European Core Technologies
for future connectivity systems and components

Call/Topic: H2020 ICT-42-2020

Grant Agreement Number: 956830

Deliverable

D3.7 Core Technologies Development Recommendations and Guidelines

Deliverable type:	Report
WP number and title:	WP3 Core technologies development recommendation and guidelines
Dissemination level:	Public
Due date:	30.06.2022
Lead beneficiary:	ST
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Document History

Version	Date	Author/Editor	Description
0.1	03.01.2022	ST	Outline, draft of section 1 & 2
0.2	15.02.2022	ST	Draft of the entire document
0.3	03/02/2022	ST	EG chairs feedbacks integration
1.0	14/03/2022	ST	Preliminary version to be shared with the consortium and EGs
2.0	24/05/2022	ST	Final version including received feedbacks

Acronyms

Acronyms	Details
3D	Three Dimension
AI	Artificial Intelligence
AR	Augmented Reality
ASIC	Application-Specific Integrated Circuit
BB	Baseband
BiCMOS	Bipolar-Complementary Metal-Oxide-Semiconductor
CMOS	Complementary Metal-Oxide-Semiconductor
EDA	Electronic Design Automation
EFECS	European Forum for Electronic Components and Systems
EG	Experts Group
eNVM	Embedded Non-Volatile Memory
FDSOI	Fully Depleted Silicon-Oxide-Insulator
FPGA	Field Programmable Gate Array
GaAs	Gallium-Arsenide
GaN	Gallium-Nitride
HBT	Heterojunction Bipolar Transistor
HW	Hardware
III-V	Chemical compounds with at least one group III (IUPAC group 13) element and at least one group V element (IUPAC group 15). In the Mendeleev table: III refers to the boron group (the table columns). V refers to the nitrogen group (the table rows).
InP	Indium-Phosphide
IoT	Internet of Things
IP	Intellectual Property
ISA	Instruction Set Architecture

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LE	Large Enterprise
MAC	Multiply and Accumulate
MCU	Microcontroller Unit
ML	Machine Learning
Mmw	Millimeter Wave
MPSoC	Multiprocessor System on a Chip
MPW	Multi-project wafer
MR	Mixed Reality
NB-IoT	Narrow Band Internet of Things
NVM	Non-volatile Memory
OS	Operating System
PCM	Phase-Change Memory
RAN	Radio Access Network
ReRAM	Resistive Random-Access Memory
RF	Radio Frequency
RFSOI	Radio Frequency circuit over Silicon-Oxide-Insulator
Si	Silicon
SiGe	Silicon-Germanium
SiP	System in Package
SME	Small and Medium-sized Enterprise
SOC	System on Chip
SOI	Silicon on Insulator
THz	Tera-Hertz
WRC	World radiocommunication conferences

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1. Introduction

One of the key COREnect objectives is to define a strategic R&I roadmap for future European connectivity systems and components, supporting European's strategic autonomy and sovereignty objectives. This roadmap has been defined based on input from all relevant stakeholders across the various domains and communities (Smart Network Services and Electronic Components and Systems), covering the main actors from industry, research, academia, associations, policy analysis etc.

The proposed roadmap was created over three phases. During the first phase, the roadmap directions were defined and roadmap inputs ("raw data") were captured and presented in deliverable D3.3 [1]. During the second phase, the roadmap data were further processed, refined, and complemented, and a common approach and structure was introduced across the contributions of the three expert groups set up within the COREnect project[1]. This uniform representation resulted in a clear representation of the key results/conclusions per expert group topic which enables to compare these findings across different expert group topics and market segments. The outcome of the second phase led to the COREnect intermediate roadmap proposition (D3.4 [2]). During the third phase, we defined a common and consolidated roadmap proposition based on the material gathered during the previous phases, and this work is presented in deliverable D3.6.

The objective of the current deliverable is to translate COREnect roadmap (D3.3, D3.4 & D3.6) into actionable recommendations and guidelines for the relevant stakeholders in both public and private sectors and raise their awareness of the required investments. This activity took place in T3.2, with the support of WP4. Throughout the entire process, the proposed roadmap was defined in close interaction with experts, internal and external to the consortium.

To maximize the potential impact of this work, we target a very concise document aiming at two objectives:

- Considering the four market segments defined in D3.4 (automotive grade connectivity, infrastructure connectivity, industrial grade connectivity, consumer grade connectivity), provide a synthetic view of the in-depth analysis and actions proposed by the expert groups in previous deliverable (D3.3, D3.4 & D3.6)
- Translate this synthesis into concrete actionable recommendations and guidelines, which could be implemented by the appropriate stakeholders, considering different impact timelines: *in short term (<2026)*, *medium term (2026-2030)* and *long term (>2030)*. Note that these time horizons do not apply to the actions themselves, which all need to be initiated in the near future, but to the time they will require to bear fruit.

The outline of this document is as follows. Section 2 provides a synthesis of the COREnect roadmap proposition for each previously defined market segments. This section can be seen as an executive summary of previous deliverables (D3.3, D3.4 & D3.6), the intent is here to underline the key messages of the expert groups. Section 3 proposes actions and guidelines considering previously proposed impact timeline and analysis. This section aims to make the

[1] In the COREnect project, the roadmap is elaborated by leveraging the contributions of experts organized into three thematic working groups: "Compute and Store", "Connect and Communicate", and "Sense and Power"

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COREnect roadmap proposal concrete, defining a reasonable set of actions which globally address the challenges underlined by the expert groups. Section 4 draws the main conclusions.

2. COREnect industry roadmap synthesis

2.1. Automotive grade connectivity

Each of the 3 expert groups proposed a SWOT analysis to identify the strengths and weaknesses of Europe on automotive grade connectivity. The table below shows a synthesis aiming to provide a global view of the challenges and opportunities that Europe must address.

