0. Introduction and Overview

0.1. PART 1 – WHY? GOALS AND PURPOSES OF ECS SRIA 2025

We are living in a period characterised by unprecedented challenges: climate crisis, ageing population, geopolitical tensions, to name a few. In particular, Electronic Components and Systems bear the promise to be key tools to allow us to overcome many of the aforementioned challenges. However, faced with a flurry of possible technology options, and limited financial and human resources, Europe needs to make sure that it aligns its research efforts and public support where it can best leverage its strengths and mitigate its weaknesses, both now and in the future.

This is the purpose of this ECS Strategic Research and Innovation Agenda (ECS SRIA), jointly developed by the experts of the European ECS community, coordinated by the three industry associations: AENEAS, Inside Industry Association (formerly ARTEMIS-IA) and EPOSS. This eighth edition describes the Major Challenges, and the necessary RD&I efforts to tackle them, in micro- and nanoelectronics for smart systems integration, all the way up to embedded and cyber-physical systems, and systems-of-systems (SoSs). By doing so, it is an essential tool to drive the ECS research and innovation efforts in Europe with the ultimate goal of creating value, growth, jobs and prosperity.

0.1.1 The ECS ecosystem: a key enabler of prosperity for Europe

The importance for Europe of the ECS ecosystem is twofold: On the one hand, it is a major contributor to European economic and political strength, due to its economical weight in terms of employment and wealth creation, and its contribution to European economical sovereignty. On the other hand, ECS bring benefits across many - if not all - aspects of our daily life.

A Strategic advantages for the EU

Globally, the long-term market trend for electronic components is expected to exceed US $1,000 billion by 2030[1]. In Europe, the semiconductor ecosystem employs some 250,000 people, with 2.5 million in the overall value chain of equipment, materials, semiconductors components, system integration, applications and services – mostly in jobs requiring a high level of education.

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[1] Europe's urgent need to invest in a leading-edge semiconductor ecosystem - Article - Kearney

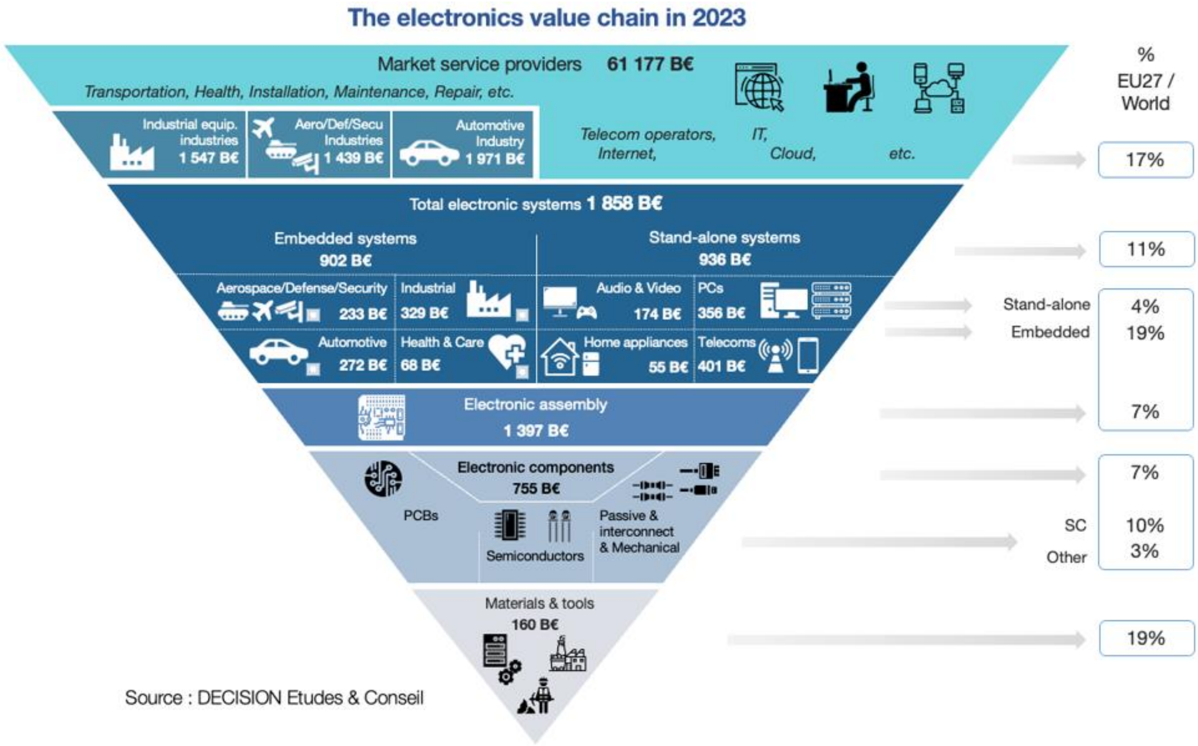


Figure 0.1 Process technology, equipment, materials and manufacturing is at the base of the digital value chain (Source: DECISION Etudes & Conseil) – 2023 market size numbers

The demand for chips is expected to double by 2030, driven by the digitalisation of society and the pervasiveness of Artificial Intelligence.

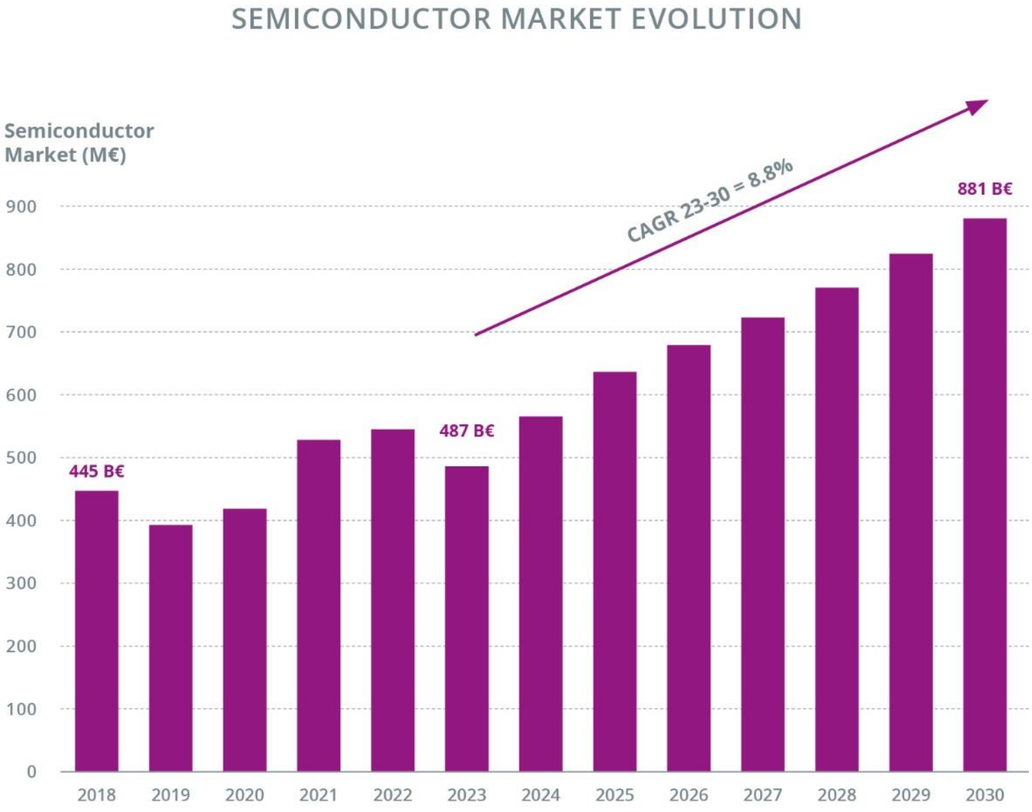
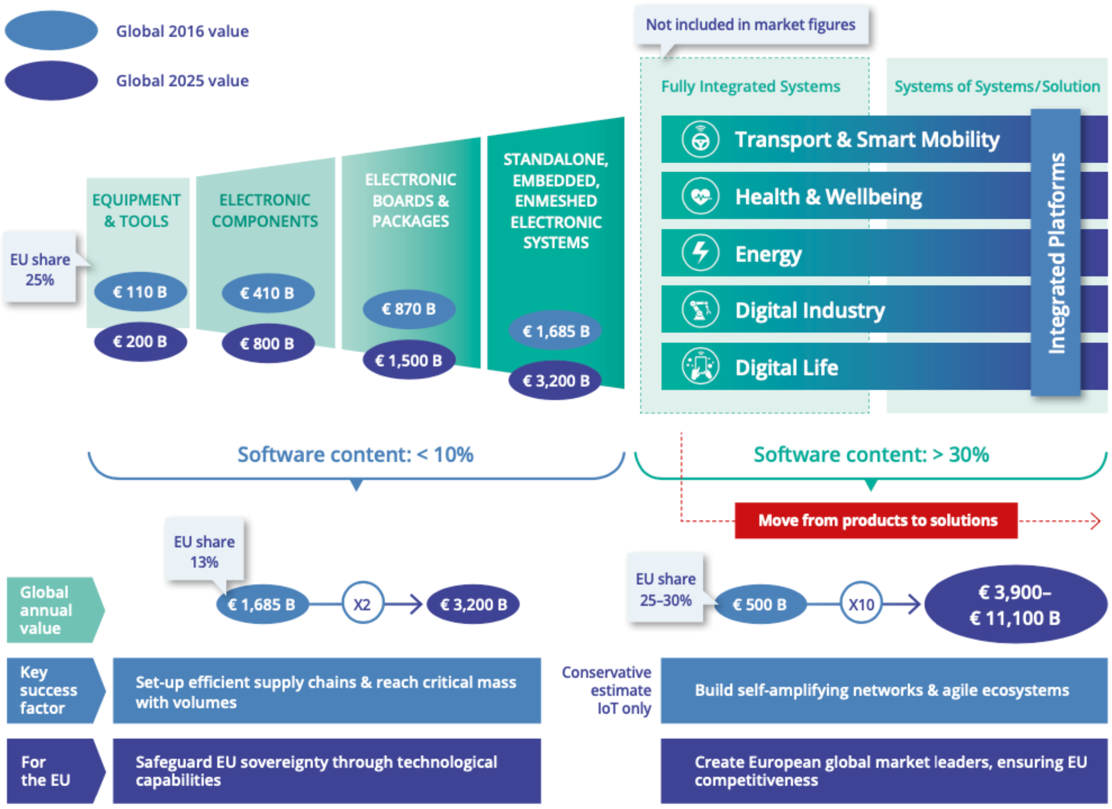


Figure 0.2 Semiconductor market evolution 2018 – 2030 (Source: DECISION Etudes & Conseil, WSTS)

Given that in the next decade, 85% of overall global growth is projected to take place outside the EU[2], it is essential that the EU maintains and increases the worldwide competitiveness of its electronics component industrial ecosystem. In turn, this increased competitiveness will stimulate all the ECS value chain and downstream industries that depend on it, including transportation, healthcare, energy, security, and telecommunications, to name a few. It is a key ingredient to maintain manufacturing as the backbone of the European economy, to guide further digitalisation of society and industry, ensure Europe's sovereignty and resilience against crises situations, facilitate the digital single market, maintain employment and move towards a better, smarter society.



Note: rounded figures. (1): 2025 estimate value potential for the Internet of Things, not the full potential for ECS end-applications.
Source: Decision, IDC, Advancy research & analysis

Figure 0.3 - Global and European value chain 2016–25[3].

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[2] European Parliament: EVP Dombrovskis speech at hearing Commissioner-Designate for Trade https://ec.europa.eu/commission/commissioners/2019-2024/dombrovskis/announcements/european-parliament-evp-dombrovskis-speech-hearing-commissioner-designate-trade_en

[3] Source: Embedded Intelligence: Trends and Challenges, A Study by Advancy, Commissioned by ARTEMIS Industry Association, March 2019

Maintaining competitiveness of the European ECS value chain

Even though the European microchips manufacturing market share is only around 10 %, the European share of integrated products and electronic systems is much higher, for example in the automotive and telecom sectors. Many European companies master specialties technologies, including integration of those technologies into smart systems, combining hardware and software - including firmware and middleware -, which allow them to grab a relatively high share of the end-product value.

Systems-of-systems[4] and their formalisation were originally conceived and studied in the defence domain, but they are (and will be) vital infrastructure for many other vertical domains. For example, the shift in the mobility sector towards electrification and autonomous mobility necessitates the adoption of systems-of-systems in e.g. vehicles and roadside infrastructure. Given current and future expectations of the market, investment in SoS research and innovation[5] is essential to European leadership in the mobility sector. Likewise, to remain at the state-of-the-art in embedded systems architecture and software Europe should continue to invest in this domain, despite fierce competition. From this perspective, the convergence between AI and edge computing - embedded intelligence - should be a top priority.

Europe is also internationally known for its high-quality products. European engineers are highly skilled in systems engineering, including integration, validation and testing, thus ensuring system qualities such as safety, security, reliability, etc, for their products, using development and test tools and frameworks enabling them to ensure these qualities in an effort- and cost-efficient manner following international and European standards. The EU has a robust and reliable safety and product liability regulatory framework, and a rigorous body of safety standards, complemented by national, non-harmonised liability regulations. This ability to provide high quality products at affordable costs has led to trustworthiness with customers on the one hand and increased competitiveness on the other hand, which have been big success factors for European embedded systems in almost all industries.

Europe should take benefit of its specific strengths, and of its ambitious plans - such as the “European Green Deal” - to make its ECS industry even more sustainable and competitive producing trustworthy products.

Sovereignty

European strategic autonomy in ECS calls for further collaboration between European companies and organizations. Design frameworks, reference architectures and integration

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[4] A collection of independent and distributed embedded and cyber-physical systems dynamically composed to generate a new and more complex system, provided with new functionalities and driven by new goals not present in the constituent embedded and cyber-physical systems individually. See full definition in the glossary

[5] From Internet of Things to System of Systems – Market analysis, achievements, positioning and future vision of the ECS community on IoT and SoS, P. Azzoni, Artemis 2020.

platforms will lead to new design ecosystems. Integration platforms[6] will provide the opportunity to leverage a high number of small and medium-sized enterprises (SMEs) and larger businesses into a platform-based economy mirroring the existing highly successful platforms of, for example, Google and Apple.

The above holds in particular for EDA Design Platforms, where global, non-European players like Synopsis and Cadence rule an overwhelming part of the market and thus de-facto control if, where and by whom such ecosystems can evolve. Providing European alternatives for such platforms will support technical enhancements e.g. the development of edge AI, embedded AI and embedded computing chips, support of the Open-Source Hardware Community (i.e., RISC-V), and many others. It will also facilitate the development of ecosystems, e.g. allowing to have a one-shop entry for start-ups/SMEs and academia to validate their innovations and new architectures into silicon, providing non-differentiating IP's, tool support, and a coherent design environment.

The Green Deal objectives will further drive the production of renewable energy and the large-scale adaptation of (bi-directional) battery electric vehicles and heat pumps. Consequently, Europe will have to modernize its energy grid towards a highly dynamic, blackout-protected energy infrastructure, also significantly reducing the dependency on imported fossil fuels.

Advancements in ECS, particularly in edge AI computing and in mastering the integration task into its products, will substantially contribute to enabling European Industries to build systems with guaranteed quality properties. Europe's strengths in creating trustworthy dependable systems by high-quality system design ("made in Europe" quality) contributes to European strategic digital autonomy.

Resilience

The Covid-19 pandemic has revealed the vulnerability of global, distributed value chains, with a disturbing and costly impact on society. In order to mitigate the impact of such disasters it is essential that strategic industrial ecosystems receive the backing from the EU. New models that will bring greater efficiency and more agile production processes need to be developed, and European manufacturing must be strengthened in key areas. This will ensure an effective and swift reaction to sudden market shocks as well as flexible manufacturing, accommodating shorter life cycles of products and fabrication-on-demand. Again, ECS innovations will play a key role here.

In semiconductor manufacturing specifically, Europe can reinforce its lead in semiconductor processing and packaging, equipment and smart systems based on the priorities set out in this ECS SRIA. The first Important Project of Common European Interest (IPCEI) on microelectronics, for example, was a successful step towards strengthening European semiconductor manufacturing in strategic areas where large-scale subsidies in other regions

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[6] An integration platform is an ECS allowing the integration of different systems, applications and services into a single system. See full definition in the glossary

have started to threaten the position of European players. The European Commission has set ambitious targets[7] in its ‘Digital Compass’ to double the ’cutting-edge semiconductor’ manufacturing share in Europe in 2030 – to maintain strategic autonomy, and to be involved in AI and other key technologies of the digital world.

Further, the EU can help national governments, companies and citizens to cooperate more easily, and develop reliable societal emergency infrastructures. This will make European societies better prepared to deal with emergency and crisis situations.

