Network energy consumption (KWh) The KVI is related to KPIs on Network energy

						consumption (KWh) and OPEX gains ($) respectively 25% lower signaling overhead compared to network core without SCP. The KVI is related to KPIs on Control-plane efficiency (%)
ORIGAMI	Reduced OPEX			Enabling efficient user-plane inference	In progress of definition of identifying methodology	
PREDICT6G	Business Value	Business impact and migration guidelines towards 6G scenarios	Smart Factory Multi-Domain Non-Deterministic Devices	TSN Networks// Non-Public Networks // Multi-Domain solutions	The validation method is in progress	The determination of Target Values is in progress
PREDICT6G	Economic Growth	Business impact and migration guidelines towards 6G scenarios	Smart Factory Multi-Domain Non-Deterministic Devices	TSN Networks// Non-Public Networks // Multi-Domain solutions	The validation method is in progress	The determination of Target Values is in progress
DESIRE6G	Increased use of robots in industrial activities	The Robotic Digital Twin UC and the Robot Control UC highlight the potential increase in the use of robots if xURLLC services are supported	Linked to the Robotic Digital Twin demo UC and Robot Control PoC, but the KVI evaluation is not directly achieved by the project UC implementations	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	The validation method is in progress	The determination of Target Values is in progress
DESIRE6G	Increased productivity in factory work	The Robotic Digital Twin UC and the Robot Control UC highlight the potential increase in the use of robots if xURLLC services are supported	Linked to the Robotic Digital Twin demo UC and Robot Control PoC, but the KVI evaluation is not directly achieved by the project UC implementations	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	The validation method is in progress	The determination of Target Values is in progress

6GXR[4]	Cost savings associated to travel expenses, accommodation, logistics, time improvement, and other associated cost sources.	Centralized team measuring the cost savings associated to the use of holographic communications	Real-Time Holographic Communications (UC1, UC2, UC3)			
6GXR	Other industrial improvements associated to the implementation of holographic communications as several industrial gaps could be covered. Remote Collaboration, supply chain optimization, remote inspections, cross functional collaboration, real time interactions and collaboration are examples of gaps covered.	Standardized assets with industrial scalability and application Potential to commercialize assets	Real-Time Holographic Communications (UC1, UC2, UC3)			
6GXR	Economical improvements associated to the production and productivity efficiency through the adoption of DT environment. Partially enabled by the ability to differentiate and	VR telepresence productivity, accessibility Part customization Product previsualization Improve try and error processes Speed up testing phases Telepresence Productivity	Collaborative 3D DT-like Environment (UC4)			

[4] 6G-XR project has not defined the validation method and target values for the KV3 Economical Sustainability & Innovation, by the time of the final editing of the present paper.

	customize the production, leading to increase economic sustainability and innovation within the processes.	Accessibility				
6G-SENSES	KVI 1: Reduction of Total Cost of Ownership for service provisioning	Stakeholder: Providers & Users Effect on: State of Being KV1 description: Economically efficient solution. KV2 description: Economically efficient service provisioning to end users	UC #3: Network DT - Storyline #1- Network Optimisation	AI/ML and sensing plane, combined with O-RAN enabling coverage optimisation and cost minimisation	Technoeconomic Study as part of 6G-SENSES solution evaluation	Not identified so far, related KPI is the following: KPI 1: Cost (CAPEX/OPEX/ TCO)
FIDAL	People's access and the potential spread of impact without requiring new infrastructure or devices.	Seamless compatibility for evolution to new capabilities.	UC2: Digital Twin for first responders, UC3:City security event/incident, UC4: Advanced sports area media services, UC5: Virtual Reality Networked music performance, UC7: Smart village engagement services	In progress of definition of enablers	% of relevant existing devices owned by stakeholders in general (inclusive of 5G compatible) related to use case scenario that are interoperable with the UC. % of current networks in Europe that offer service necessary for UC. % of Europe that have consistent availability of service necessary for UC."	Target to high percentage (%)
FIDAL	Ability to support additional functionality and content.	6G systems need to be set up in ways that support the entry of new players, with new functionality and content that they can control, in order to maintain healthy local economies and ensure the new market players are able to enter. This also means support users to maintain control of what they do on these systems.	UC4: Advanced sports area media services, UC7: Smart village engagement services	In progress of definition of enablers	Quantitative survey of stakeholders that asks if it fits to their (as customer) application and processing needs in ways that are functional for their activities.	high % of stakeholders see needed flexibility in system.
ENVELOPE	Operational Cost Savings	Assesses the savings in vehicle operation and maintenance due to optimized routes, reduced idling, and real-time information sharing.	It-UC1: Advanced In-Service Reporting for Automated Driving Vehicles It-UC2: Dynamic Collaborative Mapping for Automated Driving	1) Vertical service for Advanced In-Service Reporting for Automated Driving Vehicles. 2) Vertical service for Dynamic Collaborative Mapping for Automated Driving. 3) Zero-touch	Assessment by expert.	Operational costs less than baseline.

			Gr-UC6: CCAM use case	automation, Predictive QoS.		
ENVELOPE	CapEx Reduction	Cost reduction in acquiring, upgrading, and maintaining physical assets in comparison to baseline.	It-UC2: Dynamic Collaborative Mapping for Automated Driving	Vertical service for Dynamic Collaborative Mapping for Automated Driving.	Assessment by expert.	CapEx costs less than baseline.
ENVELOPE	Time To Market Reduction	Tracks the time taken to develop and launch new solutions or technologies.	Dt-UC3: Periodic vehicle data collection for improving digital twin Dt-UC4: Vehicle testing with mixed reality	1) Monitoring and diagnostics software running in the cloud, much easier to update and maintain compared with the baseline situation, running on ECU, installed in the vehicle. 2) Virtualization of the tests, which reduces the resources needed during test track and real-world testing.	Assessment by expert.	1) Efficient and more economical software update related to advanced diagnostic features. 2) Reduction with 20% of test track and real-world testing, by test virtualization
ENVELOPE	OpEx Reduction	Cost reduction for running the ENVELOPE system/service in comparison to baseline. These are the day-to-day expenses required to keep the business operational.	Dt-UC5: Tele-operated driving aided by DT	Implementing advanced remote monitoring, predictive maintenance using IoT sensors and analytics can prevent costly downtime and repairs.	Assessment by expert.	OpEx costs less than baseline.
ENVELOPE	Increase Productivity	Measures the improvement in productivity due to automation and optimization compared to baseline.	Gr-UC6: CCAM use case	Zero-touch automation, Predictive QoS	Assessment by expert.	Less time spent by fleet supervisors for each vehicle compared to baseline
ECO-eNET	Reduction of TCO for service provisioning	Economically efficient solution provided to network operators. Economically efficient service provisioning to end users/ other actors	UC#3: CF/D-MIMO structures enabling Immersive Communication and HRLLC Usage Scenarios.	CF/D-MIMO structures, AI/ML -optimised network management	Assessment by technoeconomic studies.	CAPEX/OPEX costs less than baseline.

			UC#4: Energy and Latency AI-optimised confluent mesh.			

4.4 KV #4 – Democracy

Democracy raises complex issues in 6G. Democracy in the digital age requires equitable access to information, protection against misinformation, transparency in processes, and mechanisms that ensure citizen participation in decision-making. In addition, the evolution of 6G technologies raises concerns about digital governance and media concentration. Strong regulatory frameworks and public engagement are necessary to ensure that emerging technologies support democratic principles rather than undermining them. Moreover, as 6G technology becomes integral to national infrastructures, safeguarding sovereignty and strategic autonomy becomes crucial.

Table 5 presents KVIs focused on Democracy, across several 6G-related projects, evaluating their technological impact, validation methods, and expected performance outcomes. Particularly, DESIRE6G explores the support of extended Ultra-Reliable Low-Latency Communications (xURLLC) services using programmable networks and autonomous Multi-Agent Systems. It focuses on increasing the footprint of cloud-rendered gaming services. The KVI evaluation is linked to a PoC use case but is not directly assessed through the project's implementation. Validation methodology and associated target values are currently under investigation.

ORIGAMI emphasizes improved service quality and increased user capacity by developing network intelligence (NI) functionalities and global APIs for service deployment with performance guarantees. It includes AI/ML-driven solutions for novel RAN use cases, ultra-low latency metadata collection, and in-band data processing. The validation methodology for ORIGAMI is currently in progress, whereas several target values have been identified regarding latency and throughput. 6GXR aims to improve accessibility and inclusivity in industrial production environments. The project focuses on VR-based telepresence, remote control, and accessible user interfaces (UI), particularly for individuals with disabilities. A collaborative 3D Digital Twin (DT) environment is used to enhance accessibility and ensure compliance with the European Accessibility Act (EAA) guidelines. As with DESIRE6G, the validation methodology and corresponding target values are currently being examined.

A key distinction between projects is the degree of standardization and validation methodologies. While some projects define target values with KPIs linked to KVIs, others are still in the early stages of developing their validation approaches and respective target values.

