INPACE

Indo-Pacific-European Hub
for Digital Partnerships

ヨーロッパとインド太平洋のための
デジタルパートナーシップ強化

디지털 파트너십 강화
유럽 및 인도 태평양의 경우

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Authors	LE GALL Franck (EGM) ENGELL Sebastian (EG) RAMFOS Antonis (ATC) BALESTRA Francis (SINANO) KAPOVITS Adams (Eurescom) GAVRAS Anastasius (Eurescom) INCHES Giacomo (Martel Innovate) CAULIER Pascale (SiNANO)
Reviewers	BALESTRA Francis (SINANO)
Abstract	The document "D3.1 Summary Panorama Report" provides an overview of advancements in key technological areas, focusing on innovation for sustainable well-being, trustworthy AI, future chips, and digital networks. It highlights collaborative efforts between the EU and Indo-Pacific partners to address challenges in sustainability, digitalization, and technology standardization. The report emphasizes international cooperation to foster innovation and achieve global strategic goals.
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* *R: Document, report (excluding the periodic and final reports)*
DEC: Websites, patents filing, press & media actions, videos, etc.
DATA: Data sets, microdata, etc.
DMP: Data management plan
ETHICS: Deliverables related to ethics issues.

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EXECUTIVE SUMMARY

The D3.1 Summary Panorama Report provides a comprehensive overview of advancements and initiatives in key technological areas, focusing on innovation and entrepreneurship for sustainable well-being, digital technologies for trustworthy decision support, enabling technologies for future chips, and future digital networks. This document synthesizes collaborative efforts and opportunities between the European Union and its partner countries, collected within the first year of the project through desk research, interactions with the experts groups built within the project as well as from discussions in events such as workshops. The report is organized along the 4 thematic clusters of the project:

Cluster 2: Innovation and Entrepreneurship for Sustainable Well-being

This section explores the technical working groups (TWGs) focused on smart cities, digitalization for sustainable ecosystems, and digitalization of industry, infrastructures, and services. It highlights initiatives such as local digital twins, the Citiverse initiative, and global frameworks for carbon-neutral cities, emphasizing the importance of digital identity and authentication in the development of smart cities. The integration of digital technologies across various environmental domains is crucial for achieving sustainable development goals and ensuring the long-term health of ecosystems.

Cluster 3: Digital Technologies - Trustworthy Decision Support

Cluster 3 focuses on the development of trustworthy AI, data technologies, and high-performance computing (HPC) infrastructures. It examines the challenges and opportunities related to explainable AI, neurosymbolic AI, low-carbon AI, and human-machine symbiotic collaboration. This section also highlights specific initiatives from partner countries to enhance trust and transparency in AI systems. The emphasis is on fostering human-centered, trustworthy, and explainable AI solutions through strategic partnerships.

Cluster 4: Enabling Technologies - Chips for the Future

This section addresses the challenges and possible solutions in the semiconductor field, emphasizing advanced computing technologies, advanced functionalities for future electronic systems, and groundbreaking technologies beyond CMOS. It underscores the importance of international cooperation to accelerate technological innovation, reduce costs, and strengthen complex value chains. The focus areas include logic devices, memories, smart sensors, smart energy, energy harvesting, and wearable and flexible electronics.

Cluster 5: Digital Technologies - Future Networks

Cluster 5 integrates the domains of 5G and beyond/6G, cybersecurity, and the emerging cloud-edge-IoT continuum. It provides an overview of research and development initiatives and programs in Europe and partner countries, focusing on standardization, resilience of digital infrastructures, and international collaboration opportunities for the development of future networks. The section highlights the need for global standardization, efficient spectrum management, energy efficiency, and robust security measures to protect against cyber threats.

ABBREVIATIONS

ADAS	Advanced Driver Assistance System
BCD	Bipolar-CMOS-DMOS
BEOL	Back-End Of the Line
CFET	Complementary Field Effect Transistor
CMOS	Complementary Metal Oxide Semiconductor
CNT	Carbon Nano-Tube
DRAM	Dynamic Random Access Memory
FDSO	Fully-Depleted Silicon-On-Insulator
HEMT	High Electron Mobility Transistor
IGBT	Insulated-Gate Bipolar Transistor
IP	Internet Protocol
LCA	Life Cycle Analysis
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MRAM	Magnetic RAM
NEMS	Nano-Electro-Mechanical System
OLED	Organic Light-Emitting Diode
OSAT	Outsourced Semiconductor Assembly and Test
PCM	Phase-Change Memory
PFAS	Per- and polyFluoroAlkyl Substances
RF	Radio Frequency
STT	Spin-Transfer Torque
TCP	Transmission Control Protocol
TDDB	Time-Dependent Dielectric Breakdown
TFT	hin-Film Transistor
TOPS	Tera Operations Per Second
WPT	Wireless Power Transfer

1 INTRODUCTION

Digital technologies are a major driver of the progress towards sustainable, open, fair, and prosperous societies. Technological advances continue to be made at a fast pace in communications and networks, electronic systems and chips, artificial intelligence and big data technologies, high performance computing, cloud and edge computing, decision support and many more. While these technologies have a huge potential to foster economic growth, sustainability and the quality of life of the citizens, their usage and implementation also pose challenges: acceptance of and trust in technologies, data and internet security, barriers to access, governance, power and material consumption, etc. After the setback by the Covid pandemic, international cooperation should now be intensified again to speed up technological developments and their socially and environmentally beneficial uptake.

The European Union is strongly interested in strengthening its connection to Indo-Pacific region to jointly realize benefits in research and innovation, deployment and commercialization of technologies, harmonization of regulations and standards and in stabilizing supply chains. In this context, the promotion of digital technologies has become one of the highest priorities. The EU has therefore established Digital Partnerships (DPs) with Japan (2022), the Republic of Korea (2022) and Singapore (2023). The European Union and India have strengthened their strategic partnership by setting up a Trade and Technology Council (TTC) in 2022 that includes digital technologies and their application as a key area.

These digital partnerships and the TTC aim at further deepening ties in research and innovation and regulatory cooperation and at expanding bilateral trade and investments, with the goal that society and businesses in both regions benefit from opportunities in the growing global digital economy. These partnerships also underline the interest of the Indo-Pacific partners in increasing their cooperation with the EU against the background of increasing tensions and sharpening competition worldwide.

Trusted digital technologies for sustainable well-being are in the centre of the priorities of Europe and of the four partner countries as defined in the strategic documents of the Digital Partnerships with Japan, the Republic of Korea and Singapore and of the TTC with India. Effective implementation of these partnerships through practical achievements and their effective communication are of prime importance for the four partner countries in the Indo-Pacific and the European Union.

The mission of the INPACE is to support the digital partnerships and the TTC and to contribute to the deepening of the collaboration between Europe and India, Japan, the Republic of Korea and Singapore in the domain of digital technologies and their application for the well-being of the citizens in Europe and in the Indo-Pacific region. Toward this goal, INPACE will work on three levels:

- Establishing regular exchanges between leading experts from Europe and the four partner countries on policies, further developments of key digital technologies, and their implementation and commercialisation

- Supporting the digital policy dialogues on the governmental and institutional level and the implementation of the Digital Partnerships and the TTC with India

- Informing and involving a large community of stakeholders in Europe and in the Indo-Pacific partner countries into the dialogues via online and in-presence events and via the INPACE Community Platform.

To support these connected activities, INPACE created a Multi-Stakeholder Hub where experts, policy makers, and the digital innovation community across Europe and Asia meet, exchange ideas, and drive digital innovation.

1.1 THE THEMATIC WORKING GROUPS OF INPACE

INPACE organises the exchanges between experts from industry, associations, government institutions and the research communities by setting up Thematic Working Groups (TWGs) that bring together forward-looking experts in specific domains from the partner countries and from Europe. The mission of these Thematic Working Groups is to analyse the research policies and the needs of the partner countries and the European Union, to exchange on new trends and latest results in specific domains, and to propose avenues for future research and innovation and possible joint funding programs. The TWGs are organized in five Clusters that are co-led by organizations from Europe and from the Indo-Pacific region:

- Cluster 1: Digital Dialogues, Policies, and Education

- Cluster 2: Innovation and Entrepreneurship for Sustainable Well-being

- Cluster 3: Digital Technologies: Trustworthy Decision Support

- Cluster 4: Digital Technologies: Chips for the Future

- Cluster 5: Digital Technologies: Future Networks

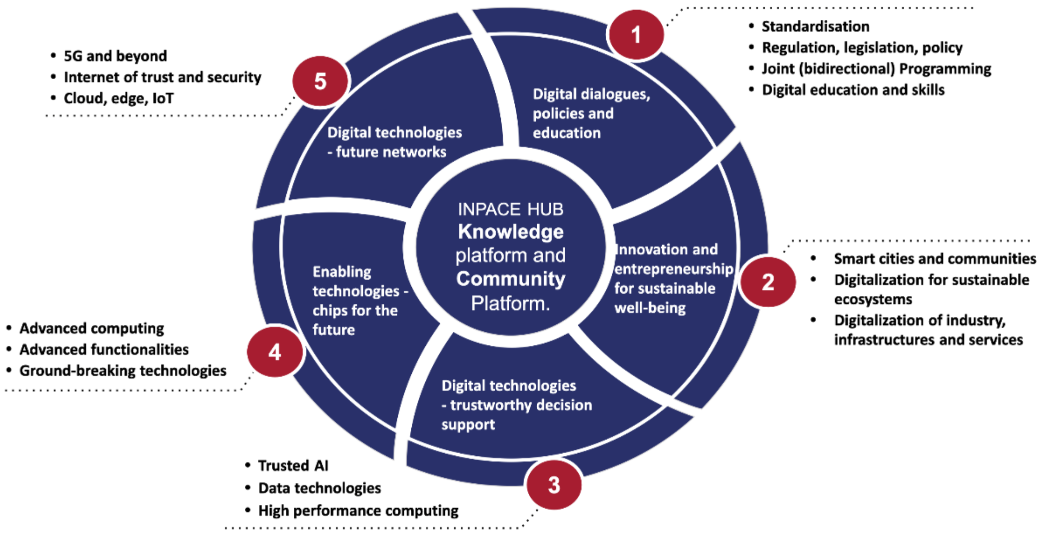

Figure 1: INPACE Clusters and Thematic Working Groups organisation

1.2 THE PANORAMA REPORT

The **D3.1 Summary Panorama** report provides an overview of advancements and initiatives in several key technological areas, focusing on innovation and entrepreneurship for sustainable well-being, digital technologies for trustworthy decision support, enabling technologies for future chips, and future digital networks. This document synthesizes collaborative efforts and opportunities between the European Union and its partner countries, aiming to strengthen international cooperation and promote advanced technological solutions.

- Cluster 2: Innovation and Entrepreneurship for Sustainable Well-being

This section explores the technical working groups (TWGs) focused on smart cities, digitalization for sustainable ecosystems, and digitalization of industry, infrastructures, and services. It highlights initiatives such as local digital twins, the Citiverse initiative, and global frameworks for carbon-neutral cities, emphasizing the importance of digital identity and authentication in the development of smart cities.

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Cluster 5 integrates the domains of 5G and beyond/6G, cybersecurity, and the emerging cloud-edge-IoT continuum. It provides an overview of research and development initiatives and programs in Europe and partner countries, focusing on standardization, resilience of digital infrastructures, and international collaboration opportunities for the development of future networks.

2 CLUSTER 2. INNOVATION AND ENTREPRENEURSHIP FOR SUSTAINABLE WELL-BEING

Cluster 2 focuses on innovation and entrepreneurship for sustainable well-being, encompassing three Technical Working Groups (TWGs): Smart cities and communities (TWG5), Digitalization for sustainable ecosystems (TWG6), and Digitalization of industry, infrastructures and services (TWG7). This comprehensive overview delves into the various aspects of these TWGs and explore the collaborative opportunities between the EU and its partner countries.

2.1 SMART CITIES AND COMMUNITIES

Smart cities and communities, as defined by the European Commission, aim to enhance the well-being of inhabitants, businesses, visitors, organizations, and administrators through digitally enabled services. This concept has gained significant traction across the EU and its partner countries, with each region developing unique approaches to urban development and sustainability.

2.1.1 Local Digital Twins

A key development in the smart cities domain is the concept of Local Digital Twins. These virtual representations of physical assets, processes, and systems drive the development of studies, architectures, standards, toolboxes, and demonstration projects. The implementation of digital twins allows city planners and administrators to simulate and optimize various urban systems, from traffic flow to energy consumption, before implementing changes in the real world.

When designing digital twins, two crucial aspects must be addressed:

1. Data Foundation: This includes the availability, quality, and interoperability of data. Ensuring that data from various sources can be integrated and analysed effectively is essential for creating accurate and useful digital twins.

2. Technical Foundation: This encompasses technologies such as IoT, cloud computing, big data, AI, and 5/6G networks. These technologies form the backbone of digital twin systems, enabling real-time data collection, processing, and analysis.

2.1.2 The Citiverse Initiative

The Living-in.EU initiative, which promotes Minimum Interoperability Mechanisms, has evolved into the Citiverse concept. This ambitious initiative aims to create a European alternative to the metaverse, based on European principles and values. The Citiverse concept seeks to create a virtual representation of cities that goes beyond mere visualization, incorporating real-time data and interactive elements to enhance urban planning, citizen engagement, and service delivery.

2.1.3 Global Frameworks for Carbon-Neutral Cities

On a global scale, the World Economic Forum has established a net zero carbon cities framework. This framework provides guidelines and best practices for cities aiming to reduce their carbon footprint and achieve sustainability goals. There is a growing need for a global Key Performance Indicators (KPIs) framework to measure progress towards carbon-neutral cities. In response to this need, an ISO New Work Item Proposal (NWIP) has been initiated to develop standardized indicators for carbon-neutral cities. These indicators will allow for better comparison and benchmarking of cities' sustainability efforts worldwide.