Strengths	Weaknesses
• Sizeable indigenous market with strong automotive actors • Presence of leading suppliers of derivative technologies (SiGe, eNVM, GaN, SIC, ...) and associated ICs (sensor, sensor processing, power electronics, specialty MCU, mmW Radar, ...) • High-quality education & strong research activities on analog, memory & power electronic process & design competences	• Std automotive qualification slows down time to market, Europe approach esp. to safety, security and regulation must adapt to world-wide competitors • Transition to electric drivetrains is a challenge for European OEMs (easier to start from scratch like TESLA rather than adapting an existing manufacturing capability) • Limited design capability of complex digital SOC (CPU, AI, ...) which requires huge investment (both for design and manufacturing)
Opportunities	**Threats**
• Car industry transformation (moving from mechanical to electronic based solution) relies on Europe core competencies (power electronics, sensor, connectivity, …) • Market with exploding growth requiring worldwide leading platform for automotive systems • Contribution to standardization in order to shape the future of this market • Europe specific privacy regulations could complement standardization to boost the rise of European AI actors and set worldwide standard (like GDPR did)	• European automotive industry moving too slowly • Softwariation puts established processes in car companies at risk vs new competitors from outside automotive community (Tesla, Google, …) • Standardization is complex and competitive process where regions sometimes vote as a block • Failure to attract and educate engineers within EU • Design and processing in advanced logic processes are expensive setting an entry barrier • Market evolution uncertain due to COVID 19, climate change, geopolitical tensions

Table 2.1.1: synthesis of 3 Expert Groups SWOT concerning automotive grade connectivity

Following previous SWOT analysis, each expert group has identified key strategic actions to address automotive grade connectivity challenges and opportunities. The table below shows a synthesis covering the main strategic actions proposed in previous deliverables.

Short Term (<2026)
• Increase EU contribution to standardization and regulation activities • Support the development of open hardware and software ecosystem • Ease access to advanced silicon technologies, design tools, license and IP • Speed up 5G deployment across EU • Maintain EU's position on derivative technologies
Medium Term (2026 – 2030)
• Increase IC design capabilities in advanced logic technologies • Grow derivative hardware technologies already present in EU and extend to new fields • Develop heterogeneous integration technologies (2.5D/3D) in EU to address complexity and performances challenges in innovative way leveraging EU derivative technology strength • Develop a power strategy for cars (datacenters on wheel), connected with edge computing • Deploy open hardware and software ecosystems targeting safety and security contexts
Long Term (>2030)

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• Educate and attract sufficient IC design engineers • Define a consistent EU spectrum policy, considering licensed and unlicensed and global and local licenses • Create incentives to attract and educate sufficient engineers' students to end-to-end system design programs • Enable the next generation of derivative technology (eNVM, THz radar, ...)

Table 2.2.2: synthesis of 3 Expert Groups proposed actions concerning automotive grade connectivity

2.2. Infrastructure connectivity

Each of the 3 expert groups proposed a SWOT analysis to identify the strengths and weaknesses of Europe on infrastructure connectivity. The table below shows a synthesis aiming to provide a global view of the challenges and opportunities that Europe must address on this topic.

Strengths	Weaknesses
• European leaders in wireless infrastructure solutions, from large enterprises (Ericsson, Nokia) to dynamic small ones • High-quality education, strong analog IC design competences • Presence of leading suppliers (IFX, NXP, ST, UMS) of mature and derived IC technologies (SiGe, SOI, GaN) • Key manufacturing equipment player from EU (ASM, ASML, Besi, SPTS, EVG, Boschman, …)	• No strong cloud providers in Europe • Weak European industry presence and less skilled personnel in communication computing domain • No big players anymore in optical comm chips/components • Ecosystems related to microelectronics are drying up in EU • Slow decision and scattered interests of members states
Opportunities	**Threats**
• Digital infrastructures as foundation of society and economy • Governmental support on speed up of frequency allocation for communication • Explosive growth of wireless market expected • Speed of CMOS saturating, opportunity for SiGe BiCMOS & InP (EU based Fab) • Complex front-end modules will require advanced heterogeneous integration • Increasing attention to openness (e.g. O-RAN) to enable faster innovation	• EU unable to keep pace with US and China on AI, SOC design in advanced logic processes is expensive • Tough competition due to large size of subsidies in China and USA (DARPA) on manufacturing process • Standardization is complex and competitive process where regions sometimes vote as a block • international companies impacted by US bans & geopolitical tensions • Failure to attract and educate engineers within EU

Table 2.2.1: synthesis of 3 Expert Groups SWOT concerning infrastructure connectivity

Following previous SWOT analysis, each expert group has identified key strategic actions to address infrastructure connectivity challenges and opportunities. The table below shows a synthesis covering the main strategic actions proposed in previous deliverables.

Short Term (<2026)
• Increase EU contribution to standardization and regulation activities • Ease access to advanced silicon technologies, design tools, license and IP in order to strengthen SOC design competency in EU • Speed up 5G deployment across EU • Monitor and evaluate open RAN principles and their suitability for Europe • Develop platform chipsets that support diverse applications on a single modem • Develop HW technologies that catering 5G/6G infrastructure market. • Maintain EU's position on derivative technologies • Adapt policy to geopolitical tension
Medium Term (2026 – 2030)

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• Ensure that future solutions will meet European security and privacy standard • Build datacenter in Europe • Increase IC design capabilities in advanced logic technologies • Grow derivative hardware technologies already present in EU and extend to new fields • Develop heterogeneous integration technologies (2.5D/3D) in EU to address complexity and performance challenges in innovative way leveraging EU derivative technology strength • Define a consistent EU spectrum policy (licensed and unlicensed) to enable fast 6G deployment in 2030
Long Term (>2030)
• Sell data centers services (e.g. storage) outside of Europe • Establish leading edge technology source in Europe • Create incentives to attract and educate sufficient engineer students to end-to-end system design programs (from low-level analog IC design up to high-level application software) • Enable the next generation of derivative technology (InP, ...)