Table 5: Democracy Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
DESIRE6G	Increased footprint of gaming services	The Cloud Rendered Gaming UC highlight the potential increase of gaming services	Linked to the Cloud Rendered Gaming PoC UC, but the KVI evaluation is not directly achieved by the project UC implementation	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	The validation method is in progress	The determination of Target Values is in progress
ORIGAMI	More users can be served with improved service quality.	Design and develop NI functionalities and global APIs that enable global deployment of services (e.g., IoT hyperscalers) with multi-domain performance guarantees	Demonstration of AI/ML solutions for novel RAN usages	NI functionalities and global APIs Innovative solutions for ultra-low latency metadata collection, in-band data processing	The validation method is in progress	Sub-ms (RAN), or sub-µs (transport) The KVI is related to KPIs on In-band ML model inference latency (ms/µs)
ORIGAMI			Demonstration of in-band intelligence		The validation method is in progress	100 Gbps. The KVI is related to KPIs on In-band ML model inference throughput (Gbps)
ORIGAMI			A cloud native implementation of the Service Communication Proxy (SCP)	Asynchronous functions, lightweight computational solutions (binarized neural networks) and cutting-edge computing technologies (quantum computing)	The validation method is in progress	50% lower latency than current procedures The KVI is related to KPIs on Control plane latency (ms)
6GXR	Measures fair opportunity as accessibility and user interface for industrial production by the DT participation. People can use the manufacturing facility even from the regions not locating manufacturing. Increasing the inclusivity of the user interface design by means of a collaborative 3D interface. It enhances and standardises the accessibility of different people with a variety of abilities, skills, background, and culture.	VR telepresence and remote control, VR UI, accessibility Digital accessibility supplementing potential limitations of people interacting with the Digital Twin like hand disabilities (i.e., voice interaction) Telepresence in a common digital environment Accessible immersive UI EAA guidelines (https://ec.europa.eu/social/main.jsp?catId=1202)	Collaborative 3D DT-like Environment (UC4)		The validation method is in progress	The determination of Target Values is in progress

4.5 KV #5 – Cultural Connection

Cultural connectivity plays a vital role in the European Union’s identity, reflecting its strength in diversity and the coexistence of various cultural identities, languages, and traditions within its borders. It allows for the exchange and celebration of this diversity, fostering mutual understanding, respect, social cohesion, and solidarity among European communities. With the advent of 6G, cultural connectivity takes on a new dimension, as the technology can lower boundaries for communication and reshape cultural production and consumption patterns. By facilitating deeper engagement with entertainment, art, and each other, 6G can also lead to a globalized digital environment, where maintaining diverse linguistic and cultural identities, content, and opportunities is crucial while also supporting activities that encourage cross-cultural and collaborative exchanges.

Table 6 presents KVIs related to cultural connection in various 6G projects, particularly DESIRE6G and FIDAL. It highlights the impact of advanced networking technologies—such as eXtended Ultra-Reliable Low Latency Communication (xURLLC), programmable networks, and autonomous Multi-Agent Systems—on thematic gaming expansion, assessing their feasibility in real-world use cases. Specifically, DESIRE6G aims to enhance cloud-rendered gaming services by increasing both the diversity and number of thematic gaming experiences. For DESIR6G the validation methodology and corresponding target values are currently under investigation.

FIDAL, focuses on enabling all individuals to maximize the benefits of 5G for active participation in cultural aspects of society. This KVI is evaluated across all use cases, ensuring broad applicability. The relevant technology enablers include all media-related use case technologies addressed by the project. Validation is conducted through subjective assessment methods, primarily surveys and focus groups, gathering feedback from actual and potential users regarding their perceived benefits, access, ability to participate, and expectations for strengthening community systems and maintaining engagement. The assessment also considers demographic factors such as age, gender, and socio-economic status. The target value for this KVI is achieving a high percentage of positive responses from users.

While there are only two KVIs to work from, which is not a rich enough basis from which to draw any conclusions about what should be measured or what makes a good measurement for KVIs under this Key Value, they raise some valuable challenges for KVIs to consider around when a KVI could be measured, e.g., during design, during trials, during demonstrations, or can a KVIs measurement fall beyond the implementation of a project.

Table 6: Cultural Connection Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
DESIRE6G	Increased number of thematic gaming	The Cloud Rendered Gaming UC highlight the potential increase of gaming services	Linked to the Cloud Rendered Gaming PoC UC, but the KVI evaluation is not directly achieved by the project UC implementation	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	The validation method is in progress	The determination of Target Values is in progress
FIDAL	The ability to help all people make the most of 5G to improve their ability to actively participate in cultural elements of society.	People expect they will have access to participate in their communities as enabled by the service.	All Use Cases	All Media UCs technologies involved	Survey/Focus Group with actual and potential users/consumers as to imagined benefits, access, and ability to participate, expectations to strengthen community systems and maintain engagement. Disaggregated by age, gender, socio-economic demographic data	High % of positive responses

4.6 KV #6 – Knowledge

The advancement of 6G is expected to significantly enhance knowledge sharing and collaboration across various sectors. To start, 6G is expected to transform the way data is collected, shared and analysed, facilitating the fusion of diverse knowledge domains, impacting how knowledge is produced, research is conducted, and insights are shared. 6G's capabilities are anticipated to support knowledge-based applications in areas such as healthcare, where timely and accurate information can lead to proactive health management and improved well-being. In addition, 6G has the potential to increase access to knowledge and education. This can include international cooperation and global standards that help establish mechanisms that support open, secure, and resilient 6G technologies. Table 7 presents KVIs from the 6GPATH,6GXR, 6G-SENSES, and ECO-eNET projects, focusing on how 6G technologies can enhance knowledge transfer, accessibility, and digital inclusion across different sectors, including agriculture, healthcare, and education.

6GPATH focuses on increasing 6G adoption in agriculture through knowledge transfer programs in water-saving techniques, validated via field trial surveys measuring number of training programs and participants. In healthcare, it assesses digital leadership, quality of life improvements, and societal upgrades enabled by 6G-driven eHealth solutions, particularly 3D hydrogel patches use case supports remote patient monitoring and reduce the need for travel. These are evaluated using opinionated questionnaires and Likert-scale surveys after field trials.

On the other hand, 6GXR advances holographic communication for education and professional development, enabling real-time participation in lectures, virtual events, and cultural visits. It also explores XR-based training innovations, where holographic simulations (of various disciplines, e.g., Industry and driving simulations) enhance skill acquisition and standardize training. Furthermore, 6GXR emphasizes digital inclusion by ensuring easy-to-use, budget-friendly holographic hardware on a variety of versions to match different society use cases.

In addition, while 6GPATH prioritizes agriculture and healthcare applications with a focus on surveys and participant engagement, 6GXR specializes in immersive education and training, relying on holographic content tracking and usability assessments. Both projects highlight 6G’s transformative potential but differ in their sectoral focus and validation approaches, demonstrating the diverse applications of next-generation connectivity in shaping future industries and communities.

6G-SENSES and ECO-eNET project focus on increasing the availability of educational and cultural products as immersive services. The KVIs include an increase in the number of such products, as well as broader population and coverage access to them. The key stakeholders are users, with an emphasis on remote and live participation in education and economically efficient engagement with educational and cultural content. The project leverages ISAC (Integrated Sensing and Communication), RIS (Reconfigurable Intelligent Surfaces) and Ubiquitous Connectivity technologies to enable immersive experiences with sufficient coverage and performance. Validation is conducted through theoretical studies as part of the project's impact assessment, whereas the KVI target values are bind to KPIs including latency, user data rate, and jitter.

Table 7: Knowledge Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
6GPATH	Increased presence of 6G in agriculture sector	How does the 6G-PATH project ensure knowledge transfer and adoption of advanced irrigation technologies using 6G among local farmers?	UC-Farming– Water Saving	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	# of programs and participants
6GPATH	Digital leadership	How does this service contribute to providing devices for connected home health services?	UC-HEALTH-1 - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials	Opinionated Questions using 5-point Likert Scale
6GPATH	Enhanced Quality of Life	How does this service contribute to improved quality of life for patients by allowing them to maintain a more normal lifestyle with fewer disruptions due to medical appointments?	UC-HEALTH-1 - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials	Opinionated questionnaire
6GPATH	Societal Upgrade	How does this service contribute to better adoption of eHealth services by reducing the need for travelling of chronic patients?	UC-HEALTH-1 - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials	Use nomadic networks which can visit multiple patients in the same day
6GPATH	Increased presence of 6G in agriculture sector	How does the 6G-PATH project ensure knowledge transfer and adoption of advanced irrigation technologies using 6G among local farmers?	UC-FARM-2 – Smart Vineyards	Knowledge transfer programs, training for farmers	Survey during and after field trial	No of programs and participants Number of training programs conducted and participants involved
6GXR[5]	Increased access to live lectures seminars and conferences enabled thanks to holographic communications. Then, real time participation via holographic can foster knowledge sharing and professional/personal development.	Retention of the lectures content via digital recording, training activities, virtual visit to cultural heritage and touristic places, virtual attendance to events Smartphones and virtual attendance to events Access to the knowledge anywhere anytime Database hosting the records of the holographic communications	Real-Time Holographic Communications (UC1, UC2, UC3)	In progress of definition	In progress of definition	In progress of definition

[5] 6G-XR project has not defined the validation method and target values for the KV6 Knowledge, by the time of the final editing of the present paper.