Employment challenges

The European electronics industry is currently facing a skill gap. Sufficient numbers of engineers with the right skills are crucial for Europe to compete with other regions and exploit the sector's true potential for the European economy. Faced with these challenges, Europe can play on two levers to develop a strategic advantage vs. other regions of the world:

- On the one hand, it must maintain and strengthen its traditionally strong and advanced educational system, and the presence of world-leading research institutes throughout the whole stack of competencies. Universities have a vital role in the supply of graduate engineers, and it is essential that graduates have access to industry-relevant design tools, leading edge technologies and training. Programs such as EUROPRACTICE are essential in providing this access in an affordable manner. Likewise, continued investment in semiconductor-related studies, as intended under the Pact for Skills[8], is crucial to reversing the current trend of declining numbers of students.
- On the other hand, there is a need to drastically increase the efficiency of engineering activities throughout the whole design / develop / test / validation process by providing new tools that are able to handle new product features which in turn are enabled by usage of AI and other new technologies. Model-based and AI-supported technologies will contribute considerably to the increase in efficiency, the increase in capabilities, the mitigation of shortage in software engineering resources, and further improve overall software consistency and quality.

While ECS is facing a skill gap, other industries are at risk of suffering job losses. For example, Europe’s automotive industry employs around twelve million people. Currently, the transportation sector is undergoing a fundamental and complex transformation across all modes. Its position is challenged by US information technology giants and aggressive and new agile Chinese automotive companies. The ECS community will contribute substantially to maintaining competitiveness, and therefore jobs, of the European car industry by using new technologies, components and systems to target areas like autonomous vehicles, electrified CO_2-neutral vehicles, Over-the-air (OTA) updates and new mobility concepts to reduce overall energy usage (e.g. mobility as a service).

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[7] Europe’s Digital Decade: digital targets for 2030 | European Commission (europa.eu)

[8] Pact for Skills - Employment, Social Affairs & Inclusion - European Commission (europa.eu) Pact for Skills - Employment, Social Affairs & Inclusion - European Commission (europa.eu)

Conclusion

The global digitalisation of society and industries is enabled by ongoing innovations in ECS. With its specific strengths Europe is well positioned to prevail in the fierce global competition. We are strong in embedded systems architecture and software, in embedded intelligence, in specialties semiconductors (Power, RF, sensors, FD-SOI, MEMS…), and in maintaining overall high quality, safety and security standards in ECS. Therefore, the European ECS market prospects are seen as strong.

Further investments in the future of electronic components, modules and systems integration have the following strategic advantages for Europe:

- Strengthening Europe’s economy through the generation of high-tech innovations.
- Increasing the added value in Europe by integrating more functional systems and products, e.g. in automotive, med tech and telecom industries.
- Enabling a successful Twin Transition (Green and Digital) in an economically feasible way through multifunctional smart devices.
- Ensuring European sovereignty and securing strategic Intellectual Property from European companies on advanced technologies in the microelectronic ecosystem with regards to heterogeneous integration.

To maintain leading positions in specific markets Europe must continue to invest in RD&I in strategic ECS technologies, including disruptive technologies like high NA lithography, 2D-materials, quantum computing and related technologies, AI based development, design and verification methodologies, scalable platform technologies and differentiating capabilities by software. With strategic initiatives like the Green Deal, the Digital single market, the Pact for Skills, and the Chips Act, to name a few, the European Commission has already taken important steps to secure a healthy future for the ECS industry in Europe, and therefore for many ECS-enabled end-product industries. The ambition of the ECS Strategic Research and Innovation Agenda is to support, enable and amplify that effort, by:

- Strengthening industry involvement: Strategic R&D and manufacturing investments in disruptive technologies, needed to cope with the transition challenges of our society (digitalization and sustainability, EU sovereignty), as depicted in the ECS SRIA, need collaborative approaches for R&D and governmental support for lowering the risks for realization and implementation. Therefore, in particular industries with high R&D intensities addressing key enabling technologies to solve global challenges, such as Electronic Components and Systems (ECS), should be supported to grow;
- Providing guidance to join forces: For our continent with federal democratic structures and a high degree of individual required solutions, joining forces in a billion-market environment is the only viable approach to be well set-up for the future despite having limited resources. Collaborative RD&I projects are one of the main instruments to that effect in our federal eco-system.

B Technology-enabled societal benefits

Besides its economical weight per se, the strategic importance for Europe of the ECS ecosystem is further strengthened due to its role as the enabler of the digitalisation of our society.

Digitised services based on smart electronic components and systems (ECS) are becoming increasingly ubiquitous, penetrating every aspect of our lives. They also provide ever greater functionality, more connectivity and more autonomy. The benefits to society are numerous: safer traffic, less carbon emission and pollution, instantaneous access to information, convenience and cost saving in e-health, more efficient factories, more social safety, and many more. In short, ECS-based applications and services are key to ensuring the stable growth and development of the European Union.

On the other hand, our dependency on ECS-based applications is also continuously growing. This reinforces people's concerns on – among others – the security of privacy and personal possessions (e.g. through cybercrime, cloud services, surveillance cameras), on personal safety (driver-assistance, e-health), and on the unclear impact of transformational technologies (AI, quantum technology). The societal concerns arising from these technologies need to be addressed. To achieve that, it is vitally important that these electronic systems are safe, secure and trustworthy. A human-centred approach is a key aspect of the EU's policy on technology development, and in line with fundamental European social and ethical values.
In the following pages, we examine in more details the societal benefits which ECS brings to Europe, and where R&I efforts are needed to ensure further gains.

Sustainability

Contribution of ECS technologies to sustainability are two-fold:

On the one hand, ECS are a major enabler of the Green Deal objectives as they foster sustainable and smart mobility; the supply of clean, affordable and secure energy, resource-efficient manufacturing, a healthy and environment-friendly food supply chain, healthcare transformation, as well as more efficient information systems.

To accelerate the shift towards sustainable and smart mobility, the mobility sector requires energy efficient mobility grade semiconductor devices, be it for vehicles or for the supporting infrastructure required for the charging of EV's. This needs to be complemented with middleware and embedded SW applications, which are often part of a cloud-to-edge continuum.

In the energy sector, the power grid architecture will be transformed into a multi-modal energy system architecture. It will comprise distributed renewable energy generation, energy conversion units for sector coupling, transmission and distribution grids allowing bi-directional power flow, and storage for all modes of energy (electric, thermal, chemical). Key to these new energy applications will be smart sensors, networks of sensors, and smart actuators that enable status monitoring on each grid level, as well as smart converters (for all voltage levels) based on highly efficient and fast-switching semiconductor power devices and modules that enable real-time control of energy system components and grids for optimised operation based on forecasts of generation and demand, but also in case of any critical event. The future grid operation, finally, requires a sophisticated information and communication infrastructure including cloud services, IT security, and AI technologies.

Besides, ECS will be at the core of implementing new ways of manufacturing, to promote an environmentally friendly production and to develop building blocks in advanced automation and control, advanced sensors, digital twins, artificial intelligence, collaborative robotics, monitoring through value chains – that will allow for better accuracy and performance, better (predictive) maintenance and higher asset utilization. It is particularly important to ensure that design processes will cover the complete lifecycle of products for future ECS-based applications. Data must be collected to this aim, and used to enable continuous updates and upgrades of products, but also in-the-field tests of properties that cannot be assessed at design-, development- or testing-time. This will as well increase the effectiveness of validation and test steps by virtual validation methods based on this data.

Another major application sector for ECS is agriculture, where policies focus on preservation of landscapes, biodiversity, and environmental protection. This will require measurement and monitoring technology which is accurate, highly scalable, and secure. In addition to these environmental requirements, Smart Internet of Things (IoT) systems support productivity growth, access to clean water, fertile soil and healthy air for all, and help fighting against pests while preserving biodiversity and restoring the planet’s ecosystems.

Healthcare digitization will enable the shift from hospital care to remote care at home, thus reducing travel-induced environmental impact, while personalized medicine will reduce waste in resources.

Finally, edge computing and embedded intelligence will allow to significantly reduce the energy consumption for data transmissions (e.g. to the cloud), will save resources in key domains of Europe’s industrial systems, and will improve the efficient use of natural resources.

On the other hand, the ECS sector is focusing on improving its own energy performance and disposability of electronic components and reducing its environmental footprint by means of cleaner and greener production processes, more circularity and less energy and material consumption. These efforts are mandatory since the demand for ECS is set to grow considerably to serve environmentally sustainable applications, and we cannot allow this to translate into an equivalent increase in the resources consumed in their production and operation.

The sustainable manufacturing of semiconductors requires the continuation of significant R&I on new processes, manufacturing techniques, equipment and materials. Advances in the manufacturing of chips and packages in the coming years will strongly contribute to Europe’s ambition to become climate-neutral by 2050. Some examples are:

- Device scaling - by moving into 3D for sub-3 nm node memory - and computing technologies will drive down energy consumption following the power, performance, area and cost (PPAC) scaling roadmaps.
- New embedded non-volatile memory technologies enable local processing and storage of configuration data, decreasing data transmission and energy needs for a wide range of automotive and IoT applications.
- New power electronics devices, either based on silicon or new (GaN, SiC) materials, will increase the energy efficiency of electric powertrains, energy storage, lighting systems, etc.
- Improved integration technologies and miniaturisation will support sustainability of products and production technologies.

One key point of attention is the development and use of replacement materials to comply with Restriction of Hazardous Substances Directive (ROHS) regulations (such as lead, mercury and other metals, flame retardants and certain phthalates, PFAS[9]) and minimization of critical raw materials (CRM) dependence. In particular, due to their unique physicochemical properties, PFAS are currently extensively used in both chip fabrication and for semiconductor manufacturing equipment and factory infrastructure. Research to identify alternative chemistries and to develop efficient abatement technologies for uses where no alternative can be found is therefore essential.

Beyond the sustainability of the components, modules and systems fabrication stage, the full life cycle and end-of-life of ECS should be considered using life-cycle assessment (LCA) as a design tool. There must be upstream considerations and design for sustainable production and condition monitoring, HW and SW upgradeability, lifetime extension, health monitoring, predictive maintenance and repair. These are all to be integrated into a lifecycle-spanning continuous development process that enable feedback of data from the later phases of the lifecycle to the former ones. Besides, reduction of CO_2 emissions during the lifetime of the system requires minimizing the power consumption at component, module and system levels while in operation by using low-power hardware and software technologies.

Moreover, eco-design has to consider re-use in a second life application, and the recovery of components and materials for recycling. Note that increased integration will cause the borders between components, modules and systems to become blurred: More diverse and complex materials will be used at each level, so that the dismantling of systems into their constituent components at the end of their useful life will become increasingly difficult, requiring significant R&I efforts to identify solutions to achieve circular economy.

Finally, another lever to decrease the overall resource consumption of ECS is at the architectural level. Embedded intelligence for instance can provide computing capabilities to the nodes and devices of the edge of the network (or edge domain) to improve the performance (energy efficiency, latency, etc.), operating cost, and reliability of applications

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[9] PFAS is a class of thousands of synthetic substances known as 'forever chemicals' since they do not break down in the environment. PFAS offer a unique set of technical characteristics, which include exceptional heat and chemical resistance, high electrical insulation resistance, high purity, low-outgassing and low coefficient of friction

and services. Above all, this new computing paradigm could significantly reduce environmental footprint by the introduction of ultra-low power and efficient computing solutions. There is plenty to explore on the trade-off between performances and power consumption reduction, and on managing complexity (including security, safety, and privacy) for embedded architectures to be used in different applications areas, which will spread the use of edge computing and artificial intelligence and their contribution to European sustainability.

Healthier life

The critical role that smart components, modules and systems can play for the world's security and health was demonstrated during the Covid-19 pandemic. Key topics here range from an acceleration in the analysis of DNA samples, the availability of automated medical support and diagnosis tools, to tracking systems for tracing and controlling the spread of the disease, as well as the recourse to robots in several hazardous situations, from disinfecting airplanes and hospital rooms, to delivering medication to isolated patients.

Even outside times of crises, advances in ECS are playing a key role towards enabling a healthier life for all citizens. The Internet of Things (IoT) is one of the main technologies enabled by smart components, modules and systems, and ongoing advancements in IoT bring more smartness to people's health and well-being via e-health, m-health, implants, ingestibles, wearables, personalised medicine, inclusion of people with a disability, etc. This trend is further accelerated by many AI-enabled positive breakthroughs which can be seen on the horizon.

The potential of these technologies is enhanced by their integration into complex systems-of-systems, relying on ubiquitous, wideband and dependable connectivity, improving medical practices and services for patients and healthcare professionals. Connected devices can allow remote monitoring and diagnosis and more efficient means of treatment. Access to healthcare for rural populations will also improve.

Smarter, more efficient society

AI and edge computing have become core technologies for the digital transformation. AI will allow to analyse data on the level of cognitive reasoning to take decisions locally at the edge (embedded AI), transforming the IoT into the Artificial Intelligence of Things (AIoT). Likewise, control and automation tasks, which are traditionally carried out on centralised computer platforms, will be shifted to distributed computing devices, making use of decentralised control algorithms.

Embedded cyber-physical systems (ECPS), or IoT systems, provide data processing and intelligence on the site/edge, while improving security and privacy, and completely changing the way we manage everyday activities. ECPS also play a critical role in modern digitalisation solutions, quickly becoming nodes in distributed infrastructures supporting systems-of-systems (SoSs) for monitoring, controlling and orchestrating supply chains, manufacturing lines, organisation's internal processes, marketing and sales, and consumer products.

Moreover, digitalisation platforms exploit embedded software flexibility and ECPS features to automate their remote management and control through continuous engineering across their entire lifecycle (e.g. provisioning, bug identification, firmware and software updates, and configuration management).

Ongoing advancements in IoT systems will drive the further digitalisation of society, by bringing more smartness to human activities, like smart cities, smart transportation, smart grids, smart manufacturing, and pull the development of cyber physical systems and embedded systems-of-systems (SoS). A clear example is the introduction of autonomous vehicles, which will become components in the complex logistics systems of cities, countries, and regions. SoS-related technologies will be key to providing efficient utilisation of autonomous vehicle assets, also offering timely delivery of goods and personnel. Another example is the integration infrastructures adopted in production, in order to meet customer demands locally. Here, the interoperability of SoS technologies across domains is an essential capability.

This evolution will in turn put high demands on the availability and reliability of high-speed, secure, low or guaranteed latency connectivity.

Another important trend is the emergence of open-source components which become the core building blocks of application software in many innovative domains[10]. Developers are being provided with an ever-growing selection of off-the-shelf possibilities, which they can use for assembling their products faster and more efficiently, where efficiency goes hand in hand with affordability and sustainability.

Privacy, Safety and Security

The efficiency and flexibility of embedded software, in conjunction with the hardware capabilities of ECS, allow to move various processing functions to local devices, such as voice and environment recognition, allowing for privacy preserving functionalities. AI also increase the capabilities to detect intrusions, thus reinforcing the protection of privacy.

Furthermore, the ever-improving detection capabilities of cameras and other long-range sensors (radar, lidar, etc…) combined with the development of AI at the edge is opening unprecedented opportunities for many safety and security-related applications that currently rely on human involvement, such as automated driving, security and surveillance and process monitoring.

Connected functionalities will extend the control and automation of a single system (e.g. a truck) to a network of systems (e.g. a truck platoon), resulting in networked control of a cyber-physical system. The benefit of this is generally better performance and safety.

As already noted regarding the support for a smarter, more efficient society, the technical trends underlying the promises for higher privacy, safety and security demand the availability

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[10] More than 81% of produced software are consuming open-source code in products or services (https://github.com/todogroup/osposurvey/tree/main/2020)

of ever better-performing connectivity networks. As an example, automated driving requires ultra-high reliability, extremely low latency and high throughput connectivity solutions. Advanced edge solutions that will integrate AI/ML schemes over secure links will also be of paramount importance. Advanced connectivity is also a key enabler for disaster relief and prevention systems.

Finally, one cannot ignore that the ever-increasing importance of ECS-based systems in our daily lives raise concerns regarding trustworthiness, privacy, safety and cybersecurity. Indeed, a degraded behaviour of cyber-physical systems or an incorrect integration among them, would affect vital properties and could cause serious damage. Shortcomings in those dimensions might even outweigh the societal and individual benefits perceived by users, thus lowering trust in, and acceptance of, new technologies. Ensuring high standards on safety, security, and reliability at affordable efforts and cost, require continuous R&I efforts on methods and tools for ECS architecture and design:

- Applying "quality by design" approaches for future ECS-based systems.
- Providing methodology, modelling and tool support to ensure end-to-end trustworthiness of new designs. This includes balancing trade-offs of quality aspects and ensuring tool-supported verification and validation (V&V) at the ECS level, providing methodology, modelling and tool support to validate safety of AI-based systems.