Table 2.2.2: synthesis of 3 Expert Groups proposed actions concerning infrastructure connectivity

2.3. Industrial grade connectivity

Each of the 3 expert groups proposed a SWOT analysis to identify the strength and weakness of Europe on industrial grade connectivity. The table below shows a synthesis aiming to provide a global view of the challenges and opportunities that Europe must address on this topic.

Strengths	Weaknesses
• Sizeable indigenous market with strong industrial actors • European leaders in industry-grade solutions on IoT, sensors and power electronics (from large enterprises to dynamic small enterprises) • Strong industrial actors (NXP, ST, IFX) in derivative technologies (SiGe BiCMOS, SOI, GaN, SiC, ...) closely link to research activities • Big player in ultra-low power component (ST, CSR, Nordic), RFID (NXP) and front-end modules (NXP, ST, IFX)	• Volume remains small vs consumer market • Chip production is still done mainly outside EU • Ecosystems mainly related to microelectronics (few system/solution providers in EU enabling to move higher in the value chain) • Global spectrum licenses limiting competitiveness in industrial grade connectivity • Reliance on consumer area products
Opportunities	**Threats**
• Base new system on European values and ethical principles to improve security and user-controlled privacy, which is becoming attractive also for other region • Demand for low power or ultra-low power design will be high driven by industry 4.0 needs • Increasing attention to openness (e.g. O-RAN) to enable faster innovation • Foreign investments to expand the growing facilities all around Europe	• EU unable to keep pace with US and China on AI, SOC design in advanced logic processes is expensive •Big cloud providers offer integration of (their) services and IoT platforms • Standardization is complex and competitive process where regions sometimes vote as a block • Failure to attract and educate engineers within EU

Table 2.3.1: synthesis of 3 Expert Groups SWOT concerning industrial grade connectivity

Following previous SWOT analysis, each expert group has identified key strategic actions to address industrial grade connectivity challenges and opportunities. The table below shows a synthesis covering the main strategic actions proposed in previous deliverables.

Short Term (<2026)
• Increase EU contribution to standardization and regulation activities (authentication, encryption, ...) • Support the development of open hardware and software ecosystem • Ease access to advanced silicon technologies, design tools, license and IP in order to strengthen SOC design competency in EU • Speed up 5G deployment across EU • Maintain EU's position on derivative technologies (analog, RF and WBG)
Medium Term (2026 – 2030)

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• Increase IC design capabilities in advanced logic technologies • Grow derivative hardware technologies already present in EU and extend to new fields • Develop heterogeneous integration technologies (2.5D/3D) in EU to address complexity and performances challenges in innovative way leveraging EU derivative technology strength (for example eNVM) • Deploy open hardware and software ecosystems targeting safety and security contexts • Define a consistent EU spectrum policy (licensed and unlicensed) to enable fast 6G deployment in 2030
Long Term (>2030)
• Create incentives to attract and educate sufficient engineer students to end-to-end system design programs (from low-level analog IC design up to high-level application software) • Enable the next generation of derivative technology (InP, ...) • Develop and deploy a modular low resource secure operating system framework

Table 2.3.2: synthesis of 3 Expert Groups proposed actions concerning industrial grade connectivity

2.4. Consumer grade connectivity

Each of the 3 expert groups proposed a SWOT analysis to identify the strengths and weaknesses of Europe on consumer grade connectivity. The table below shows a synthesis aiming to provide a global view of the challenges and opportunities that Europe must address on this topic.

Strengths	Weaknesses
• Strong research ecosystem in institutes (FHG, IMEC, TNO, CEA Leti) and universities • High-quality education, strong analog IC design competences • Strong industrial actors (NXP, ST, IFX) in derivative technologies (eNVM, SiGe BiCMOS, SOI, GaN, SiC, ...) closely link to research activities (GaN, InP, ...) • Big players in front-end modules (NXP, ST, IFX) closely link to research activities • Patent position	• No strong European companies for consumer devices, ODMs industrial base is limited in EU • OSATs and ecosystem dominated by Far East • No big EU players anymore in wireless and optical comms chips/components • Difficult access to venture capital • Europe is out of the CMOS race (FinFET) since many years • Slow decision and scattered interests of member states
Opportunities	**Threats**
• Base new system on European values and ethical principles to improve security and user-controlled privacy, which is becoming attractive also for other region • Explosive growth of wireless market expected • Speed of CMOS saturating, opportunity for SiGe BiCMOS & InP (EU based Fab) • Complex front-end modules will require advanced heterogeneous integration • Increasing attention to openness (e.g. RISC V) to enable faster innovation	• Foreign companies (largely) controlling European data on mobile devices enabling to secure the domination of their services and products • Standardization is complex and competitive process where regions sometimes vote as a block • Failure to attract and educate engineers within EU • Tough competition due to large size subsidies in China and USA on manufacturing process • international companies impacted by US bans & geopolitical tensions • Attracting foreign companies to manufacture most advanced CMOS node in Europe may be a threat if it is not complementary with EU players manufacturing capabilities/strategies • Growing number of citizens afraid of technology

Table 2.4.1: synthesis of 3 Expert Groups SWOT concerning consumer grade connectivity

Following previous SWOT analysis, each expert group has identified key strategic actions to address consumer grade connectivity challenges and opportunities. The table below shows a synthesis covering the main strategic actions proposed in previous deliverables.