6GXR	Enhancements of the training activities using holograms communications avoiding displacements of trainers at the same time it is closed the personal gap between trainer and trainee. In addition, it is possible to integrate users in realistic and interactive XR scenarios for training in a wide variety of scopes and disciplines (e.g., Industry, driving simulators.	Rapid and effective skills acquisition Knowhow retention within upper organizations Standardization of the pedagogical way to transmit the content SDK which improves the training creation process	Real-Time Holographic Communications (UC1, UC2, UC3)	In progress of definition	In progress of definition	In progress of definition
6GXR	Easiness to use of accessible Hardware (HW), which improves the digital inclusion of the whole society.	Holographic meeting, smartphones Rapid and effective skills acquisition Budget-friendly HW in which holographic communications can be operated Globalization of the compatible HW Easy to use HW A variety of versions to match different society use cases	Real-Time Holographic Communications (UC1, UC2, UC3)	In progress of definition	In progress of definition	In progress of definition
6GXR	Measure the increased participation and involvement of the local community in knowledge sharing and transfer among global communities. Then it is transferred to the collaborative 3D Digital Twin environment. It is boosted thanks to the cross-cultural collaboration, idea exchange, and individual know-how shared.	Utilization rate of the application and usability, and accessibility Cultural exchange Amount of content stored in the environment Type of content consumed Number of ideas generated Category of the people using and consuming the collaborative information and environments	Collaborative 3D DT-like Environment (UC4)	In progress of definition	In progress of definition	In progress of definition
6G-SENSES	KVI 1: I Increase in # of educational/cultural products available as immersive services. KVI 2: Increase in areas (population/coverage) having access to these products KVI 3: Increase in areas (population/coverage) having access to these products	Stakeholder: Users Effect on: Activities KV1 description: Remote/Live Participation in education. KV2 description: Economically efficient participation in education and cultural products	UC #1 – Storyline #1: Exploiting sensing information to improve communication services, &, UC#1 - Storyline #2: Enabling Active Sensing with Wi-Fi system and Wi-Fi sensing standardization design. UC #2: Ubiquitous Connectivity & Immersive Services	*ISAC enabling Immersive services*	Theoretical study as part of project impact assessment	Not identified so far

6G-SENSES	KVI 1/KVI 2: Increase in # of educational/cultural products available as immersive services KVI 3: Increase in areas (population/coverage) having access to these products	Stakeholder: Users Effect on: Activities KV1 description: Remote/Live Participation in education. KV2: Economically efficient participation in education and cultural products	UC #2: Ubiquitous Connectivity & Immersive Services	ISAC and RIS enabling Ubiquitous coverage with sufficient performance for Immersive Services	Theoretical study as part of project impact assessment	Not identified so far
ECO-eNET	Increase in # of educational products (lessons, material, etc.) that are available as immersive services	Remote, high-quality participation in education.	Provisioning of Immersive Communication and HRLLC usage scenarios.	CF/D-MIMO structures, AI/ML network orchestration	Theoretical study of impact.	# educational products (as types) that can be enabled. # of potential participants.

4.7 KV #7 – Privacy & Confidentiality

Privacy and confidentiality are essential digital rights that must be protected as 6G technologies advance. While high-speed connectivity and AI-driven systems enhance services, they also raise risks related to data surveillance, breaches, and exploitation. The growing connectivity blurs the lines between private and public life, as activities once confined to private spaces become public. 6G innovation also has the potential to be constantly collecting data. This opens up new avenues for privacy concerns, especially with the collection of sensitive data like health information.

But access to strong data protection may not be equal—wealthier regions may have stronger safeguards, while poorer areas could face greater vulnerability. As societal attitudes toward privacy evolve, individuals, public authorities, and private companies must weigh the benefits of new technologies against the risks. Thus, data protection and security features, user control over personal data, understanding responsibility in situations of increased surveillance, building awareness of different privacy needs in different contexts and for different populations, transparency in what data is collected and how it is shared across complex ecosystems, and ensure compliance with all laws and relevant guidance.

Only 6 SNS projects out those projects that provided input work on privacy and confidentiality, where the definition of this KVI by SNS projects participated in this questionnaire are varied as:

- Perceived security by users (confirmed by a survey)
- Security/resilience as the ability to adapt and recover from unforeseen situations
- Identification of anomalies and intrusion detection
- Privacy and security in 3D digital twin environments
- Confidentiality of sensitive information and data protection
- Security and privacy issues related to software-defined networking and the use of AI

The main conclusion from the Questionnaires, is that there is a range of different point of views toward this KVI by the projects, which varies from security of infrastructure and network technologies to confidentiality of cyberspace, data and information. Table 8 presents the projects approach towards defining and estimating the Privacy and Confidentiality KV.

Table 8: Privacy & Confidentiality Key Value: Definitions, Description and Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
TrialsNet	Reported confidence in sustainable digital devices, systems, and services used in the use-case development and operation- to be updated	% of the users expressing positive evaluation regarding the sustainability of the devices, net- work, developed applications and services.	UC2 - Proactive Public Infrastructure Assets Management	In progress of definition of enablers	Survey after field trials/	In progress
TrialsNet	Reported perceived security of the digital devices, systems, and services used in the use-case development and operation.	% of the users expressing positive evaluation regarding the secureness of the devices and of the E2E system.	UC2 - Proactive Public Infrastructure Assets Management	Qualitative Methodology	In progress of definition of target value	Qualitative Methodology
PREDICT6G	Security	Security resilience is defined as the ability to adapt and recover from challenging and unforeseen situations.	To be defined	AICP Framework	In progress	In progress
ORIGAMI	Optimized and secure infrastructure	Monitoring resources from different providers to identify anomalies and intrusion detection	PoC of anomaly detection in production-grade systems	Orchestration policies of resources across multiple domains while maintaining service quality guarantees	To be identified	> 0.85 The KVI is related to KPIs on Anomaly detection recall and sensitivity
6GXR	Measure the effectiveness of the privacy and security of 3D DT environments. Key points to check are user data, privacy and confidentiality, and other potential security leaks. Virtual interaction needs to comply with general and industry standards.	VR telepresence avatars, edge cloud, E2E communications SDK to implement masks in communication and video streaming Edge and cloud combination to reduce potential points of attack Encrypted information	Collaborative 3D DT-like Environment (UC4)	In progress of definition of enablers	In progress	In progress
FIDAL	% of collected use case user security concerns that are addressed.	Ensuring that as the complexity of networking increases, the systems, platforms, and apps consider the security needs of the organisations and users who are impacted by these tools.	UC4: Advanced sports area media services, UC7: Smart village engagement services	Existence of security features	Existence of necessary security features (as hypothesized by use case) and Users articulate security concerns are met"	100% matched concerns with technological features.
FIDAL	% of collected use case user privacy concerns that are addressed.	Ensuring that as the complexity of networking increases, the systems, platforms, and apps consider the privacy needs of the users and citizens who are impacted by these tools.	UC5: Virtual Reality Networked music performance, UC7: Smart village engagement services	Existence of security features	Compare this list to the list of privacy technical features in place and focus group of users (or potential users) discussing privacy	100% matched concerns with technological features.

					concerns that emerge as a result of learning about or using the service, if any. "	

4.8 KV #8 – Simplified Life

Simplified life, in a broader sense, is about using technology, innovation, and social systems to make everyday life easier, more accessible, more resource-conscious in ways that supports long-term environmental, social, and economic well-being. This can include making public services more accessible to underserved populations, improving food production and access, improved water management, better transportation systems, or the opportunity for more flexible work environments. It also relates to the physical and emotional consequences of the emotional consequences of living in a constantly connected system. This Key Value is determined as the simplification of the reduction of the world's complexity through technology use while enhancing efficiency, accessibility, and of course, sustainability in daily activities.

As related to the advancements of the 6G networks, it refers to the seamless integration of emerging technologies into daily life for the resolution of society's everyday problems and challenges in ways that make daily living more efficient, seamless, and convenient for individuals and communities. Within this perspective, Simplified Life, actually aims to guarantee that users can interact with advanced networks effortlessly, with minimal cognitive and technical burdens. Within 6G, this could involve leveraging a set of tech catalysts or enablers, such as ubiquitous connectivity, AI-driven automation, and intelligent resource allocation and slicing, to achieve the dual goal for a more sustainable, user-friendly, and flexible digital ecosystem.

In general, some implications and real-world activities that could be considered as core examples for 6G, AI-powered personalized so that agents could adapt connectivity for an optimal experience of the user, zero-touch for IoT devices integration and testing, holographic and immersive communication, closing distance and DIY activities and minimizing of human intervention in smart systems and applications.

From the collection of the feedback by the 6G SNS projects, several definitions and descriptions have been posed and utilised for the measurement of the Simplified Life Key Value. Although each approach and definition are directly linked with the vertical and its evaluation framework. More specifically, Simplified Life concept can be conceptualized as the ways and channels through which the advanced features of 6G manage to save time through efficiency in everyday practice, or the upgrade of the user's satisfaction and quality of the users' experience from the (near) real-time services and the accuracy of using advanced features of 6G without disruptions.

Main Characteristics and Findings from the Questionnaires show that “a Simplified life”, is characterised by time saving for daily activities and efficiency, users' level of satisfaction and easiness of use, accuracy and consistency of data and services supporting decision-making accessibility to real-time data, advanced featured capabilities, overall trustworthiness, security, reliability, speed and stability of the network (6GPath), Perceived easiness, enjoyment and emotional quality of the experience in the venue (TrialsNet), number of additional services (ORIGAMI), family and work-life balance, productivity and enhancement of the people focus on their comfort zone, interaction capabilities, utilization rate of application and usability, accessibility (6G-XR).

As far as the technology enablers are concerned, the projects highlight the user-friendly interfaces, training and support additional services, real-time data accessibility on the platforms, cloud-based solutions, scalable cloud architecture, flexible sensor networks, seamless integration of existing systems with reliable connectivity. It worths mentioning that all projects indicate as a unique method for validation of the KVIs the “Survey after field trials/ Qualitative Methodology” as the only approach, comparing the target values (in the cases where the TV have been defined), in comparison with the corresponsive metrics and KVIs before the 6G testing and implementation. This shows an awareness that the technical measure or enabler is best contextualised within the experience of the stakeholders, where a blend of objective and subjective measures is the strongest approach.

Table 9 presents the projects approach towards defining and estimating the Simplified Life KV.

Table 9: Simplified Life Key Value: Definitions, Description and Verticals, technology enablers, validation method, target value.