Connected society / social inclusion

The further integration of "smart everything" into "ubiquitous smart environments" will introduce large and very complex systems of systems with complex physical interactions. In this context the technology competence and innovation in the field of embedded and cyber-physical based SoS will be a critical asset.

ICT technologies have long been recognised as promoting and facilitating social inclusion, as well as digital inclusion (i.e. the ability of people to use technology). These aspects span dimensions as diverse as disaster relief, food security and the environment, as well as citizenship, community cohesion, self-expression and equality. One illustration is the use of AI to enhance conversational interfaces, improving the human-machine interface with reliable understanding of natural language.

0.1.2 The ECS SRIA: An agenda aligned with European priorities

For each technology and application domain it covers, the ECS SRIA identifies specific so-called Major Challenges, with a focus on the most critical aspects to be tackled from the perspective of innovation. The analysis of each Major Challenge illustrates the state of the art of the associated technology and/or application domains, describes the vision of the ECS community for the future, identifies potential outcomes, and defines research and engineering activities on the key focus areas that are fundamental to successfully address the challenge.

ECS are the key technology, enabler and differentiating factor behind all mass applications and their innovations, serving a market of over 61 trillion Euro (see figure 0.1). Therefore, a very broad scope in the applications, in the design, the underlaying technologies, the requirements and in the manufacturing is addressed in this document, resulting in the identification of 70 Major Challenges.

They are frequently interdependent – they influence each other, become increasingly demanding, and have an impact on many areas, including technology innovation, industrial competitiveness, security, safety, business and environmental sustainability, society, etc. From this perspective, the Major Challenges represent key factors for the achievement of four Main Common Objectives, which are aligned with the European Commission's strategic priorities (see table in Appendix):

- Boost industrial competitiveness
- Ensure EU digital autonomy
- Establish and strengthen sustainable and resilient value chains
- Unleash the full potential of intelligent and autonomous ECS-based systems

A Main Common Objective 1: boost industrial competitiveness through interdisciplinary technology innovations

As mentioned earlier, investing in the Research and Innovation topics described in this document will not only translate into a more competitive and sovereign European ECS value chain, but it will also boost European industrial competitiveness across all sectors.

Electronic components and systems, by their inherent nature, are the result of interdisciplinary research and engineering. These require competencies in diverse technology domains, including process technology, equipment, materials and manufacturing, electronics, and telecommunications, as well as cross-sectional technologies such as edge computing, artificial intelligence, high-speed connectivity, and cybersecurity.

As a result, ECS research needs to be interdisciplinary to benefit from the multiple available sources of innovation, as well as research-intensive and market-oriented. This will ensure forthcoming ECS innovations will be of strategic value for Europe and boost its industrial competitiveness in all its value chains, and help building the strong industrial base essential for European strategic autonomy.

With the Chips Act, the KDT JU has transited to the Chips JU, with a mandate extended to capacity building activities and related research and innovation activities of four operational objectives of the Chips for Europe Initiative, as set out in the Chips Act article 4:

1. building up advanced design capacities for integrated semiconductor technologies;
2. enhancing existing and developing new advanced pilot lines across the Union to enable development and deployment of cutting-edge semiconductor technologies and next-generation semiconductor technologies;
3. building advanced technology and engineering capacities for accelerating the innovative development of cutting-edge quantum chips and associated semiconductor technologies;

4. establishing a network of competence centres across the Union by enhancing existing or creating new facilities.

These objectives translated in particular into the following additional activities for the JU:

- The development of new capabilities to design, prototype and test innovative chips through pilot lines on semiconductor technologies, with the close collaboration of European RTOs and industrial vertical sectors.
- The establishment of competence centres, which will address the lack of skills that is affecting the European labour market, trying to provide training support for future professionals in the whole ECS domain, consolidating and strengthening the rich knowledge base required by interdisciplinarity.
- The setting up of a new Virtual Design Platform and specific funding instruments which will provide support to the rich, diverse and multidisciplinary ecosystem of European SMEs and start-ups, facilitating investments in research, development, and production and simplifying the process of bringing innovation from “the lab to the fab”.

This SRIA is the reference document for all research and innovation activities of both the former (under KDT) and these new Chips JU activities. This extension reflects the intrinsic interdisciplinarity of the SRIA and further strengthens it from different perspectives.

All the new initiatives introduced by the Chips Act have been conceived to boost European competitivity in the ECS market and ECS-based application domains, guiding investments and resources towards strategic areas of semiconductor technology that are most critical for the European industry's competitiveness. This SRIA contributes to the identification of these critical areas and of the associated challenges that will characterise their development in the next ten years. The role of the SRIA is fundamental to identify the key starting points for RD&I and to setup multi-annual synergies with the pilot lines that will focus on more mature prototyping. The SRIA will also potentially provide the elements for the “first-of-a-kind facilities” envisioned by Pillar 2: the synergies between these three steps represent the key strategy to increase European capacity building, to boost competitiveness, and to anticipate, prevent and effectively manage future crises.

B Main Common Objective 2: ensure EU digital autonomy through secure, safe and reliable ECS supporting key European application domains

The benefits for European strategic autonomy of the development of innovative ECS technologies focused on security, safety, reliability, dependability and privacy was discussed in the section “strategic advantages for the EU”. European technology-based, secure, safe and reliable ECS, combined with European AI solutions, are critical to securing global leadership and strategic autonomy in key areas such as ICT and to ensure compatibility with EU values.

These innovative technologies will simplify the implementation of the European Strategy for Data[11,12], and ensure security, privacy-by-design and strategic autonomy all along the industrial and digital value chains.

Threats to Europe's strategic autonomy are to be found in the microelectronics value chain, and then downstream in the component user segments of the electronics industry. In this context, the Major Challenges identified by the ECS SRIA will help develop innovations in secure, safe and reliable ECS technologies for creating EU-based/-made solutions in the key European application domains of:

- Aerospace, defence, security.
- Automotive, transportation.
- Machinery, robotics, electrical equipment, energy.
- Communications, computing.
- Healthcare and well-being, etc.

The Chips Act aims at consolidating and strengthening European strategic autonomy, extending and boosting the KDT with a new specific focus on the upstream of the ECS value chain. Reducing the dependency on non-European suppliers and avoiding future shortages represent the main steps towards strategic autonomy: reaching the independence on non-European suppliers for critical ECS is crucial to ensure European industries and key application domains to have a stable supply of semiconductors, even during future global disruptions or geopolitical tensions. Technological leadership and strategic autonomy are the primary ingredients required to:

- Control ECS manufacturing to produce solutions designed to meet stringent security requirements; an essential aspect for maintaining secure digital infrastructures and key applications (e.g. automotive, defence, energy, etc.).
- Ensure resilient supply of semiconductors produced in Europe to support the resilience of critical infrastructure, including energy, transportation, and healthcare systems, which rely on advanced chips.
- Achieve a greater control over the technology infrastructure that underpins the European digital economy, ensuring that critical data and systems remain under European jurisdiction.
- Enhance Europe's economic competitiveness, leading to the creation of high-tech jobs, stimulating innovation, fostering economic growth, and making Europe less dependent on external economic forces.

C Main Common Objective 3: establish and strengthen sustainable and resilient ECS value chains supporting the Green Deal

European strategic autonomy will also require the sustainability and resilience of the entire ECS value chain since the development of innovative technologies focused on sustainability and the Green Deal will support ambitions to achieve a green, resilient and competitive Europe.

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[11] https://ec.europa.eu/digital-single-market/en/policies/building-european-data-economy

[12] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52021DC0118

Moreover, the serious effects of climate change that we are experiencing daily and the current geo-political situation, which highlights our dependency on non-European fossil energy providers, further reinforce the need for Europe to accelerate its transition to climate neutrality by 2050.

This challenge must be perceived as an opportunity to create a new environment for boosting innovative aspects of technology and business models through achieving the following:

- Relying extensively on ECS-based technologies and digitalisation as key factors for lowering our global energy footprint at all levels of the economy, and by placing sustainability at the heart of combined digital and green transitions.
- Positioning the European players in hardware as front-runners in sustainability to secure a wider market so they can become world leaders. This will need European companies to consider the circular economy, new market positioning (by turning small market shares into specialisation areas), the environmental impact of global manufacturing, etc.
- Establishing this carbon-neutrality challenge, based on a close link between the digital and green transitions at the core of future funded collaborative research and innovation in ECS. This will help ensure a positive impact for each stage of the value chain, and achieve carbon neutrality right down to the final application/digital service.

This new context is required to fight and reduce the effects of climate change.

As developed earlier in the section “Sustainability” of “Technology-enabled societal benefits”, advances in ECS technologies are both a major enabler of the Green Deal for all ECS-based application fields, and a direct contributor through their significant impact on power and resource consumption of ECS manufacturing and use.

Furthermore, the **strategic autonomy** introduced by the Chips Act contributes to **economic sustainability and security**, through a reduced dependency on non-European suppliers, an increased production capacity, more competitive manufacturing processes and products, a resilient supply chain, circular economy promotion, etc.

D Main Common Objective 4: unleash the full potential of intelligent and autonomous ECS-based systems for the European digital era

ECS must have intelligence and autonomy capabilities to control their complexity more efficiently and more cost-effectively. This will help provide novel advanced functionalities and services, limit human presence to only where it is strictly required, improve the efficiency of vertical applications, etc. Intelligence and autonomy are also required for the role of ECS in the application domains, representing an important factor for the sustainability and resilience of the value chains: an ECS-based system that provides intelligent energy management, relying on technologies such as AI, represents a key building block – for example, for smart home and energy applications. Moreover, it also improves the resilience required to ensure optimal energy consumption in critical conditions and contributes to the sustainability of the value chain associated with vertical applications, since it reduces operational costs and environmental impact, improves the quality of service (QoS), return on investment (ROI), etc., thereby strengthening the global competitiveness of European companies and helping to achieve the objectives of the EU’s Green Deal.

With an innovative and strong semiconductor industry Europe can improve its competitiveness in the global AI landscape, and this will contribute attracting AI talent, companies, and research initiative in Europe. Supporting the key focus areas identified in the SRIA will be crucial to consolidate the European future position in the AI market and contribute to the supply chain resilience, supported by a robust semiconductor industry in AI hardware. Boosting the RD&I activities described in Chapter 2.1 of this SRIA will ensure a solid support for all the vertical domains covered by the Application chapters.

0.2. PART 2 – WHAT ? CONTENTS OF ECS SRIA 2025

0.2.1 Scope

This SRIA is intended to be funding-programme-agnostic, and can be used as a basis for the various cooperative programmes across Europe.

However, the scope of our work, and of this document, is firmly within the ECS domain. For details on developments in the specific application areas further up the value chain, please consult the SRIAs of other associations or public/private partnerships (PPPs) addressing those specific areas.

The range of this ECS SRIA is very wide, going from transistors within silicon chips acting as individual electrical switches for integration in smart systems up to global system-of-systems performing complex cognitive tasks and interacting with numerous humans and machines over a wide geographical spread. A very simplified view of this ECS technology “stack” is illustrated in Figure 0.4 with an example.

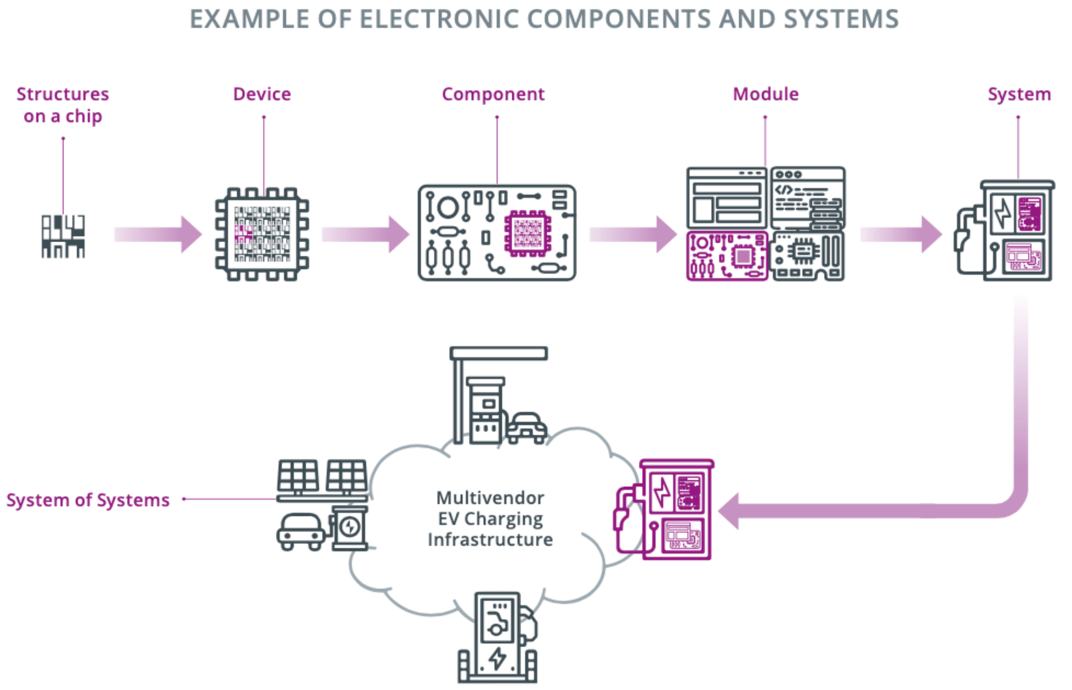

Figure 0.4 Different integration levels illustrated by the example of an EV charging infrastructure[13] *(Source: Eurotech)*

Designing such artefacts requires an interdisciplinary hierarchical approach, whereby various ECS specialists are working at different abstraction levels. As a result, the same term can have different meanings for specialists of different ECS domains: for instance, a

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[13] Structure on a chip: elementary building blocks of an integrated circuit, such as a FDSOI or FinFET transistor, or more complex structures such as an embedded memory block.

“system” designed and implemented within a given development process may be integrated as a “component” into a higher-level “system” within another development step of the engineering process. Nevertheless, to avoid confusion, since 2021 the ECS SRIA includes a glossary, where many of the key terms are defined, to avoid inconsistency across the various chapters. It was also felt that developing a common language was important in building a strong and integrated ECS community. In addition, some of the bricks of the ECS technology “stack” are further detailed below.

- Device: in the context of the ECS SRIA, and if it is not further qualified, a device will be defined as a “packaged chip”, whether it is a packaged integrated circuit (e.g. system on a chip, memory, processor, or microcontroller) or a micro-electromechanical system (MEMS)/micro-opto-electro-mechanical system (MOEMS). A device performs a general electrical, electronic or electrical/electronic/physical transduction role.

- Component: a combination of devices and other elements (such as passives) that fulfil a specific need, such as transduction of a single physical parameter within a well-specified case. A component is not self-contained in all its functions, as it requires the close support of other components for operation (e.g. in data processing, power handling, and embedded software).

- Module: a combination of correctly integrated components in which their assembly embodies a specific functionality required for the proper working of a system (e.g. sensing and actuation module, control module, communication module, energy provision module). A module is self-contained in hardware and software, making it interchangeable between systems, and allowing a higher abstraction level in systems design.

- System: for the purpose of this SRIA, a system is a set of electronic-based constituents (subsystems, modules and components, realised in hardware, software, or both) that are integrated in a way that allows the system to perform a desired (set of) function(s). Due to ECS typically being constructed hierarchically, a “module” (e.g. camera or other sensor) being part of the electronic “system” in an autonomous car might itself be referred to as a “system” when being designed (e.g. while integrating lower-level components together to achieve the “camera” function).

- System-of-systems (SoS): a collection of independent and distributed embedded and cyber-physical systems dynamically composed to generate a new and more complex system, provided with new functionalities and driven by new goals not present in the constituent embedded and cyber-physical systems individually. The difference between a “system” (comprising subsystems, modules and components) and a “system-of-systems” (also comprising subsystems) is that the subsystems of a system are chosen and integrated during design-time (i.e. completely under the control of the engineers), while in a system-of-systems the constituent (sub)systems are physically independent and dynamically form a system-of-systems at run-time.

0.2.2 The structure

The first part of the ECS SRIA is composed of four chapters focused on the **Foundational Technology Layers** and their technical challenges along the technology stack, from materials and process technology to components, modules and their integration into electronic systems, embedded software developments and software technologies, to full systems and systems-of-systems. These foundational layers are characterised by hierarchical dependencies due to the inherent nature of ECS and the way they compose and integrate in complex structures. Advances in all **Foundational Technology Layers** will be essential to creating new electronic chips, components, modules, systems, and systems-of-systems along the value chain: these are the fundamental elements required to build the digitalisation solutions of the future.