Short Term (<2026)

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• Define and enforce regulation for consumer markets (e.g. safety related standards) • Support the development of open hardware and software ecosystem • Ease access to advanced silicon technologies, design tools, license and IP in order to strengthen SOC design competency in EU • Speed up 5G deployment across EU • Work on conditions for social acceptability of 5G and 6G • Maintain EU's position on derivative technologies (analog, RF and WBG)
Medium Term (2026 – 2030)
• Increase IC design capabilities in advanced logic technologies • Strengthen derivative hardware technologies already present in EU and extend to new fields (RF filters, ...) • Develop heterogeneous integration technologies (2.5D/3D) in EU to address complexity and performance challenges in innovative way leveraging EU derivative technology strength (for example eNVM) • Deploy open hardware and software ecosystems targeting safety and security contexts • Define a consistent EU spectrum policy (licensed and unlicensed) to enable fast 6G deployment in 2030
Long Term (>2030)
• Design a new OS-based software stack definition through higher level abstraction methods • Create incentives to attract and educate sufficient engineer students to end-to-end system design programs (from low-level analog IC design up to high-level application software) • Enable the next generation of derivative technology (InP, ...) • Support start-up that may become GAFA-like companies to enable big European end users

Table 2.4.2: synthesis of 3 Expert Groups proposed actions concerning consumer grade connectivity

3. Recommendations, guidelines & actions proposal

In the previous section, we have reviewed a synthesis of the roadmap proposed by COREnect consortium to address the identified key connectivity market segments. Now, we translate this roadmap into actionable recommendations and guidelines, addressing globally Europe connectivity challenges and opportunities (across the market segments).

To do so, we divide our analysis in 4 sections:

- The first section deals with issues that can only be addressed at political level and are mandatory to create the condition of success for European actors
- The second section focusses on the short term (<2026), illustrating generic recommendations and guidelines to make this proposal actionable
- The third section is focusing on the medium term (2026 – 2030), illustrating generic recommendations and guidelines to make this proposal actionable
- Finally, the fourth section addresses the long term (>2030) recommendations, guidelines and actions using the same approach as the two previous sections.

As for the first part of this document, we target a concise document to maximize its clarity and impact. Proposed recommendations and guidelines address the most urgent topic identified during the work of the three expert groups. The proposed actions focus on challenges which seems today the most stringent for Europe's connectivity ecosystem. The previous roadmap deliverables (D3.3, D3.4 & D3.6) provide a more detailed analysis.

3.1. Proposed common strategic actions requiring political intervention

This section details recommendation and guidelines that can only be addressed at political level. The objective is here to create the environment in Europe that provides the European ecosystem with the means to compete with other continents and to be successful (both from

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an academic and industrial point of view). To do so, 7 main recommendations have emerged among the work of the 3 expert groups.

3.1.1. Speed up 5G deployment in Europe and define a consistent EU spectrum policy for 6G associated to clear deployment timeline and coverage objectives

Supporting and promoting the initial stages of 5G deployment, especially in the sub-6 GHz spectrum, is recognized as a key issue in Europe. The leadership of China on 5G infrastructure, having deployed in 2021 70% of the world's total base stations [3], is clearly related to China's Ministry of Industry and Information Technology (MIIT) actions and policies:

- ✓ December 2018: MIIT granted the right to use frequencies to test 5G networks
- ✓ June 2019: MIIT issued 5G commercial licenses to allow the commencement of commercial 5G services nationwide
- ✓ March 2020: MIIT issued the Circular on Accelerating 5G Development, launching 18 measures, including accelerating the building and deployment of 5G networks.

To ensure Europe to be at the fore front of 6G deployment, it must implement a coordinated policy across all state members in the 2022 – 2030 timeframe, with a clear leadership and long-term vision:

- To define a consistent and pragmatic EU spectrum policy (6.45 GHz – 7.15 GHz and THz spectrum being the most anticipated one for 6G) to ease the deployment and enable Europe to be among the early adopter of new connectivity technologies
- To define and implement a global deployment agenda at European Union scale with a clear timeline and coverage objectives

3.1.2. Support Europe's contribution to standardization activities

Standardization is recognized as a key enabler to gain strategic advantage other competition. On this topic, Europe is today clearly overtaken by China and US. The push of Chinese companies such as Huawei on international standardization bodies is a global concern: "We must have a vocal presence at the standards bodies that are defining the rules for 5G. We have been woefully absent and need to make participation a priority," wrote Mike Rogers [4] as a former US representative.

The main issue being the human and economic resources a given institution can dedicate to standardization activities to be able to compete with US and Chinese players, Europe can adopt here some pragmatic actions:

- Implement tax incentive on standardization activities supporting European companies to dedicate more resources to the topic
- Define clear objectives on standardization activities to European research institutes to reinforce actions of the European industrial actors

3.1.3. Secure access to leading edge CMOS technologies

Since no European manufacturing capability is available <28/22 nm, the access to leading edge CMOS technologies (e.g., 16 nm FinFET and below) is identified as a key issue. This is especially true for academic and research institutes. Only 2 European Universities, for example, are among the partners of TSMC University Shuttle Program [5]. This issue severely limits the capability of European Universities to educate the required work force and to compete in top notch international conferences and journals.