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
6GPATH	Increased time savings in agricultural activities	How do advanced features of 6G save time through efficient crop management practices?	UC-Farming– Water Saving UC-Farming – Smart Vineyards	Survey during and after Field Trial	Survey after field trials/ Qualitative Methodology	% decrease compared to current (>10%) The KVI is related to KPIs on time spent on manual tasks
6GPATH	Increased user satisfaction	What is the users' level of satisfaction with the advanced features of 6G in the agriculture process?	UC-FARM-1 – Water Saving	User-friendly interfaces, training and support	Survey after field trials	Level of increase
6GPATH	Increased ease of use	What is the users' level of satisfaction with the ease of using the advanced features of 6G in the agriculture process?	UC-FARM-1 – Water Saving	User-friendly interfaces, training and support	Survey after field trials	Level of increase
6GPATH	Increased network reliability	What is the users' rating on the accuracy of using advanced features of 6G without disruptions in agricultural activities?	UC-FARM-1 – Water Saving	*In progress*	Survey after field trials	Level of increase
6GPATH	Increased data reliability	What is users' rating on the accuracy and consistency of data collected from sensors and drones using advanced features of 6G to support decision-making processes in agriculture?	UC-FARM-1 – Water Saving	*In progress*	Survey after field trials	Level of increase
6GPATH	Increased data accessibility	What is the users' rating on the ease of access to real-time data on hydric states, weather conditions, and crop phenology using advanced features of 6G?	UC-FARM-1 – Water Saving UC-FARM-2 – Smart Vineyards	Real-time data access platforms, cloud-based solutions	Survey after field trials	Level of increase
6GPATH	Increased system scalability	What is the users' rating on the ability of advanced features of 6G to handle increasing volumes of data and expanding sensor networks as the crop cultivation operations grow?	UC-FARM-1 – Water Saving UC-FARM-2 – Smart Vineyards	Scalable cloud architecture, flexible sensor networks	Survey after field trials	Level of increase
6GPATH	Increased trust	What is the users' rating of the overall trustworthiness of 6G advanced features in agricultural activities?	UC-FARM-1 – Water Saving	In progress	Survey after field trials	Level of increase
6GPATH	Reliability and Stability	What are the user experiences regarding the reliability and stability of smart vineyard technologies, including network connectivity and data processing?	UC-FARM-2 – Smart Vineyards	Seamless integration of vineyard systems, reliable connectivity	Survey after field trials	Reliability and stability as reported by users (qualitative)

6GPATH	Adaptability to Conditions	What is the user feedback on the system's adaptability to varying vineyard conditions, such as changes in weather or crop health?	UC-FARM-2 – Smart Vineyards	Seamless integration of vineyard systems, reliable connectivity	Survey after field trials	Reliability and stability as reported by users (qualitative)
6GPATH	Seamless Integration	What is the operator feedback on the integration of different components (Crates, Terraview OS, AAVs, AGVs) with 6G technology and their smooth functioning together?	UC-FARM-2 – Smart Vineyards	Seamless integration of vineyard systems, reliable connectivity	Survey after field trials	Reliability and stability as reported by users (qualitative)
6GPATH	Increased operational efficiency	What is users' feedback on how real-time data and analytics from the smart vineyard system have improved their decision-making processes and, on the speed, and effectiveness of responses to vineyard issues, such as pest infestations or equipment malfunctions, enabled by the smart vineyard system?	UC-FARM-2 – Smart Vineyards	Data analytics tools, real-time decision support systems	Survey after field trials	Feedback on improved decision-making efficiency (qualitative)
6GPATH	Technology Adoption	How does this service contribute to secured and reliable small nomadic networks designed for eHealth?	UC-HEALTH-1 - 3D hydrogel patches	In progress	Survey after field trials	Adhere the need for remote Aδhealthcare services and the desire to learn/extend the business plan of the healthcare institutions can be evaluated.
TrialsNet	Perceived easiness, enjoyment and emotional quality of the experience in the venue	Questionnaires, 5-point likert scale, Partial least squares structural equation model (PLS-SEM)	UC – Entertainment – Immersive fan engagement	low latency, seamless change of positions	Survey after field trials/ Qualitative Methodology	70% of users ex- pressing positive evaluation
TrialsNet	Perceived easiness, enjoyment and emotional quality of the experience at home	Questionnaires, 5-point likert scale, Partial least squares structural equation model (PLS-SEM)	UC – Entertainment – Immersive fan engagement	audio clarity, image resolution, immersive experience,	Survey after field trials/ Qualitative Methodology	70% of users ex- pressing positive evaluation
TrialsNet	Perceived usefulness and ease of use	Questionnaires, 5-point likert scale, Partial least squares structural equation model (PLS-SEM)	UC – Entertainment – Immersive fan engagement	user-friendly device, immersive experience	Survey after field trials/ Qualitative Methodology	In progress of definition of target value
DESIRE6G	Increased options for in-home entertainment	The Cloud Rendered Gaming UC highlight the potential increase of gaming services	Linked to the Cloud Rendered Gaming PoC UC, but the KVI evaluation is not directly achieved by the project UC implementation	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	Not identified so far	Not identified so far

ORIGAMI	Food security and availability	How does using advanced agriculture practices facilitated by 6G improve the contribution to local food security by improving the yield and quality of grapes and ensuring a stable supply for local markets?	UC-FARM-2 – Smart Vineyards	Efficient crop management systems, local food distribution platforms	Survey during and after Field Trial	Opinionated questionnaire
6GXR[6]	Virtual meetings contribute to saving time due to unnecessary travels.	Family and work balance Productivity Enhancement of the people who focus on their comfort zone SDK standardization of the meeting rooms with the necessary interactive material	Real-Time Holographic Communications (UC1, UC2, UC3)			
6GXR	Reduced travel and immersive experience which improve quality of life by saving time and increasing quality of communication.	Holographic meeting and smartphones	Real-Time Holographic Communications (UC1, UC2, UC3)			
6GXR	Reduced travel and immersive experience which improve quality of life by saving time and increasing quality of communication	Utilization rate of the application and usability, and accessibility	Collaborative 3D DT-like Environment (UC4)			
6GXR	Improvement of the communications and effectiveness of the information shared while people's time is saved as no travel is needed.	Utilization rates of the application Time saved while using the application in comparison with travel Reduction of misunderstandings due to the immersion of the solution Common asset as centre of discussion	Collaborative 3D DT-like Environment (UC4)			
6G-SENSES	"KVI 1: Increase in # events available as immersive services KVI 2: Increase in areas	KV1 description: Remote/Live Participation in various events (enabled by Immersive services support)	UC #1 – Storyline #1: Exploiting sensing information to improve communication services, &, UC#1 - Storyline #2: Enabling Active Sensing with Wi-Fi	ISAC enabling Immersive services	Theoretical study as part of project impact assessment	KPI 1: Latency KPI2: User Data Rate & Jitter

[6] 6G-XR project has not defined the validation method and target values for the KV, by the time of the final editing of the present paper.

	(population/coverage) having access to these events"		system and Wi-Fi sensing standardization design.			
6G-SENSES	Quality of Life "KVI 1: Increase in # events available as immersive services.	KV1 description: Remote/Live Participation in various events (enabled by Immersive services support).	UC #2: Ubiquitous Connectivity & Immersive Services	ISAC and RIS enabling Ubiquitous coverage with sufficient performance for Immersive Services	Theoretical study as part of project impact assessment	KPI 1: Latency KPI2: User Data Rate & Jitter
6G-SENSES	Sustainable Cities KVI 2: Increase in areas (population/coverage) having access to these events."	Stakeholder: Industries Effect on: Activities KV1 description: Enablement of Industry 5.0 (enabled by Immersive services support) – Effective Manufacturing. KV2 description: Resource efficient Manufacturing	UC #2: Ubiquitous Connectivity & Immersive Services	ISAC and RIS enabling Ubiquitous coverage with sufficient performance for Immersive Services	Theoretical study as part of project impact assessment	KPI 1: Latency KPI2: User Data Rate & Jitter
FIDAL	Flexible to adapt to new requirements, use contexts, and new use objectives.	Alternative approaches possible for each system configuration.	UC6a: AR for improving Law Enforcement Agents (LEA) situational awareness, UC6b: On-site XR-assisted emergency surgical operations	Scalability of networks to different conditions.	"Suggested Objective Measure for Assessment Ability of use cases (service applications and platforms) to adapt to various network conditions and scales of activity without compromising user's ability to engage. Suggested Subjective Measure for Assessment Ability of users to complete goals across different scales and network loads (e.g. with different number of users or amount of data)."	matched objective and subjective. Related KPIs are the following: Connectivity (users simultaneous connected); Throughput uplink and downlink (multiple cases), Network App deployment and provisioning (multiple cases); Video Resolution
FIDAL	Optimal resource allocation	Ability to Scale System with Need or System functions as needed in different contexts	UC1: Internet of Senses / Haptic sensing, UC2: Digital Twin for first responders, UC3: City security event/incident.	Acceptable response times.	"Suggested Objective Measure for Assessment System response times within acceptable limits in emulated versions of different crisis-related environmental conditions."	within acceptable limits Latency and Reset Times under different stress loads/times
FIDAL	Process components can be reconfigured	the ability to implement and deploy a system in the regions where it can provide the most benefit.	, UC4: Advanced sports area media services, UC5: Virtual Reality Networked music	Existing of modularity in processing chain.	Existence of modularity in the processing chain so there could	Existence of Enabler

	without losing function.		performance, UC7: Smart village engagement services		be add-ons for tethering to any application.	

4.9 KV#9 – Digital Inclusion

Digital inclusivity is the principle that all individuals, regardless of socioeconomic status, geographic location, or personal ability, should have equal access to digital technologies, services, and the benefits they provide. The goal is to ensure that new technologies do not exacerbate, and ideally reduce, existing inequalities. Within 6G initiatives, this principle emphasizes global accessibility, availability, affordability, and the ability to participate in the digital economy, aiming to reduce disparities caused by the digital divide. This includes support for various languages and cultural interactions, addressing digital skills and the evolving nature of work, and promoting innovations that are accessible to all, regardless of gender, age, or background.

