# EMBEDDED INTELLIGENCE: TRENDS AND CHALLENGES

## A STUDY BY ADVANCY, COMMISSIONED BY ARTEMIS INDUSTRY ASSOCIATION

March 2019

ARTEMIS Industry Association

advancy

# Economic and technical outlook for Embedded Intelligence in the context of the Electronic Components and Systems value chain

ARTEMIS Industry Association

advancy

www.artemis-ia.eu

www.advancy.com

# TABLE OF CONTENTS

# TABLE OF FIGURES

Dear reader, esteemed colleague,

Following the very valuable work of the SRA on Electronic Components and Systems (ECS), issued in 2018 by AENEAS, ARTEMIS-IA and EPoSS (the associations that together form the Private Member Board of ECSEL), we estimated that there was a clear need to position this work in the wider context of the global economic and technological challenges for Europe in the years to come, specifically for Embedded Intelligence, which is the domain of the ARTEMIS-IA community.

In order to bring the EU Commission, EU Parliament, Member States and Associated Countries up to date, we thought it was a good opportunity to verify that the scope of ARTEMIS-IA is heading in the right direction. This scope concerning the area of components, embedded and intelligent systems and software for the future goes beyond assessing the perimeter of research projects. It must be based on a thorough analysis on the global positioning of Europe's economic value chains from electronic components to final applications. In short, we aim to assess those themes where Europe can create value in the global competition for embedded systems.

For this report we engaged an independent consultant, Advancy, to make a high-level analysis that indicates the scope of the value chain. This multi-sector value chain study is absolutely key for determining the future scope of R&D&I for Embedded Intelligence. This report provides insight into the economic, social and technological contexts, highlights the challenges for Europe and provides the context to the ECS Strategic Research Agenda, supported by an international benchmark on the position of Europe with respect to Asia and the Americas.

I hope this study will help not only ARTEMIS-IA but also nurture further reflections for the fellow associations of ECSEL (AENEAS and EPoSS) and the broader digital community to generate accurate content for the future of ECSEL. This study could also bring some comparative material and food for thought to the community of evaluators. It may stimulate the community of Member States, at digital decision maker level, to bringing closer the very much needed coordination in a smart, agile and constructive digital policy for Europe.

With my best regards,

Jean-Luc di Paola-Galloni,

*President of the ARTEMIS Industry Association*

## CHAPTER 0

# INTRODUCTION

**This report has been commissioned to Advancy by the ARTEMIS Industry Association.**

**For Artemis-IA, Embedded Intelligence results from the fusion of six technology domains:**

- Embedded and Cyber-Physical Systems
- Secure IoT and System of Systems
- Edge computing and Embedded Artificial Intelligence
- Embedded High-Performance Computing
- System of Systems Integration platforms for Digitalisation
- Embedded Software Technologies and Software Engineering Tools

CHAPTER 1

# ECONOMIC, SOCIAL AND TECHNOLOGICAL CONTEXT

1.1

## WHY EUROPE NEEDS TO INVEST IN EMBEDDED INTELLIGENCE

In 2018, European countries faced a series of challenges that could shape the decades to come.

- **The external geopolitical context is unfavourable:** this includes terrorism, Brexit, US tariffs and international tensions with North Korea.
- **Technology is becoming a source of worry** due to a rise in disinformation and cybersecurity threats.
- **The achievement of environmental transition objectives is hindered by political decisions made around the world.**
- **EU economies are experiencing slow GDP growth due to declining demographic growth (c.+0.05% p.a. through 2065) and stagnation in productivity.**
- **Social tensions are on the rise.**

In order to succeed in its objectives of achieving inclusive growth, empowering European youth and concurrently addressing responsibility and competitiveness, the EU needs to actively build the economic growth engines of tomorrow.

Economic growth can be seen as a mathematical product of two factors: demographic growth and aggregate efficiency (i.e. productivity). Since demographic growth is expected to remain very low (+0.05% p.a. through 2065), the main challenge is achieving a step change in aggregate efficiency.

This challenge is particularly difficult to address as value chains are becoming increasingly longer and more complex. In the meantime, however, companies and states around the world are laying the foundations of technologies and solutions that could help economies to achieve a step change in productivity. Indeed, we are at the verge of the **creation of a new General-Purpose Technology (GPT) platform**, combining 4 major factors that pave the way to a new industrial revolution:

- **A digitalised, communication-oriented Internet:** the Internet and Cyberspace have matured.
- **A shared, connected, automated and $CO_2$-neutral transportation network**: industrial-scale mobility solutions for electrified, connected and autonomous vehicles are possible thanks to the maturity and accessibility of new technologies.
- **An energy-oriented Internet:** Smart Grids and optimised power-generation technologies are based on renewable and clean energies, as well as smaller, decentralised production units and grids.
- **A smart and automated world based on the Internet of Things: s**ensors, real-time activity monitoring and communication between things (machines, devices, etc.) and the rest of the Internet all enable smart living.