2.1.4 Digital Identity and Authentication

The eIDAS v2 regulation, which establishes a framework for digital identity and authentication across Europe, is another important aspect of smart cities development. This regulation aims to create a secure and interoperable system for digital identities, facilitating seamless access to online services across EU member states. As smart cities increasingly rely on digital services, having a robust and standardized digital identity system becomes crucial for ensuring security, privacy, and user convenience.

2.1.5 On-Life Human-Centered Vision

The concept of On-Life human-centered vision investigates emerging challenges in the digital realm, particularly focusing on "cold spots" and "disposable identities." This approach seeks to address the potential negative impacts of digitalization on human experiences and social interactions. By considering these aspects, smart city initiatives can strive to create more inclusive and human-centric urban environments that balance technological advancements with social well-being.

2.2 DIGITALIZATION FOR SUSTAINABLE ECOSYSTEMS

The Digitalization for Sustainable Ecosystems TWG focuses on leveraging digital technologies to address environmental challenges and promote sustainable practices across various sectors. This wide-ranging initiative encompasses several key areas:

2.2.1 Environmental Protection

Digital technologies play a crucial role in monitoring and mitigating environmental impacts. Advanced sensors, satellite imaging, and AI-powered analytics enable more accurate and real-time monitoring of air and water quality, deforestation, and biodiversity loss. These technologies allow for quicker responses to environmental threats and more informed decision-making in conservation efforts.

2.2.2 Sustainable Agriculture

In the agricultural sector, digitalization is driving significant advancements in precision farming techniques. IoT sensors, drones, and AI-powered analytics help farmers to optimize resource use, reduce chemical inputs, and increase crop yields. Smart irrigation systems, for instance, can significantly reduce water consumption while improving crop health.

2.2.3 Forestry and Fisheries Management

Digital technologies are revolutionizing the management of forests and fisheries. Satellite imaging and AI algorithms can detect illegal logging and fishing activities, while blockchain technology can enhance supply chain transparency, ensuring the sustainable sourcing of timber and seafood products for example.

2.2.4 Water Resource Management

The monitoring and management of water resources benefit greatly from digital technologies. Smart water meters, leak detection systems, and AI-powered demand forecasting help utilities optimize water distribution and reduce waste. In addition, advanced water treatment technologies, supported by digital control systems, improve the efficiency and effectiveness of wastewater management.

2.2.5 Biodiversity Conservation

Digital tools are enhancing efforts to protect and study biodiversity. DNA sequencing technologies, coupled with big data analytics, allow for more comprehensive biodiversity assessments. AI-powered image recognition systems help in species identification and population monitoring, while digital platforms facilitate citizen science initiatives, engaging the public in biodiversity conservation efforts.

2.2.6 Environmental Health Monitoring

The TWG also explores the environmental impacts on human health, focusing on monitoring and reducing pollution and exposure to noxious substances. IoT-enabled wearable devices and environmental sensors can provide real-time data on air quality and personal exposure to pollutants, enabling individuals and policymakers to take preventive measures.

2.2.7 Habitat Protection and Restoration

Digital technologies support habitat protection and restoration efforts through improved mapping, monitoring, and modelling of ecosystems. Virtual and augmented reality technologies can be used for educational purposes, raising awareness about the importance of habitat conservation and engaging the public in restoration projects.

The integration of these digital technologies across various environmental domains is crucial for achieving sustainable development goals and ensuring the long-term health of ecosystems. By leveraging data-driven insights and advanced analytics, policymakers and environmental managers can make more informed decisions and implement more effective conservation strategies.

2.3 DIGITALIZATION OF INDUSTRY, INFRASTRUCTURES AND SERVICES

The digitalization of industry, infrastructures, and services is a major driver for enhanced productivity and sustainability across various sectors. This TWG is divided into two subgroups: Manufacturing industries and Process industries and infrastructures.

2.3.1 Manufacturing Industries

In the manufacturing sector, there is a significant investment trend across all participating countries. The European Union, Japan, South Korea, and Singapore are placing a strong emphasis on robotics development, with Japan and Singapore specifically concentrating on collaborative robotics. This focus on robotics aims to enhance productivity, improve worker safety, and address labor shortages in aging societies.

The European Union's draft funding plan for 2025/2026 underscores several key priorities in industrial research and innovation, each aimed at enhancing competitiveness, sustainability, and technological advancement across various sectors.

2.3.1.1 Digitalization and Industrial Automation

With a proposed budget of €60 million, the EU aims to achieve a 30% reduction in downtime and a 35% increase in automation across sectors. This initiative focuses on integrating digital twins and IoT technologies to boost production resilience and operational efficiency. Such efforts align with the EU's broader strategy to create a digitally advanced industrial landscape, fostering innovation and economic growth.

2.3.1.2 Predictive Maintenance and Supply Chain Optimization

Allocating €45 million, this priority seeks to reduce logistics costs by 30% through data optimization. By enhancing AI integration in logistics, the EU aims to develop smarter, more adaptive supply chains, improving efficiency and responsiveness to market demands. This initiative supports the EU's commitment to advancing industrial competitiveness and economic resilience.

2.3.1.3 Generative AI in Robotics and Industrial Automation

With an €85 million budget for two large projects, the EU plans to develop advanced foundation models for robotics. These models will enhance autonomy and adaptability, enabling robots to learn and interact with their environments in real-time. The expected outcomes include increased productivity, resource-efficient industrial automation, and streamlined processes from installation to decommissioning. This initiative reflects the EU's focus on maintaining a competitive edge in AI and robotics.

2.3.1.4 Digital Twins and 3D Printing

The EU proposes a €35 million investment to scale digital twins and 3D printing technologies in new manufacturing environments. Objectives include a 35% reduction in time-to-market through advanced prototyping and a 40% improvement in predictive maintenance accuracy. This aligns with the EU's strategy to promote advanced manufacturing technologies, enhancing industrial efficiency and innovation.

2.3.1.5 Smart Supply Chain and IoT Integration

With a €75 million budget, this initiative aims to expand IoT and blockchain applications across various sectors, targeting a 25% reduction in supply chain costs through real-time data monitoring. The focus is on creating interconnected, transparent, and efficient supply chains, supporting the EU's goals for a digital and resilient economy.

2.3.1.6 Worker Assistance Technologies

Allocating €78 million across three calls, the EU intends to broaden AI and IoT applications in energy systems to ensure a flexible, sustainable, and resilient power grid. Expected outcomes include a 30% reduction in energy distribution costs and expanded adoption of smart grid technology, covering 60% of the EU's energy infrastructure. This initiative supports the EU's commitment to a green transition and energy efficiency.

2.3.2 Process Industries

The development of technologies to support the decarbonization of the process industries and the evolution towards a circular economy is supported by the public-private partnership (PPP) Processes4Planet (P4P) of the European Commission with the private sector represented by the association A.SPIRE. Processes4Planet funds research and innovation projects with a total volume of 1.4 B€ over 7 years, thus 200 M€ per year. Most calls target the development of process technologies. Digitalization is an element of many calls as a supporting technology. There was a large call on the use of AI in the process industries in 2020. A CSA on the transfer of the concept of Industry 5.0 to the process industries is currently planned for 2025.

2.3.3 Power Grids

The European Union invests continuously into the transformation of the power system towards being fed mostly by power from renewable sources. The goal of digitalization is to enhance grid stability, integrate renewable energy sources, and improve overall energy efficiency across Europe. Focal areas are the use of IoT- and AI-driven energy management systems, development of smart grids to enable real-time energy distribution and monitoring, and large-scale renewable energy storage solutions. India, Japan, Singapore and South Korea similarly invest into the transformation of the energy systems. Similarly, the energy management systems should be empowered by IoT and AI to balance electricity supply and demand efficiently, integrating supply from renewable sources into the national grid.

2.4 COUNTRY-SPECIFIC INITIATIVES AND COLLABORATIONS

2.4.1 European Union

The EU's Horizon Europe program serves as the primary funding instrument for research and innovation across various sectors, including those relevant to Cluster 2. This comprehensive program supports projects ranging from fundamental research to market-ready innovations, fostering collaboration between academic institutions, industry partners, and public entities.

Examples of key initiatives within the EU framework include:

- The Processes4Planet (P4P) public-private partnership: This initiative supports the decarbonization of process industries and the transition to a circular economy, with a total funding of 1.4 billion euros over seven years.
- Clean Steel Partnership: Focusing on the development of technologies to reduce CO_2 emissions in steel production.
- Clean Hydrogen Partnership: Supporting research and innovation in hydrogen technologies for various applications, including industry and energy.
- Circular Bio-based Europe: Promoting the development of sustainable bio-based industries.

These partnerships and programs demonstrate the EU's commitment to foster innovation in sustainable industrial practices and clean energy technologies.

2.4.2 India

India's collaboration with the EU is primarily structured through the India-EU Trade and Technology Council (TTC). The TTC, established in 2022, serves as a platform for coordinating political and technical efforts to advance cooperation in digital technologies, green energy, and trade resilience. It operates through three Working Groups, each focusing on specific areas of collaboration. The relevant one in relation to INPACE Cluster 2 are :

- Working Group 1: Strategic Technologies, Digital Governance and Digital Connectivity
    - Responsible AI development, coordinating within the Global Partnership on Artificial Intelligence (GPAI)
    - Promoting interoperable IT and telecom standards
    - Enhancing Digital Public Infrastructure (DPI)
    - Advancing secure, privacy-preserving solutions for developing countries
- Working Group 2: Green and Clean Energy Technologies
    - Renewable and Low Carbon Hydrogen

    - Electric Vehicle Batteries
    - Standards development
    - Wastewater treatment and waste-to-energy projects
    - Marine plastic pollution mitigation
    - Battery circularity and raw material recovery
- Working Group 3: Trade, Investment and Resilient Value Chains
    - Establishing principles for resilient value chains

2.4.3 Japan

Japan's approach to research and innovation in areas relevant to Cluster 2 is primarily driven by two key programs:

2.4.3.1 Strategic Innovation Promotion Program (SIP)

The SIP promotes interdisciplinary research and development covering fundamental studies to industrial applications. It identifies 12 key areas crucial for Japan's economic resurgence, including:

- Big-data and AI-enabled Cyberspace Technologies
- Intelligent Knowledge Processing Infrastructure
- Cyber Physical Security for IoT Society
- Materials Integration for Revolutionary Design System of Structural Materials
- Photonics and Quantum Technology for Society 5.0
- Energy System for an IoE Society
- Smart Logistics Services

With a total budget of approximately 180 million euros in 2023, the SIP supports programs in competitive research funding system, fostering industry-academia-government cooperation.

2.4.3.2 BRIDGE Program

The BRIDGE program focuses on implementing and accelerating government policies in areas where public and private R&D investment is expected to expand. It emphasizes environmental and health-related topics, with a total budget of approximately 60 million euros in 2023.

Japan's initiatives in robotics and AI align closely with those of the EU, with a particular focus on collaborative robotics and the development of safe AI in technical applications.

2.4.4 Republic of Korea

South Korea places a strong emphasis on trusted AI across all fields of application. The country's initiatives in robotics and AI align closely with those of the EU, Japan, and Singapore, focusing on:

- Collaborative robotics development
- Safe AI implementation in technical applications
- Advanced manufacturing technologies
- Smart city solutions

While specific program details are not provided in the search results, it's evident that South Korea is actively pursuing digital transformation in industries and urban environments, with a particular focus on ensuring the reliability and safety of AI systems.

2.4.5 Singapore

Singapore's approach to research and innovation in areas relevant to Cluster 2 is outlined in its RIE 2025 plan. This comprehensive plan is organized along four strategic domains:

1. Manufacturing, trade and connectivity
2. Human health and potential
3. Urban solutions and sustainability
4. Smart nation and digital economy

The plan encompasses various ICT projects with the ultimate objective of establishing the country's ambition as a Smart Nation. Key initiatives and programs include:

2.4.5.1 AI Singapore (AISG)

AISG is a national program launched by the National Research Foundation to enhance Singapore's capabilities in artificial intelligence. Notable initiatives under AISG include:

- 100 Experiments (100E): This initiative aims to solve industry AI problems and help organizations build their own AI teams.
- AI Grand Challenges: These open-ended, outcome-driven challenges address important issues faced by Singapore and the world that can be effectively addressed with AI technologies and innovations. Current grand challenges include:
    - AI for Materials Discovery
    - Robust AI Grand Challenge
    - AI in Education Grand Challenge
    - AI in Health Grand Challenge

2.4.5.2 Centre for Advanced Robotics Technology Innovation (CARTIN)

CARTIN focuses on developing game-changing, affordable, safe, and user-friendly robotics technologies for various sectors, including logistics, manufacturing, and eldercare.

2.4.5.3 Renewable Energy and Energy Efficiency Initiatives

Singapore has allocated an estimated 20 billion dollars for renewable energy and energy efficiency initiatives, sourced via government agencies and companies like Sembcorp Industries and SP Group. Key focus areas include:

- Improving energy management systems empowered by IoT and AI to balance electricity supply and demand efficiently
- Integrating solar energy into the national grid
- Developing floating solar farms, such as the Tengeh Reservoir Solar Farm, which employ AI to manage energy efficiency

These initiatives demonstrate Singapore's commitment to sustainable urban development and digital transformation across various sectors.

3 CLUSTER 3. DIGITAL TECHNOLOGIES - TRUSTWORTHY DECISION SUPPORT

Cluster 3 focusses on Digital Technologies for Trustworthy Decision Support. The Cluster examines how AI technologies can be developed so that they can be trusted and adopted by citizens and the industry in the EU and its partner Indo-Pacific countries. The Cluster is composed of 3 working groups: TWG 8: Trusted AI which focuses on methods and tools to develop trustworthy AI models; TWG 9: Data Technologies, which focuses on how to generate and make available data needed for the training, testing and operation of trustworthy AI models and systems; and TWG 10: HPC, which focusses on the HPC computing infrastructure needed for the development, testing and operation of AI models and systems. In the following, a comprehensive overview of the various aspects of these TWGs will be presented to explore the collaborative opportunities between the EU and its Digital Partnerships' countries.