Key challenges include ensuring last-mile connectivity, interoperability and bridging the digital divide. However, risks remain that advanced technologies, like 6G, could initially benefit affluent regions, potentially widening the gap between different societal groups unless proactive inclusion policies are put in place. Fostering participation in the digital public space, as outlined in the European Declaration on Digital Rights and Principles, and ensuring everyone has the skills to use technology, as envisioned in the Digital Decade [12], are crucial for achieving true digital inclusivity.

4 SNS projects out of those that participated in the questionnaire deal with Digital Inclusion (Table 10). The aspects that are considered in this regard are:

- Accessibility of required hardware, in terms of availability, affordability, compatibility, and efficiency, will facilitate digital inclusion in society.
- Accessibility via suitable user interfaces and enhanced digital tools, such as Digital Twin
- Improved service quality and use of global APIs.

These all primarily revolve around the accessibility and availability of a service. This area has a broad range of examples to draw inspiration from for measures. The other facets of digital inclusion--such as the increased ability to participate or the decreased unequal experience because of this availability--need further exploration within the projects to produce a holistic set of measures to consider.

The clear trend in the Digital Inclusion KVIs used and worked out by projects shows that advanced technologies, such as DT and APIs, can be used to facilitate easier and wider access to the infrastructure, information, and digital technologies. A challenge foreseen in this regard is the complexity and compatibility of the required infrastructure and hardware. Hence, some projects are proposing solutions to reduce this impact.

Table 10: Digital Inclusion Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Methods and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
6GPATH	Digital inclusion	Digital Inclusion and Equitable Access	UC-CITIES-1 Connected and sensing city	6G will allow cloud-based digital services for inclusion	Not identified so far	Not identified so far
6G-XR	Easiness of using accessible Hardware (HW), which improves the digital inclusion of the whole society.	Holographic-meeting, smartphones Rapid and effective skills acquisition Budget-friendly HW in which holographic communications can be operated Globalization of the compatible HW Easy to use HW Variety of versions to match different society use cases	Real-Time Holographic Communications (UC1, UC2, UC3)	Not identified so far	Not identified so far	Not identified so far
6G-XR	Measures fair opportunity as accessibility and user interface for industrial production by the DT participation. People can use the manufacturing facility even from the regions not locating manufacturing. Increasing the inclusivity of the user interface design by means of a collaborative 3D interface. It enhances and standardises the accessibility of different people with a variety of abilities, skills, background, and culture.	VR telepresence and remote control, VR UI, accessibility Digital accessibility supplementing potential limitations of people interacting with the Digital Twin like hand disabilities (i.e., voice interaction) Telepresence in a common digital environment Accessible immersive UI EAA guidelines (https://ec.europa.eu/social/main.jsp?catId=1202)	Collaborative 3D DT-like Environment (UC4)	Not identified so far	Not identified so far	Not identified so far
FIDAL	This includes both social and digital inclusion, reducing the digital divide of who has access, serving the historically under-served to be able to fully participate in activities and society	Access to service for all users.	All UCs	Not identified so far	> Suggested Objective Measure for Assessment % of successful compatibility testing across relevant devices and infrastructure, if these are pre-defined. OR > Self-declaration of compatibility (e.g. towards testbeds, relevant infrastructure, or devices) that states that the service offered will work in XYZ situations such that it can be peer-reviewed.	Match technical and social

					Suggested Subjective Measure for Assessment % of stakeholders who deem the use case system useful for their communities.	
ORIGAMI	More users can be served with improved service quality.	Design and develop NI functionalities and global APIs that enable global deployment of services (e.g., IoT hyperscalers) with multi-domain performance guarantees	Demonstration of AI/ML solutions for novel RAN usages Demonstration of in-band intelligence A cloud native implementation of the Service Communication Proxy (SCP)	NI functionalities and global APIs Innovative solutions for ultra-low latency metadata collection, in-band data processing. Asynchronous functions, lightweight computational solutions (binarized neural networks) and cutting-edge computing technologies (quantum computing)	To be identified	Sub-ms (RAN), or sub-µs (transport) 100 Gbps 50% lower latency than current procedures
6G-SENSES	KVI 1: Increase in coverage footprint	Stakeholder: Users Effect on: Activities KV1 description: Connecting the unconnected thus fostering inclusion of remote populations in digital services	UC #3: Network DT - Storyline #1- Network Optimisation and Storyline #2- EE	AI/ML and sensing plane, combined with O-RAN, enabling energy-efficient coverage optimisation	Theoretical study as part of the project impact assessment	Not identified so far
FIDAL	Acting in ways that enable communities to prosper, support the needs of all, including the under-represented, and bridge the digital divide.	The ability to show that these innovations matter not just for the mainstream and wealthy (e.g. those with easy access) but that they can support the lives and well-being of all.	All Use Cases	Refers to a framework	"Objective Measure for Assessment: Percentage of those involved compared to who should be involved via how use case participants are representative of the target communities in which the use cases are intended to take place, disaggregated by Age, Gender, Region. Subjective Measure for Assessment/Enabler: Existence of defined target communities with specific benefits, with routes defined for expected impact."	Percentages close to matching; an enabler exists, such as app/server accessibility

4.10 KV#10 – Personal Freedom

Beginning with the simple definition of “Personal freedom”, the original definition includes the capability to choose and act, which is essential for human development. It encompasses political freedoms, economic facilities, social opportunities, transparency guarantees, and protective security. More specifically, within the 6G sustainability landscape, the Key Value focuses on empowering users with unrestricted, secure, and ethical access to digital services while ensuring environmental and operational efficiency, mainly in key aspects of the future of networks, including, personal data protection and privacy, data sovereignty, while guaranteeing autonomy and transparency. Furthermore, the term is also interlinked with openness, equitable access, fairness and inclusivity network’ concepts, and when it comes to AI penetration in the modern workplaces and society, the concerns about biases in AI algorithms.

Despite this potential important, the use of KVIs “Personal Freedom” does not appear in many projects. It is currently materialised as the increase of accessibility for people with disabilities, supported by the benefits of 6G value offering within the context of three concrete Use Cases on Real-Time Holographic Communications. This could be due to the overlap in themes (e.g. disability is also a key feature of inclusivity, autonomy is also related to privacy and democracy, etc.). Further exploration of the value is required in order to draw any conclusions about KVIs and their measurements in this category. The approach from 6GXR project is summarised in Table 11 below.

Table 11: Personal Freedom Key Value: Definitions, Description and Verticals

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated
6GXR	Increase accessibility for people with disabilities or those who are unable to travel.	Holographic meeting, smartphones. Cost reduction. Breaking physical and geographic barriers SDK and functionalities to allow people change the hologram appearance covering potential disabilities Connectivity available in potential remote regions where people are located	Real-Time Holographic Communications (UC1, UC2, UC3)

Note: 6G-XR project has not defined the validation method and target values for the KV, by the time of the final editing of the present.

4.11 KV#11 – Personal Health & Protection from Harm

6G technologies have the potential to significantly improve personal health and protection from harm through innovations like telemedicine, remote diagnostics, and improved situational awareness tools for disaster responders. However, it is essential to address concerns regarding digital well-being, such as cognitive overload, decreased physical activity, and mental health effects, to ensure that technology enhances rather than undermines overall health. Additionally, occupational safety is critical, as highlighted in the EU Strategic Framework on Health and Safety at Work (2021-2027). Sustainable Development Goal (SDG) 3 aims to ensure healthy lives and promote well-being for all ages, emphasizing that good health is integral to sustainable development. The 2030 Agenda recognizes the interconnectedness of health with economic and social factors, focusing on reducing preventable deaths, strengthening prevention efforts, and improving mental health. Key areas of improvement include increasing access to healthcare, enhancing early warning systems, and strengthening health and safety risk management. Furthermore, addressing road traffic safety, environmental health (including the reduction of illnesses from hazardous chemicals and pollution), and emergency preparedness are essential components of this holistic approach to health and safety.

The projects offer a variety of examples of how this value is articulated and thus measurable in different vertical contexts. Table 12 presents the core KVIs across six (6) 6G-related projects, highlighting their impact on various verticals, such as agriculture, healthcare, manufacturing, and PPDR and human safety. One of the major issues highlighted is the enhancement of food security through 6G-enabled agricultural advancements (6GPATH project), the use of smart farming techniques, such as water-saving irrigation and autonomous machinery, optimizes resource utilization, improves crop resilience, and ultimately contributes to a stable food supply. Additionally, public health and nutrition benefit from the increased availability and quality of agricultural products, demonstrating how technology-driven solutions can directly influence societal well-being.

In addition, in healthcare projects and their use cases improvements are assessed through indicators such as reduced healing times, increased healthcare access, and workforce safety enhancements. The 3D hydrogel patches used in remote healthcare applications not only reduce hospital visits but also accelerate patient recovery and improve provider satisfaction. Similarly, exoskeleton-assisted workplaces in industrial settings are evaluated based on reductions in work-related injuries and enhanced worker well-being.

Moreover, field trials, qualitative surveys, and real-time data collection methods ensure that the effectiveness of innovations is assessed in practical environments and leveraged as validation methods, with the main target values relying on vertical KPIs. Some popular KPIs, improved worker safety and health conditions, number of patients, duration of therapy, etc. Two projects, DETERMINISTIC6G and 6GXR, also introduce theoretical KVIs. These advancements, supported by 6G technology, reinforce the broader goal of improving quality of life while ensuring sustainable and efficient operations across industries and mobility.

A challenge presented by these measures, however, is that many are not measurable within the context of the projects (e.g. it is unlikely that, during a project's lifetime, a technology would be deployed in a factory and thus it is possible to count if there are fewer injuries over time). This suggests that there might be some approaches to KVIs that assume it is to be measured at a later date or that what is measured will only be partial. It further raises the challenge of working with data that is not produced by the projects, but by stakeholders or related institutions.