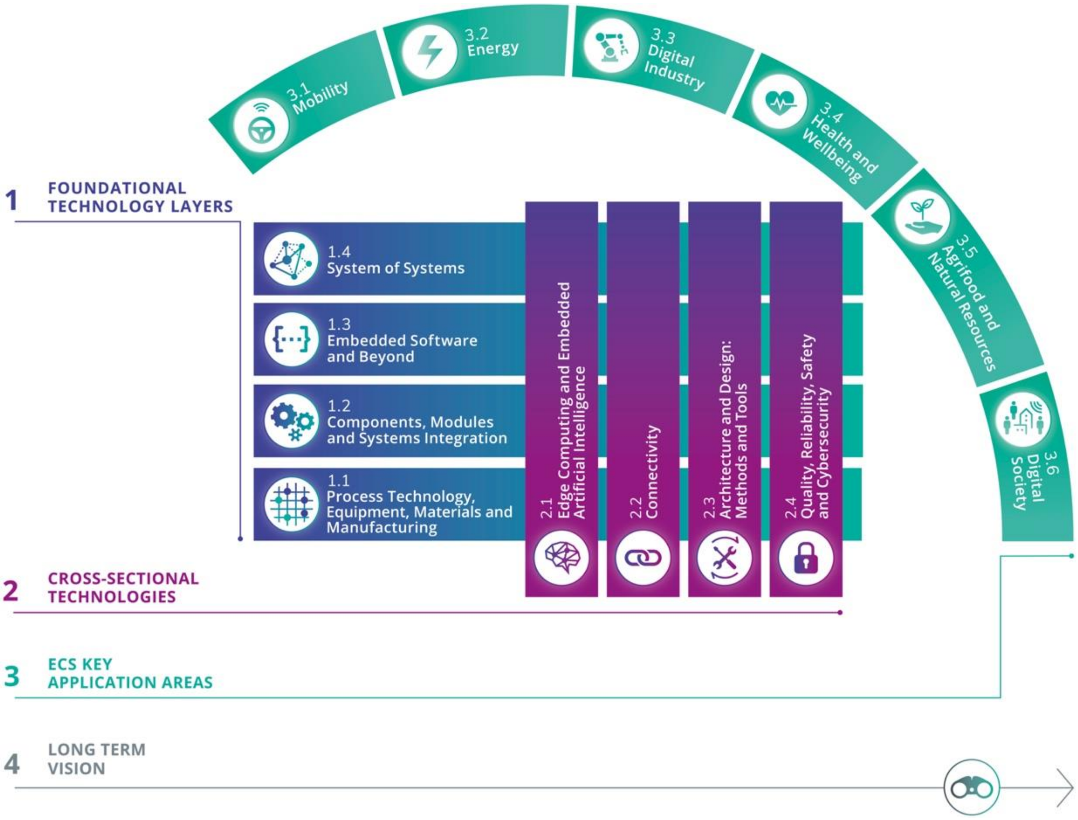

Figure 0.5 The structure of the ECS SRIA

The foundational layers represent a very fertile ground where new interdisciplinary technologies, products and solutions can grow. They are then complemented in the second part of the ECS SRIA by four **Cross-Sectional Technology** chapters that focus on transversal areas of scientific research and engineering, where innovative results emerge from the joint contribution of the foundational layers to those specific areas. **Edge Computing and Embedded Artificial Intelligence**, or **Connectivity** (e.g. 5G to 6G) will require new integrated circuits to develop innovative electronic components that can be used to develop smarter and more connected components, modules and entire systems, running smart software that will offer new functionalities and capabilities. That will allow these systems to interact, cooperate and merge in larger systems-of-systems. Similarly, **Architectures and Design: Methods and Tools** have to be further developed to provide support to each of the foundational layers, covering all domains along the technology stack, across the entire lifecycle of technologies and products. The same applies to **Quality, Reliability, Safety and Cybersecurity** concepts that can only be addressed successfully if they are encompassing the whole ECS process flow along the entire value chain.

The innovation generated by these cross-sectional technologies will be applied across foundational layer stacks and amplify the effect of innovation in all key ECS application domains. Of course, there is some overlap among the eight technology chapters since they are closely linked, but as they examine the individual challenges from different perspectives, this overlap is extremely constructive and generates valuable synergies.

In the third part of the ECS SRIA, six **Application** chapters describe the challenges arising from specific ECS application domains that are key for Europe and identify the RD&I efforts required by these application domains as regards ECS.

Finally, the **Long-Term Vision** chapter illustrates our vision of the ECS beyond the time horizon covered by the other chapters. It seeks to identify the research subjects that must be addressed at low TRL levels as foundation and preparation for the crucial developments in European industry over the next decade. Based on the trends and plans described in the preceding chapters, the long-term industrial requirements are also examined to help research programmes understand which hardware, software and system solutions should be produced most effectively for the continuous improvement of European digital technology.

While the overall structure of the ECS SRIA is unchanged with respect to the previous edition, the internal chapter structure has undergone a significant revision: In particular, the sections “Strategic advantages for the EU” and “Technology-enabled societal benefits”, which were scattered across chapters in the previous edition, have been regrouped and summarised, to be now part of this introductory chapter. The rationale behind that restructuring is that many arguments developed in those sections were not chapter-specific but rather generic in nature. This allowed to avoid redundancies, refocus the messages of the individual chapters on their specificities, and reduce the overall ECS SRIA text size.

In the same spirit, the chapter editing teams have been reviewing their text with the goal to achieve greater conciseness, while of course eliminating outdated materials and providing new data.

0.2.3 The ECS SRIA and its position in the technology landscape

Electronics components and systems are key digital technologies enabling the development of numerous applications. As such, the ECS research and innovation priorities are significantly driven by application roadmaps and needs. To that effect, the **Key Application Areas** part of the ECS SRIA translates application roadmaps into requirements for ECS. Conversely, the **Foundational Technology Layers** part maps out future advances and potential new breakthroughs in applications. The ECS SRIA therefore promotes synergies with many neighbouring application-oriented communities. For example, the **Mobility** Chapter (3.1) has strong links with ERTRAC; the **Digital Industry** Chapter (3.3) with EFFRA; and the **Agrifood and Natural Resources** Chapter (3.5) with the working group of the Alliance for the Internet of Things Innovation (AIOTI) in Smart Farming and Food Security, and with Water Europe[14]. In each case, experts participated in the work of both groups. There are also close interactions and alignments with European PPP initiatives, such as 2Zero and CCAM, IHI, etc.

The **Cross-Sectional Technologies** part also leverages the links of the ECS community with other technology-oriented domains, such as the European Technology Platform for High Performance Computing (ETP4HPC), EuroHPC, the European Working Group on High-Performance RISC-V based reference processing architectures, and Big Data Value Association (BDVA), with strong relations with the **Edge Computing and Embedded Artificial Intelligence** Chapter (2.1). Likewise, the **Connectivity** Chapter (2.2) benefited from fruitful exchanges with the 5G Infrastructure Association, SNS and inputs from the European Cyber Security Organisation (ECSO), as reflected in Chapter 2.4.

Several contributors of the **Technology** parts are also actively involved in the elaboration of international roadmaps (e.g. the Heterogeneous Integration Roadmap (HIR)[15] in electronic packaging and integration, the IEEE International Roadmap for Devices and Systems (IRDS)[16] for the semiconductor industry), and the RISC-V Roadmap of RISC-V International[17] and the European Working Group[18].

To summarise, this ECS SRIA combines application-pull and technology-push with the objective of enhancing the fertile dialogue between technologists and technology users, and strives to include discussions of upcoming strategic value chains.

0.2.4 New and growing trends

Content wise, this revision was conducted with the goal to reflect the most recent technological and strategic trends of our industry. While already present in earlier editions, quantum technologies are getting additional attention in this new edition. The same holds for the irruption and disruption of AI tools in the practices of the ECS community, and the digital society at large. The importance of the RISC-V and Open-Source Hardware trend is further reiterated. Finally, the emergence of chiplets as a potential game-changer of our industry is discussed in this introduction, with several chapters going into the related technology requirements. The next pages provide some more details on the main changes of this edition.

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[14] https://watereurope.eu/wp-content/ uploads/2019/07/Water-Europe-SIRA.pdf

[15] https://eps.ieee.org/technology/ heterogeneous-integration-roadmap/2019- edition.html

[16] https://irds.ieee.org/

[17] RISC-V-Introduction-_-Aug-2021.pptx (live.com)

[18] https://digital-strategy.ec.europa.eu/en/library/recommendations-and-roadmap-european-sovereignty-open-source-hardware-software-and-risc-v

A Chiplets

A chiplet is a tiny integrated circuit (IC) that contains a well-defined subset of functionality. It is designed to be combined with other chiplets in a "Lego-like" assembly[19].

In a sense, chiplets can be seen as a continuation of the trend already initiated with System-in-Package (SiP). With respect to System-on-Chip (SoC), the SiP approach allows to reduce the cost per square millimetre of silicon, since it is not required to fabricate all the circuit blocks using a process which could meet the performance criteria needed by all functions.

However, with respect to the monolithic SoC approach, SiP is impaired by limitations in bandwidth and latency for data transfer between its building blocks. Recent advances in heterogeneous integration technologies now allow to envision to have the “best of both worlds”: keep the advantages of SiP with circuit blocks built using, for each of them, the most adequate process technology in term of cost, power and performance, optimized for the chiplet particular function, while ensuring data transfer capabilities between those blocks close to what is currently achieved with a SoC. Other advantages of the chiplet approach (already present with SiP) are the possibility to reuse intellectual property and to test individual chips before assembly, improving the yield of the final device.

Chiplet technology has therefore the potential to lead to versatile and customizable modular chips, enabling reduced development timelines and costs. In addition, IP reuse improves design flexibility and efficiency. With all those promises, chiplets are sometimes touted as a revolutionary advancement in semiconductor technology[20]. It is especially relevant for Europe, as a path to deliver innovative solutions while keeping the dependence relative to the dominant, non-EU advanced CMOS manufacturers to a minimum.

While several vendors are now selling systems using chiplet technology, there is still many advances to be done before realising the vision of an open chiplet marketplace, including standardized interfaces, that would allow designers to select and assemble chiplets best suited for the system they want to design. In this SRIA, research focus areas relevant for the progress and enablement of the chiplet approach, as well as consequences of this technology trend, are mainly dealt with in chapter 1.2, but are mentioned in many other chapters, making it a cross-cutting theme of this document.

B Open-Source Hardware

Open-source hardware is hardware whose design is made publicly available so that anyone can study, modify, and further distribute the design, and/or freely make and sell hardware based on that design. The use of open-source hardware drastically lowers the barrier to design innovative SoCs. Indeed, this allows research centers and companies to focus their R&D effort on innovation, leveraging an ecosystem of pre-validated IP that can be freely

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[19] Don Scansen, EE Times "Chiplets: A Short History », https://www.eetimes.com/chiplets-a-short-history/, consulted 25 July 2024

[20] Cadence PCB solutions, https://resources.pcb.cadence.com/blog/2023-all-about-chiplet-technology, consulted 25 July 2024

assembled, modified, and customized for specific applications, whereas currently the cost of design of a set of IPs in-house is available to only few companies. And the use of alternative 3rd party IPs licensed by companies imposes constraints on innovation due to architecture. Open-source is also a sovereignty tool and avoids licensing IPs from foreign third parties, in a geopolitical context characterised by trade wars and export control restrictions.

While open-source SW approaches are now in wide use, open source HW has really drawn attention beyond the academic circles only in recent years. In China, USA and India, large governmental funded programmes have been created in order to stimulate the use of RISC-V and Open-Source in industry and products. The widespread adoption of this approach in Europe would have many benefits.

Creating an ecosystem to support open-source hardware is essential as it cultivates innovation and aids dissemination. This can be first based on the implementation of a strategic “Governance Initiative’’ to coordinate activities, maintain and promote the repository. Open-source projects only work well when they are attractive and provide innovation, but also when they are useful and trusted, so that at this point they can be self-supported by the community. One needs to make sure that knowledge is shared, accessible, maintained and supported on a long-term basis, as the success of open-source depends not only on the IP blocks but also on the documentation, support and maintenance provided. In particular, a one-stop-shop model with long-term activities and overall support (e.g., advice for licensing, productisation, etc.) can be promoted to help SMEs and start-ups.

The European strategy on open-source hardware should focus on application domains where there is a stronger impact, i.e. automotive, industrial automation, communications, health and aeronautics/defense. As these fields convey specific requirements (safety, security, reliability, power and communication efficiency…), the key differentiator between European core design efforts and existing players will be the attention given to the aforementioned requirements and also the extensibility with custom operations. Above all, a special focus should be placed on safety and security solutions, dealing with key aspects of collaboration, documentation, verification and certification in open-source communities.

A working group gathering European stakeholders was established in 2022. It drafted a technological roadmap, attached in Appendix A of this SRIA edition, starting with processors (RISC-V, beyond RISC-V, ultra-low power and high-end). The chiplet-based approach mentioned above is identified by the roadmap as a unique opportunity to leverage European technologies and foundries to create European HW accelerators interposers that could foster European More-than-More technology developments. Die-to-Die communication remains a missing link to leverage that approach, and its development in open-source is advocated by the working group.

In conclusion, the emergence of a European open-source hardware community should be encouraged and its initiatives be guided towards application domains where there is a strong impact. A technological roadmap has been drafted to build on the strengths of European industry and fill its gaps, while building blocks being developed will also need to be supported by the required tools, software supports, tests and documentation.

C Quantum Technologies

Disruptive technologies, where market positions are not established yet, are level-playing fields where Europe has all its chances to gain leadership. Quantum technologies fall in that category and therefore their evolution and maturity are closely monitored by the ECS SRIA expert community.

Quantum technologies are very diverse in nature, encompassing quantum computing and simulation, quantum communication, and quantum sensing and metrology[21]. As such, they go much beyond the scope of the ECS SRIA. Nevertheless, as identified in the European Quantum Flagship SRIA, the two domains overlap along two tracks:

- Technologies for dedicated quantum chips, required to fulfil the quantum challenges.
- Classical chips technologies for quantum (enabling technologies) required to support the industrialization and scaling of quantum technology.

In particular, the emerging field of quantum computing poses its own challenges for the ECS community in process technology, equipment, and materials:

- As there are still several candidates for becoming the standard quantum computing technology, a wide range of materials is relevant, together with innovations in process technology.
- New metrology capabilities are required, especially the measurement of electrical properties, such as local carrier mobility.
- To achieve practical applications, reliable fabrication, connection, and read-out of qubits need to be developed. The low temperatures at which most quantum systems are operated requires the development of cryogenic devices, to interface conventional electronics.

Beyond quantum computing, all quantum technologies related to sensing, communications and computing, including software, present significant challenges today relevant for the ECS SRIA. Given the level of maturity of those technologies, especially when it comes to quantum computing, those challenges are mainly discussed in the Long Term Vision chapter, but research focus areas derived from the needs of quantum technologies can also be found in other chapters of this document. This reflects that quantum technologies maturity is expected to evolve rapidly in the years to come, and that Europe should leverage its assets, with excellent research centres and a dynamic ecosystem of start-ups, to gain leadership in that promising field.

D Silicon Photonics

With the development of the global internet traffic, AI/ML and IoT, the demand for data centers and high-performance computing (HPC) is increasing. An extremely large link capacity for high-speed datacom interconnects between multi-cores or local/distant caches becomes compulsory. However, it is becoming increasingly difficult for the conventional electrical Cu

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[21] Strategy Research and Industry Agenda, Published in February 2024 by the European Quantum Flagship

interconnects to meet such an ever-growing capacity requirement since they severely suffer from limited bandwidth and significant power consumption.

Silicon photonic integrated circuit (PIC), referred to as Si-photonics, is the technology that realizes photonic components and circuits on Si substrates using materials and fabrication process flows in the well-established microelectronic industry. Replacing electrons with photons to transmit data brings advantages including high-speed operation, low power consumption and high-capacity transmission. Building photonic integrated circuits (PICs) on a industry-standard Si platform promises additional merits, namely ultra-low cost, high-volume manufacturing, large integration density, advanced functionality and high scalability.

Furthermore, Si-photonics, with their CMOS compatibility and small size, weight, area, and power consumption, have the capability of accommodating growing volumes of computer data arriving in real time and at very high rates in large-scale distributed computing systems. The wavelength and spatial multiplexing properties of optics are beneficially translatable to executing critical bandwidth and communications-intensive connections between increasingly parallel computational resources.

Benefiting from an ideal Si/SiO_2 interface and a large refractive index contrast, Si is an ideal platform for implementing passive optical devices such as low-loss waveguides, mode converters, and multiplexers/demultiplexers. Although Si is a centrosymmetric crystal and, thus, not an ideal material for optical modulators, high-performance modulators have been demonstrated. Efficient Ge- and SiGe-based photodetectors operating in the telecom bands are also selectively grown on Si-photonics wafers.