3.1 TRUSTED AI

AI systems are "software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems). The ambition is to foster, leverage and support such AI solutions that are human-centered, trustworthy and explainable, through strategic partnership of mutual interest and benefit between EU and Indo-Pacific area. Experts of TWG 8 have started discussion on research challenges of interest in the field of Trustworthy AI, which are presented below.

3.1.1 Explainable AI (xAI)

xAI pertains to the ability of AI models to generate explanations for their conclusion, for the chain-of-thought they followed, and for exploring why a certain output was obtained instead of another. Explainability enhances transparency and engenders trust. Nevertheless, not only are many of the most successful AI models to date completely opaque, but also existing methods for generating accurate and informative explanations tend to compromise the accuracy or the efficiency of the underlying model.

3.1.2 Neurosymbolic AI

Research in neurosymbolic AI methods tries to find a principled approach to combining reasoning and learning, by coupling knowledge-based formal representations with sub-symbolic data-driven models. Such hybrid approaches aim to balance interpretability and predictability to promote trustworthiness and verification. They will be of particular value for providing the guarantees needed by the upcoming AI regulations. It is noteworthy that research in this direction was mainly driven by European research groups, before starting to get global recognition over the last few years.

3.1.3 Safe and low-carbon AI on the edge

Although the global trend is to rely heavily on huge AI models requiring enormous HPCs and cloud-computing infrastructures, which Europe intends to follow but can hardly play a leading role, an alternative direction has recently obtained gravity among European policy makers, which concerns the support for safe and low-carbon AI on the Edge. Edge AI involves running models on local devices with edge computing capacity. This direction serves much better the commitment of Europe in principles, such as privacy, trustworthiness and reduced carbon footprint.

3.1.4 Commonsense AI

Modern intelligent systems are affecting our everyday lives at an increasing pace. Future intelligent machines, as they increasingly engage with non-expert human users in long-living interactions, will need to exhibit capabilities that are not only effective, but also closer to human intuition and intellect. To achieve a reliable human-machine symbiotic collaboration, AI systems need, among others, to present progress in obtaining a general understanding of how the world works, and in the exploitation of commonsense knowledge that is hidden, yet pervasive, in most human-to-human interactions. Failing to accomplish this will cause the non-expert users to experience interactions with intelligent entities that will feel unnatural, leading steadily to the loss of trust in the underlying systems. Empowering AI systems with commonsense reasoning capacities constitutes a step towards more cognition-empowered intelligent systems that have stronger perception, learning and self-awareness abilities.

3.1.5 Fair and Accountable AI

We live in an information age where most of our information and communication needs are satisfied by on-line systems like search engines, social networks and news portals. These platforms use sophisticated Machine-, Deep-Learning, and AI algorithms for filtering, ranking, recommendation, and automated text generation purposes to satisfy their users, shaping their opinions and guiding their decisions on everyday matters. At the same time, the users not only consume, but also produce information through the content they contribute, as well as the relationships they form, the choices they make, and the actions they take. The data are then used to fuel and train the algorithms in an iterative process. However, this virtuous circle can break due to the presence of bias in the behavior of human users and in the decisions of the deployed algorithms and models. Human biases produce biased training data, while algorithmic biases reinforce the input biases and expose them to the users. Research in Fair and Accountable AI aims to define the notions of fairness and bias for different AI algorithms and measure them in practice, including human biases that emerge in social networks. The goal is to provide a formal way to measure the systemic and human biases in the different parts of the process, model their emergence, and propose algorithmic techniques for alleviating their effect in different stages of the pipelines. This will result in the deployment of algorithms that have measurable guarantees about the fairness or bias of their results.

3.1.6 Human-Machine Symbiotic Collaboration

The tremendous progress of AI technologies over the last years is already transforming almost every aspect of the life of citizens, especially in developed countries, and there seems to be no doubt that it will continue to impact society at an increasing pace. Non-expert humans are not only using intelligent autonomous machines but are progressively becoming dependent on them to perform even simple everyday tasks. Almost without noticing, intelligent systems are obtaining new roles as our assistants, our companions, and soon our long-living -virtual or even physical- friends. The challenges from the symbiosis of humans with intelligent autonomous systems are too important to ignore, introducing societal, economical, cognitive, and of course technological aspects to consider. The latest wave of progress in AI foreshadows the kind of achievements we anticipate experiencing in the future. By 2030, strong symbiotic relationships will not be uncommon; yet, without proper consideration, the interactions will not meet the desirable standards. Future human-machine symbiotic environments need to be built on top of responsible technologies and ethical values, in order to be reliable, trustworthy, safe, harmonious, and closer to human intuition and intellect. Research excellence for promoting ethical and trustworthy human-machine collaboration will have strong impact both on the individual and at a societal scale.

The symbiosis among humans and machines has and will increasingly have several incarnations in different forms of environments, ranging from industrial settings to homes, offices, autonomous vehicles, healthcare organizations and all forms of service provisioning. The pervasive nature of AI-enhanced systems renders the topics listed in section 1 particularly important.

3.2 DATA TECHNOLOGIES

AI systems are driven by complex mathematical models trained on data. Hence, data is a critical component of materialising AI systems and building high-performance, robust and accurate data-driven AI systems relies on wider availability of high-quality data, across sectors and across regions. The TWG 9: Data Technologies plans to focus on the development of trusted data sharing between the EU and the Indo-Pacific countries to enable new data value chain opportunities, building upon existing initiatives and investments.

Based on the European data strategy (February 2020), a data infrastructure named Common European Data Spaces has been defined to make high-quality data available for access and reuse in a trustworthy and secure environment. Data Spaces provide a data sovereign, interoperable and trustworthy data sharing environment that enables data reuse within and across sectors, fully respecting EU values, and supporting the European economy and society. European Data Spaces are for the benefit of AI technology implementors as they can provide high-quality data for the training and testing of sector specific as well as general-purpose AI models.

The Data Spaces Support Centre, DSSC, is an effort funded by the EC, to support the successful implementation of European Data Spaces. The Data Spaces Support Centre establishes best practices to accelerate the formation of sovereign data spaces as a crucial element of AI models and systems development. Common European Data Spaces were created in several strategic fields: health, agriculture, manufacturing, energy, mobility, financial, public administration, skills, the European Open Science Cloud, the green deal, media and cultural heritage. The created Common European Data Spaces will gradually be interconnected to form the European single market for data. Interoperating between European Data Spaces as well as between EU's partnering countries will extend the size and reach of the European data market.

There are, however, important business, organisational and legal constraints that can block the realisation of Data Spaces, such as:

- the lack of motivation to share data due to ownership concerns;
- the risk of losing control of the shared data to competition;
- lack of trust between the sharing parties;
- lack of understanding of the sharing potential of data;
- the lack of data valuation standards in marketplaces;
- the legal blocks to the free-flow of data and the uncertainty around data policies between different regions.

In addition, experts of TWG 9 have identified significant technical challenges which have a direct impact on the data made available for sharing, such as data interoperability, data verification and provenance support, data quality and accuracy, decentralised data sharing and processing architectures, and maturity and uptake of privacy-preserving technologies for big data. There are also research challenges in the alignment and integration of data sharing technologies and solutions between different architectures and governance models that unlock data across the data sharing ecosystems of the EU and its Indo-Pacific partnering countries. Experts of TWG 9 will look at such challenges so that AI-enhanced digital services that make analysis and predictions on cross-regional data will be enabled. This will give way to new business models that help to exploit the value of data assets of participating stakeholders including industry, local, national authorities, institutions, research entities and even private individuals of both the EU and the Indo-Pacific regions.

3.3 HIGH PERFORMANCE COMPUTING

High Performance Computing (HPC) plays a central role in addressing complex computational challenges across various sectors, aligning with the strategic priorities of INPACE. Within INPACE Cluster 3, the INPACE TWG 10 HPC is focused on leveraging HPC to address key issues across academic research, industry, and manufacturing, driving innovation and progress in these areas.

3.3.1 Energy Consumption Optimization

Energy consumption has become a critical challenge in the HPC field, as increasing computational demands, particularly with the rise of quantum computing and AI technologies, are rapidly outpacing energy production capabilities. This creates significant concerns for sustainability and operational costs. To tackle this issue, several solutions can be pursued: One key approach is to integrate machine learning and evolutionary algorithms to optimize task scheduling, ensuring energy efficiency. Additionally, advancements in processor architecture and disk storage systems can help reduce overall energy consumption. A further step involves encouraging the shift towards renewable energy sources to power HPC systems, while also exploring the use of natural cooling solutions, such as cold-air cooling, to minimize energy requirements for system cooling.

3.3.2 Quantum HPC Integration

The integration of quantum computing with traditional HPC systems is both a challenge and an opportunity. This integration aligns with INPACE’s commitment to advancing digital technologies and enabling cutting-edge innovations. To achieve successful quantum-HPC convergence, it’s crucial to first identify gaps in current infrastructure and identify the corresponding quantum solutions. Once these gaps are addressed, the next step is to design and implement quantum-based solutions that complement existing HPC frameworks. Additionally, a hybrid approach, combining quantum and classical computing, must be developed to effectively address a broader range of computational problems. The ultimate goal is to enable a seamless integration between quantum and classical computing systems, paving the way for fault-tolerant quantum computing that can significantly enhance computational capabilities.

3.3.3 HPC Applications in Key Sectors

HPC is making a profound impact across a variety of industries, driving advancements in several key areas.

3.3.3.1 Healthcare and Genomics

In healthcare, HPC is crucial for accelerating early disease detection and advancing preventive healthcare measures. It is also enabling rapid genomic sequencing, which is pivotal for personalized medicine, as well as expediting vaccine development processes, particularly in response to emerging health threats.

3.3.3.2 Drug Design and Discovery

In drug design, HPC is revolutionizing the field by enabling virtual screening, which helps identify promising drug candidates more efficiently. It also facilitates drug repurposing efforts, speeding up the process of finding new uses for existing drugs. Additionally, HPC is essential for simulating complex molecular dynamics, providing deeper insights into how drugs interact at the molecular level.

3.3.3.3 Autonomous Vehicle Innovation

The rise of autonomous vehicles has led to an increasing demand for HPC to process the vast amounts of data generated by sensors and other systems. HPC is also crucial in validating perception models and refining decision-making algorithms, ensuring that autonomous vehicles can operate safely and efficiently. Additionally, HPC plays a key role in simulating crash scenarios, improving vehicle safety systems like airbags and crash avoidance mechanisms.

3.3.3.4 Environmental Pollution Monitoring

HPC is instrumental in enhancing weather forecasting and environmental monitoring, enabling more accurate predictions of weather patterns and tracking pollution levels. These capabilities support better urban planning, including optimizing public transportation systems, and help create more sustainable, livable cities. Furthermore, HPC is used to simulate and model urban environments, aiding in pollution control strategies and the design of greener cities.

3.3.4 General research challenges

In addition to energy consumption optimization and seamless integration of quantum computing with classical HPC infrastructures listed earlier, there exist research challenges common to these application areas, which sometime coincide with one from other INPACE TWGs.

First, the ability to process and analyze massive, multidimensional datasets at high speeds is a fundamental requirement for many sectorial applications. This necessitates the development of efficient parallel computing algorithms, the enhancement of real-time data processing capabilities, and the improvement of data storage and retrieval systems.

Security and privacy considerations are particularly critical in domains such as healthcare and financial services, where the integrity of sensitive data must be preserved while leveraging HPC capabilities. Ensuring robust security frameworks and compliance with data protection regulations remains a pressing research focus.

Equally important is the challenge of scalability and accessibility. Expanding the availability of HPC resources to a broader range of industries and research domains, especially for small and medium-sized enterprises, is essential for fostering innovation and maximizing the societal benefits of advanced computing technologies.

Interdisciplinary collaboration plays a vital role in tailoring HPC solutions to sector-specific needs. Strengthening the synergy between HPC experts and domain specialists will drive innovation in areas such as drug discovery, autonomous systems, and climate modeling. In this regard, algorithm development remains a cornerstone, requiring continuous refinement to optimize computational efficiency for diverse applications.

3.4 COUNTRY-SPECIFIC INITIATIVES AND COLLABORATIONS

3.4.1 European Union

The EC-funded R&D Programmes are the main funding mechanisms for collaborative research. In addition, there exist national R&D Programmes of EU states that encourage bilateral projects with countries of the Indo-Pacific, such as the [Data Economy - Business Finland] Programme. In addition, the European Digital Infrastructure Consortium, (EDIC), is a legal framework aiding Member States to set up and implement multi-country projects. Also, "Important Projects of Common European Interest", (IPCEI), constitutes a key strategic instrument regarding the implementation of the European Union Industrial Strategy.

Common European Data Spaces have been created in several strategic fields via the Digital Europe Programme: health, agriculture, manufacturing, energy, mobility, financial, public administration, skills, the European Open Science Cloud, the green deal, media and cultural heritage.