To address such challenge, pragmatic solutions should be implemented to serve as foundation to other long-term actions (as proposed by Chip's Act recently released by EU Commission):

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- Establish key partnerships at European level with leading foundries and fund a yearly shuttle to secure the access to advanced CMOS technologies to selected European universities and research institutes
- Set up a dedicated organization managing the access to these technologies as well as the access to dedicated CAD environments using cloud solution (with IT infrastructure, licenses cost, IP issue management as key showstoppers)

3.1.4. Take measure to boost the European micro-electronics community

Worldwide, production Champion China has the largest demand for semiconductors. However, domestic suppliers are only able to meet one-third of domestic demand and there is a worry concerning dependency and vulnerability. Thus, the government set a plan to become a global leader by 2030 in all segments of the semiconductor industry. It sets its strong focus on achieving the required know-how for advanced semiconductor manufacturing. To bridge the gap between consumption and production, huge spending in semiconductor investments, acquisitions, and talent recruitment take place. A major driver of the market seems to be huge capital offerings and tax incentives to IC makers and prepared a huge state-backed fund to further reduce dependencies from mainly US technologies. Nonetheless, China still relies on foreign suppliers for high-end products, because they require specific know-how, that is built with years of experience. Mostly, China relies on a "fabless" semiconductor production, which manufacturing being handled by specialist companies like TSMC.

The European countries are limited in their actions since their economy is not as centrally directed as in China. On the other hand, the EU also aims to reduce dependencies and to further secure the European supply chain for semiconductors. Therefore, elements from the Chinese approach such as specific investments and incentives (which is already part of the Chip's Act recently released by EU Commission) as well as greater focus on talent recruitment regarding IC design should be considered. The latter can be realized by specific talent attraction programs targeting international graduate students as well as experts and through a greater focus on the required competencies during university education.

3.1.5. Adapt policy to geopolitical tension

European companies have been strongly impacted by US bans & geopolitical tensions between US and China. It also makes at risk the concept of global free trade and poses key question concerning the ability of Europe to speak for itself and defend its interests.

While European leadership on some key technologies (semiconductor manufacturing equipment, etc.) offers some leverage, when EU engage with the US in the Trade and Technology Council it is important to remind that Europe is not treated by the US as like-minded equals.

- Consequently, political will and export control tools are here mandatory to define appropriate policies and regulation enabling to defend the freedom that technology leadership can bring to Europe. Without this political will, it may be impossible to leverage the concept of balanced interdependencies to keep global markets open and connected (since it is agreed by all stake holder that being entirely self-sufficient is neither possible nor desirable).

3.1.6. Define and enforce new regulation aligned with European values and ethical principles on privacy, security and sustainability

The SWOT analysis has underlined that foreign companies are today largely controlling European data on mobile devices enabling to secure the domination of their services and products. It is both a weakness and an opportunity:

- By defining and enforcing new regulation in Europe based on European values and ethical principles to improve security and user-controlled privacy (similarly to

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GDPR), new market conditions could be created to enable the entry on the market of European actors and solutions (which may be attractive also for other regions).

Moreover, Europe's digitalization must be sustainable and it consequently imposes to support a green transition of our society, industry and economy. Europe is today the most ambitious continent in the world targeting to be climate neutral by 2050. This objective can also represent an opportunity for the connectivity and semi-conductor industries:

- By enforcing stringent power efficiency regulation on the European market, it could speed up the adoption of innovative and clean technologies developed in Europe (for example wide band gap power electronic technologies for which Europe is today in the fore front).

Meanwhile, it should be noted that the ICT industry is facing an exponential growth in data traffic. With broad deployment of 6G, an increase of greenhouse gas (GHG) emission is expected by the rising number of accompanying data centers, networks, user devices and new application areas, as well as notable rebound effects. It is worth mentioning that an increase in efficiency and the use of renewables will most likely not suffice to offset the environmental challenges involved, although it offers other sectors opportunities for GHG reductions. Thus, major political and industrial efforts are needed to cushion the impact of the growing ICT sector's footprint to keep aligned with the Paris Agreement. Following actions can pave the way for a purposeful strategy to lower environmental impacts:

- Further research on the environmental impact of ICT.
- Sector-wide net zero commitment, enforced through incentives and compliance mechanisms.
- Application of constraints on consumption for the end-user and industry.
- A strategy towards global alignments, enforcing sector-wide climate target compliance.

3.1.7. Strategic Infrastructure program lead by state members and the commission

The pandemic crisis illustrated the importance of sufficient and reliably available broadband and cloud infrastructure to effectively support digitalization in Europe. Governments now acknowledge the need for such broadband infrastructure investments to harmonize digitalization between all regions in Europe. Equivalent comments can be made on cloud services since most of the leading actors are today either US or Chinese.

Only long-term infrastructure programs coordinated at the scale of the European Union, led by state members and the commission, can address this challenge. GAIA-X is an example. The proposals below are good starting point to illustrate potential actions:

- Financially support the deployment of state-of-the-art broadband infrastructure (both wired and wireless) targeting a clear timeline, coverage, and data rates (defined at political level) to ensure best in class services availability across Europe
- Support the raise of European cloud solution providers by allocating public contracts on sensitive areas (such as eHealth, defense, government agencies, …), similar to the US (e.g., NSA 10 B$ Cloud contract with AWS [6])

3.2. Short term core technologies development actions proposal

In this section, we review the actionable recommendations and guidelines proposed by the COREnect consortium to address in the short term (<2026) Europe connectivity challenges and opportunities (across the different market segment).

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3.2.1. Strengthen Europe's position on semiconductor manufacturing equipment

No single region possesses end-to-end capabilities for semiconductor design and manufacturing. There are interdependencies throughout the global value chain, different geographic areas having specialized capabilities [7]. Consequently, collaboration is the key to success, as far as a given area can provide specific products and technologies that other regions need. Europe is the home to global powerhouses in state-of-the-art semiconductor manufacturing equipment and materials [7]. Europe's competitiveness in these parts of the semiconductor value chain must be further strengthened, ensuring European semiconductor manufacturing technologies to remain relevant. Innovation is key to secure Europe position in the global semiconductor ecosystem and associated interdependencies. European incentives and R&D funding should not only focus on chip production. It needs to secure Europe's relevance in the global semiconductor ecosystem by increasing the capabilities and performance of European products and technologies that others rely on. Consequently, a special focus must be dedicated to semiconductor manufacturing equipment in the project calls such as the ones issued by the KDT Joint Undertaking.