This platform is destined to become the distributed neural network prosthetic that complements today's physical economy, inducing a paradigm shift in the way that production means are organised:

- A move from **centralised** to **decentralised** operations in the production of goods and services;
- A shift away from **proprietary** solutions towards **collaborative** solutions;
- An evolution from **vertically-integrated** value chains (mainly hardware-oriented) towards **laterally-scaled** ecosystems (mainly software-oriented).

The deployment of this new General-Purpose Technology[1] is a long-term endeavour, requiring the participation of several generations and multiple players as every aspect of our economy is progressively integrated into this Vision. In the meantime, the biggest challenge we are facing today is preparing for a robust transition.

Embedded Intelligence – incorporating Systems of Systems, Embedded & Cyber-Physical Systems, Electronic Components and Embedded Software Technologies – will become the essential backbone and **an inherent part of every value chain** when this revolution is complete. As such, it is probably **the most critical technology for harvesting tomorrow's growth** and competing with the likes of China, which is investing $100 b+ as part of its Five-Year Plan and the Made in China 2025 initiative. This is in order to prepare for this 'new industrial revolution' and global leadership (please refer to the international benchmarks presented in section 4).

[1] *A general-purpose technology or GPT is a term coined to describe a new method of producing and inventing that is important enough to have a protracted aggregate impact - Landes, David S. (1976), Rosenberg, Nathan (1982)*

## 1.2

# EMBEDDED & CYBER-PHYSICAL SYSTEMS KEY CHARACTERISTICS

Embedded & Cyber-Physical Systems act as bridges between:

- a Cyberetic world that is data-rich, driven by applications & services and allows lateral interaction;
- a Physical world that is technology-rich, driven by products & applications and vertically-integrated.

As such, they need to cover both worlds, including different players and different logics:

- **Different paradigms for business and operations**
  - Physical world: structured around value chains and product-oriented business models.
  - Software & Cyber world: built around value networks/ecosystems and solution-oriented business models, providing a new support level for Business & Operations and relying strongly on lateral scalability (inclusion of an extended value network covering a wide range of players, SMEs and start-ups).

- **Different key success factors for industry and research**
  - Physical world: need to invest in the right set of proprietary technologies, attract volumes and reach critical mass.
  - Software & Cyber world: need to be inclusive in terms of players that deliver the solution, thus creating an ecosystem of partners across the value network; this goes from start-ups & SMEs that play an important role in European economies all the way up to industry leaders and large European companies. Need to invest in SoS integrations platforms, the software technology that allows the existence of these new value networks with a product-oriented business model.

- **Different strategic focus points for Europe**
  - Physical world: maintain Europe's sovereignty to ensure that it can be independent in terms of material, equipment and technology, in preparation for this next industrial revolution.
  - Software & Cyber world: capture growth, productivity and value through the deployment of innovative, application-specific solutions in a European ecosystem of large companies, SME and start-ups.

- **Different implications on research focus**
  - Physical world: ensure that hardware and software can meet high-performance application expectations while mastering technologies that can be reapplied across applications.
  - Software & Cyber world: design application-specific architectures that minimise HW dependency, are reusable and can be easily updated, and also develop application-specific know-how in AI and Analytics to deliver the expected application value. The availability of innovative and new sophisticated software technologies is essential for this and is crucial for managing the heterogeneous nature of existing vertical ecosystems (i.e. System of Systems, humans, etc.).