Examples of key initiatives within the EU framework include:

- **Big Data Value Association** (BDVA), an industry-driven research and innovation association with a mission to develop an innovation ecosystem that enables the data-driven and AI-driven digital transformation of the economy and society in Europe
- **AI, Data and Robotics Partnership** (ADRA), the European focal point for AI, Data and Robotics, and the entry point for organisations willing to collaborate and shape directly with the European Commission the direction these three domains of application will take.
- **European Alliance on Industrial data, Edge and Cloud**, open to businesses, representatives of EU countries and relevant experts, facilitated by the EC, and fostering the development and deployment of the next-generation cloud and edge capacities for the public and private sectors.
- **GAIA-X**, that has the mission to create the de facto standard to enable federated and trusted data and infrastructure ecosystems, by developing a set of specifications, rules, policies, and a verification framework
- **International Data Spaces Association** (IDSA), a non-profit organisation committed to establishing standards for data spaces, ensuring secure data sharing between participants while supporting trust and data sovereignty

The European Union has made significant strides in high-performance computing (HPC) through the EuroHPC Joint Undertaking. Launched in 2018, this initiative has established a network of supercomputers across six Member States, with three of these machines ranking among the top ten globally. The EU is planning to further expand its HPC capabilities with the introduction of two exascale computers in the near future. This infrastructure, initially focused on scientific research, is now being gradually opened to AI startups, SMEs, and the broader AI community to support training and algorithmic development of AI models

3.4.2 Republic of Korea

The Republic of Korea is renowned for its high level of innovation, ranking sixth in the Global Innovation Index 2022, and invests heavily in R&D, particularly in AI. The Republic of Korea has a highly educated workforce, with a strong emphasis on science and engineering, making it a top contender in AI talent globally.

The budget for R&D across all ministries was 26.5 trillion won in 2024 and the budget approved for Ministry of Science and ICT (MSIT) was 18.6 trillion won. The funding Programmes of the Ministry of Science and ICT (MSIT) aim to identify new businesses and services that can drive economic growth and job creation through AI and digital innovation. Also, MSIT funding Programmes aim at creating an inclusive AI and digital society, ensuring that people from anywhere in the country can benefit from AI and digital technologies.

The Republic of Korea's initiatives in HPC are not explicitly detailed in the search results. However, given the country's focus on advanced manufacturing technologies and smart city solutions, it is likely that HPC plays a crucial role in these endeavors. The emphasis on safe AI implementation in technical applications also suggests a need for significant computational resources, which HPC can provide.

3.4.3 Singapore

The ICT R&D Programme of Singapore is focused on the Digital Economy and Smart Nation. This is a program that supports the development of technologies that align with Singapore's vision of becoming a Smart Nation. This includes AI, cybersecurity, IoT (Internet of Things), and data analytics.

Singapore's government allocates significant funding to ICT R&D through its Research, Innovation, and Enterprise (RIE) Plans. These plans outline the strategic direction for research and development across various sectors, with ICT being a major focus.

Additionally, agencies like the National Research Foundation (NRF) and the Infocomm Media Development Authority (IMDA) play key roles in driving ICT R&D by providing grants, infrastructure, and support to research institutions, universities, and private companies. Other national funding mechanisms include the Ministry of Digital Development and Information (MDDI), the Cyber Security Agency (CSA), the Smart Nation and Digital Government Office (SNDGO), and the Agency for Science, Technology and Research (A*STAR).

Singapore's approach to HPC is likely encompassed within its RIE 2025 plan, particularly under the "Smart nation and digital economy" domain. Initiatives like AI Singapore (AISG) and its AI Grand Challenges in areas such as materials discovery and health suggest a need for substantial computing power.

3.4.4 Japan

There are several entities in Japan that fund research activities. These include JSPS which mainly funds Curiosity Driven / Bottom-up research, AMED that funds medical research, NEDO which is driven by industrial demand and JST.

Japan Science and Technology (JST) Agency is one of the main actors in promoting science and technology by implementing ambitious projects in collaboration with universities, research institutions and industry in Japan and overseas. These projects involve both basic and applied research following Japan's National Strategy. There is a variety of programs within JST focusing on different aspects, including the Strategic Basic Research Programs (SBRP) and the International Collaboration Programmes (SICORP, SATREPS and ASPIRE). The landscape is quite complex as it involves several ministries and other bodies.

Within ICTs, the CREST programme funds collaborative research in several areas including Mathematical Foundations, Computing Foundations, Trusted Quality AI systems and Symbiotic Interaction.

In terms of international collaboration, SBRP and SICORP provide opportunities such as the appointment of international advisors, cooperation with overseas funding agencies, joint symposia and research exchanges. SICORP funds joint research between Japan and developed / developing countries on an equal partnership basis. Specific actions include Bilateral or Multi-lateral cooperation, and collaboration hubs. SATREPS focuses on joint research with developing countries towards the goal of resolving global issues. ASPIRE aims to stimulate international researcher mobility and international networks for cutting-edge research with specific actions targeting young researchers.

Japan's ICT R&D scene is fueled by both government and private investment. Total expenditure on R&D during fiscal year (FY) 2022 reached a record high of 20.70 trillion yen, reflecting a 4.9% increase from the previous year. Japan remains well-positioned to be a global leader in ICT, with exciting opportunities in the AI area.

National funding agencies include the National Institute of Information and Communications Technology (NICT), the Council for Science, Technology and Innovation (CSTI), the New Energy and Industrial Technology Development Organization, the Japan Science and Technology Agency, the

National Agriculture and Food Research Organization and the Japan Agency for Medical Research and Development

On the European side, besides bi-lateral cooperation agreements between Japan and European countries (e.g., France, Germany), the opportunities for collaboration with Japan are summarized in the attached document of the European Commission. Moreover, collaborative mechanism between the EU and Japan includes the participation of Japan in the Coordinated Joint Calls of EC R&D Programmes. Also, the researcher's mobility under European Research Council (ERC) - Japan Society for the Promotion of Science (JSPS) and Marie Sklodowska-Curie Actions scheme (MSCA). Also, cooperation for projects between Japan and several European countries (target countries in Europe are France, Germany, Spain and Turkey) are supported under the programme EIG CONCERT-Japan.

Japan's approach to HPC is integrated within its Strategic Innovation Promotion Program (SIP). The program's focus on "Big-data and AI-enabled Cyberspace Technologies" and "Intelligent Knowledge Processing Infrastructure" suggests a strong emphasis on advanced computing capabilities. These areas inherently require substantial computational power, indicating Japan's commitment to developing and utilizing HPC resources for cutting-edge research and innovation.

3.4.5 India

India has launched AI mission in 2024 towards encouraging the Development of Artificial intelligence in India. The India AI Mission aims to build a comprehensive ecosystem that fosters AI innovation by democratizing computing access, enhancing data quality, developing indigenous AI capabilities, attracting top AI talent, enabling industry collaboration, providing startup risk capital, ensuring socially impactful AI projects, and promoting ethical AI. This mission drives responsible and inclusive growth of India's AI ecosystem. One important pillar of this mission is Safe & Trusted AI. This new strategy strives to systematically increase India's research and development (R&D) expenditures, which remains less than one percent of its GDP, considerably lower than the world average of about 2.2%. The low participation of corporates in Indian R&D has indeed been recognized as a major challenge in the country's innovation landscape.

The Safe and Trusted AI pillar focuses on ensuring the responsible development, deployment, and adoption of AI. It aims to design and develop adequate guardrails for the above.

- Implementing Responsible AI projects
- Developing indigenous tools and frameworks
- Creating self-assessment checklists for innovators
- Establishing guidelines and governance frameworks

Several Indian Universities are working on Trusted and Responsible AI. Some of these are IIT Kharagpur, IIT Madras, IIT Delhi and IIIT Delhi.

The Global Partnership on Artificial Intelligence (GPAI) Summit 2023, hosted by India, focused on responsible AI development and deployment. Key outcomes included discussions on AI's potential to address global challenges, the importance of inclusive AI development, and the need for robust AI governance. India's leadership in GPAI aims to shape the future of AI for the benefit of humanity.

IIT Madras has a Centre for Responsible AI to to promote research in the domains of Ethical and Responsible AI. The major themes are Explainable and Interpretable AI to make AI understandable. Ai and Safety focuses on aspects such as data privacy, security, data consent, data anonymization, adversarial robustness, performance guarantees, model monitoring and maintenance. There is also an emphasis on the societal aspects of AI models such as Fairness and Ethics.

IIT Kharagpur has several researchers working on trusted and explainable AI. There are funded projects on Controlled Ethical Content Generation Through Safety Alignment and Model Arithmetic to address the vulnerabilities of large language models and multimodal systems in generating ethical content. Another project focuses on building responsible image and text processing tools with applications to face recognition system, and automatic speech recognition by developing diverse large-scale datasets, audits of existing systems and mitigation strategies to address bias.

Eight Responsible AI projects were chosen for funding in the first call under the Safe and Trusted AI Pillar of the IndiaAI Mission. The initial projects funded include topics such as Machine Unlearning in Generative Foundation Models, Synthetic Data Generation for mitigating bias in datasets, AI Bias Mitigation, AI Ethical certification Frameworks, Explainable and Privacy preserving AI, AI Governance Testing, and Algorithm Auditing Tools. These projects are granted to several institutions such as IIT Jodhpur, IIT Roorkee, NIT Raipur, DIAT Pune, IIT Delhi, IIIT Delhi, IIT Dharwad, Amrita Vishwa Vidyapeetham.

The Prime Minister's Science, Technology, and Innovation Advisory Council (PM-STIAC) is a high-level advisory body that provides strategic direction on science, technology, and innovation (STI) matters. It has approved several important missions, including the AI Mission which focuses on Artificial Intelligence to solve complex societal problems. The AI Mission focuses on sectors like healthcare, education, agriculture, smart cities, mobility, and infrastructure. Additionally, the Ministry of Electronics and Information Technology (MeitY) is the central authority in India responsible for shaping and implementing policies related to Information and Communication Technology (ICT).

Three leading companies from the Information, Communication, and Technology (ICT) sector—Tata Consultancy Services (TCS), HCL Technologies, and Infosys—are among the top 20 R&D spenders in India focusing on responsible AI.

The Ministry of Electronics and Information Technology (MeitY) offers regular calls for EU-India joint research proposals in HPC to develop integrated early warning systems to address cascade effects in multi-hazard scenarios. The intended proposals are prioritized based on the target applications and their relevance in the European and Indian perspectives.

The EU and India also organize joint workshops and conferences to foster collaboration in advanced computing technologies. These events provide a platform for researchers and industry experts to exchange ideas and start new cooperative projects.

Finally, the EU-India Joint Research and Development (R&D) initiatives under the EU's Horizon Europe program are aimed at strengthening partnerships in artificial intelligence, fostering innovation, and addressing global challenges.

4 CLUSTER 4. ENABLING TECHNOLOGIES - CHIPS FOR THE FUTURE

International cooperation in the semiconductor field is key for the Chips of the future, and could contribute to speed up technological innovation, reduce cost by avoiding duplicated research, and strengthen complex value chains. These international cooperations are supported by the new strategies of leading semiconductor countries in EU and Indo-Pacific. This cluster 4 is indeed in line with the semiconductor areas of the Digital Partnerships with Japan, ROK, Singapore and the Trade and Technology Council with India. Possible areas of cooperation in Cluster 4 cover the main enabling technologies, from materials to systems, in the field of More Moore, More than Moore, Beyond-CMOS, New computing architectures, Heterogeneous integration and Packaging, and Sustainable electronics. These international cooperations will lead to overcome the following main challenges in the semiconductor area, which are summarized below.

4.1 MAIN CHALLENGES AND POSSIBLE SOLUTIONS IN THE SEMICONDUTOR AREA

4.1.1 Advanced Computing Challenges and Possible Solutions :

The main challenges and possible solution in this area are the following:

- Ground rule scaling is expected to slow down and saturate around 2028. Extreme-ultraviolet (EUV) technology will be the enabler of ground rule scaling while keeping the cost under control and providing process complexity reduction. Transition to 3D integration and use of beyond CMOS devices for complementary System-on-Chip (SoC) functions are projected after 2028.

- Ground-rule scaling needs to be accompanied with the design-technology-co-optimization (DTCO) constructs that accommodate the area reduction as well as tightening the critical design rules that limit the overall SoC area scaling.

- GAA (Gate-All-Around) devices (Nanosheets, CFET, etc.) are expected to become a mainstream device in 2025 and requires significant attention on the capacitance reduction to maintain performance scaling target.

- A main challenge in 3D integration is how to partition the system to produce better utilization of devices, interconnect, and sub-systems such as memory, analog, and input/output.

- Parasitics improvement will become a major knob for performance improvement, such as with the introduction of low-κ device spacer.

- 2D material channels are gaining importance complementing the Si channels but are likely to be introduced after 2030 since those did not reach manufacturing maturity.

- It becomes increasingly difficult to control interconnect resistance, electromigration, and time-dependent-dielectric-breakdown limits. Interconnect resistance has now entered an exponential increase regime because of non-ideal scaling of barriers for Cu bringing less metallization volume and increased scattering at the surface and grain-boundary interfaces. Therefore, there is a need for new barrier materials, atomic layer deposition (ALD) based barrier deposition, and/or high aspect-ratio non-Cu metallization solutions, with the latter using direct metal etch. In addition to the resistance scalability, TDDB is putting a limit on the minimum space between the adjacent lines for a given low-κ dielectric, forcing a slow-down in the permittivity (κ-value) scaling and forces introduction of air-gap in tight-pitch metals to cope with the capacitance at high aspect-ratio local interconnect.

- Power density poses a significant challenge for scaling, particularly because of 3D integration after 2031. Therefore, it is necessary to factor in thermal considerations in devices and architectures.

- Energy per switching reduction significantly slowed down because of a slow-down in capacitance and supply voltage reduction. Solutions need to be proposed for this major challenge of future electronic systems.

- DRAM needs to maintain sufficient storage capacitance and adequate cell transistor performance is required to keep the retention time characteristic in the future

- 2D Flash memory density cannot be increased indefinitely by continued scaling of charge-based devices because of controllability limits of threshold voltage distribution. Flash density increase will continue by stacking memory layers vertically, leading to the strengthening of 3D Flash technology.

- Ferroelectric RAM (FeRAM) is a fast, low power, and low voltage non-volatile memory (NVM) alternative and thus is suitable for radio frequency identification (RFID), smart card, ID card, and other embedded applications. Processing difficulty limits its wider adoption. Recently, HfO2-based ferroelectric field-effect transistor (FET), for which the ferroelectricity serves to change the threshold voltage (Vt) of the FET and thus can form a 1T cell like Flash, has been proposed. If developed to maturity, this may serve as a low-power and fast, Flash-like memory.