However, if Si can efficiently transmit, modulate, and detect light, its indirect band structure precludes efficient light emission. The achievement of on-chip light sources, using Ge alloys for instance, represents a significant milestone in advancing the complete integration of silicon-based PICs. Therefore, III-V material (InP, GaAs) on-chip lasers are currently embedded in PICs using 2.5 and 3D heterogeneous integration. Monolithic integration of III-V materials is an attractive alternative due to its low cost and high integration density. However, it introduces a high density of crystalline defects, significantly degrading the laser's performance. Exploring methods of reducing these defects is paramount to advance monolithic integration toward high-density, large-scale silicon-photonic integration.

Similarly, for applications that require high-speed modulation, the properties of Si-based modulators are not sufficient. Hence, ferroelectric electro-optic materials such as $LiNbO_3$ and $BaTiO_3$ should be embedded in the PIC using heterogeneous integration (die-to-die, die-to-wafer, or wafer-to-wafer bonding).

The most established form of the technology is optimized for operation in the telecommunication wavelength bands near 1310 and 1550nm and has waveguides defined in the top Si device layer of a silicon-on-insulator (SOI) wafer. It is enabling power-efficient transceivers and large-scale PICs that address the demands of data communications, three-dimensional (3D) sensing, and computation accelerators. In addition to these established applications, there is a growing demand to develop silicon-photonic for new product applications that include chip-to-chip electrical/optical interconnect, automotive LiDAR, quantum computing, infrared imaging and biomedical and environmental sensing. The later applications require the development of PICs in the mid-IR region wavelength range (2–20μm) as it contains strong absorption signatures of many molecules.

E Artificial intelligence topics in the ECS SRIA

While not a totally new topic (it is used for example in several embedded systems for vision, enabling autonomous vehicles), artificial intelligence (AI) really came to the forefront for the public at large in 2023, with tools such as Chat-GPT (released for public use only on November 30th, 2022) and other generative AI (Dall-E, Stable Diffusion) that grabbed the headlines in mainstream media. The ECS Research and Innovation roadmap interacts with the development of AI tools and algorithms in two symmetrical ways: ECS are an enabler for new AI developments, and AI can in turn be a significant enabler for new ECS advances. Those two aspects are extensively discussed in this current edition of the SRIA.

- ECS as enabler of AI: Chapters 1.1 and 2.1, as well as the Long-Term Vision Chapter, stress the importance of moving the processing of AI algorithms locally on a hardware device (in deep-edge devices, edge devices or on-premise computing resources, depending on the application) close to where the data is generated (e.g. by a sensor), a trend known as “embedded AI” or “edge AI”. Benefits include reducing the energy consumption of the data infrastructure by transmitting only relevant data or pre-treated information, improving data protection, increasing security and resilience due to a reduced reliance on telecommunication links, reducing latency, and decreasing memory footprint. Many of the focus research areas identified in Major Challenge 1 (Advanced computing, memory and in-memory computing concepts) of Chapter 1.1 support this move towards AI at the edge. Likewise, the four Major Challenges (increasing energy efficiency, managing system complexity, increasing device lifespan and ensuring European sustainability in AI), identified by Chapter 2.1, all cover research topics which will enable the development of a strong European embedded AI ecosystem. Energy consumption of AI solutions is an overarching issue due to the expected widespread increase of their usage, and it is essential to explore new concepts and architectures (bio-inspired and other ones) to respond to that concern, which could turn out to be a major roadblock if not addressed properly.
- AI as enabler of ECS: this aspect is discussed in Chapter 2.3, where several examples of AI use are listed to tackle Major Challenge 3 (managing complexity), such as AI-based methods for the architecture exploration and optimisation, to achieve a global optimum, AI-based guidance in the V&V process, and automatic generation of test cases with AI support. Moreover, in its entirely new section devoted to Machine Learning and Artificial Intelligence, the Long-Term Vision Chapter states that AI/ML methods are increasingly adopted in design space exploration at several stages of circuit design, as well as in design testing and verification. The potential of these AI-based methods is not limited to circuit design and extend to large-scale ECS products encompassing HW and SW, as well as multi-physical, distributed systems. They are also expected to provide guidance to engineers in multi-risk (safety, security, privacy, and other trustworthiness risks) optimisation problems. Gathering / generating the

appropriate data to train the models is identified as one of the most difficult issues to be addressed.

A third aspect is that AI adds complexity to the systems it empowers. This in turn raises additional issues at the design phase, as addressed by Chapter 2.3. There, Major Challenge 1 (Extending development processes and frameworks to handle connected, intelligent, autonomous, evolvable systems) and Major Challenge 2 (Managing new functionality in safe, secure and trustworthy systems) stress the need to develop new design and verification and validation methods for AI-based ECS, including ECS evolving during lifetime.

Finally, a purely technical approach to develop trustworthy and explainable AI, or having AI in the loop with verification of its results might not be enough to address the growing public concerns about the potential dangers of AI (pushing many governments across the world to sign the Bletchley Declaration on AI safety). In the years to come, cooperation between multidisciplinary partners with backgrounds in AI, ECS and social sciences, as well as access to "foundation models" by European academia and industry will be required to achieve and ensure the acceptance of efficient and responsible AI-based ECS, reflecting European values.

F Ensure engineering support across the entire lifecycle of complex ECS-based systems

Modern ECS-based systems are complex, and they cannot be properly elaborated and used without the appropriate engineering support across the entire lifecycle, from requirements analysis to design, development, deployment/commissioning, operation/management, remote-maintenance repair and overhaul, retirement/recycling and evolution.

Engineering support represents a key factor for achieving the four Main Objectives as it:

- impacts industrial competitiveness by simplifying life cycle management, and improves the quality of the engineering process, making it more cost-effective and agile.
- simplifies and improves the development of trustworthy ECS technologies, products and applications.
- supports sustainability and resilience that reduce lifecycle management costs, as well as ensuring the automation and continuity of operations.
- is fundamental to unleashing the full potential of intelligent and autonomous ECS, which requires completely new approaches to engineering, design and development methodologies, as well as toolchains and tools.
- improves professional training and education by strengthening and developing new and specific skills.

ECS engineering plays a key role in Pillar 1 of the Chips Act, which includes specific instruments to support the engineering process, specifically in the critical area of new chips design, to increase design activities and create a strong design ecosystem in Europe. A Virtual Design Platform (VDP), providing design tools, an IP library for various technologies, and PDKs to access the fabs, will be established to simplify and accelerate the process of going "from the lab to the fab", and make that process more accessible for EU companies, start-ups and SMEs, especially fabless. Specific Design Enablement Teams (DET) will support this process providing targeted assistance on designing chips and more complex systems, with the presence of experts in the design flow, foundries, and pilot lines, from virtual prototyping via tape-out and engineering samples to high volume production. To this regard, Competence Centres will be established to address the skills challenges that Europe is experiencing and provide education and professional training solutions for the next generation of chip designers: DET and a Competence Centre will provide advice, training, and skills-building solutions, supported by the industry-grade training framework offered by the Virtual Design Platform. Chapter 2.3 and other chapters address many of the RD&I challenges that the VDP and Competence Centres will have to face in the next decade.

0.2.5 Further changes vs. previous edition

On top of these general trends, individual chapters also reflected the latest evolutions: The respective scopes of Chapter 1.1, Process Technology, Equipment, Materials & Manufacturing, and 1.2, Components, Modules & Systems Integration, were refined to have clear boundaries: The former chapter covers all process technologies, equipment and materials' research and innovation to enable CMOS compatible semiconductor chip and packaged chip manufacturing inside a cleanroom environment, as long as the wafer is not diced, while the latter one covers packaging, integration on board and module level. Text and Major Challenges in these two chapters have been revisited accordingly, including the addition in chapter 1.1 of a Major Challenge on Advanced packaging, assembly and test equipment solutions. That chapter also added a MC on "Sustainable semiconductor manufacturing". Chapter 1.3, Embedded Software and Beyond, addresses needs deriving from the advent of software defined vehicles, requiring collaborative embedded SW development processes and toolchains. New concepts for programming languages, such as Rust, have been introduced, and software engineering practices in the AI-assisted engineering era are discussed. Updates in lifecycle management and hardware virtualization for efficient SW engineering were also introduced. In Chapter 1.4, System of Systems, the two Major Challenges "Control in SoS composed of embedded and cyber-physical systems" and "SoS monitoring and management" have been merged.

Regarding Cross Sectional chapters, Chapter 2.1, Edge Computing & Embedded AI, has been heavily restructured, to regroup the two formerly separate sections on Edge Computing and Embedded AI, reflecting the convergence of the two domains. Major trends such as complexity management utilising AI and the decomposition of complex SoCs into chiplets and interposers are discussed in details. Chapter 2.2, Connectivity, was edited to reflect the decisions taken during ITU World Radiocommunication Conference 2023 (*WRC-23*)[22], as well as the latest thoughts of the industry regarding the use of the various frequency bands when deploying 6G. In Chapter 2.3, Architecture and Design: Methods and Tools, the two former Major Challenges "Extending Development Processes and Frameworks" and "Managing new functionality in safe, secure and trustworthy systems" were merged into one, "Enabling cost- and effort-efficient Design and Validation of High Quality ECS", while a new MC was introduced on "Enabling Design for Sustainability", with associated new research focus areas.

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[22] This conference took place in Dubai, United Arab Emirates, from 20 November to 15 December 2023

Among the Application chapters, in Chapter 3.1, Mobility, the challenges regarding the software-defined vehicle have been expanded into two Major Challenges, “SDV hardware platforms: modular, scalable, flexible, safe & secure” and “SW platforms for SDV of the future: modular, scalable, re-usable, flexible, safe & secure, supporting edge2cloud applications”, while a new Major Challenge has been introduced on “Edge2cloud mobility applications: added end-user value in mobility”. The multimodal mobility topic has been moved to Chapter 3.6, Digital Society. Chapter 3.2, Energy, insists on the challenge of meeting significant energy demand by new technologies and their applications, used by an interconnected society and based on the availability of an infinite number of accessible data – AI, generative AI, large language models, crypto currency and the exponential use of them in our connected world. This challenge comes in addition to the targets set by the European Union for a renewable energy share of 32 percent and a Greenhouse gas emission reduction of 55 percent by 2030. Chapter 3.4, Health and Wellbeing, is putting more focus on demographic change as one of the major drivers (and listing of possible technical solutions to cope with it). The update of Chapter 3.5, Agrifood and Natural Resources, develops the themes of climate-smart agriculture, wearable plant sensors, carbon sequestration and agriculture passport. In Chapter 3.6, Digital Society, more attention is paid to the use of AI-based tools (such as ChatGPT and Claude). Measures against fake video and audio are included, as well as the increasing importance of cybersecurity and trustworthiness. Furthermore, diagrammes have been updated with more recent versions and post-Covid aspects have been made less prevailing.

0.2.6 The ECS global timeline for Europe

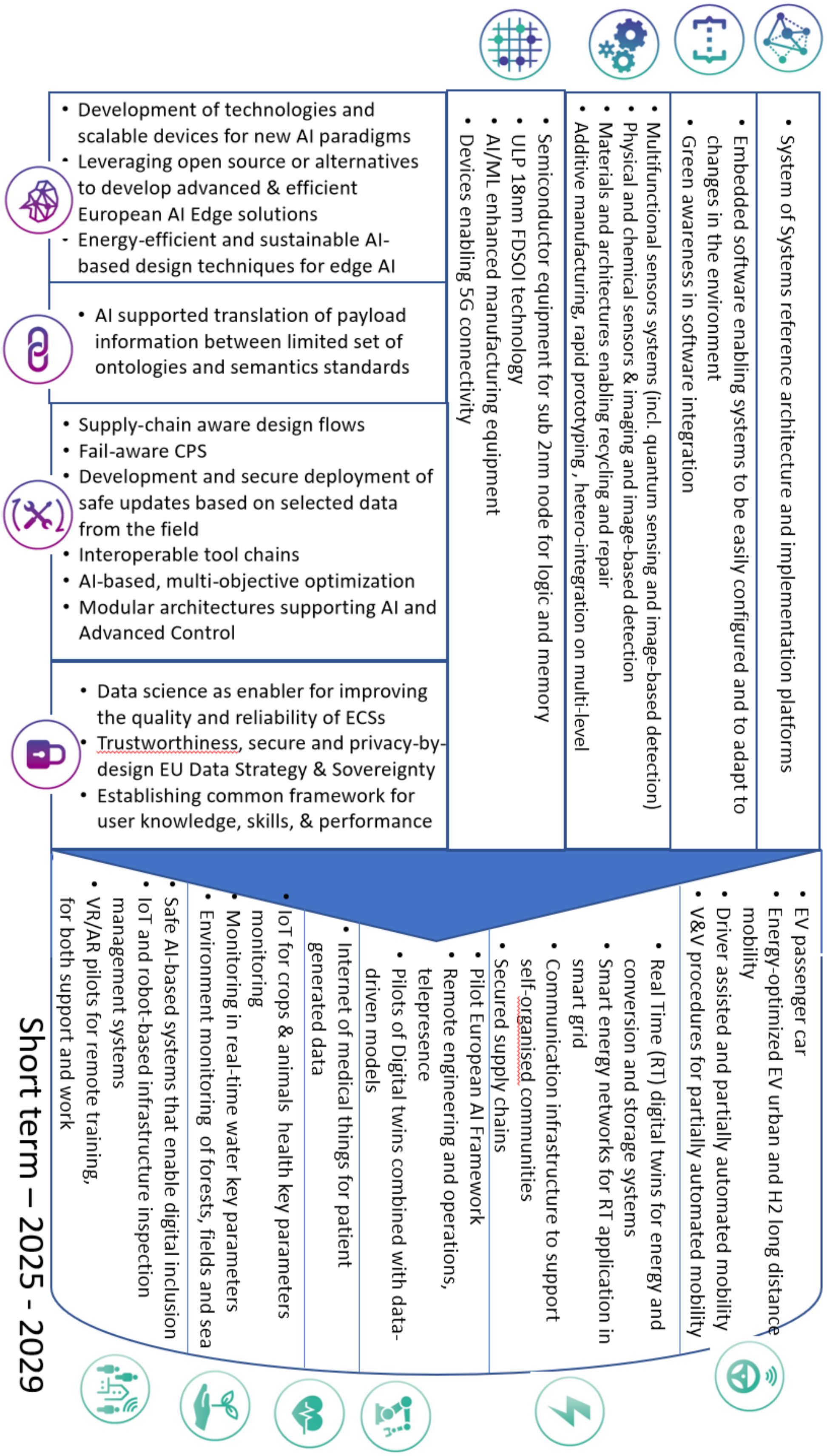
The 2025 ECS SRIA lists a number of milestones to be reached in the short term (2025–2029), medium term (2030–2034) and long term (2035 and beyond) via collaborative research projects across Europe, reflecting the ambition of the ECS industry towards the achievement of the four Main Objectives identified above.

The following figures summarise the most salient milestones to be reached in the various domains covered by the ECS SRIA over the three time periods:

- **Short term (2025–2029)**
  The industry has a precise idea of what will be achieved during this short-term timeframe.
- **Medium term (2030–2034)**
  There is already reasonably good knowledge of what can possibly be achieved.
- **Long term (2035 and beyond)**
  Expected achievements are more of a prospective nature.

Including a milestone in each of these time periods means that the described features are expected to be available at TRL levels 8–9 (prototype or early commercialisation) within that timeframe. For example, the **Components, Modules and Systems Integration** Chapter expects that, within the next five years (short term), the materials that enable recycling and repair will be available. These materials will allow for the deployment of the monitoring of forests, fields and oceans, as envisioned by the **Agrifood and Natural Resources** Chapter over the same time horizon. In parallel, this monitoring will gain in efficiency due to the development of advanced AI edge solutions leveraging open source or alternative strategies, as forecast by the Chapter on **Edge Computing and Embedded Artificial Intelligence**.

The above example also clearly shows that progresses in the various domains covered by the ECS SRIA are deeply interconnected. Innovation in one area is building upon, or being driven by, innovation in other areas. Similar examples could, of course, be developed for the other time horizons, as represented in Figure 0.6, 0.7 and 0.8. More detailed diagrams, including additional milestones, are presented in the individual chapters.