3.2.2. Strengthen EU leadership on mature technologies

Even if in the long run Europe intends to become a stronger player across the connectivity semiconductor value chain, in the short term, it is necessary to build on Europe's strengths. Europe is a global leader in some specific areas, such as automotive, industrial electronics and wired and wireless infrastructure. Having such strong industrial base in these end-market segments makes it easier to develop semiconductor innovation and investment roadmaps for these specific end-market segments, as opposed to others (such as personal computing, cloud and data storage) where Europe does not play a leading role at this point time.

Automotive, industrial electronics and wired/wireless infrastructure end markets need a mix of mature and advanced chips. In the case of automotive and industrial end markets, technologies down to 16/12 nm are expected to correctly address the needs for the next 10 years. Moreover, the latest investigation of the US department of commerce revealed that the current chip shortage is mainly explained by inadequate manufacturing capability for mature semiconductor technologies [8]. Europe must strengthen its strong ecosystem for mature semiconductors to address the technology requirements of relevant end-market for the next 5 to 10 years by:

- Providing the appropriate incentives for the installation in Europe of state-of-the-art 300 mm manufacturing facilities dedicated to those mature technologies
- Support the R&D activities to develop the next generation of associated technologies (SiGe BiCMOS, FD SOI, RF SOI, GaN, BCD, POI RF Filters, …)

3.2.3. Strengthen Europe's position on EDA solution market

Electronic design automation (EDA) comprises the software, hardware and services primarily used to design integrated circuits. The global EDA sector is dominated by US actors, with the three main competitors – Synopsys, Siemens EDA (Mentor Graphics) and Cadence Design Systems – controlling ~80% of the market. This highly concentrated market is the result of those 3 leaders' merger and acquisition (M&A) strategies to buy smaller companies having a competitive advantage in niche technologies (~200 M&A deals reported so far [9]). This EDA monopoly and the reliance on US made tools is clearly a weakness in the supply chain which is

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acknowledged by China. The number of China-based EDA companies increases rapidly over the past few years. The most well-knowns are Empyrian (IP and EDA solution provider) and Primarius Technologies, which EDA tools supports advanced process nodes down to 3 nm (its products having been adopted by foundries such as TSMC, Samsung and SMIC). Consequently, it is of prime importance for Europe to remain competitive in this field. We propose the following actions:

- Support start-up and SMEs to develop innovative EDA tools and IP solution leveraging AI and Machine Learning (for example through dedicated EU programs)
- Enable M&A activities in the EU by securing dedicated funds to ensure a dynamic European EDA ecosystem

3.2.4. Support the development of open-source hardware and software ecosystems

Open-source software and hardware are key trends having broad support in the connectivity and semiconductor ecosystems. The U.S. Defense Advanced Research Projects Agency, for example, sponsors such initiative [10]. By leveraging the knowledge associated to existing chip designs, chip engineering becomes more affordable and predictable. Consequently, open-source software and hardware's value proposition is to deliver innovative, transparent, scalable, flexible, and reliable technologies. This opens many opportunities for institutional and private organization to leverage innovation, optimize cost, accelerate speed, increase agility, and ultimately to create a unique competitive advantage. Open-source software and hardware is believed to ensure to boost European innovation in the connectivity and semiconductor markets. The following actions can stimulate this evolution:

- Provide more R&D funding to open-source software and hardware programs, in particular targeting SMEs, to support and accelerate the creation of open-source software and hardware technologies in Europe.
- Implement tax incentive on activities contributing to open hardware and software ecosystems to incite the involvement of European companies

3.2.5. Support the development of components/HW technologies catering needs of connectivity markets

Network evolution towards 5G/6G requires the development of advanced components/HW technologies, e.g., generic HW with appropriate accelerators, advanced modem for additional spectrum bands and further advance on fronthaul and backhaul technologies. The rising societal demands on sustainability and security on digital infrastructure will lead to both great challenges and opportunities for those components/HW technologies. Europe's capability on mastering those technologies will greatly impact its leadership position in 5G/6G market. It is therefore highly important to:

- Allocate funding for projects to work on the abovementioned areas that are critical for European industry leadership in 5G/6G, e.g., RAN compute platform, scalable modems, programmable accelerators, energy/cost efficient transceiver/front-end for FR1, FR2 and beyond and optical and electronic components.
- Establish communication links among the KDT and SNS JUs and coordinate the development in these two communities, ensuring synergies and strong demand-supply correlations in European R&I scene.

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3.2.6. Support the development of platform chipsets enabling a wide range of applications on a single modem

As digitalization grows and deepens in all sectors of economy and society, the need for chipsets and the number of applications will grow as well, many of which share similar requirements and functionalities. This will open business opportunities for platform chipsets that could potentially cater the needs of a wide range of applications, e.g., 5G/6G, automotive, health, logistics, manufacturing etc., as well as consumer products considering Europe's strong industry base. It provides flexibility and customization for implementing applications and at the same time support high manufacturing volumes bringing overall cost down. Taking advantage strong system knowledge/demand in 5G/6G/automotive/consumers, Europe should invest in the development of platform chipsets by:

- Promoting vertical industry alliances and fostering common interests across sectors, creating common technical requirements, pooling resources and increasing demand on platform chipsets developed in Europe.
  Providing R&D funding (low-mid TRL activities) and state-aid support (mid-high TRL activities) to platform chipset design programs, building European capability and ecosystem in this area.