- STT-MRAM is now mostly considered not as a standalone memory but an embedded memory. STT-MRAM would also be a potential solution for embedded Flash (NOR) replacement. This may be particularly interesting for low-power IoT applications.

- High-density resistive RAM (ReRAM) development has been limited from the lack of a good selector device, since simple diodes have limited operation ranges. Recent advances in SCM memories, however, seem to have solved this bottleneck and ReRAM could make rapid progress if other technical issues, such as erratic bits, are solved.

- PCM provides a good scaling trajectory overcoming the burdens such as high variability in RRAM and low Ron/Roff ratios in MRAM.

- More convergence of embedded memories with computing is expected giving the performance and energy losses by moving data from/to the memory to/from the compute, which is the so-called memory-wall problem. This will bring in compute-in-memory (CIM) and compute-near-memory (CNM) arrays to evolve for AI applications. CIM/CNM arrays will take advantage in DRAM for high-performance AI computing and in embedded NVM devices that could be integrated in the BEOL stack bringing a better area footprint for improvement of the TOPS/mm2 metric.

4.1.2 Advanced functionalities Challenges and Possible Solutions:

Advanced functionalities for future electronic systems cover the following areas: Smart sensors, Smart energy, Energy harvesting, Wearable and flexible electronics.

4.1.2.1 Main challenges and possible solution for Smart Sensors:

The main challenges for future sensors, covering Motion Sensors, Pressure Sensors, Advanced Drive Assistance Systems, Environmental Sensors, Agri-food *Sensors*, Sensors for Medical and Healthcare Applications, Molecular Diagnostics, Native CMOS-based physical sensor interfaces, Sensors for energy, Sensors for Smart Cities, are mentioned below.

Key challenges remain to develop smart sensor systems that are fit-for-purpose for final deployments. To this end, sensor development, integration and packaging need to be driven by user-specified problem statements. The mains challenges are: improvement in different sensing approaches in terms of sensitivity, selectivity, repeatability, robustness, precision and accuracy, which are key requirements. Edge analytics and AI at the edge will be key, not only to reduce power consumption, but essential to achieve these requirements. Successful translation of emerging research devices and systems from the lab to real world deployments, i.e., increase the technology readiness levels will require investment in new and appropriate infrastructural test-beds and development of an early adopters/social scientist ecosystem.

The use of nanotechnologies is foreseen to increase the performance of all the concepts in general. Flexible and low-cost approaches should be developed, where appropriate, and environmentally benign deployment paradigms such as “Deploy and Forget” of “Deploy and Dissolve” should be explored. Adoption of innovative power management circuits, energy storage and generation, will enhance the efficiency of deployments. While it is accepted that a “one size fits all” approach is not possible, sensor fusion, judicious selection of materials coupled with the most suitable sensing modality and transductions mechanisms coupled with edge analytics will provide a route for future sensing challenges to be successfully addressed. Finally, investigation into disruptive sensing approaches and technologies, such as quantum sensors, must be undertaken to provide solutions to heretofore unanswered challenges.

4.1.2.2 Main challenges and possible solution for Smart Energy

The smart energy domain cover innovative silicon devices (superjunction, IGBT, MOSFETs) and the two main wide bandgap semiconductors, (SiC and GaN) as well as other promising materials like Ga_2O_3, AlN, and diamond. The main challenges deal with : i) materials and processing issues (including device architectures); ii) applications; iii) technology and design challenges, and iv) figures of merit.

Power devices based on wide bandgap semiconductors (WBS) like GaN, SiC, Ga_2O_3, are poised to play an important role in future power electronics systems in addition to Si based workhorse technologies like IGBTs, superjunction MOSFETs, low/medium voltage (trench) MOSFETs and smart power BCD devices. WBS have a high breakdown strength and, in the case of GaN, allows for fabrication of high electron mobility lateral transistors, for which the electron mobility is not degraded as would be the case for traditional silicon MOSFETs. Together, these facts allow the fabrication of devices, which have orders of magnitude better trade-off between the specific on-resistance and the breakdown voltage.

The challenges for the new power devices based on GaN and SiC materials are the following :

-For GaN devices, the sheet resistance to be reduced by adopting highly polarized AlN barriers or by using lattice matched InAlN barriers. Recent work also demonstrated that heterostructures based on alloys of scandium (AlScN/GaN) can benefit of a strong increase of the polarization, leading to much higher 2DEG density in GaN HEMTs. On the other hand, an increased 2DEG density will increase the device capacitance, which is undesirable for switching.

-For SiC devices, It is highly recommended to focus on the growth of thick epitaxial layers with low defect densities and high carrier lifetimes for high-voltage devices, e.g., bipolar devices. To really deal with high voltages, the passivation on chip, e.g., junction termination only or advanced in-chip passivation, as well as in the module for 3D integration has to be addressed. Formation of high-quality SiC/SiO_2 structures by excluding oxidation process with H_2 etching is also reported to achieve low interface state density. It implies to improve the performance of SiC based MOSFETs. Next to the costs and the yield of the SiC devices, the reliability issues have to be addressed. The current devices show a high robustness against voltage and temperature. But to derive adequate reliability and lifetime predictions, novel accelerating lifetime testing and modeling of these devices has to be established. To exploit all the benefits of high-current, high-voltage devices, advanced 3D integration concepts have to be developed.

4.1.2.3 Main challenges and possible solution for Energy Harvesting:

As the communicating systems market is booming, especially with the emergence of the Internet-of-Things (IoT), the role of energy harvesting (EH) will increase commensurately. Indeed, the number of connected devices is planned to increase by a huge factor in the next years.

The main challenges are mentioned below and focus on several promising technologies for EH and power management circuits including photovoltaic cells for outdoor/indoor light EH; thermal energy harvesting; mechanical EH based on three concepts: 1) piezoelectric materials, 2) electrostatic and 3) electromagnetic energy conversion; RF energy harvesting/wireless power transfer; power management circuits, and finally microbatteries and microcapacitors for energy storage.

For vibrational, solar, thermal, RF EH and power management, the improvement of their performance and efficiency is as important as the development of “green” materials, replacing toxic/rare materials used nowadays (lead-based piezoelectrics, Bi2Te 3 for thermoelectrics, rare earth-based magnetic material, e.g., NdFeB, for electromagnetic conversion). Flexible and low-cost approaches for wearable applications (i.e. e-health) should be developed as well. Increasing the bandwidth at a low frequency target will help to fit applications for vibration-based mechanical energy harvesters. Utilizing spin in thermoelectric EHs and other energy conversion systems is the promising and challenging idea. Concerning indoor photovoltaic applications, adapted structures and materials (light intensity and spectra, etc.) should be developed; on the other hand, standard procedures for indoor photovoltaic cells characterization should be defined (light intensity and spectra, direct and diffuse light, temperature, etc.). Intentional far-field RF WPT will exploit the mm-wave band for enhancing rectenna miniaturization and focusing of the energy transfer. Energy storage is required as a hybrid device with the EH options to alleviate any transient effects and assist with higher power operation. There is a need of innovative power management circuits, such as: topologies, impedance matching, cold start, dynamic configuration, storage device interface, etc. It would be key to investigate size reduction of inductors; enhance the efficiency of inductor-less power converter circuit topologies; develop planar alternative to inductors, and tune microelectronic process parameters and technologies to reduce leakage for reduced power consumption and allowing low input voltages. Finally, the comprehensive system design combining all aspects of the fabrication process, harvester structure, power conversion circuits and storage will be the potential solution for increasing the power generation efficiency.

4.1.2.4 Main challenges and possible solution for Wearable and Flexible Electronics:

The field of the flexible, printed and organic electronics has progressed enormously in the last 10-15 years. It is expected that the printed electronics industry will grow substantially in the next years, for future markets such as textiles buildings, notebook computers, transport, health and at home.

Technological improvements are needed in order to increase mobility values and threshold voltage stability in TFTs, reducing the voltage operating range, reducing bias and light stress instability, and reducing the voltage operating range. High-k dielectrics are helpful to reduce the bias operating range. A suitable complementary TFT technology is still a challenge, but can be achieved by using an n-type oxide TFT and a p-type organic TFT. Another possible solution is the control of doping to balance charge transport in complementary circuits.

For biomedical devices, high thermal stability is essential. This is possible in flexible electronics. Indeed, several TFT technologies (including organic ones) already show high thermal stability.

On the other hand, further progress in printed electronics needs better inks in order to achieve higher mobility TFTs with improved uniformity and reliability. A reduction of the costs of inks would also help in the extension of printed electronics applications.

Regarding the growing concerns of e-waste, it is recommended to develop devices in fully biodegradable substrates. Paper as a substrate is a very promising choice.

Other important challenges to be surmounted in organic electronics are the improvement of roll-to-roll processing (which is very much restricted by the substrates) and the improvement of environmental stability, which can be achieved by encapsulation.

Besides, there is still a need for the development of 3D printing electronics with the same precision as 2D printing technology. 3D printing flexible electronics is especially useful in the healthcare sector, where 3D printers can be used for direct printing of biomedical devices onto human skin and can facilitate the manufacturing of flexible electronic sensors of body pressure. 3D printed flexible electronics has also applications in the field of prosthetic organs for the disabled.

Regarding OLEDs, double-doped polymers can lead to an increase of efficiency.

Concerning the extension of organic photovoltaics (OPVs) technologies, efficiency needs to be improved. A 20% efficiency is foreseen, thanks to newly developed polymers with improved solar light absorption and higher mobilities. Also, flexible crystalline organic cells with 19% efficiency have been developed.

Finally, microwave flexible electronics is still a major challenge. It may be surmounted with substrates with high thermal conductivity or single crystalline nanomembranes.

4.1.3 Ground-breaking Technologies Challenges and Possible Solutions:

Dimensional and functional scaling of CMOS is driving information processing technology into a broadening spectrum of new applications. Scaling has enabled many of these applications through increased performance and complexity. As dimensional scaling, performance and power consumption of CMOS will eventually approach fundamental limits, new information processing devices and microarchitectures for both existing and new functions are necessary. This is driving interest in new devices for information processing and memory, new technologies for heterogeneous integration of multiple functions, and new paradigms for system architecture.

The main challenges and possible solutions in this field are the following;

- Exploration of alternative materials for Beyond CMOS Devices (e.g., 2D materials, CNT, Nanowires, (multi)ferroics, magnetic)
- Exploration of very low power devices, e.g. small-slope switches (FeFET, Tunnel FET, NEMS, etc.), spin devices
- Solutions using Beyond CMOS devices for improving Power-Performance-Area-Cost and Environmental Impact
- Added functionality (e.g., near- and in- memory computing, neuromorphic) through the introduction of new materials, novel memories and memristors
- Solid-state devices (e.g., superconducting, semiconducting, photonic) for quantum information processing
- Alternative processing using bottom-up technologies

4.2 STRATEGY, JOINT ACTIVITIES AND PROJECTS BETWEEN EU AND INDO-PACIFIC COUNTRIES

The main strategic objectives, joint projects and activities, cooperation instruments, for EU and India, Japan, ROK and Singapore are summarized below.

4.2.1 European Union

The EU's overall semiconductor (INPACE TWG 11-12-13) ecosystem accounted for 10% of the global semiconductor industry. The global demand for semiconductors is booming. The global semiconductor market has doubled its size in 10 years, from €277 billion in 2012 to €545 billion in 2022. It is also expected to double its size from 2022 to 2032, driven by the numerous innovations in semiconductors driving new applications such as artificial intelligence, big data, etc. and many applications specifically linked with the EU end-user industries such as: edge computing, industry 4.0, automotive ADAS, infotainment, software defined vehicle, etc. The EU semiconductor consumption should therefore also nearly double by 2030, exceeding €80 billion. In 2021, the European Union announced a challenging goal to double its share of global production capacity from 10% in 2021 to 20% by 2030. Considering the expansion of the semiconductor industry worldwide, expected to double its output from 2022 to 2030, this would mean that the EU would have to quadruple its current semiconductor production to reach 20% of global production.

The European Union strategy in the framework of the European Chips Act with its three pillars, is to jointly create a state-of-the-art European chip ecosystem, that includes a world-class research, manufacturing, design and testing capacities, resilience in the semiconductor value chain, and skill development. International cooperation is part of the Chips Act and a key part of European strategy with:

- Exchange Academic knowledge and research in semiconductor technologies in areas of common interest and mutual benefit
- Strengthen the security and resilience of the global semiconductor supply chain
- Explore joint monitoring and effective early warning mechanisms to anticipate periods of crisis

International Partnerships have also been signed:

- Digital Partnerships with Japan (May 22), South-Korea (November 22), Singapore (Feb 23)
- Trade and Technology Council (TTC) with India (Feb 2023)
- Trade and Technology Council (TTC) with US (June 2021)

The *main European Instruments* supporting semiconductor projects are the following:

- Horizon Europe, Pillars 1 (ERC, MSCA, Research Infrastructures), 2 (Cluster Digital-Industry-Space), 3 (EIC Pathfinder, Transition and Accelerator ; EITs Raw Materials and Manufacturing ; EIE)
- Chips Joint Undertaking
- Digital Europe
- Cluster EUREKA Xecs
- EUROSTARS

- ERASMUS+

TWGs 11-12-13 of INPACE Cluster 4 are in line with the semiconductors topics defined in the Partnerships between EU and the 4 Indo-Pacific countries targeted by INPACE.

4.2.2 Japan

Japan is promoting the semiconductor research and development, design and manufacturing, which is one of the important topic for the Digital Partnership between EU and Japan.

The semiconductor industry is critical for the Japanese economy. At the end of the 1980s, the industry accounted for over 50% of world production; however, this figure had fallen to 9% by 2022. Today, the Japanese industry lags behind in terms of technology. Japan is adopting major new industrial policies with the objective of restoring the international competitiveness of its semiconductor industry.