Short term – 2025 - 2029

- System of Systems reference architecture and implementation platforms
- Embedded software enabling systems to be easily configured and to adapt to changes in the environment
- Green awareness in software integration
- Multifunctional sensors systems (incl. quantum sensing and image-based detection)
- Physical and chemical sensors & imaging and image-based detection
- Materials and architectures enabling recycling and repair
- Additive manufacturing, rapid prototyping, hetero-integration on multi-level
- Semiconductor equipment for sub 2nm node for logic and memory
- ULP 18nm FDSOI technology
- AI/ML enhanced manufacturing equipment
- Devices enabling 5G connectivity

- Development of technologies and scalable devices for new AI paradigms
- Leveraging open source or alternatives to develop advanced & efficient European AI Edge solutions
- Energy-efficient and sustainable AI-based design techniques for edge AI

- AI supported translation of payload information between limited set of ontologies and semantics standards

- Supply-chain aware design flows
- Fail-aware CPS
- Development and secure deployment of safe updates based on selected data from the field
- Interoperable tool chains
- AI-based, multi-objective optimization
- Modular architectures supporting AI and Advanced Control

- Data science as enabler for improving the quality and reliability of ECSs
- Trustworthiness, secure and privacy-by-design EU Data Strategy & Sovereignty
- Establishing common framework for user knowledge, skills, & performance

- EV passenger car
- Energy-optimized EV urban and H2 long distance mobility
- Driver assisted and partially automated mobility
- V&V procedures for partially automated mobility

- Real Time (RT) digital twins for energy and conversion and storage systems
- Smart energy networks for RT application in smart grid
- Communication infrastructure to support self-organised communities

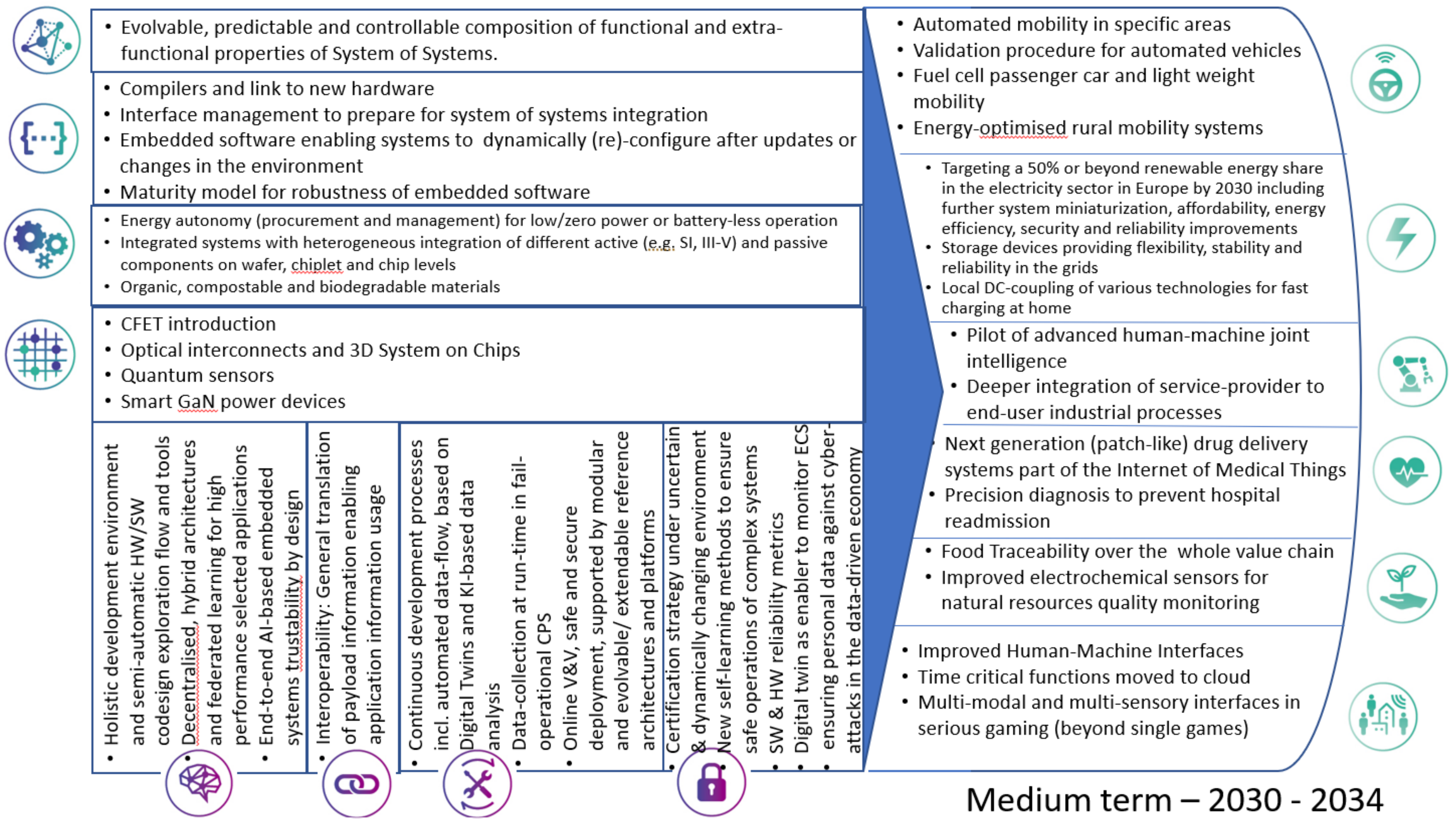
- Secured supply chains
- Pilot European AI Framework
- Remote engineering and operations, telepresence
- Pilots of Digital twins combined with data-driven models

- Internet of medical things for patient generated data

- IoT for crops & animals health key parameters monitoring
- Monitoring in real-time water key parameters
- Environment monitoring of forests, fields and sea

- Safe AI-based systems that enable digital inclusion
- IoT and robot-based infrastructure inspection management systems
- VR/AR pilots for remote training, for both support and work

Figure 0.6 Global Timeline: Short term 2025–2029



- Evolvable, predictable and controllable composition of functional and extra-functional properties of System of Systems.

- Compilers and link to new hardware
- Interface management to prepare for system of systems integration
- Embedded software enabling systems to dynamically (re)-configure after updates or changes in the environment
- Maturity model for robustness of embedded software

- Energy autonomy (procurement and management) for low/zero power or battery-less operation
- Integrated systems with heterogeneous integration of different active (e.g. SI, III-V) and passive components on wafer, chiplet and chip levels
- Organic, compostable and biodegradable materials

- CFET introduction
- Optical interconnects and 3D System on Chips
- Quantum sensors
- Smart GaN power devices

- Holistic development environment and semi-automatic HW/SW codesign exploration flow and tools
- Decentralised, hybrid architectures and federated learning for high performance selected applications
- End-to-end AI-based embedded systems trustability by design

- Interoperability: General translation of payload information enabling application information usage

- Continuous development processes incl. automated data-flow, based on Digital Twins and KI-based data analysis
- Data-collection at run-time in fail-operational CPS
- Online V&V, safe and secure deployment, supported by modular and evolvable/ extendable reference architectures and platforms

- Certification strategy under uncertain & dynamically changing environment
- New self-learning methods to ensure safe operations of complex systems
- SW & HW reliability metrics
- Digital twin as enabler to monitor ECS
- ensuring personal data against cyber-attacks in the data-driven economy

- Automated mobility in specific areas
- Validation procedure for automated vehicles
- Fuel cell passenger car and light weight mobility
- Energy-optimised rural mobility systems

- Targeting a 50% or beyond renewable energy share in the electricity sector in Europe by 2030 including further system miniaturization, affordability, energy efficiency, security and reliability improvements
- Storage devices providing flexibility, stability and reliability in the grids
- Local DC-coupling of various technologies for fast charging at home

- Pilot of advanced human-machine joint intelligence
- Deeper integration of service-provider to end-user industrial processes

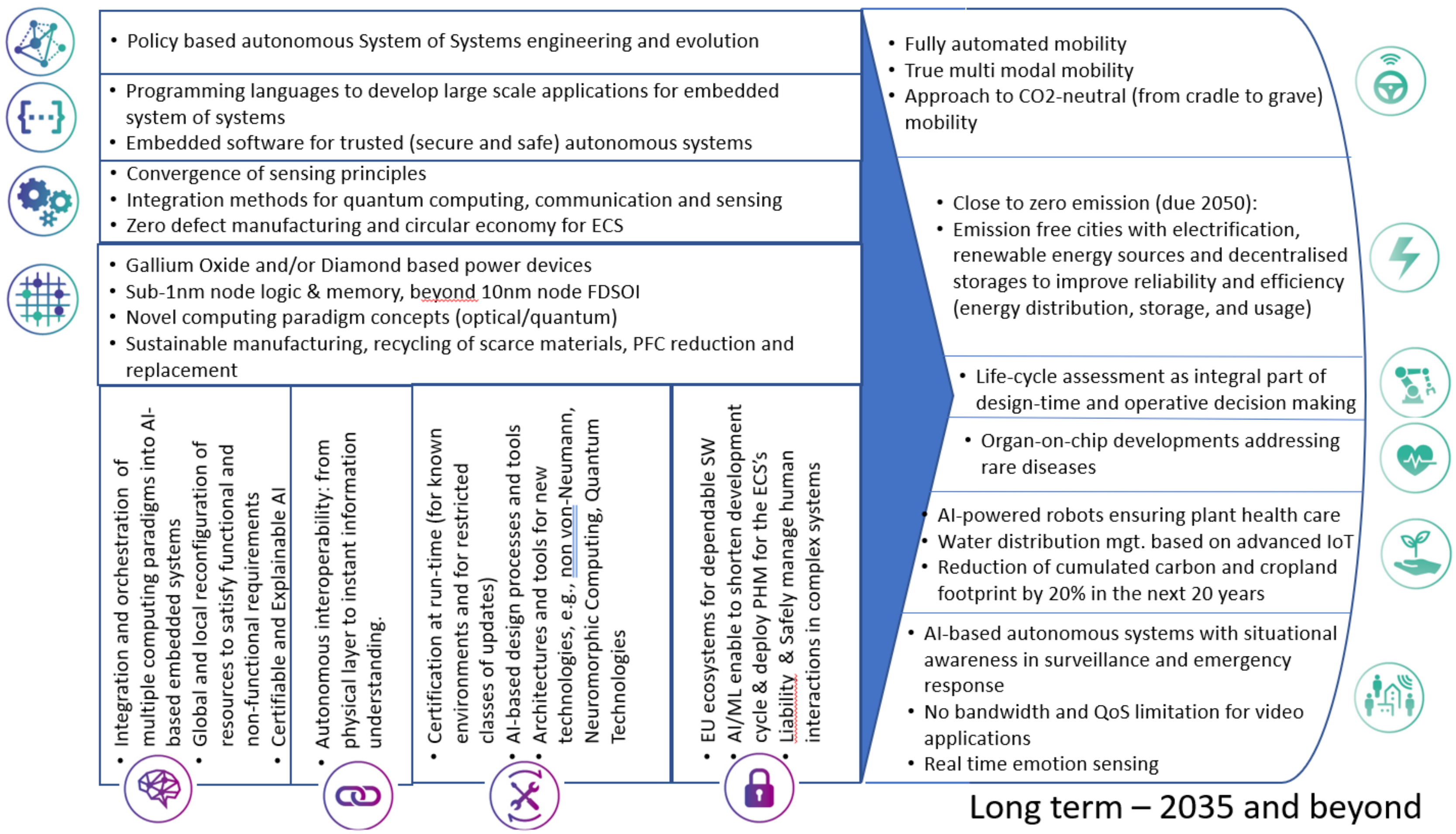
- Next generation (patch-like) drug delivery systems part of the Internet of Medical Things
- Precision diagnosis to prevent hospital readmission

- Food Traceability over the whole value chain
- Improved electrochemical sensors for natural resources quality monitoring

- Improved Human-Machine Interfaces
- Time critical functions moved to cloud
- Multi-modal and multi-sensory interfaces in serious gaming (beyond single games)

Medium term – 2030 - 2034

Figure 0.7 Global Timeline: Medium term 2030–2034



- Policy based autonomous System of Systems engineering and evolution

- Programming languages to develop large scale applications for embedded system of systems
- Embedded software for trusted (secure and safe) autonomous systems

- Convergence of sensing principles
- Integration methods for quantum computing, communication and sensing
- Zero defect manufacturing and circular economy for ECS

- Gallium Oxide and/or Diamond based power devices
- Sub-1nm node logic & memory, beyond 10nm node FDSOI
- Novel computing paradigm concepts (optical/quantum)
- Sustainable manufacturing, recycling of scarce materials, PFC reduction and replacement

- Integration and orchestration of multiple computing paradigms into AI-based embedded systems
- Global and local reconfiguration of resources to satisfy functional and non-functional requirements
- Certifiable and Explainable AI

- Autonomous interoperability: from physical layer to instant information understanding.

- Certification at run-time (for known environments and for restricted classes of updates)
- AI-based design processes and tools
- Architectures and tools for new technologies, e.g., non von-Neumann, Neuromorphic Computing, Quantum Technologies

- EU ecosystems for dependable SW
- AI/ML enable to shorten development cycle & deploy PHM for the ECS's
- Liability & Safely manage human interactions in complex systems

- Fully automated mobility
- True multi modal mobility
- Approach to CO2-neutral (from cradle to grave) mobility

- Close to zero emission (due 2050):
- Emission free cities with electrification, renewable energy sources and decentralised storages to improve reliability and efficiency (energy distribution, storage, and usage)

- Life-cycle assessment as integral part of design-time and operative decision making

- Organ-on-chip developments addressing rare diseases

- AI-powered robots ensuring plant health care
- Water distribution mgt. based on advanced IoT
- Reduction of cumulated carbon and cropland footprint by 20% in the next 20 years

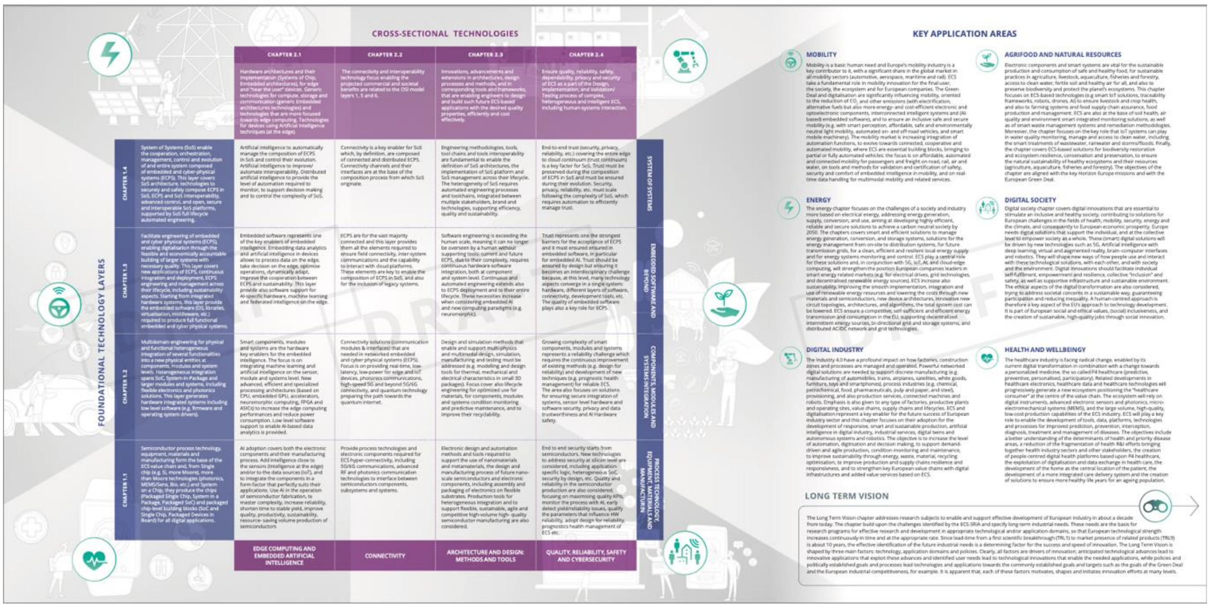
- AI-based autonomous systems with situational awareness in surveillance and emergency response
- No bandwidth and QoS limitation for video applications
- Real time emotion sensing

Long term – 2035 and beyond

Figure 0.8 Global Timeline: Long term 2035 and beyond

0.2.7 The ECS SRIA outline

The following diagram provides an outline of the entire ECS SRIA to clarify the roles of the chapters, the technology domains they cover and the synergies between them, simplifying the comprehension of the ECS SRIA and its “navigation”.