Table 12: Personal Health & Protection from Harm Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Method and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
6GPATH	Increased contribution to food security	How do advanced features of 6G contribute to maintaining a stable agricultural food supply by improving crop resilience to climate change and optimizing resource utilization in agricultural production?	UC-Farming– Water Saving	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	% increase compared to current (>10%)
6GPATH	Increased contribution to public health and nutrition	How do advanced features of 6G contribute to better nutritional outcomes for the local population by improving the quality and availability of agricultural products?	UC-Farming– Water Saving	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	Rating of increase compared to current
6GPATH	Improved Public health	How does this service contribute to improved health service to the patients' by visiting patients (reducing the number of missed hospital visits) while at the same time serving multiple patients with a reduced number of highly trained personnel?	UC-HEALTH - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials/ Qualitative Methodology	"a) risk of complication decreases, number of hospitalisation days also decreases.
6GPATH	Increased workforce safety and health	How does using advanced agriculture practices facilitated by 6G improve worker safety and health conditions due to the reduction of manual labour-intensive tasks and the implementation of autonomous machinery?	UC-FARM-2 – Smart Vineyards	Autonomous machinery, health and safety monitoring systems	Survey after field trials/ Qualitative Methodology	Opinionated questionnaire. The KVI is related to KPIs on Survey results on improved worker safety and health conditions
6GPATH	Improved Healthcare Access	How does this service contribute to increased access to high-quality medical care for patients in remote and underserved areas?	UC-HEALTH-1 - 3D hydrogel patches	In progress of definition of enablers	Survey during and after Field Trial	Opinionated questionnaire. The KVI is related to KPIs on number of patients/areas that can be served with the new system
6GPATH	Reduction in healing time	How does this service wound healing time duration compared to conventional dressings?	UC-HEALTH-1 - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials	Reduce average healing time with customized patches. The KVI is related

						to KPIs on weeks and days to heal, risk of complication
6GPATH	Empowerment of Healthcare Providers	How does this service contribute to enhanced job satisfaction and professional growth opportunities for nurses and other healthcare providers with advanced tools and remote support?	UC-HEALTH-1 - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials	Opinionated Questions using 5-point Likert Scale. a) The young healthcare providers will be more satisfied and attracted to have a supporting tool as the mobile App together with good connectivity, instead of filling in data on paper and scanning it, which is tedious. b) The healthcare providers will get accustomed to a new digital system that documents the wounds in a visual format, will have the support of wound experts, and thus, do not carry the whole responsibility of wound treatment.
6GPATH	Resilience in Healthcare Delivery	How does this service contribute to the continuity of care during emergencies or natural disasters, improving community resilience?	UC-HEALTH-1 - 3D hydrogel patches	In progress of definition of enablers	Survey after field trials	Opinionated Questions using 5-point Likert Scale. Evaluate how much of the infrastructure can be used in case of natural disaster.
DESIRE6G	Increased operational efficiency in saving lives in remote areas	The AR/VR demo UC of the project could be extended to rescue operations	Linked to the AR/VR UC of the project, but the KVI evaluation is not directly achieved by the project UC demo implementation	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	Not identified so far	Not identified so far
DESIRE6G	Reduced injuries in the human workforce	The Robotic Digital Twin UC and the Robot Control UC highlight the potential increase in the use of robots if xURLLC services are supported	Linked to the Robotic Digital Twin demo UC and Robot Control PoC, but the KVI evaluation is not directly achieved by the project UC implementations	Support of xURRLC services by means of programmable networks and autonomous networking based on Multi Agent Systems	Not identified so far	Not identified so far
DETERMINISTIC6G	1. Number work-related injuries 2. Severity of work-related injuries 3. Indicators of workers' well-being (e.g. frequencies and severity of musculoskeletal discomfort episodes)	6G network would enable: (i) the feasibility of the integration of a occupational exoskeleton in a network able to connect exoskeletons and a series of environmental, task-related, and	Exoskeleton in industrial context	1. Network coverage in the entire relevant environment 2. Network capabilities enabling exoskeleton's offloaded control	Theoretical KVI: No validation within project	Theoretical KVI: No defined target value within project. The KVI is related to KPIs on Survey results on Percentage reduction of weight and encumbrance

		user-status sensors; (ii) the offloading of the control algorithms of the exoskeletons. This, in turn, would enable (i) the instant-by-instant optimization of the exoskeleton's assistive strategies mainly in terms of adaptation to user and context needs, and (ii) the delocalization of part of the exoskeleton's hardware, which would lead to a reduction in the exoskeleton's weight and encumbrance, in its power consumption and, thus, in its cost. Therefore, the acceptability and the spread of occupational exoskeletons would be boosted, and thus, having exoskeletons demonstrated their capability of reducing the physical load of workers and to improve the quality of work, the following consequences would be expected: improvement of the working conditions of workers; improvement of the quality of life of workers; possible decrease of the number/severity of work-related injuries.		3. Availability of highly detailed digital twin (human+exoskeleton)		(with respect to "standard" exoskeleton use case, i.e. exoskeleton with onboard controller), number of sold exoskeletons/number of companies adopting exoskeletons
DETERMINISTIC6G	Number of required devices/production facilities	Adaptive production lines allow to produce different types of products on the same production system. This reduces the need for materials by reusing the same processing modules for multiple production lines.	Factory automation: Adaptive Manufacturing	Dependable mobile communication between mobile production modules and the production line.	Theoretical KVI: No validation within project	Theoretical KVI: No defined target value within project
DETERMINISTIC6G	Number of killed wild animals	Automated wildlife detection via drones flying ahead of a harvesting machine may prevent wild animals to be killed.	Mobile automation: Smart Farming	Dependable mobile communication and time synchronization between drones and harvester.	Theoretical KVI: No validation within project	Theoretical KVI: No defined target value within project
6GXR	By using realistic holo-portation, learning, training and visiting activities can be safe, avoiding risky situations in terms of machinery manipulation or dangerous environments.	Costs and risks minimization Increased user confidence Hands on safety collaboration	Real-Time Holographic Communications (UC1, UC2, UC3)	In progress of definition	In progress of definition	In progress of definition

FIDAL	The ability to use tools while keeping a focus on the final goals (saving lives and preventing harms).	The ability to make the decisions at difficult times requires that users do not have to focus on their work with the tools but instead they are able to use the tools to support the vulnerable people they are seeking to protect.	All Use Cases	No technical enabler is involved	Subjective assessment of impact of technology on task load via User (and ideally organizational) assessment, building upon NASA TLX which looks at different areas of effort to use a tool and the interrelationships between them. A high index results suggests that a tool is taking attention and resources away from the end-goals or desired outcomes.	Low overall TLX index, User (and ideally organizational) assessment, building upon NASA TLX
FIDAL	Citizens Feeling safe. if people do not feel safe, or feel their safety is compromised or not improved, then they will be less likely to use the service or trust it.	Stakeholder perception of personal and community safety resulting from solution use.	UC4: Advanced sports area media services, UC5: Virtual Reality Networked music performance, UC6b: On-site XR-assisted emergency surgical operations, UC7: Smart village engagement services	No single specific enabler has been defined but focus in given on the impact of the system as a whole.	% of stakeholders (via survey after participating in use case) they feel safe in using the tool and in the spaces where the tools are used. "	High Percentage in Survey of Users
FIDAL	Greater protection of citizens by better understanding, seeing, and communicating about the kinds of hazards and vulnerabilities they face.	Information needs to be the right kind for the right person for the right kind of assessment in order for a public safety practitioner to be able to do their jobs. Improved awareness of vulnerabilities and risks faced by citizens.	UC2: Digital Twin for first responders, UC3:City security event/incident.UC6b: On-site XR-assisted emergency surgical operations	In progress of definition of enablers	Stakeholders surveyed after use or demonstration of tools see potential for improvements towards their awareness of risks and vulnerabilities in ways support their ability to make better and faster decisions.	100% see potential for improvement
FIDAL	Improve practitioners' ability to perform and make necessary decisions.	Tools to be used in the field or for learning need to be able to be used in both training exercises and day-to-day activities by public safety organisations in order to be valuable or relied upon in real-world practice. Trainings with the system are able to be aligned with organisational objectives and goals.	UC1: Internet of Senses / Haptic sensing, UC2: Digital Twin for first responders, UC3: City security event/incident. UC6a: AR for improving Law Enforcement Agents (LEA) situational awareness,	Scaffold enabler: e.g. on the training and service support surrounding a technology for it to be usable.	Organisational reflection on if the kinds of training Use Cases are able to provide and receive match with organisational goals.	high alignment
FIDAL	Security matches sensitive nature of user and data	The ability for a system to work in ways that support the unique security needs of mission critical	UC1: Internet of Senses / Haptic sensing, UC6a: AR for improving Law	privacy and security features included	Percentage, based on an assessment by user organisations, of	100% aligned data flow with confidentiality needs