In June 2021, Japan’s Ministry of Economy, Trade, and Industry (METI) announced a core strategy for the nation’s semiconductor and digital industries. The priority was to establish partnerships with the US, with whom Japan has a long-standing historical relationship.

- A partnership with the US aims to design and manufacture next-generation chips. This goal is being pursued through the creation of Rapidus, a consortium of Japanese firms, IBM, and European labs like IMEC, LETI and FhG.

- The development of an R&D center, LSTC (Leading-Edge Semiconductor Technology Center), with support from IBM.

- Subsidies for domestic chip manufacturing, covering 1/3 of the capital costs, are conditioned on a minimum of 10 years of domestic production and prioritization of domestic supply in case of a shortage.

Japan’s effort to reinforce its chipmaking capabilities will also include the "back-end" of the production process—assembly, testing, and, in particular, packaging, which is seen as playing a crucial role in the development of advanced chips. "More than Moore," which refers to innovation beyond Moore's Law, is seen as the greatest opportunity for the Japanese semiconductor industry to regain its leadership.

Some joint EU-Japan calls have been published:

Joint co-funded calls (NMBP 2016) have been launched in the area of Advanced Materials for Power Electronics based on wide bandgap semiconductor devices technology and Innovative and sustainable materials solutions for the substitution of critical raw materials in the electronic power system (TWG 12). A joint call with the Netherlands for research cooperation has also been planned (ASPIRE 2025) in the field of semiconductors, photonics, quantum and neuromorphic technologies (TWG 11-12-13). Another joint call (ASPIRE 2024) between Japan Science and Technology Agency (JST) and Austria, Belgium, Czech Republic, EU, Finland, France, Germany, Italy, Netherlands, Poland, Portugal, Spain, Sweden and Switzerland, has been launched for semiconductor research related to promoting the semiconductor industrial sector (TWG 11-12-13). A NEDO's (New Energy and Industrial Technology Development Organization) "Deep Tech Startup Support Fund/International Joint Research and Development" call was published in 2024, including semiconductors, for cooperation between Japan and Czech Republic, France, Spain, and Netherlands (TWG 11-12-13). From the latest 2nd EU-JAPAN DIGITAL PARTNERSHIP COUNCIL MEETING, some recommendations that might be potentially implemented to nurture EU-Japan digital partnership include a call to strengthen the semiconductor supply chain, invest in digital skills development, and establish digital maturity centers within universities to drive competitiveness and innovation (TWG 11-12-13).

Joint Workshops:

Several joint Workshops in the field of semiconductors (TWG 11-12-13) have been organized, featuring policy and industry sessions with key representatives from the European Commission and Japan:

- April 2023, Grenoble
- January 2024 (Hybrid Workshop)
- July 2424 (Online)

The 2nd Meeting of the EU-Japan Digital Partnership Council was held in Brussels on April 30, 2024:

One of the key deliverable was the implementation of the EU-JP Memorandum of Cooperation on Semiconductors, in particular:

- Establishing a team of experts to develop a collaborative research programme covering sustainable manufacturing, heterogeneous integration and leading-edge production processes (TWG 11-12-13) ;
- Announcing finalisation of an Administrative Arrangement on Public Support Transparency Mechanism.

Detailed topics for the collaborative research programme have been *finalised during online meeting with EU and Japanese experts in July 2024:*

The potential elements for R&I actions on **Sustainable Semiconductor Manufacturing** (TWG 11-12-13) are the following:

- Optimize use of resources (e.g. water, gases, wet chemicals, energy) and processes in production environments with potential in-situ re-use and regeneration of base materials and chemicals.
- Reduce energy consumption (and greenhouse emissions) in cleanrooms using renewable energy sources and energy-efficient technologies or tools.
- Develop alternatives to potentially hazardous materials such as PFAS compounds, reduce use and develop recyclability of PFAS, develop environmental friendly materials, solvents, liquids, strengthen international cooperation on this topic
- Develop open reference databases dedicated to semiconductor materials and components and an associated methodology to allow a common and complete evaluation of the impact due to producing and using ICT which covers all environmental footprint factors, improve them for semiconductor grade materials taking into account purification impacts
- Develop a common methodology for the assessment of sustainable manufacturing, e.g. LCA assessment needs standardization
- Include front-end, back-end and packaging
- Use AI to speed development of possible solutions (e.g. material development)

The potential elements for R&I actions on **Heterogeneous Integration and Packaging** are the following (TWG 11-12-13):

- Wide bandgap devices can operate at higher temperatures, hence packaging to explore higher operational temperature and rad-hard environment is vital for the coming electrification needs and for space and aeronautics.
- Packaging for both quantum and photonics should be explored for co-packaging with electronics. This includes also cryo-packaging.
- Packaging for medical devices is a fast-growing area which should be included. This field should also include biocompatible devices and for flexible systems.
- 2.5D and 3D integration is a very important field and must be a focus area. Included also technology to handle heat dissipation.
- Explore new materials innovation for advanced packaging.
- Ultra-thin wafer and die handling and packaging solutions.
- Simulation / modelling of packaging processes & architectures and co-design methods for chip-package-board including new metrology/inspection methods.

The potential elements for R&I actions on **Cutting-edge process technologies** (Towards 2 nm node) are the following (TWG 11):

- Explorations of the scaled Si technology roadmaps of the 2nm, A14 and A10 nodes including FinFET/Trigate and stacked gate-all-around horizontal or vertical nanowires, A7->A2 nodes (Forksheet, CFET), next generations FDSOI, 3D integration, and further device and pitch scaling where parallel conduction paths (nanowires, nanosheets, nanoribbons, etc.) are brought even closer together.
- To carry out preliminary and assessment studies of these technologies, characterization, metrology, modelling and simulation of advanced technologies and devices are mandatory activities.
- The emergence of new applications like GPUs for machine learning training and inference, augmented and virtual reality (AR/VR) and autonomously driven electric vehicles will need rethinking of conventional architectures. Novel device, circuit, and systems concepts for optimum power, performance, and cost specifications, high-energy efficiency, and novel paradigms such as for near/in-memory, neuromorphic computing and optical interconnects will be critical. The new architectures will need a cross-domain understanding and research into system technology co-optimization.
- New embedded non-volatile memory (eNVM) technologies to enable local AI processing and storage of configuration data, which decrease data transmission volume, energy needs and allow for more efficient control of electric powertrains and batteries, along with many other applications in the IoT and secure devices domains.
- Connectivity solutions like 2.5D and 3D interconnect technologies at tight pitches, Si photonics based optical links at die and wafer level enabled by co-packaged optics and advanced 5G/6G RF technologies will increase system performance beyond conventional scaling of logic and memory.

- Materials and module innovations such as using oxide semiconductors or 2D materials or employing high NA EUV lithography to enable compact and manufacturable devices will be important to keep logic scaling going.
- Circuit and System Design must be “technology aware” (Design Technology Co-Optimization and Packaging-Design Co-Optimization). Success of Fabless companies in the US highlights the importance of complex circuit design.

4.2.3 Republic of Korea

Semiconductors (TWG 11-12-13) are important topics for the Digital Partnership between EU and Republic of Korea (ROK).

Strategic objectives:
South Korea's semiconductor industry is one of the largest in the world, and the country particularly dominates the memory sector. In 2022, semiconductors were crucial to the nation's economy, accounting for 18.7% of its total exports. Samsung Electronics and SK Hynix, leaders in the memory sectors, are now also ambitiously expanding into non-memory semiconductor industries.

In terms of technological advancement, South Korea has begun production of 3nm chips and is on track to develop even more advanced 2nm chips by 2025, followed by 1.4nm chips by 2027. Recognizing the sector's importance, the South Korean government is actively supporting this growth. Initiatives include providing tax incentives and subsidies, as well as establishing training centers to bolster the development of the semiconductor industry.

Despite these advancements, South Korea faces significant challenges in its quest to become the leading global semiconductor powerhouse. Key obstacles include a shortage of skilled talent, the need for more advanced technology, and the localization of semiconductor equipment and materials.

Faced with the high volatility of the memory market, a major challenge for the South Korean semiconductor industry, the government launched the K-Belt Plan in 2022. This comprehensive strategy aims to bolster the industry through several key initiatives:

- Establishment of a 'K-semiconductor belt': The plan envisions creating a geographic cluster dedicated to semiconductor production.
- Doubling the Workforce: A significant focus is placed on expanding the industry's workforce to support growing production needs.
- Investment Tax Credits: The plan introduces tax credits for manufacturing investments to stimulate further growth in the sector.
- R&D Tax Credits: To encourage innovation, the plan offers up to 50% in R&D tax credits.

The Ministry of Science and Information & Communication Technology is fostering leading global technologies in AI semiconductors, compound semiconductors, and advanced packaging.

Joint projects:

The first EU-Korea-Semiconductor Researchers Forum has been organized in Brussels in March 2024, featuring policy and industry sessions with key representatives from the European Commission and ROK.

Following this matchmaking event, the European Union and the Republic of Korea recently supported four jointly funded projects in semiconductors as a deliverable of the EU-Republic of Korea Digital Partnership, in the framework of Chips Joint Undertaking.

The projects will advance heterogeneous integration technologies (TWG 11-12-13) i.e. technologies combining multiple components onto one chip as well as neuromorphic computing technologies (TWG 11-13) i.e. technologies imitating the functioning of the human brain.

These projects will bring together research and innovation partners from both the EU and the Republic of Korea. Their cooperation will involve setting up joint research teams, shared access to cutting-edge facilities and infrastructures, as well as frequent knowledge exchange through workshops, conferences, as well as through the EU-Korea-Semiconductor Researchers Forum – a forum to connect researchers from the EU and the Republic of Korea.

Other Projects and cooperation:

Research and Innovation collaboration is a key component, where both sides engage in joint research activities. This includes leveraging programs like, MSCA, EUREKA, Horizon Europe and Korea's national R&D projects to explore cutting-edge technologies such as semiconductors. Harmonizing standards and aligning policies between the two regions is also an important joint activity.

In the semiconductor industry, there is a concerted effort to enhance transparency and resilience in the supply chain, with cooperation on export controls being a critical area of focus.

4.2.4 Singapore

Semiconductors (TWG 11-12-13) are important topics for the Digital Partnership between EU and Singapore.

Strategic objectives:

Singapore's strategic location, political stability and safe environment have made it a recognized player in the semiconductor industry. The semiconductor industry accounts for 7% of Singapore's GDP.

Singapore has a stable government, business-friendly environment, and comprehensive infrastructure required for semiconductor manufacturing, coupled with strong IP protection and a world-class education system.

As part of its ambitions to expand the manufacturing sector by 50% by 2030, Singapore government aims to further grow its electronics sector, with the semiconductor industry as its backbone. The objective is to ensure Singapore will remain a critical node in the global semiconductor value chain amidst the intensified competition from China and other countries such as Vietnam and Malaysia.

To support the growth in the semiconductor sector, the government has continued to partner key companies across the value chain, many of whom are global leaders in the sector, to invest in leading edge manufacturing capacities and workforce training in Singapore. The government also works with partner manufacturers to conduct complementary activities in Singapore, including in R&D and supply chain management, to diversify their base of activities and deepen their operations here.

A*STAR's Institute of Microelectronics (IME) and I2R are teaming up with local semiconductor component supplier arQana Technologies to develop supporting infrastructure for 5G applications like drone detection radars and satellite communications.

Funded by the European Union

4.2.5 India

Semiconductors (TWG 11-12-13) are important topics for the Trade and Technology Council between EU and India.

Strategic objectives:

India's semiconductor manufacturing, particularly in front-end, is still developing. India's share remains small, but its semiconductor market is estimated to reach €60 Billion by 2026. Semiconductor manufacturing involves complex and capital-intensive processes, and India currently lacks a robust ecosystem for domestic wafer fabrication. The National Policy on Electronics 2019 (NPE 2019) aims to position India as a global hub for Electronics System Design and Manufacturing (ESDM), with strategies to set up semiconductor wafer fabrication facilities. There have been historical challenges in setting up manufacturing fabs units in India for a long time: lack of infrastructure and skilled labor in the country, workforce specialized in design and software aspects, competition with China, Vietnam, etc.

There are also a few initiatives in the field of OSAT. For instance, Sahasra is an OSAT company who intend to package basic memory products like MicroSD cards and chip-on-board, to be followed by advanced packaging of products like internal memory chips. Building OSAT capabilities in India is seen as a key step towards accelerating efforts to establish semiconductor fabs.

India has a strong footprint in semiconductor design, with 20% of the world's semiconductor design engineers and a few startups & academic projects are emerging such as 4G and 5G modem chips, chipsets for defense application, satellite communication and broadcast, open-source IP ecosystem for microprocessors in mobile computing devices.

Despite the thriving design ecosystem and a considerable talent pool, most Intellectual Property (IP) generated is held by foreign companies and India's domestic semiconductor design industry remains weak. The total electronic design market in India is growing rapidly, necessitating the development of domestic semiconductor design capabilities.

India had historically a plan to create a strong semiconductor manufacturing sector with the ambition to have access to advanced technologies and be an important semiconductor hub. However, India failed to convince large companies such as TSMC to set-up operations in the country. The government must now review its ambition and settle less advanced chips manufacturing.

To position India as a global hub for Electronics System Design and Manufacturing (ESDM), the Government of India has approved a comprehensive program for the development of the semiconductor and display manufacturing ecosystem. This program, with an outlay of > €10 billion, includes various schemes to boost investment in semiconductor and display manufacturing.

- Fiscal Support for Semiconductor and Display Fabs
- Support for Compound Semiconductors and OSAT Facilities
- Encouraging Semiconductor Design
- Development of an R&D ecosystem
- India Semiconductor Mission (ISM), which is an independent entity, led by global semiconductor and display industry experts, and has been established to drive long-term strategies for developing a sustainable semiconductor and display ecosystem.