CROSS-SECTIONAL TECHNOLOGIES

FOUNDATIONAL TECHNOLOGY LAYERS

		CHAPTER 2.1	CHAPTER 2.2	CHAPTER 2.3	CHAPTER 2.4	
		Hardware architectures and their implementation (Systems of Chip, Embedded architectures), for edge and "near the user" devices. Generic technologies for compute, storage and communication (generic Embedded architectures technologies) and technologies that are more focused towards edge computing. Technologies for devices using Artificial intelligence techniques (at the edge).	The connectivity and interoperability technology focus enabling the projected commercial and societal benefits are related to the OSI model layers 1, 5 and 6.	Innovations, advancements and extensions in architectures, design processes and methods, and in corresponding tools and frameworks, that are enabling engineers to design and build such future ECS-based applications with the desired quality properties, efficiently and cost effectively.	Ensure quality, reliability, safety, dependability, privacy and security of ECS as a part of the Design, Implementation, and Validation/ Testing process of complex, heterogeneous and intelligent ECS, including human-systems interaction.	
CHAPTER 1.4	System of Systems (SoS) enable the cooperation, orchestration, management, control and evolution of and entire system composed of embedded and cyber-physical systems (ECPS). This layer covers SoS architecture, technologies to securely and safely compose ECPS in SoS, ECPS and SoS interoperability, advanced control, and open, secure and interoperable SoS platforms, supported by SoS full lifecycle automated engineering.	Artificial intelligence to automatically manage the composition of ECPS in SoS and control their evolution. Artificial intelligence to improve/ automate interoperability. Distributed artificial intelligence to provide the level of automation required to monitor, to support decision making and to control the complexity of SoS.	Connectivity is a key enabler for SoS which, by definition, are composed of connected and distributed ECPS. Connectivity channels and their interfaces are at the base of the composition process from which SoS originate.	Engineering methodologies, tools, tool chains and tools interoperability are fundamental to enable the definition of SoS architectures, the implementation of SoS platform and SoS management across their lifecycle. The heterogeneity of SoS requires automated engineering processes and toolchains, integrated between multiple stakeholders, brand and technologies, supporting efficiency, quality and sustainability.	End-to-end trust (security, privacy, reliability, etc.) covering the entire edge to cloud continuum (trust continuum) is a key factor for SoS. Trust must be preserved during the composition of ECPS in SoS and must be ensured during their evolution. Security, privacy, reliability, etc. must scale following the complexity of SoS, which requires automation to efficiently manage trust.	SYSTEM OF SYSTEMS
CHAPTER 1.3	Facilitate engineering of embedded and cyber physical systems (ECPS), enabling digitalisation through the feasible and economically accountable building of larger systems with necessary quality. This layer covers new applications of ECPS, continuous integration and deployment, ECPS engineering and management across their lifecycle, including sustainability aspects. Starting from integrated hardware systems, this layer provide the embedded software (OS, libraries, virtualisation, middleware, etc.) required to produce full functional embedded and cyber physical systems.	Embedded software represents one of the key enablers of embedded intelligence. Embedding data analytics and artificial intelligence in devices allows to process data on the edge, take decision on the edge, optimise operations, dynamically adapt, improve the cooperation between ECPS and sustainability. This layer provide also software support for AI-specific hardware, machine learning and federated intelligence on the edge.	ECPS are for the vast majority connected and this layer provides them all the elements required to ensure field connectivity, inter-system communications and the capability to interact with cloud platforms. These elements are key to enable the composition of ECPS in SoS, and also for the inclusion of legacy systems.	Software engineering is exceeding the human scale, meaning it can no longer be overseen by a human without supporting tools: current and future ECPS, due to their complexity, requires continuous hardware-software integration, both at component and system level. Continuous and automated engineering extends also to ECPS deployment and to their entire lifecycle. These necessities increase when considering embedded AI and new computing paradigms (e.g. neuromorphic).	Trust represents one the strongest barriers for the acceptance of ECPS and it must ensured ensured in embedded software, in particular for embedded AI. Trust should be ensured by design but ensuring it becomes an interdisciplinary challenge because, at this level, many technology aspects converge in a single system: hardware, different layers of software, connectivity, development tools, etc. The quality of embedded software plays also a key role for ECPS.	EMBEDDED SOFTWARE AND BEYOND
CHAPTER 1.2	Multidomain engineering for physical and functional heterogeneous integration of several functionalities into a new physical entities at components, modules and system levels. Heterogeneous integration spans SoC, System-in-Package and larger modules and systems, including flexible electronics and photonics solutions. This layer generates hardware integrated systems including low level software (e.g. firmware and operating system drivers).	Smart components, modules and systems are the hardware key enablers for the embedded intelligence. The focus is on integrating machine learning and artificial intelligence on the sensor, module and systems level. New advanced, efficient and specialized processing architectures (based on CPU, embedded GPU, accelerators, neuromorphic computing, FPGA and ASICs) to increase the edge computing performances and reduce power consumption. Low level software support to enable AI-based data analytics is provided.	Connectivity solutions (communication modules & interfaces) that are needed in networked embedded and cyber physical systems (ECPS). Focus is on providing real-time, low-latency, low-power for edge and IoT devices, photonics communications, high-speed 5G and beyond 5G/6G connectivity, and quantum technology preparing the path towards the quantum internet.	Design and simulation methods that enable and support multi-physics and multimodal design, simulation, manufacturing and testing must be addressed (e.g. modelling and design tools for thermal, mechanical and electrical characteristics in small 3D packages). Focus cover also lifecycle engineering for optimized use for materials, for components, modules and systems condition monitoring and predictive maintenance, and to improve their recyclability.	Growing complexity of smart components, modules and systems represents a reliability challenge which requires the continuous improvement of existing methods (e.g. design for reliability) and development of new techniques (e.g. prognostic health management) for reliable ECS. The area also focuses on solutions for ensuring secure integration of systems, sensor level hardware and software security, privacy and data trustworthiness and AI Hardware safety.	COMPONENTS, MODULES AND SYSTEMS INTEGRATION
CHAPTER 1.1	Semiconductor process technology, equipment, materials and manufacturing form the base of the ECS value chain and, from Single chip (e.g. Si, more Moore), more than Moore technologies (photonics, MEMS/Sens, Bio, etc.) and System on a Chip, they produce the chips (Packaged Single Chip, System in a Package, Packaged SoC) and packaged chip-level building blocks (SoC and Single Chip, Packaged Devices in Board) for all digital applications.	AI adoption covers both the electronic components and their manufacturing process. Add intelligence close to the sensors (Intelligence at the edge) and/or to the data sources (IoT), and to integrate the components in a form factor that perfectly suits their applications. Use AI in the operation of semiconductor fabrication, to master complexity, increase reliability, shorten time to stable yield, improve quality, productivity, sustainability, resource- saving volume production of semiconductors	Provide process technologies and electronic components required for ECS hyper-connectivity, including 5G/6G communications, advanced RF and photonics communication technologies to interface between semiconductors components, subsystems and systems.	Electronic design and automation methods and tools required to support the use of nanomaterials and metamaterials, the design and manufacturing process of future nano-scale semiconductors and electronic components, including assembly and packaging of electronics on flexible substrates. Production tools for heterogeneous integration and to support flexible, sustainable, agile and competitive high-volume high- quality semiconductor manufacturing are also considered.	End to end security starts from semiconductors. New technologies to address security at silicon level are considered, including application-specific logic, heterogeneous SoC, security by design, etc. Quality and reliability in the semiconductor production are also considered, focusing on maximising quality KPIs, monitor the process with AI, early detect yield/reliability issues, qualify the parameters that influence HW reliability, adopt design for reliability prognostics health management of ECS etc.	PROCESS TECHNOLOGY, EQUIPMENT, MATERIALS AND MANUFACTURIN
		EDGE COMPUTING AND EMBEDDED ARTIFICIAL INTELLIGENCE	CONNECTIVITY	ARCHITECTURE AND DESIGN: METHODS AND TOOLS	QUALITY, RELIABILITY, SAFETY AND CYBERSECURITY	

KEY APPLICATION AREAS

MOBILITY

Mobility is a basic human need and Europe's mobility industry is a key contributor to it, with a significant share in the global market in all mobility sectors (automotive, aerospace, maritime and rail). ECS take a fundamental role in mobility innovation for the final user, the society, the ecosystem and for European companies. The Green Deal and digitalisation are significantly influencing mobility, oriented to the reduction of CO_2 and other emissions (with electrification, alternative fuels but also more energy- and cost-efficient electronic and optoelectronic components, interconnected intelligent systems and (AI-based) embedded software), and to ensure an inclusive safe and secure mobility (e.g. with smart perception, affordable, safe and environmentally neutral light mobility, automated on- and off-road vehicles, and smart mobile machinery). The mobility market is increasing integration of automation functions, to evolve towards connected, cooperative and automated mobility, where ECS are essential building blocks, bringing to partial or fully automated vehicles: the focus is on affordable, automated and connected mobility for passengers and freight on road, rail, air and water, on tools and methods for validation and certification of safety, security and comfort of embedded intelligence in mobility, and on real-time data handling for multimodal mobility and related services.

ENERGY

The energy chapter focuses on the challenges of a society and industry more based on electrical energy, addressing energy generation, supply, conversion, and use, aiming at developing highly efficient, reliable and secure solutions to achieve a carbon neutral society by 2050. The chapters covers smart and efficient solutions to manage energy generation, conversion, and storage systems, solutions for the energy management from on-site to distribution systems, for future transmission grids, for a clean, efficient and resilient local energy supply and for energy systems monitoring and control. ECS play a central role for these solutions and, in conjunction with 5G, IoT, AI and cloud-edge computing, will strengthen the position European companies leaders in smart energy related markets (e.g. for electrical drives, grid technologies, and decentralised renewable energy sources). ECS increase also sustainability, improving the smooth implementation, integration and use of renewable energy resources and lowering the costs through new materials and semiconductors, new device architectures, innovative new circuit topologies, architectures, and algorithms, the total system cost can be lowered. ECS ensure a competitive, self-sufficient and efficient energy transmission and consumption in the EU, supporting decentralized intermittent energy sources, bi-directional grid and storage systems, and distributed AC/DC network and grid technologies.

DIGITAL INDUSTRY

The Industry 4.0 have a profound impact on how factories, construction zones and processes are managed and operated. Powerful networked digital solutions are needed to support discrete manufacturing (e.g. manufacturing of automobiles, trains, airplanes, satellites, white goods, furniture, toys and smartphones), process industries (e.g. chemical, petrochemical, food, pharmaceuticals, pulp and paper, and steel), provisioning, and also production services, connected machines and robots. Emphasis is also given to any type of factories, productive plants and operating sites, value chains, supply chains and lifecycles. ECS and digitalisation represent a key enabler for the future success of European industry sector and this chapter focuses on their adoption for the development of responsive, smart and sustainable production, artificial intelligence in digital industry, industrial services, digital twins and autonomous systems and robotics. The objective is to increase the level of automation, digitisation and decision making, to support demand-driven and agile production, condition monitoring and maintenance, to improve sustainability through energy, waste, material, recycling optimisation, to improve production and supply chains resilience and responsivness, and to strengthen key European value chains with digital infrastructures and added value services based on ECS.

AGRIFOOD AND NATURAL RESOURCES

Electronic components and smart systems are vital for the sustainable production and consumption of safe and healthy food, for sustainable practices in agriculture, livestock, aquaculture, fisheries and forestry, access to clean water, fertile soil and healthy air for all, and also to preserve biodiversity and protect the planet's ecosystems. This chapter focuses on ECS-based technologies (e.g smart IoT solutions, traceability frameworks, robots, drones, AI) to ensure livestock and crop health, and also to farming systems and food supply chain assurance, food production and management. ECS are also at the base of soil health, air quality and environment smart integrated monitoring solutions, as well as of smart waste management systems and remediation methodologies. Moreover, the chapter focuses on the key role that IoT systems can play in water quality monitoring, manage and access to clean water, including the smart treatments of wastewater, rainwater and storms/floods. Finally, the chapter covers ECS-based solutions for biodiversity restoration and ecosystem resilience, conservation and preservation, to ensure the natural sustainability of healthy ecosystems and their resources (agriculture, aquaculture, fisheries and forestry). The objectives of the chapter are aligned with the key Horizon Europe missions and with the European Green Deal.

DIGITAL SOCIETY

Digital society chapter covers digital innovations that are essential to stimulate an inclusive and healthy society, contributing to solutions for European challenges in the fields of health, mobility, security, energy and the climate, and consequently to European economic prosperity. Europe needs digital solutions that support the individual, and at the collective level to empower society as a whole. These (smart) digital solutions will be driven by new technologies such as 5G, Artificial intelligence with deep learning, virtual and augmented reality, brain–computer interfaces and robotics. They will shape new ways of how people use and interact with these technological solutions, with each other, and with society and the environment. Digital innovations should facilitate individual self-fulfilment, empowerment and resilience, collective "inclusion" and safety, as well as supportive infrastructure and sustainable environment. The ethical aspects of the digital transformation are also considered, trying to address societal concerns in a sustainable way, guaranteeing participation and reducing inequality. A human-centred approach is therefore a key aspect of the EU's approach to technology development. It is part of European social and ethical values, (social) inclusiveness, and the creation of sustainable, high-quality jobs through social innovation.

HEALTH AND WELLBEINGY

The healthcare industry is facing radical change, enabled by its current digital transformation in combination with a change towards a personalized medicine, the so called P4 healthcare (predictive, preventive, personalised, participatory). Related developments in healthcare electronics, healthcare data and healthcare technologies will progressively generate a new ecosystem positioning the "healthcare consumer" at the centre of the value chain. The ecosystem will rely on digital instruments, advanced electronic sensors and photonics, micro-electromechanical systems (MEMS), and the large volume, high-quality, low-cost production capabilities of the ECS industry. ECS will play a key role to enable the development of tools, data, platforms, technologies and processes for improved prediction, prevention, interception, diagnosis, treatment and management of diseases. The objectives include a better understanding of the determinants of health and priority disease areas, a reduction of the fragmentation of health R&I efforts bringing together health industry sectors and other stakeholders, the creation of people-centred digital health platforms based upon P4 healthcare, the exploitation of digitalisation and data exchange in health care, the development of the home as the central location of the patient, the development of a more integrated care delivery system and the creation of solutions to ensure more healthy life years for an ageing population.

LONG TERM VISION

The Long Term Vision chapter addresses research subjects to enable and support effective development of European industry in about a decade from today. The chapter build upon the challenges identified by the ECS-SRIA and specify long term industrial needs. These needs are the basis for research programs for effective research and development in appropriate technological and/or application domains, so that European technological strength increases continuously in time and at the appropriate rate. Since lead-time from a first scientific breakthrough (TRL1) to market presence of related products (TRL9) is about 10 years, the effective identification of the future industrial needs is a determining factor for the success and speed of innovation. The Long Term Vision is shaped by three main factors: technology, application domains and policies. Clearly, all factors are drivers of innovation; anticipated technological advances lead to innovative applications that exploit these advances and identified user needs lead to technological innovations that enable the needed applications, while policies and politically established goals and processes lead technologies and applications towards the commonly established goals and targets such as the goals of the Green Deal and the European industrial competitiveness, for example. It is apparent that, each of these factors motivates, shapes and initiates innovation efforts at many levels.

Figure 0.9 SRIA outline

0.3. PART 3 - HOW ?

0.3.1 Navigating the ECS SRIA

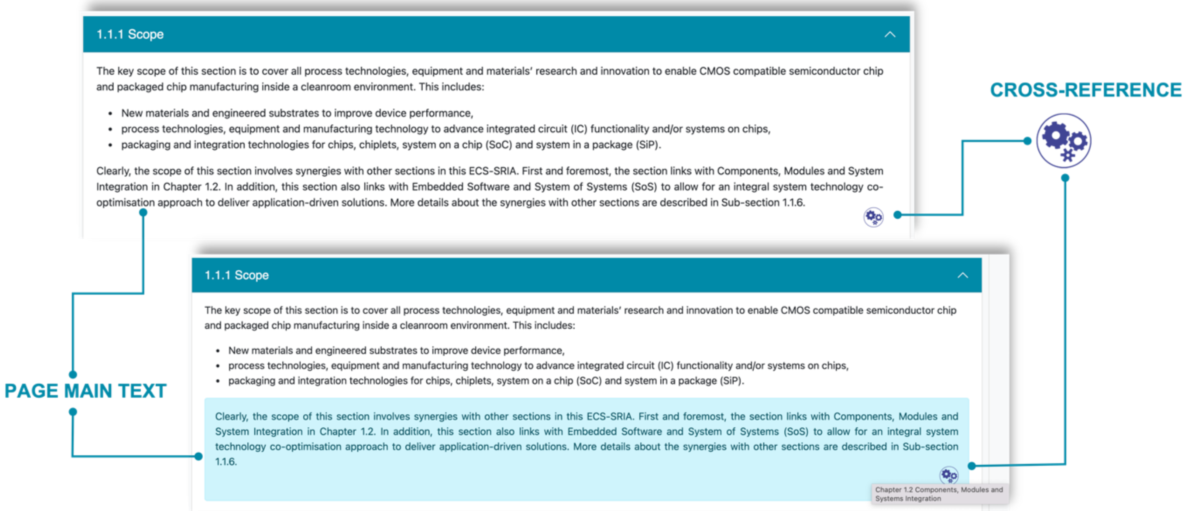
As mentioned, the ECS covered by this document is very wide-ranging, and involves many technical disciplines in materials, processes, hardware and software. Therefore, most readers will only want to read those chapters that cover the disciplines of their interest, without being willing to go through all the technical details presented in the ECS SRIA.