		work. Confidentiality of sensitive information	Enforcement Agents (LEA) situational awareness, UC6b: On-site XR-assisted emergency surgical operations		confidential data and communications shared on a need-to-know basis (e.g. is only sent or accessible to appropriate user, as designed towards administrative policy.)	
ENVELOPE	Accident Rate Reduction	Assesses the effectiveness of ENVELOPE solutions in preventing accidents	IT-UC1: Advanced In-Service Reporting for Automated Driving Vehicles It-UC2: Dynamic Collaborative Mapping for Automated Driving GR-UC6: CCAM use case	(1) & (2) Vertical service for Advanced In-Service Reporting for Automated Driving Vehicles, 3). Driver assistance system that helps reducing safety risks, predictive QoS.	Assessment by expert	1) 50% reduction in accidents compared to not using the driver assistance system implemented in ENVELOPE 2) Reduction in accidents compared to not using the driver assistance system implemented in ENVELOPE 3) Reduction of accidents due to early notification of hazards ahead, compared with baseline
ECO-eNET	KVI 1: Increase of communication services availability during these events. Decrease in communication outages in emergency/ disastrous situations. KVI 2: Faster response in environmental or man-caused incidents especially affecting large areas. KVI 3: Increase in the number of incidents mitigated thanks to the availability of communication services (PPDR advanced services).	Stakeholder: Users Effect on: Activities KV1: Fast response in emergency situations. KV2: Mitigation of disastrous situations	UC#1: Optical Network enabling HRLLC Usage Scenarios, UC#2: Wireless Transport Network enabling High Capacity and HRLLC Usage Scenarios	Optical and Wireless transport resilience enabling 6G-network resilience.	Technical assessment, and impact assessment study.	Increase in network availability
6G-EWOC	Injuries in urban traffic	Joint communication and sensing	Connected Mobility	Connected LiDAR	Demonstration of an enhanced pulsed MEMS-based LIDAR with sensing (high density point clouds within a camera-like FOV of 30ºx20º at 7 fps) and FSO communication capabilities up to 200 m and <500 kHz PRR (bitrate) for ISAC applications in autonomous navigation systems	-High density point clouds within a camera-like FOV of 30ºx20º at 7 fps - FSO communication capabilities up to 200 m and <500 kHz PRR
6G-EWOC	Injuries in urban traffic	Joint communication and sensing	Connected Mobility	Connected radar	Demonstration of a connected radar, showing simultaneously detection	Detection and communication for a range

					and communication capabilities for a range of <200 m and between 0.5 and 1 Gbps	of <200 m and between 0.5 and 1 Gbps
6G-EWOC	Injuries in urban traffic	Multi-agent supporting network architecture	Connected Mobility	AI-assisted energy-efficiency algorithm(s) and/or heuristics for multi-layer (packet/optical) networks	Provisioning of traffic flows in less than 60 seconds, considering packet and optical layers	Traffic flows in less than 60 seconds, considering packet and optical layers

4.12 KV #12 – Trust

Trust in technology is a multifaceted concept that includes interpersonal trust (between individuals), group trust (in organizations, communities, and social groups), institutional trust (confidence in governments and corporations), and generalized social trust (belief in the reliability of broader systems). When people trust the institutions, organizations, businesses, groups, and individuals responsible for developing, regulating, and implementing new technologies, they are more likely to accept and adopt these innovations. In addition to trust in people and organizations, there are trust features embedded within technology itself, such as zero-trust techniques. In the 6G era, trust is essential for the adoption of new technologies, as it influences public perception and the willingness to engage with innovations. Trust also plays a key role in economic growth and technological adoption. Factors like institutional transparency, security measures, and the ethical deployment of technology are vital in building and maintaining trust. However, trust is highly context-dependent and evolves over time, shaped by elements such as reliability, truth, ability, vulnerability, perceived benefit, control, security, reputation, and shared norms.

5 SNS projects out of those projects provided the questionnaire work, one way or another, on key value 'Trust', with some focusing on it as a feature internal to the technical design, with others focusing on a user's trust of the technology, (Table 13). One criterion in the trust evaluation is the robustness and resilience of the devices and infrastructure, as expressed by 2 projects. Another project indicates the use of holographic remote interaction as a means to increase the level of trust among those involved in such interactions. For other projects, trust is a multi-facet value encompassing safety, privacy, availability, security and resilience, and so enhancements on any of these elements would end up in increasing the trust.

As the trustworthy KVIs mature, it is important to distinguish between what they are measuring. For example, levels of trustworthiness can speak to the extent of zero-trust features in a technology that form technical security features that, through their existence, are assumed to improve the likelihood a user will trust the technology. In other cases, levels of trustworthiness focus on whether a person using a technology feels like they can trust it with their data or is it dependable for their intended use. In yet other cases it can reference if a user trusts the company or governance system that provides the technology. Each of these implies a different measure. Any standardised approach to measuring would need to be clear about these various facets within the key value of trust.

Table 13: Trust Key Value: Definitions, Description, Verticals, Technology Enablers, Validation Method and Target Values

Project	KVI	Description of the KVI in the context of the project	PoC/ UC where this KVI is/ will be evaluated	Technology Enablers	Validation Method	Target Value
SAFE-6G	Level of Trustworthiness	"Level of trustworthiness provided to a user is the result of combined actions taken by the cognitive AI coordinator of the 6G system simultaneously at the application plane, core network plane and resource/cloud continuum plane, using the openness and programmability capabilities of these planes. By deploying Trust Functions (i.e. specialised AFs) that interface with these planes, the cognitive coordinator achieves to apply security, privacy, safety, resilience, and reliability actions/measures that aim to accommodate the user's intent and realize a user-centric trustworthy service provision over 6G.	UC- Industrial Metaverse UC – Metaverse for Education	1) User-centric Safety Function. 2) User-centric Security Function. 3) User-centric Privacy Function. 4) User-centric Resilience Function. 5) User-centric Reliability Function	Use case/user-intent-based validation trials	Low / Medium / High[7]
TrialsNet	Reported confidence in the digital devices, systems, and services used in the use-case development and operation.	% of the users expressing positive evaluation regarding the robustness of the devices, the trustworthiness of the used AI algorithms, the E2E privacy of the system.	UC2 - Proactive Public Infrastructure Assets Management	In progress of definition	Questionnaires	In progress of definition of target value
PRIVATEER	Level of Trustworthiness	"Trustworthiness encompasses multiple facets, such as 'security, privacy, availability, resilience, compliance with ethical frameworks"]. Other sources use similar descriptions, which have in common that security and privacy are considered crucial properties of trustworthy systems. A relevant aspect is how to translate and assess the trustworthiness properties of 6G systems. A potential solution is to	UC (ITS) privacy-friendly security service	Level of Trust Assessment Framework, Privacy-Aware Orchestrator, Attestation	Actual system	N/A[8]

[7] This KVI is related to a number of KPIs per function, as defined in the 3GPP definition and target values. These KPIs, deal with (a) SAFETY, meaning Tunnel latency, Tunnel Packet Loss, Tunnel Jitter, Tunnel Throughput, Tunnel establishment attempt, Tunnel establishment success, Tunnel establishment failure, Function creation attempt, Function creation success/failure, Authentication Attempt, Successful Authentication and Authentication Failure, (b) SECURITY, meaning Peer Count, Transaction Latency, Block Finalization, Transaction Throughput, Network Uptime, Smart Contract, Deployment Success Rate, Smart Contract Execution Success Rate, Smart Contract Response Time, (c) PRIVACY meaning Privacy Score Calculation Latency, Privacy Action Recommendation Latency, Privacy Function Uptime, AI Orchestrator Satisfaction Rate and (d) RELIABILITY meaning Inference Time, Training Time, Number of metrics, Type of alerts, Number of ML models, NFV green deployment, Energy aware ML models.

[8] The KVI is related to KPIs 1) Level of Trust: A composite metric calculated from several indicators (e.g., attestation levels, traffic attestation, traceability, security issues) to assess the trustworthiness of 6G services., 2) Level of Assurance: Defined by ETSI, these levels range from 0 to 5, representing the scale of relative trust, with higher numbers denoting greater levels of trust.

		combine several of the above-mentioned metrics into the concept of a Level of Trust (LoT) and consider it part of SLA demanded by 6G system. The LoT can be calculated as a combination of several metrics that can be monitored on different domains, through a Trust management Service, or the combination of them into services and offer the user assurance of the trustworthiness of the given service. The metrics can include the following: Attestation level (SW, HW), Traffic path attestation (confirmed Proof-of- Transit), Traceability (e.g., via Smart Contracts: allows conducting verifiable accounting & SLAs), Security issues related to the SDN Controller, NFVO & Slice Manager (e.g., compromised slices), AI-related and Privacy KPIs.	orchestration for logistics UC (multi-domain infrastructure verification and Proof-of-Transit)	mechanisms, Proof-of-Transit		
6GXR	Facial relief visualization of the people we are interacting with helps in the enhancement of the inter-personal relations. Then, it increases the level of thrustless, cooperation, and understanding.	Holographic meeting, Smart devices SDK to measure the trust level of the people you are interacting	Real-Time Holographic Communications (UC1, UC2, UC3)	In progress of definition	In progress of definition	In progress of definition
FIDAL	Users trust a system's behaviour, process, and governance; Users trust fellow users; Users trust infrastructures and networks.	Building systems that continue to be trusted by users and society. Building an understanding of how one elements of a trusted system, dependability, works in different domains and activities might relate to different technical features. Stakeholders deem system dependable for their activities. User has tolerance of disconnection or gaps in service in how they use it.	All Use Cases	Reconnection and network access capabilities.	"Objective Measure for Assessment: Time between pressing a button and getting data out there and activity seen, expressed via consistent latency across different situations of use, expressed during different loads across the system. Subjective Measure for Assessment: Service response times are consistently within acceptable limits for users as they work towards their goals, assessed via survey of users."	high correlation between meeting KPIs and Subjective Responses. Latency; Content Load time/time to first picture; Content/Stall/Freeze
	Able to perform the session successfully, no matter their location	Able to perform the session successfully, no matter their location. User has tolerance of disconnection or gaps in service in how they use it.	All Use Cases		"Objective Measure for Assessment: Did you receive the data at the rate you were supposed to receive it? As expressed in data from trials on packet loss and logged connections that data being sent was received. and	high correlation between meeting KPIs and Subjective Responses. Content Download and Upload

					Re-instantiation times: how fast to gain access without having to re-log in? As expressed via log of reconnection times and numbers. Subjective Measure for Assessment: Assess how tolerant user is of the disconnections to services, via a survey asking if, during large-scale field trial they felt loss of connectivity and if they received data well-enough to trust the service towards their objectives in using it."	Throughput, packet loss, disconnects, Network App deployment and provisioning (multiple cases)

5 SUMMARY & CONCLUSIONS

As the evolution from 5G/B5G toward 6G networks progresses and the related research advances, there is a pronounced shift in focus, from traditional KPIs, which measure the performance, to broader considerations of the implications of 6G networks for society and the environment. This ongoing transition emphasizes the importance of KVIs, which reflect the need for research and technology to consider the values and priorities of society, including all 12 Key Values analysed in Section 4. The TMV sub-Working Group on KVIs works effectively on the identification and promotion of robust and accurate qualitative or quantitative methodologies for the effective estimation and assessment of the impact of 6G networks and enabled use cases on targeted KVIs’ Target Values.