Joint activities:

In November 2023, the signing of a Memorandum of Understanding (MoU) on semiconductors aims to deepen cooperation on the semiconductor ecosystem under the EU-India Trade and Technology Council (TTC). The agreement focuses on strengthening resilience in semiconductor supply chains, promoting research and development, enhancing skills, and ensuring transparency in public subsidies. Both sides will share best practices, collaborate on innovation, and encourage stakeholder engagement, including industry and academic institutions.

The first EU-India Joint Researchers Workshop in the field of semiconductor ecosystem, its supply chain and innovation, has been organized in October 2024. This initiative aims to enhance bilateral cooperation in trade, technology, and innovation. On November 23, 2023, the EU and India finalized a Memorandum of Understanding on deepening collaboration in the semiconductor ecosystem. The workshop focused on topics like "More than Moore" functionalities, heterogeneous integration, sustainable manufacturing, and IC & system design, featuring policy and industry sessions with key representatives from the European Commission and India's Semiconductor Mission.

5 CLUSTER 5. DIGITAL TECHNOLOGIES - FUTURE NETWORKS

Cluster 5 focuses on the integration of three closely related domains: 5G and beyond/6G, cybersecurity, and the emerging cloud-edge-IoT continuum. Each of these domains presents unique challenges that need to be addressed to advance future networks.

5.1 5G AND BEYOND/6G

The development of 5G and beyond/6G technologies is crucial for the future of digital communications. The primary challenges in this domain include the need for global standardization to ensure interoperability across different regions and technologies. This involves the development of comprehensive standards that can be adopted worldwide, facilitating seamless communication and data exchange.

Efficient spectrum management is another critical challenge. As the demand for high-speed, low-latency communication increases, the allocation and management of spectrum resources become increasingly complex. This requires innovative approaches to spectrum sharing and utilization to maximize the efficiency of available resources.

Energy efficiency is also a significant concern. The deployment of 6G networks must prioritize sustainability, reducing the energy consumption of network infrastructure to minimize environmental impact. This involves the development of energy-efficient technologies and practices that can be integrated into the design and operation of 6G networks.

The integration of terrestrial and non-terrestrial networks is essential for providing seamless global coverage. This includes the use of satellite and other non-terrestrial communication technologies to complement terrestrial networks, ensuring connectivity in remote and underserved areas.

Security and privacy are paramount in the development of 6G networks. As the complexity and scale of digital communications increase, so do the potential threats. Robust security measures must be implemented to protect against cyber threats and ensure the privacy of users' data.

Main European initiatives in the field include

- Smart Networks and Services Joint Undertaking (SNS JU)

The SNS JU is a public-private partnership between the European Commission and the 6G Smart Networks and Services Industry Association (6G-IA), focusing on research and innovation towards 6G. The SNS JU has allocated 900 million euros in public funding for the period 2021-2027. The private sector will contribute at least equal resources (i.e., EUR 900 million) to the SNS JU activities. This initiative aims to reinforce European leadership in developing and deploying next-generation network technologies, as well as connected devices and services through an ambitious R&I roadmap and a solid deployment agenda. The SNS JU contributes to the UN's Sustainable Development Goals (SDGs) by promoting sustainable, resilient, and climate-neutral network infrastructures and services.

The SNS JU selected in October 2022 its first portfolio of 35 research, innovation, and trial projects to enable the evolution of 5G ecosystems and promote 6G research in Europe. With a combined funding of around 250 million EUR under Horizon Europe, these projects aim to build a first-class European supply chain for advanced 5G systems and develop Europe's 6G technology capacities. As of 1 January 2024, an additional 27 projects were started with a SNS JU funding of around 139 M€. A further 16 projects were selected and will start on 1. January 2025 with a 127 million EUR funding boost, totaling the public investment in the JU to more than 500 million. The full list of running projects is maintained under the project portfolio web pages of the SNS JU (https://smart-networks.europa.eu/project-portfolio).

The SNS JU technology roadmap is aligned with adjacent fields, such as Microelectronics, Photonics, NTN, Security, Wireless and Cloud/Service Provision, including alignment and synergies with the Microelectronics for Europe and Chips Joint Undertaking, the Photonics Public Private Partnership, and regarding Non-Terrestrial Networks and Space with the European Union's Secure Connectivity Programme (IRIS2) and activities financed by the European Space Agency.

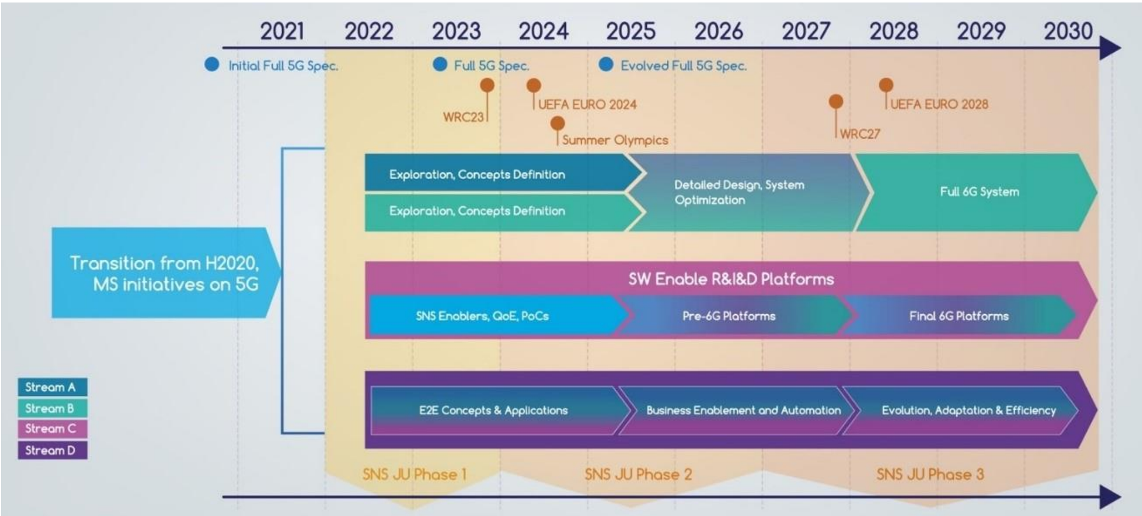

Figure 2: SNS JU roadmap (source SNS JU Work Programme 2025[1])

All SNS JU projects are organised in streams:

- **Stream A** covers smart communication components, systems, and networks for 5G evolution, focusing on advancing the development of 5G technologies and laying the groundwork for future 6G systems.
- **Stream B** covers research for both evolutionary and revolutionary technology advancements
- **Stream C** focuses on SNS Enablers and Proof of Concepts (PoCs) used to further develop and consolidate experimental infrastructure(s), in support of the various phases of the SNS JU.
- **Stream D** targets SNS Trials and Pilots with Verticals, including the required infrastructure. The aim is to explore and demonstrate technologies and advanced applications and services for vertical domains.

- Hexa-X Project

The Hexa-X project is a flagship initiative under the SNS JU, aiming to lay the groundwork for 6G by exploring key technological enablers. The project focuses on developing new radio access technologies, integrating AI and machine learning into network management, and exploring the

[1] https://smart-networks.europa.eu/wp-content/uploads/2024/12/sns-ju-ri-wp-2025_final-publication.pdf

potential of new spectrum bands. Hexa-X also aims to address sustainability by developing energy-efficient network solutions and promoting the use of renewable energy sources in network operations

- 6G-IA (6G Infrastructure Association)

The 6G-IA is a key player in the SNS JU, representing the private sector in the partnership. The association brings together industry leaders, research institutions, and public authorities to drive the development of 6G technologies. The 6G-IA focuses on fostering collaboration, promoting standardization, and ensuring that Europe remains at the forefront of global 6G research and development

5.2 CYBERSECURITY

Cybersecurity is a critical component of digital infrastructure, and it faces numerous challenges. One of the primary challenges is enhancing the ability to detect and respond to sophisticated cyber threats in real-time. This requires advanced threat detection technologies and rapid response mechanisms to mitigate the impact of cyber-attacks.

Securing the supply chain is another significant challenge. Cyber threats can target various points in the supply chain, potentially compromising critical infrastructures. Ensuring the security of the supply chain involves implementing robust security measures and protocols to protect against these threats.

Data privacy is a growing concern as the volume of personal data collected and processed increases. Ensuring compliance with data protection regulations and safeguarding personal data from unauthorized access and misuse is essential.

Building resilient systems that can withstand and recover from cyber-attacks is crucial. This involves the development of robust cybersecurity frameworks and practices that enhance the resilience of digital infrastructures.

Promoting international collaboration is essential for addressing global cybersecurity challenges. Cyber threats are not confined by national borders, and international cooperation is necessary to develop effective strategies and solutions, A number of policies and initiatives are in effect and are operating in Europe:

- EU Cybersecurity Act

The EU Cybersecurity Act strengthens the role of the European Union Agency for Cybersecurity (ENISA) and establishes a cybersecurity certification framework for ICT products, services, and processes. This framework aims to reduce fragmentation in the internal market and ensure a high level of cybersecurity across the EU. ENISA supports national authorities, promotes capacity building, and facilitates operational cooperation among stakeholders

- EU Cyber Resilience Act

The EU Cyber Resilience Act enhances the cybersecurity of products with digital elements sold within the EU, ensuring they meet specific cybersecurity requirements throughout their lifecycle. This regulation mandates that products undergo a conformity assessment to ensure they meet cybersecurity standards, and manufacturers must report exploited vulnerabilities and serious security incidents to relevant authorities.

- Network and Information Systems Directive (NIS 2)

The NIS 2 Directive aims to achieve a high common level of cybersecurity across the Union by setting stricter cybersecurity requirements and enhancing cooperation among member states. The directive expands the scope to include more sectors and types of entities, sets enhanced security requirements, and introduces more stringent supervisory measures and harmonized sanctions to ensure compliance.

- European Cybersecurity Competence Centre (ECCC)

The ECCC, headquartered in Bucharest, Romania, aims to enhance Europe's cybersecurity capabilities and competitiveness. The centre works with a network of National Coordination Centres (NCCs) to support innovation and industrial policy in cybersecurity. The ECCC develops a strategic agenda underpinning a comprehensive cybersecurity strategy for technology development and deployment, utilizing funding from the Digital Europe Programme and Horizon Europe.

- Digital Operational Resilience Act (DORA)

DORA aims to strengthen the IT security of financial entities, ensuring that the financial sector in Europe remains resilient in the event of severe operational disruptions. The regulation establishes principles and requirements for managing ICT risks, focuses on monitoring and managing risks associated with third-party ICT service providers, and mandates the reporting of major ICT-related incidents to competent authorities.

- European Cyber Security Organisation (ECSO)

ECSO is a public-private partnership that aims to develop a competitive cybersecurity industry in Europe. The organization brings together a wide range of stakeholders, including large companies, SMEs, research centres, universities, and public administrations. ECSO focuses on policy development, innovation and research, market development, education and skills, and international cooperation.

5.3 CLOUD-EDGE-IOT CONTINUUM

The convergence of cloud, edge, and IoT technologies presents unique challenges and opportunities. Efficient data management is a primary challenge, as the volume of data generated by IoT devices continues to grow. This requires innovative approaches to data storage, processing, and analysis to ensure efficient and effective data management.

Ensuring seamless integration and interoperability between different IoT devices and platforms is essential. This involves the development of common standards and protocols that facilitate interoperability and enable seamless communication between devices.

Reducing latency and increasing bandwidth are critical for supporting real-time applications. This requires the development of advanced networking technologies and infrastructure that can deliver high-speed, low-latency communication.

Implementing robust security measures to protect data and devices in the IoT ecosystem is crucial. This involves the development of comprehensive security frameworks and practices that address the unique security challenges of IoT.

Developing scalable solutions that can handle the growing number of IoT devices and data is essential. This requires innovative approaches to system design and architecture that can scale to meet the demands of a rapidly expanding IoT ecosystem. Overall cloud-edge-IoT contionuum

- EUCloudEdgeIoT.eu Initiative

The EUCloudEdgeIoT.eu initiative promotes the convergence of cloud, edge, and IoT technologies, enhancing supply-demand dialogue and collaboration. The initiative is driven by two Coordination and Support Actions (CSAs): NexusForum.eu and CEI-Sphere. NexusForum focuses on providing a forward-looking vision in new areas and directions, while CEI-Sphere addresses emerging industry challenges through the coordination of multiple Large-Scale Pilots (LSPs)

- Important Project of Common European Interest on Next Generation Cloud Infrastructure and Services (IPCEI-CIS)

IPCEI-CIS is a strategic initiative involving over 120 companies from 12 EU member states, aiming to build a multi-provider cloud-edge continuum for Europe. The project covers the entire datacenter-cloud-edge value chain, from private on-prem resources to cloud-edge continuum infrastructure and federated capabilities for distributed data processing. Use cases in fields such as mobility, energy, industry, and healthcare will bring the results to their first industrial deployment

- European Alliance for Industrial Data, Edge, and Cloud

The European Alliance for Industrial Data, Edge, and Cloud aims to improve the development and deployment of next-generation edge and cloud technologies. The alliance brings together Member States representatives and experts from the industry to foster collaboration and drive innovation in the cloud-edge-IoT continuum

5.4 ONGOING INITIATIVES IN PARTNER COUNTRIES

5.4.1 Republic of Korea

- 6G Society Initiative

The Ministry of Science and ICT (MSIT) in South Korea has launched the '6G Society' initiative, aimed at strengthening technological exchange and cooperation between the 6G mobile communications field and the satellite communications field. This initiative promotes communication and interchange between these two critical areas, which are essential for implementing hyperspace communication services connecting land, sea, and air. The 6G Society acts as a bilateral consultation body between the 6G Forum and the Satellite Communications Forum, sharing standardization trends and discussing technology development and measures to connect relevant technologies.