The structure of all the **Foundational Technology** and **Cross-Sectional** chapters is identical. In the **Key Application Areas** chapters, the authors explore each domain with the application demands as the main focus, not the technical challenges.

A **Glossary** describing the terms used in the document, as well as a List of **Acronyms** used in the document, can be found in the **Appendix**. The Analytical Index available in earlier releases of the ECS SRIA is now substituted by an advanced Search functionality. At the end, the reader can also find a **List of Contributors** who collectively wrote this ECS SRIA.

Finally, to highlight the synergies/links between the chapters and provide hints to the reader, cross-references have been introduced alongside the text.

Cross-references consist of the Chapter icon and appear alongside the text. When hovered on, they indicate the relevant chapter number and the topic or concept described in the text is also highlighted. When clicked on, they will navigate you to the referenced Chapter.



1.1.1 Scope

The key scope of this section is to cover all process technologies, equipment and materials' research and innovation to enable CMOS compatible semiconductor chip and packaged chip manufacturing inside a cleanroom environment. This includes:

- New materials and engineered substrates to improve device performance,
- process technologies, equipment and manufacturing technology to advance integrated circuit (IC) functionality and/or systems on chips,
- packaging and integration technologies for chips, chiplets, system on a chip (SoC) and system in a package (SiP).

Clearly, the scope of this section involves synergies with other sections in this ECS-SRIA. First and foremost, the section links with Components, Modules and System Integration in Chapter 1.2. In addition, this section also links with Embedded Software and System of Systems (SoS) to allow for an integral system technology co-optimisation approach to deliver application-driven solutions. More details about the synergies with other sections are described in Sub-section 1.1.6.

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Figure 0.10 Cross Reference

References within a text are indicated by small numerical markers embedded in the content, e.g. 0. Upon clicking one of these markers, readers are instantly directed to the corresponding entry within the References section. This feature allows readers to seamlessly access the sources from which the information has been derived.

Furthermore, by clicking on the same footnote number located in the **References** section, readers can effortlessly return to the exact point within the main text where the reference was initially cited. This interactive function not only enhances the reader's comprehension but also streamlines the process of verifying and exploring the sources behind the presented information.

0.3.2 Make it happen

Whatever their scientific and technological excellence, research projects can achieve significant societal and economic impact for the EU only if several "innovation accelerators" are in place, which will bring the research results to market. Standardisation and regulation, education and training, international cooperation, and research infrastructures are a few of these accelerators.

Discussing those topics is beyond the scope of the ECS SRIA, which is the expression by the industry of its Research and Innovation vision. In essence, the SRIA is designed to be funding instrument agnostic, so that it can constitute the basis of calls for various programmes, such as Horizon Europe, Eureka, or national initiatives. That being said, some of the accelerators listed above are being set up in the frame of the Chips Act. In particular, the Design Platform and the Pilot Lines included in the Chips for Europe Initiative have the objective of supporting and accelerating technological capacity building and innovation in the Union by bridging the gap between the Union's advanced research and innovation capabilities and their industrial exploitation.

While it is outside of its scope to indicate how these research infrastructures and services should be run, the ECS SRIA covers the technological challenges to be addressed, from the Design Platform, via the different Pilot Lines towards accelerator projects to speed up the transfer from the lab to the fab. It is therefore important to ensure that their implementation most effectively supports the research needs exposed in the SRIA. To that effect, the following table identifies, for the Design Platform and for the Pilot Lines identified as of the time of writing of this SRIA edition, research topics which are expected to be supported by those instruments.

	Design platform	Advanced 2nm and beyond	FD-SOI
1.1 Process Technology, Equipment, Materials and Manufacturing		Launching ground for new processes, equipment technologies and materials	Low-power consumption, radiation hardness, More than Moore app.
1.2 Components, Modules and Systems Integration	Improve design capabilites to become a closed loop (i.e., to include feedbacks from the production process and from the field use, respectively) as well as define the new sets of interfaces for the complex integration solutions at die / module / system levels as needed for implementing heterogeneous and chiplet approaches - in particular for ECS applications that will be exposed to demanding and harsh environments (as these ECS are essential for our European backbone industry -automotive, energy, industry, health, ...- and not sufficiently and securely addressed by the worldwide leading players).	Impact of advanced node inflections like backside power distribution networks, forksheet, CFET and 2D material channels 3D heterogeneous integration in chiplet implementation	Provision of advanced logic building blocks with advantageous trade-offs in terms of speed, power consumption, robustness with respect technological simplicity and cost
1.3 Embedded software and Beyond		Design Technology Co-Optimisation	Design Technology Co-Optimisation
1.4 System of Systems		System Technology Co-Optimisation	System Technology Co-Optimisation
2.1 Edge Computing and Embedded Artificial Intelligence	Provide non-differentiating IPs (I/Os, memory interfaces, etc) Support the Open Source Hardware community in Europe Provide tools for embedded AI, such as tools allowing to quantize and decrease the size of Neural Networks for embedded accelerators	Drive PPACE (Power - Performance - Area - Cost - Efficiency) improvements for advanced nodes to increase the energy efficiency of computing systems Research PDK's to support managing the increasing complexity of systems	Energy efficiency, embedded non-volatile memories
2.2 Connectivity			* Enable the development of power efficient connectivity solution leveraging European-based semiconductor technology * Enable the development of innovative connectivity solution at mmW and THz frequencies
2.3 Architecture and Design : Methods and Tools	Support EDA research and innovation, in particular: - Exponentially increasing design complexity (MC 3) and Increasing Diversity (MC 4) - Sustainability (MC1) - Emerging technologies (MC1) - Increased automation and operability (MC1, MC2, MC3) - Multidisciplinary design (MC4)		Automated application of back-biasing for adjusting power and performance
2.4 Quality, Reliability, Safety and Cybersecurity	Widen the implementation of Design for X (DfX) besides the design for functionality and performance - in particular for the heterogeneous and chiplet implementations to be used in demanding and harsh environments. Implement 'closed loop design' approaches (= with feedbacks from manufacturing, testing, ... field use) X ... manufacturing, testing, reliabiltiy, safety, security, repairability, disassembly+reuse, sustainability, ... Chapter 2.4 highlights the importance of secure design environments to protect against cyber threats and secure and reliable environment both in terms of robust cybersecurity measures and safety properties that are needed due to the complexity and interdependencies of modern ECS. Chips JU Design platform aims to provide secure, cloud-based design facilities, integrating tools and support services to enhance cybersecurity. New cybersecurity measures and technologies implemented in a controlled environment before bringing them in real-world systems. This could include testing new encryption algorithms, security protocols, or methods for protecting privacy, enhancing resilience of electronic systems against cyber threats and fostering a safer digital ecosystem across the EU.	Design and integration, is crucial for developing advanced semiconductors. The pilot line can benefit from insights on how to optimize system architecture, integrate components, and ensure efficient communication between different parts of the chip. Security and Privacy Considerations: The pilot line should incorporate robust security measures to protect chips from cyber threats. In addition, it should establish rigorous testing protocols to ensure the functionality, reliability, safety and security of the developed chips including vulnerability assessments and penetration testing.	

	Design platform	Advanced 2nm and beyond	FD-SOI
3.1 Mobility	High Performance automotive SOC for Software Defined Vehicles based on RISC-V (including necessary accelerators and support for automotive bus systems as well as automotive trust-ability concepts)		
3.2 Energy	Energy efficiency is one of the major factors to reduce energy consumption - design for energy efficient devices, process technologies for energy efficient operation and integration and packaging technologies for all the advanced technologies, either logic or power electronics. To manage the demand of the interlinked society for more and more communication and in parallel a sustainable way of operation including fulfilling the transition towards the Green Deal objectives plenty of control and forecasting systems will be required in addition to highly miniaturized, safe, connected and efficient power conversion and distribution systems.		
3.3 Digital Industry			
3.4 Health			
3.5 Agrifood and Natural Resources	New advanced circuits needed to develop innovative and cost-effective solutions related to the chapter challenges could be designed (through the Design platform programme) and fabricated (through the Pilot lines programme). Examples include sensors for water quality monitoring, GHG emission measurement, plant and soil health.		In agriculture, low cost, highly energy-efficient and self-contained components are essential. They include highly innovative types of sensors related to agriculture and intended to preserve natural resources, highly efficient processors including AI capabilities and long-range RF solutions.
3.6 Digital Society			
Long Term Vision		Foundational studies for new processes, equipment technologies and materials	

	Advanced Packaging and Heterogeneous Integration	Wide Band Gap	Integrated Photonics	Quantum technologies	Other pilot lines
1.1 Process Technology, Equipment, Materials and Manufacturing	Introduce materials and process innovations as well as advanced manufacturing, test and inspection equipment for future AP/HI systems.				
1.2 Components, Modules and Systems Integration	Enable enhanced and diversified functionalities (e.g. combined sensing, processing, communication, ...) in small form factor electronic components and systems. Chapter 1.2 is the natural playground for the reunion of the components provided by the other PLs by means of the advanced heterogeneous system integration enabled by this one.	Provision of electronic components and modules made around alternative semiconductors that allow improved systems for energy/power management or operation in harsh (thermal, electric, radiation…) environments	Provision of photonic components and modules that on their own or hybridized with electronics either enable physical-digital interaction of actionable systems by means of light or boost the performance of digital communications	Mature quantum devices to be integrated in high performance/high sensitivity/highresolution sensor systems, and breakthroughs in quantum comunications and quantum computing	Platforms leading to the scalability of elements enabling connection between the digital and physical worlds (e.g. MEMS, integrated photonics, power electronics, quantum approaches…) in silicon or silicon alternative technologies will provide, together with logical circuitry, additional essential building blocks to be integrated in full fledged electronic systems
1.3 Embedded software and Beyond					
1.4 System of Systems					
2.1 Edge Computing and Embedded Artificial Intelligence	Advanced packaging technologies allow the integration of diverse and specialized components such as processors, GPU/FPGA, memory, sensors and communication chips in a single package. This enables new, more powerful and energy-efficient edge computing, AI and communication solutions in small form factors.				
2.2 Connectivity	* Enable a European ecosystem that can support heterogeneous integration (multi-die system in a package, advanced assembly capability, advanced substrate manufacturing, etc.) to help European players capture higher value in the connectivity market. * Enable the development of innovative Antenna in package solution at mm-wave and THz frequencies * Enable a sovereign European packaging ecosystem to secure the supply chain of European semiconductor players (especially in key areas such as space were required manufacturing scale limits the possibility to have access to Asian OSAT)				
2.3 Architecture and Design : Methods and Tools	Proving ground for new design methods mastering the differences in materials, technologies, and processes that are heterointegrated into a single package.				

	Advanced Packaging and Heterogeneous Integration	Wide Band Gap	Integrated Photonics	Quantum technologies	Other pilot lines
2.4 Quality, Reliability, Safety and Cybersecurity	Develop new processes ensuring quality, reliability and safety of hetero-integrated chips and systems. Heterogeneous integration involves connecting diverse components (e.g., CPUs, memory, sensors) within a single package. interconnect challenges are identified in this chapter such as signal integrity and reliability. The pilot line should explore innovative interconnect solutions. The pilot line could address also robustness via testing methodologies, failure analysis, and reliability prediction defined in the chapter. This includes stress testing and fault tolerance.	Developing efficient power devices requires careful design and integration of device architecture to optimize performances as well as guidance on designing RF circuits, minimizing losses, and achieving high-speed performances.	Photonic Integrated Circuits (PIC) development involves novel system designs and explore integration techniques for miniaturize and consolidate optical elements, similarly to how electronic components are integrated on microchips in traditional integrated circuits. The pilot line should supports breakthrough technologies like quantum computing, AI, and neuromorphic systems as well as functionalities such as security and energy efficiency to be considered during development.	Quantum Computing: development of quantum computers leverages on quantum bits (qubits) to perform complex calculations exponentially faster than classical computers. this implies improving qubit stability, error correction, and scalability. Links with the chapter are identified on optimizing the architecture of quantum computers in terms of efficient integration of quantum components. Quantum Communication/criptography to ensures secure transmission of information using quantum key distribution (QKD), exploring quantum encryption, and entanglement-based communication. Links with chapter are: communication protocols and encryption techniques Quantum Sensing: unprecedented precision in measuring physical quantities such as time, acceleration, and magnetic fields. Applications impacted include navigation, imaging, and environmental monitoring. Link with chapter are sensors to ensure quality and reliability. Quantum Materials and Devices: novel materials (e.g., superconductors, topological insulators) and develop quantum devices (e.g., single-photon detectors, quantum memories). Links with the chapter are material properties that could be relevant to quantum technologies Quantum Algorithms and Software: quantum algorithms and tools for solving real-world problems. links with chapter are in terms of algorithm approaches and software development approaches.	

	Advanced Packaging and Heterogeneous Integration	Wide Band Gap	Integrated Photonics	Quantum technologies	Other pilot lines
3.1 Mobility	New generation of environmental sensors (or combined sensors), which simplify and improve object and lane detection, work in difficult (severe) weather conditions and situations (as tunnel exit). Can be supported via Heterogenous integration pilot line. Chiplets will allow for higher functionality and future capabilities to combine processing, sensing, and memory out of different nodes		New generation of environmental sensors (or combined sensors), which simplify and improve object and lane detection, work in difficult (severe) weather conditions and situations (as tunnel exit). Can be supported via Heterogenous integration pilot line, but also via other PL on photonics, quantum sensors.		
3.2 Energy	Energy efficiency is one of the major factors to reduce energy consumption - design for energy efficient devices, process technologies for energy efficient operation and integration and packaging technologies for all the advanced technologies, either logic or power electronics. To manage the demand of the interlinked society for more and more communication and in parallel a sustainable way of operation including fulfilling the transition towards the Green Deal objectives plenty of control and forecasting systems will be required in addition to highly miniaturized, safe, connected and efficient power conversion and distribution systems.				
3.3 Digital Industry	Facilitate advanced, cost- and energy-efficient integrated systems for key application areas.				
3.4 Health					
3.5 Agrifood and Natural Resources	In agricultural devices with a minimal form factor, low power consumption and low cost are essential. The wide variety of devices, related to the multiple applications, requires modular and heterogeneous integration including multiple sensors, advanced processors and multiple RF protocols.				
3.6 Digital Society	Facilitate advanced, cost- and energy-efficient integrated systems for key application areas.				
Long Term Vision	Establish and nurture advanced packaging and heterointegration expertise in EU. Facilitate and promote AP/HI technology and infrastructure access to foster electronics device and systems innovations.				

The Design Platform, as proposed in the European Chips Act, should also support research in several cross-sectional technologies:

- On the one hand, the development of edge AI and embedded computing chips (Chapter 2.1) will be facilitated if the Design Platform covers the following aspects:
  - Providing as many non-differentiating IPs (for instance I/O's, memory and communication interfaces, etc.) as possible, allowing to have a one-shop entry for start-up/SMEs and academia to validate into silicon their new architecture ideas in the field of accelerator for IA (at the edge) and embedded systems.
  - Supporting the Open-Source Hardware community in Europe, where the Design Platform could be linked with Open-Source repositories and allowing access of the instances (and the tools to use them, such as compilers, OS and basic middleware).
  - One specific topic that the Design Platform should add is to give access to the tools specific for embedded AI, such as tools allowing to quantise and decrease the size of Neural Networks for embedded accelerators (and perhaps to learning databases) so that it will be a single entry for using all those tools in a coherent environment. That will imply certainly to bridge to other platforms either from European projects (NeuroKit2E for example), but perhaps also with non-European repositories such as HuggingFace.

- On the other hand, the Design Platform could be used to investigate many EDA challenges identified in Chapter 2.3, such as:
  - Exponentially increasing design complexity (Major Challenge 3) and diversity (Major Challenge 4), including multidisciplinary design.
  - Sustainability (Major Challenge 2)
  - Support for emerging technologies: quantum computing, neuromorphic, edge AI, …

- Increased automation and interoperability in the design flow, including for multi-vendor solutions

In a nutshell, the Design Platform and the Pilot Lines included in the Chips for Europe Initiative have the potential to offer a valuable research, development and testing ground, a learning environment to advance innovation, enhance manufacturing capabilities, and accelerate the development of cutting-edge electronic products. To make that promise come true, it is of utmost importance that their research roadmaps are established in strong synergy with the contents of the ECS SRIA and that the results are prepared for transfer into volume manufacturing.

The ECS community is positive toward those two new instruments under the pre-condition of appropriate involvement of industrial stakeholders in advisory bodies of these two instruments. For the Pilot lines the projects have to be designed to explore new technologies with clear outcome for the European industry at large, and with feedback mechanisms ensuring this is implemented and established over time. For the Design Platform the rules of access and use of the resulting designs (Silicon IP) or chips for companies or laboratories will have to be clearly and carefully crafted to avoid competition distortion.