3.2.7. Improve EU technical university attractivity and admissibility to increase the pool of talents available in EU

Semiconductor manufacturing facilities rely on highly skilled and specialized personnel. Access to graduates with advanced degrees (master's, doctoral, or equivalent) is crucial to design, manufacture and use leading edge semiconductors. On a global scale, Europe is best in class to provide these highly skilled experts. It is the region that educates the highest numbers of master's and PhD level graduates in Science, Technology, Engineering and Math (414,000 European graduates annually vs. 274,000 in China and 201,000 in the US [11]). However, European academic professionals are witnessing a decrease of interest from student. Moreover, women have been traditionally under-represented in STEM studies.

While it is essential to attract students to current STEM education, addressing tomorrow's challenges and enabling Europe to move higher in the value chain require more experts with a broader technical field of expertise. It is especially true for system level experts who need to have both skills: a higher level of abstraction expertise to design and model complex system, and detailed level hardware expertise to understand the key technologies required by such complex system. Enabling the training of a highly skilled workforce is critical for European success in the future. Offering broader education requires setting up new courses and to rethink teaching methods and concepts stimulating their attractiveness.

Consequently, it is essential to maintain the attractivity of STEM studies both for local and international students, as well as improve gender equality in STEM education. To achieve this goal, the following actions can be considered:

- Include more interactive teaching and hands-on activities through lab project using open-source software and hardware solutions
- Improve the collaboration with STEM industries to simulate the cohesion and alignment between education and industry.

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- Provide dedicated funding e.g., through scholarships, to make STEM education accessible for everyone
- Easier admission to university for non-European students by offering more English programs
- European agreements promoting the issue of student and working visas in the STEM field.
- Reinforce executive program to adapt the existing workforce (including other industries) to the new needs (leveraging here the experience of our most senior workforce)

3.2.8. Create acceptance for sensitive data sharing

For each personal data sharing act, one evaluates the advantages and risks of the action. The perceived risks arise from on the one hand media coverage and data protection scandals, on the other hand from individual doubts concerning the company's purpose of handling the users' personal data. Depending on the domain, users distinguish greatly in their acceptance to share sensitive, personal data. The financial and medical market has the highest acceptance, because direct benefits and the reason for the need of sharing that sensitive information is comprehensible. Therefore, the medical wearables and a record should be confronted with a greater acceptance than devices and services from other domains. To further increase the willingness to share personal data, the psychological effect of motivational reasoning can be taken advantage of through incentives and gamification elements.

However, security and reliability should be first priority within the development of devices, that require sensitive data from its' users. Today, two techniques are used to increase reliability, which are either retransmission of the entire packet of information, or redundancy, where some coding is added. But with the increase of connected sensor devices, new challenges for its reliability arise. Therefore, the gaps are:

- to evaluate sensor data reliability with a confidence level to identify a defective device into a subset of devices.
- to track performance thanks to rapid monitoring and feedback systems, even allowing remediation actions to enable self-healing wherever possible (e.g. software updates).

3.3. Medium terms core technologies development actions proposal

In this section, we review the actionable recommendations and guidelines proposed by COREnect consortium to address in the medium term (2026-2030) Europe connectivity challenges and opportunities (across the different market segments).

3.3.1. Increase IC design capabilities in digital and analog to ensure a sufficiently large pool of resources in EU

For Europe to enhance its strategic autonomy, chip design is an essential part of the value chain in Europe and a precondition to secure IPRs and improved security and for increased manufacturing in Europe. From a strategic autonomy perspective, designers underpin the modern economy just as much as manufacturers. Focusing on design over the medium term need not be seen as complementary to manufacturing, since strengthening Europe design industry could support more advanced manufacturing capacity further down the line. China has demonstrated that it is significantly easier to catch up in design than in manufacturing. China rapidly achieved a strong position in the value chain without abandoning the benefits of interdependence. To do so, we definitively need the associated workforce in Europe to be both available and trained at the appropriate level of expertise. To secure this point, we propose the following actions:

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- Support existing academic institution focus on analog design with appropriate funding to secure Europe track of record of excellence in education and research in this field
- Strengthen digital IC design educational programs to improve Europe pool of resources and secure the capability to address complex SOC design in the future
- Stimulate research institutes to organize advanced technical training courses to extend the expertise in local and international industry

3.3.2. Develop heterogeneous integration technologies (2.5D/3D) in the EU to address complexity and performances challenges in an innovative way leveraging EU mature technology strength

Advanced packaging technology has enabled heterogeneous integration of disaggregated functionality where different process technologies can be selected to offer the best cost/performances tradeoff for each functionality. This approach has been particularly effective for the image sensor market where the sensor and signal processing are integrated using different technologies. But heterogeneous integration is not limited to "more than Moore" technologies. Today, advanced packaging is key in the TSMC technology roadmap to support the "chiplet" architecture used by the more advanced digital IC [12]. To secure its position in the semiconductor value chain, Europe must strengthen its current assets on heterogeneous integration. As such, we propose the following actions:

- Allocate more R&D funding to collaborative programs dedicated to heterogeneous integration and advanced packaging (a flagship project could help to federate and improve the focus on those key topics)
- Upgrade European research facilities dedicated to heterogeneous integration and advanced packaging, and consequently develop new pilot lines to speed up the transfer of developed innovation to the industry

3.3.3. Establish a European fabless ecosystem developing complex SOC achieved in leading edge CMOS technologies to serve the domestic and international market