- 6G R&D Implementation Plan

In November 2023, MSIT unveiled a KRW 440.4 billion (approximately $324.5 million) research and development plan for future 6G networks. This plan includes developing technologies related to wireless communications, mobile core networks, 6G wired networks, 6G systems, and the standardization of 6G. The ministry aims to standardize locally-developed 6G technologies in line with international requirements, which are expected to start being established soon.

In addition to the above, there is a 6G Commercialization Technology R&D programme that runs from 2024 until the end of 2028.

Finally, there is a separate programme for 6G Low Earth Orbit (LEO) Technology R&D that will start in January 2025 and will last until the end of 2030. This last programme has a volume of 260 million USD.

Altogether, the three programme elements amount to a volume of 900 million USD. The 900 million USD volume includes both public and private funding.

- Korean 6G Forum Collaboration with the Next G Alliance

The 5G Forum (now 6G Forum) in Korea has signed a Memorandum of Understanding (MoU) with the Next G Alliance, an initiative by the Alliance for Telecommunications Industry Solutions (ATIS) to advance North American wireless technology leadership. This collaboration focuses on developing a 6G roadmap, global standardization, spectrum management, and analyzing the socioeconomic aspects of 6G. The partnership aims to leverage the experience and resources achieved in 5G promotion for use in 6G and beyond.

- Cybersecurity Initiatives

South Korea places a strong emphasis on cybersecurity, with several initiatives aimed at enhancing the country's cyber resilience. The Korea Internet & Security Agency (KISA) is responsible for promoting internet security and managing cybersecurity incidents. KISA operates the Korea Computer Emergency Response Team Coordination Center (KrCERT/CC) and facilitates international cooperation on cybersecurity. Recently, KISA identified generative AI as a key cybersecurity issue and is working on establishing security standards and guidelines to address related threats.

- Cloud-Edge-IoT Initiatives

The National IT Industry Promotion Agency (NIPA) promotes the distribution and expansion of cloud services, AI-based cloud services, and IoT applications. NIPA's initiatives include, among other, the K-Cloud Project, which aims to create a cloud ecosystem, and the IoT Market Entry Support program, which supports the development and deployment of IoT solutions. These initiatives are designed to enhance the competitiveness of the ICT industry and contribute to economic growth. In addition to that, several specific applicative areas have been identified: Healthcare services, Manufacturing, Agricultural ecosystem.

5.4.2 Japan

- Beyond 5G Promotion Strategy

Japan's Ministry of Internal Affairs and Communications (MIC) has developed the Beyond 5G Promotion Strategy, which outlines the country's vision for the next generation of information and communications infrastructure. This strategy aims to realize Society 5.0, an inclusive, sustainable, and dependable society expected in the 2030s. The strategy focuses on intensive R&D on advanced core technologies for Beyond 5G, strengthening manufacturing bases, and enhancing 5G functions. Key features include ultra-fast and large-capacity communication, ultra-low power consumption, scalability, autonomy, and ultra-safety and reliability.

The strategy includes a vision for a digital infrastructure. The envisioned infrastructure aims to support an AI-driven society in the 2030s. Key elements include:

- **Integration of Multi-Layered Networks:** Combining terrestrial (RAN) and non-terrestrial networks (NTN) with all-photonics networks (APN).
- **Support for Various Technologies:** Connectivity for diverse users, objects, sensors, and distributed AI systems.
- **Sustainability and Green Energy:** Data centers leveraging renewable energy.

- **Applications:** Autonomous vehicles, surgical robots, drones, and smart logistics systems.

This infrastructure will enable direct and flexible access to computing resources, promoting innovation and societal problem-solving.

In March 2023 a permanent research and development fund was established for NICT. For Fiscal Year 2023 17 new projects were funded with a total budget of ¥116.1 billion (approximately 774.3 million USD). This reflects the Japanese government's strong commitment to innovation in the Beyond 5G/6G landscape. The initiative aligns with the "G7 Vision for Future Networks in the Beyond 5G/6G Era," as endorsed in the 2023 G7 Digital and Technology Ministerial Declaration.

Japan's Beyond 5G strategy is transitioning from the initial stages of vision formulation and technological groundwork to the phase of social implementation. This involves integrating research outputs into real-world applications that benefit society, industries, and the environment.

- Priority Plan for the Advancement of a Digital Society

The Japanese government has also launched the Priority Plan for the Advancement of a Digital Society, which enhances research and development, international standardization, social implementation, and overseas deployment of Beyond 5G (6G). This plan aims to create a flexible, low-cost, high-speed, high-capacity, low-latency, and low-power consumption communications infrastructure.

The Beyond 5G Promotion Strategy 2.0 outlines three primary areas:

1. **Radio Access Network (RAN):**
    - Expansion of Sub-6 GHz and millimeter-wave utilization.
    - Development of Stand Alone (SA) network systems and high-frequency R&D.
    - Traffic growth management and RAN upgrades.
2. **Non-Terrestrial Networks (NTN):**
    - Development of satellite communication systems for global service integration.
    - Research to ensure smooth service introduction in Japan.
3. **All-Photonics Network (APN):**
    - Research to realize ultra-fast and energy-efficient networks.

Support extends to testbeds, R&D, and standardization efforts aimed at achieving milestones by 2030.

- XG Mobile Promotion Forum (XGMF)

XGMF was established as a strategic response to the evolving demands for mobile communications by establishing a new forum that combines 5GMF and the Beyond 5G Promotion Consortium. Its primary goal is to enhance the growth potential of the information and telecommunications industry by developing groundbreaking technologies and pioneering new use cases that are not bound by conventional paradigms, with Japan taking a global leadership role in developing the 5G and Beyond 5G(6G) communications and in promoting international collaborations.

XGMF objectives, inter alia, include the following:

- Sharing 5G/6G Global information
  - Gathering global information on 5G deployment, 6G technology development, understanding trends and landscape, etc., and disseminating the 5G/6G information in Japan.
- Strengthening international coordination
  - Building consensus in pre-standardization activities in preparation for the full-scale launch of 6G standardization activities.
- Promoting international industry-academia collaboration
  - Building a human resource network for international industry-academia collaboration, such as organizing 5G/6G events and academic conferences in Japan and overseas.

- Cybersecurity Initiatives

Japan has a robust cybersecurity architecture designed to protect its digital infrastructure and enhance its cyber resilience. The National center of Incident readiness and Strategy for Cybersecurity (NISC) coordinates cybersecurity policy and strategy across government entities and promotes partnerships between industry, academia, and the public sector. The Japan Computer Emergency Response Team Coordination Centre (JPCERT/CC) acts as a coordination center for cybersecurity incidents, working with network service providers, security vendors, government agencies, and industry associations.

- Cloud-Edge-IoT Initiatives

Japan is actively building 6G testbeds and research facilities to support the development and deployment of 6G technologies. These testbeds provide a platform for researchers, industry stakeholders, and academia to collaborate on innovative 6G solutions. The government is investing in establishing a robust 6G research infrastructure to foster innovation and growth in the telecommunications sector. Additionally, Japan's initiatives in the cloud-edge-IoT continuum focus on developing advanced IoT solutions and integrating them with cloud and edge computing technologies to enhance data management and processing capabilities.

5.4.3 Singapore

- 5G and 6G Readiness

Singapore is actively building its 5G capabilities, aiming to become a global hub for research and development in this field. The Infocomm Media Development Authority (IMDA) has partnered with the Singapore University of Technology and Design (SUTD) to establish the first 6G lab in Southeast Asia. This lab focuses on developing advanced 6G technologies and fostering innovation in the telecommunications sector.

- 5G Living Lab@PIXEL

IMDA's innovation space, PIXEL, has added a 5G testing facility to facilitate industry efforts to develop new 5G solutions and build up technical capabilities. This facility supports businesses, including SMEs, in experimenting and testbedding their 5G applications and use cases. Projects are supported with design-centric capabilities to enhance digital experiences.

- Urban Mobility and Smart Estates

Singapore is leveraging 5G technology to develop smart urban mobility solutions and smart estates. CapitaLand has partnered with Navinfo Datatech and TPG Telecom to create a 5G-enabled smart estate in Science Park 1 and 2. This initiative aims to deploy and test innovative estate-level solutions using 5G standalone networks. Additionally, M1 and the Nanyang Technological University (NTU) are collaborating to deploy 5G technology for autonomous vehicle trials and connected mobility solutions.

- Industry 4.0 Trials

IMDA, M1, IBM, and Samsung have announced Singapore's first 5G Industry 4.0 trial to demonstrate the transformative impact of 5G for enterprises. This trial aims to develop insights and showcase the benefits of 5G in Industry 4.0, driving the next bound of Singapore's digital economy. The trial is ongoing and focuses on developing 5G-based solutions for manufacturing and industrial applications.

- Cybersecurity Initiatives

Singapore has a well-structured cybersecurity architecture designed to protect its digital infrastructure and enhance its cyber resilience. The Cyber Security Agency of Singapore (CSA) is the national agency overseeing cybersecurity strategy, operations, education, outreach, and ecosystem development. The Government Cybersecurity Operations Centre (GCSOC) is an integrated initiative that aims to upgrade the government's monitoring and detection technologies, automate and augment cyber threat detection and response, and develop capabilities to proactively hunt for sophisticated threats.

Cloud-Edge-IoT Initiatives

Singapore's Smart Nation and Digital Government Office (SNDGO) leads initiatives to integrate technology into daily life, focusing on big data analytics, IoT, and edge-cloud architecture. The Agency for Science, Technology, and Research (A*STAR) drives research and innovation in ICT, with a focus on photonic processors, IoT, and edge cloud computing, with a focus on Intelligence and architecture

5.4.4 India

- Bharat 6G Vision and Bharat 6G Alliance

India is emerging as a major player in 6G development, with initiatives like the Bharat 6G Vision and the establishment of the Bharat 6G Alliance (B6GA). The Bharat 6G Vision aims to establish India as a leader in 6G technology design, development, and deployment by 2030. The B6GA is a collaborative platform uniting industry stakeholders, academia, and international partners to drive 6G innovation and growth.

- Next Generation Wireless Research and Standardization

The Ministry of Electronics and Information Technology (MeitY) is supporting several ongoing projects focused on next-generation wireless research and standardization on 5G and beyond. These projects are being implemented by leading institutions such as IIT Madras, Indian Institute of Science Bangalore, and other IITs across India. The research focuses on developing advanced wireless communication technologies, including sub-THz wireless communication with intelligent reflecting surfaces and MIMO-based microwave imaging systems.

- Cybersecurity Initiatives

India's cybersecurity architecture is designed to address the growing cyber threats and ensure the security of its digital infrastructure. The National Cyber Security Policy (NCSP) aims to protect information and infrastructure, build capabilities to prevent and respond to cyber threats, and reduce vulnerabilities. The Indian Computer Emergency Response Team (CERT-In) is the national agency responsible for responding to cybersecurity incidents, providing alerts and advisories, and coordinating efforts to mitigate cyber threats.

- Cloud-Edge-IoT Initiatives

India is investing substantially in establishing 6G testbeds and research infrastructure to support start-ups, researchers, and industries. This infrastructure aims to foster innovation and growth in the telecommunications sector, enabling India to secure a significant share of global 6G patents by 2030. Additionally, the Ministry of Electronics and Information Technology (MeitY) supports several projects focused on developing advanced IoT solutions and integrating them with cloud and edge computing technologies to enhance data management and processing capabilities.

5.5 JOINT INITIATIVES AND COLLABORATION PROJECTS BETWEEN EU AND INDO-PACIFIC COUNTRIES

Regarding 6G, SNS JU had two targeted calls for aligned activities, one with Japan and one with the Republic of Korea as part of the respective Digital Partnerships. These yielded to the 6G MIRAI project and the 6G ARROW project, respectively. Both projects will start in 2025.

Additionally, we would like to note that the European Space Agency has an MoU with NICT Japan concerning Non-Terrestrial Network (NTN) topics. From the European side a small consortium of the ESA SATis5 project collaborated with the NICT selected Japanese industrial consortium team. This collaboration will conclude in 2025, but a new round of collaboration is being sought by the two sides.

More recently, in October 2024 ESA concluded a Memorandum of Understanding (MoU) regarding 5G/6G Non-Terrestrial Networks cooperation with the Satcom Forum of South Korea,

It has to be noted that there is a very active collaboration between Germany and Japan regarding 6G. The multitude of ongoing collaborative research projects will have their 4th joint workshop in January 2025 in Sendai, Japan.

Finally, regarding EU – Indo-Pacific collaboration strategy and roadmap the 6G expert team has identified research infrastructures and the availability of standard compliant open protocol implementation(s) as critical enablers and noted that there seems to be an increased interest in Non-Terrestrial Networks in some of the Indo-Pacific countries, specifically in the Republic of Korea, but also in Japan.

6 CONCLUSIONS

The D3.1 Summary Panorama Report highlights the significant advancements and collaborative efforts in digital technologies across Europe and its partner countries. The report underscores the importance of international cooperation in addressing the challenges and opportunities in key technological areas, including smart cities, sustainable ecosystems, trustworthy AI, advanced semiconductors, and future networks.

The initiatives and programs detailed in the report demonstrate a strong commitment to foster innovation, enhance technological capabilities, and ensure the development of secure, efficient, and sustainable digital infrastructures. By leveraging these initiatives, Europe and its partner countries aim to position themselves as global leaders in digital technologies, driving economic growth and societal progress.

The report also emphasizes the need for continued collaboration and dialogue between stakeholders, including industry leaders, research institutions, and policymakers. This collaborative approach is essential for addressing the complex challenges posed by rapid technological advancements and for ensuring that the benefits of digital technologies are realized across all sectors of society.

In conclusion, the D3.1 Summary Panorama Report provides a valuable roadmap for future research and innovation in digital technologies. It highlights the critical role of international cooperation in achieving sustainable development goals and underscores the importance of fostering a collaborative and inclusive approach to technological advancement. By building on the foundations laid out in this report, Europe and its partner countries can continue to drive innovation and create a more sustainable, secure, and prosperous future.