The KVIs framework is vital for fusing into 6G research the UN SDGs' vision on values towards a prosperous, sustainable future for the planet and societies. To this end, and given the 6G research maturity, the progress and expected outcomes focus on setting up a common vision, as well as the specific determination of definitions for the Key Values and specific measurable KVIs. Incorporating KVIs into the design and operation of 6G networks ensures that technological progress aligns with societal values and addresses global challenges. As a result, KVIs do have the potential to guide 6G projects and coordinate support activities and initiatives on sustainability, enhancing accountability and transparency, not simply as indicators with specific target values, rather than benchmarks of continuous improvement. The SNS JU and the TMV WG, can inform and shape policies, definitions, and new standards for driving meaningful transition into the emerging 6G landscape.

The key findings of this work can be summarized as follows:

- As KPIs are focusing on the measurement of the related performance benefits of the 6G networks and are utilized for the definitions and the requirements specification, KVIs focus on the long-term impact and the broader benefits of 6G networks and technologies. (HEXA-X-II Deliverable D2a). However, in most of cases, the measurement methodologies and the validation processes for the KVIs are in a phase of low maturity.
- For many key values and KVIs, the measurement approaches seem to converge with KPIs well-defined definitions for the measurement of the long-term impact. The great majority of the projects still have not finalized the work required to define in a concrete way the validation methods used and their target values, which seems to be one of the greatest challenges for 6G. So, despite the broad impact and clearly understood benefits of 6G technologies for all sustainability aspects, the processes and roadmaps of the projects for quantifying specific metrics for measuring the Key Values are progressing closely to already existing KPIs. To this end, KVIs

and KPIs seem to walk hand-in-hand, especially for the impact generated from the technical characteristics of the projects and the alternate verticals.

- The great heterogeneity among the KVIs addressing the same KV is driven by the great differentiation among several verticals and use cases. This research domain requires further exploration, given the criticality of the existence of metrics that can be generalized across multiple verticals (multi-domain KVIs) and sector specific measures.
- The determination of Key Enablers is also premature, although from the input received, it is clear that innovations in 6G technologies will facilitate the sustainability of the 6G networks and applications. For instance, AI/ML utilization seems pivotal in managing the impact of 6G networks and the applications developed and tested. They enable dynamic network optimization, predictive maintenance, and adaptive resource allocation, all of which contribute to improved energy/resources efficiency, as well as better performance (in terms of speed) and (in)direct socioeconomic impact. The SNS JU emphasizes the integration of AI/ML to meet critical 6G objectives, such as enhanced performance, energy efficiency, and advanced security for trusted networks and applications.
- There is a need for harmonization and standardization of the Key Values definitions so that KVIs definitions can also be defined accurately. The well-defined terminology within the KVIs research is mandatory for the generation of new metrics and indicators for the measurement of the usage of social benefits and the methodological frameworks that could be used for validation. Unified metrics and frameworks will facilitate collaboration, promote interoperability, and streamline the development of 6G systems worldwide, also addressing the major challenge for the measurement of sustainability and socioeconomic footprint.

The present white paper provided a synthesis on the work performed by this date on the 6G Key Values and the KVIs within multiple SNS JU projects and the utilisation of the related work toward a more sustainable society and planet. So far, the research and work aim to consolidate the alternate views coming from the research community on 6G networks and utilise methodological frameworks and validation methodologies (both qualitative and quantitative) for the measurement of the long-term impact of the projects. The KVIs for specific Key Values seem to differentiate based on the vertical and the use cases established by the projects. Given the fact that 6G research is at initial phases, it shall be considered as an initiation of an iterative process to reach these goals, along with the updates on the measurement and validation methodologies.

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ABBREVIATIONS AND ACRONYMS

Acronym	Description
5G PPP	5G Public Private Partnership
6G IA	6G Smart Network and Services Industry Association
AI / ML	Artificial Intelligence / Machine Learning
AR	Augmented Reality
CCL	Compute Continuum Layer
EMF	Electromagnetic Field
ETSI	European Telecommunications Standards Institute
HW	Hardware
ISAC	Integrated Sensing and Communication
KV(s)	Key Value(s)
KVI(s)	Key Value Indicator(s)
LoT	Level of Trust
NASA TLX	NASA Task Load Index
NFV	Network Function Virtualization
PoC	Proof of Concept
QoS	Quality of Service
RIS	Reconfigurable Intelligent Surfaces
SDGs	Sustainable Development Goals

SDN	Software-Defined Networking
SDO	Standards Development Organisation
SNS JU	Smart Networks and Services Joint Undertaking
SW	Software
UC	Use Case
UN	United Nations
UX	User Experience
xURLLC	eXtended Ultra-Reliable Low Latency Communication

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SUPPORTING PROJECTS

1. CENTRIC (Stream B)
2. DESIRE6G (Stream B)
3. 6G-XR (Stream C)
4. TrialsNet (Stream D)
5. Deterministic6G (Stream B)
6. PREDICT-6G (Stream B)
7. PRIVATEER (Stream B)
8. SAFE-6G (Stream B)
9. ORIGAMI (Stream B)
10. 6G-PATH (Stream D)
11. FIDAL (Stream D)
12. ENVELOPE (Stream D)
13. 6G-SENSES (Stream B)
14. 6G-EWOC (Stream B)
15. ECO-eNET (Stream B)

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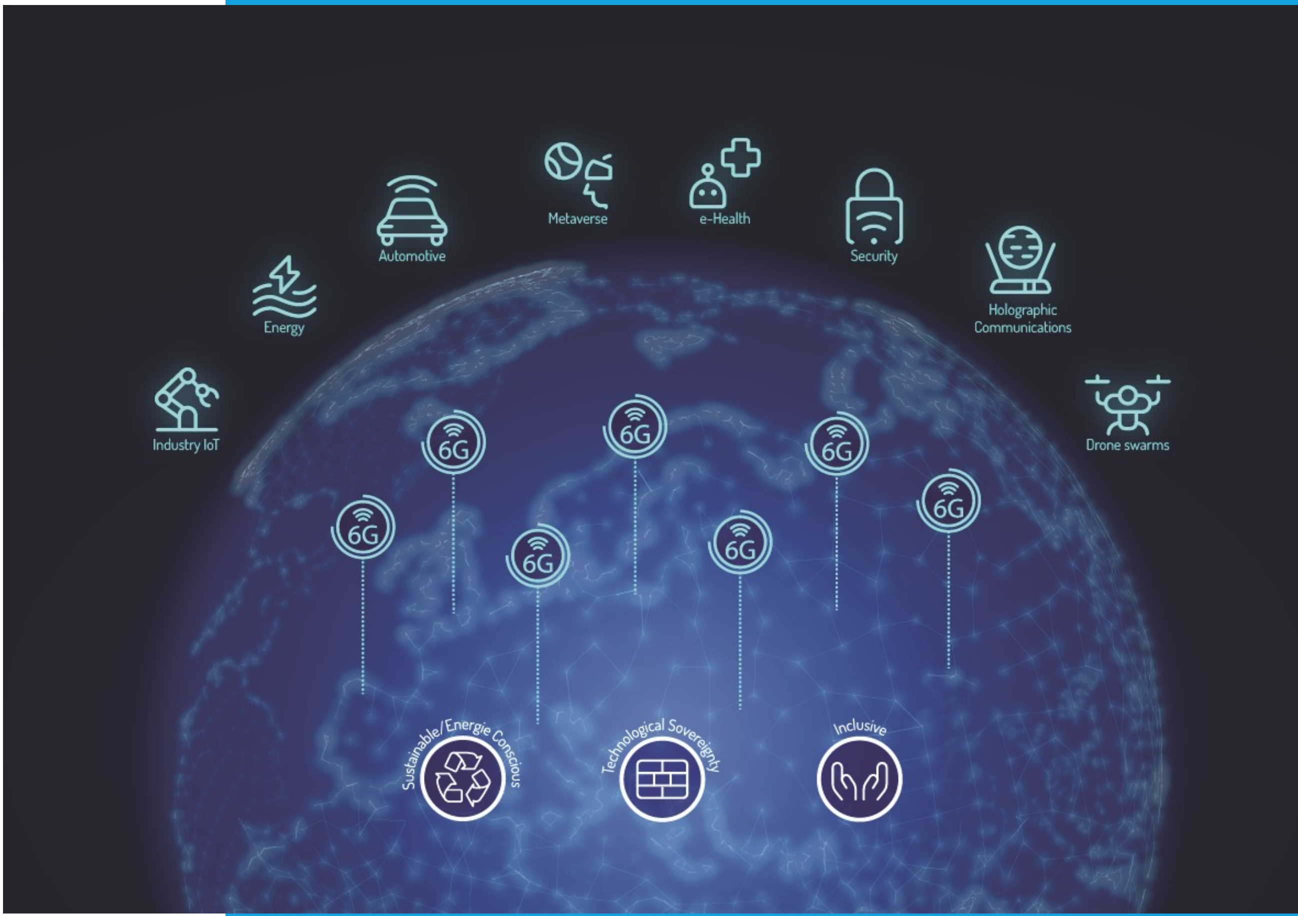

Website: https://smart-networks.europa.eu/sns-ju-working-groups/

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