To increase Europe's share in global semiconductor capacity, increasing Europe chip's production capacity may not be sufficient. It will be necessary to increase Europe relevance in the global semiconductor ecosystem. For example, while the US only represents today 12% of the global semiconductor manufacturing (vs 9% for Europe) [7], US captures more than 50% of the entire semiconductor value chain [13]. This situation can be explained by the strong position US holds on EDA, semiconductor equipment and fabless companies. On this last item, Europe clearly has a weakness. As such, we propose the following actions:

- Facilitate investments in European fabless SMEs to enable a dynamic European ecosystem
- Provide more R&D funding to IC design programs led by SMEs and start-up targeting key digitalization program led by the commission

3.3.4. Deploy open-source hardware and software ecosystems targeting safety and security contexts

Leveraging previously proposed short terms support to open-source software and hardware ecosystems, Europe could harvest strong economical and societal benefits. It is estimated that companies located in the EU have invested around €1 billion in open-source software in 2018, which resulted in an impact on the European economy [14]. The analysis estimates a cost-benefit ratio of above 1:4 and predicts that an increase of 10% of in open-source software contributions would annually generate an additional 0.4% to 0.6% GDP as well as more than 600 additional ICT start-ups in the EU. Moreover, open-source software and hardware technologies are also key to promote digital autonomy and technological sovereignty. Consequently, we

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propose the actions below in order to strengthen the deployment and adoption of open-source technologies in Europe connectivity market:

- Integrate open-source software and hardware technologies and their communities not only into European research and innovation policies, but also into general policy frameworks, such as the European Green Deal and European industrial strategy
- Enforce the public sector to favor the procurement of open-source hardware and software technologies instead of proprietary solution to reduce the total cost of ownership, avoid vendor lock-in and thus increase Europe digital autonomy

3.3.5. Establish leading edge technology source in Europe

Europe must invest in advanced semiconductor manufacturing to secure the procurement of its own demand. However, investments in advanced European fabs need to be strongly incentivized to mitigate both the high risks involved [7] and the higher total cost of ownership experienced in Europe vs other regions [11]. Leveraging on previously proposed short and mid-terms guidelines and recommendation, we believe the following actions are practical solutions to address such challenge:

- Support the European semiconductor manufacturer ecosystem with long period incentives to build more advanced logic fab to address their key end markets' (automotive, industrial, wireless infrastructure, …) long terms needs
- Attract one industry frontrunners (for example Intel which has already announced a new Fab in Germany near Magdeburg) with strong incentives to establish an advanced logic fab in Europe to serve both its industrial and automotive current player (as done by Japan with TSMC 28/22 nm and 16/12 nm Fab in Kumamoto [15]), as well as developed European fabless ecosystems (which may require more advanced nodes)

3.4. Long term core technologies development actions proposal

In this section, we review the actionable recommendations and guidelines proposed by the COREnect consortium to address in the long term (>2030), Europe connectivity challenges and opportunities (across different market segments).

3.4.1. Enable the development of next generation derivative technologies to secure European leadership on the long terms

To secure and strengthen Europe's ecosystem on mature semiconductors on the long terms (>2030), preliminary research topics are identified. We propose the following actions:

- Support the development of InP on Si technologies to enable innovative (sub-) THz and optical applications
- Strengthen advanced packaging activities to enable innovative heterogeneous integration schemes leveraging Europe's mature technology portfolio

3.4.2. Enable European Cloud solution & service providers to address domestic and international markets

While the US achieved a dominant position with GAFA (Google, Apple, Facebook, Amazon) and Chinese digital companies' growth has been impressive during the past few years with BATX (Baidu, Alibaba, Tencent, Xiaomi), Europe still lack significant digital players (only players like Spotify in Sweden, Deliveroo in the UK, OVH in France come to mind). Focusing on the cloud, while OVH achievements are remarkable generated business cannot be compared to market

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leader (€663 million revenue in 2021 vs $71 billion for Amazon Web Services). Large digital end users drive the connectivity and semiconductor ecosystem and capture a significant part of the value chain. Consequently, on the long term, this European weakness must be addressed. To do so, we propose to consider the following actions:

- Build a common and unified digital market by establishing common regulation rules to enable more start-ups to scale up and help European champion to emerge
- Set up an innovative financing strategy, for example by enabling investors to create European funds in a simple and standard way to orientate European savings towards risk and innovation, to bridge the current venture capital gap with the US and China.

3.4.3. Strengthen leading edge technology source in Europe

To support on the long run the growth of a European fabless ecosystem developing complex SOC using leading edge CMOS technology, it will be necessary to ensure for Europe a competitive and resilient supply chain.

- Support the European semiconductor manufacturer ecosystem with long period incentives to build advanced logic fab able to compete with foundry leaders (leveraging the technology R&D development performed in Europe).
- Attract additional industry frontrunners (namely TSMC and Samsung since Intel has already announced a new Fab in Germany near Magdeburg) with strong incentives to establish advanced logic fabs in Europe and enable a resilient and competitive supply chain for European Fabless ecosystem.

4. Conclusion

In this report, we translated the COREnect roadmap proposition reported in (D3.3, D3.4 & D3.6 into actionable recommendations and guidelines for the relevant stakeholders both in the public and private sectors and raise their awareness of the required investments. The document proposed an executive summary of the analysis proposed by expert groups and a translation into concrete actionable recommendations and guidelines, which could be implemented by the appropriate stakeholders, considering different impact timelines: in short term (<2026), medium term (2026-2030) and long term (>2030).

While the challenge in front of us is not easy to overcome, we remain confident that the capacity of the European ecosystems and stakeholders is up to this task. Proposed recommendations and guidelines do not pretend to be exhaustive, but they should give a solid foundation for the required long-term European roadmap on connectivity systems and components to support European strategic autonomy and sovereignty objectives.

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