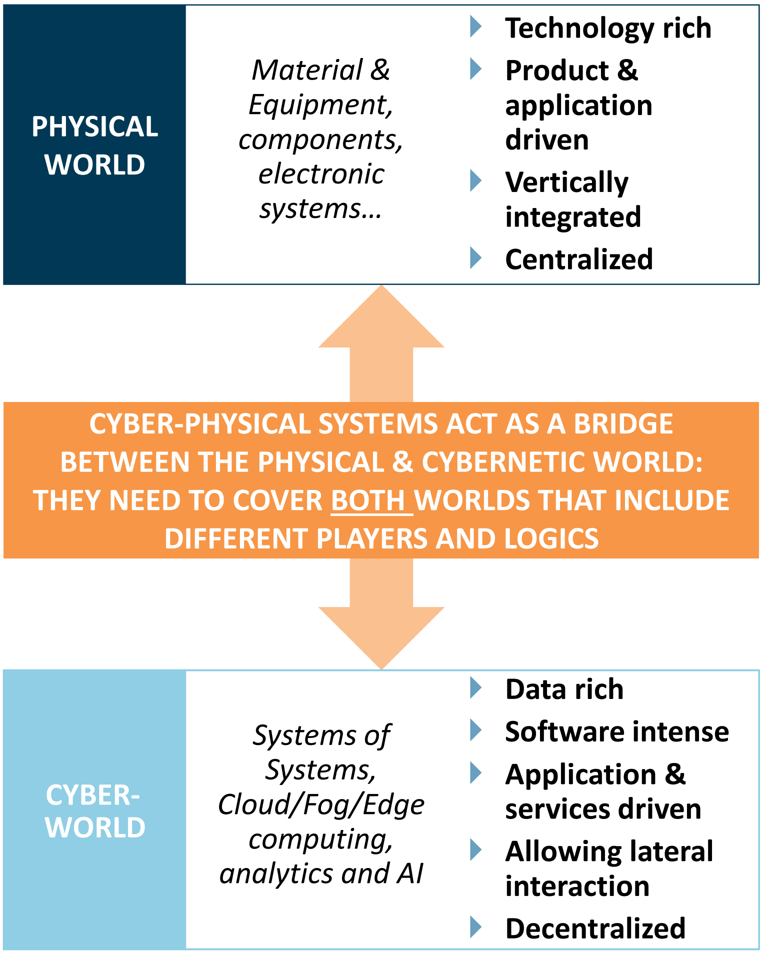



**Figure 1:** *Embedded & Cyber-Physical Systems, the bridge between the Physical & Cyber- worlds*

A differentiating characteristic between Embedded and Cyber-Physical Systems is their scale. Whereas Embedded Systems are considered to have a limited scale, a CPS operates on a much larger scale, potentially including many interconnected Embedded Systems or other devices and systems as well. This may also include human and socio-technical systems. The inherent complementarity between the two means that it is crucial to address them as one single, strategic technological topic.

In conclusion, addressing the Embedded & Cyber-Physical Systems research roadmap will require us to tackle both Physical challenges (Materials & Equipment, Components, Electronics Systems) and Cybernetic challenges (Systems of Systems, New Design Paradigms, Human-CPS interactions, Interoperability, Cloud/Fog/Edge computing, Analytics and AI), all of which will differ heavily from application to application.

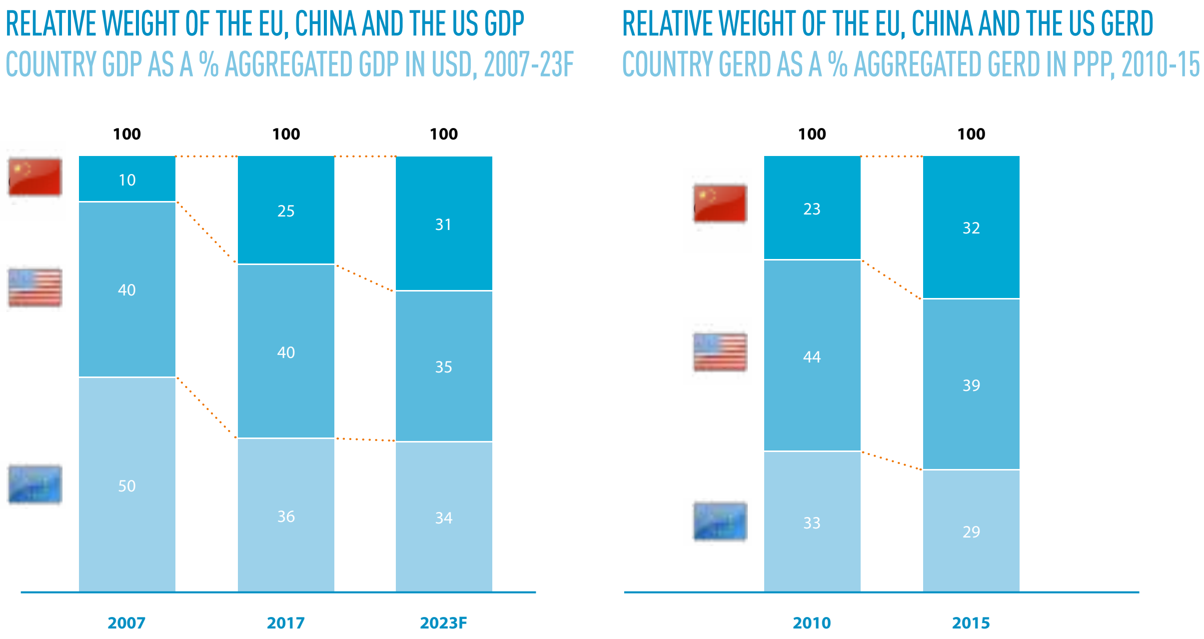
## CHAPTER 2

# CHALLENGES FOR EUROPE

2.1

## VALUE IS SHIFTING GEOGRAPHICALLY

Over the last few decades, value has continuously shifted away from Western, developed countries, including the EU, towards emerging countries such as China. This shift can be observed in the global split of GDP or (as is even more relevant to today's topic) in R&D spending. This shift is expected to continue over the coming years, urgently requiring the EU to safeguard its historically strong position in certain businesses.




Source: IMF, UN, Advancy analysis

**Figure 2:** *Relative weight of GDP (Gross Domestic Product) and GERD (Gross Domestic Expenditure on R&D) for the EU, US and PRC*

## 2.2

# VALUE IS SHIFTING ALONG THE VALUE CHAIN

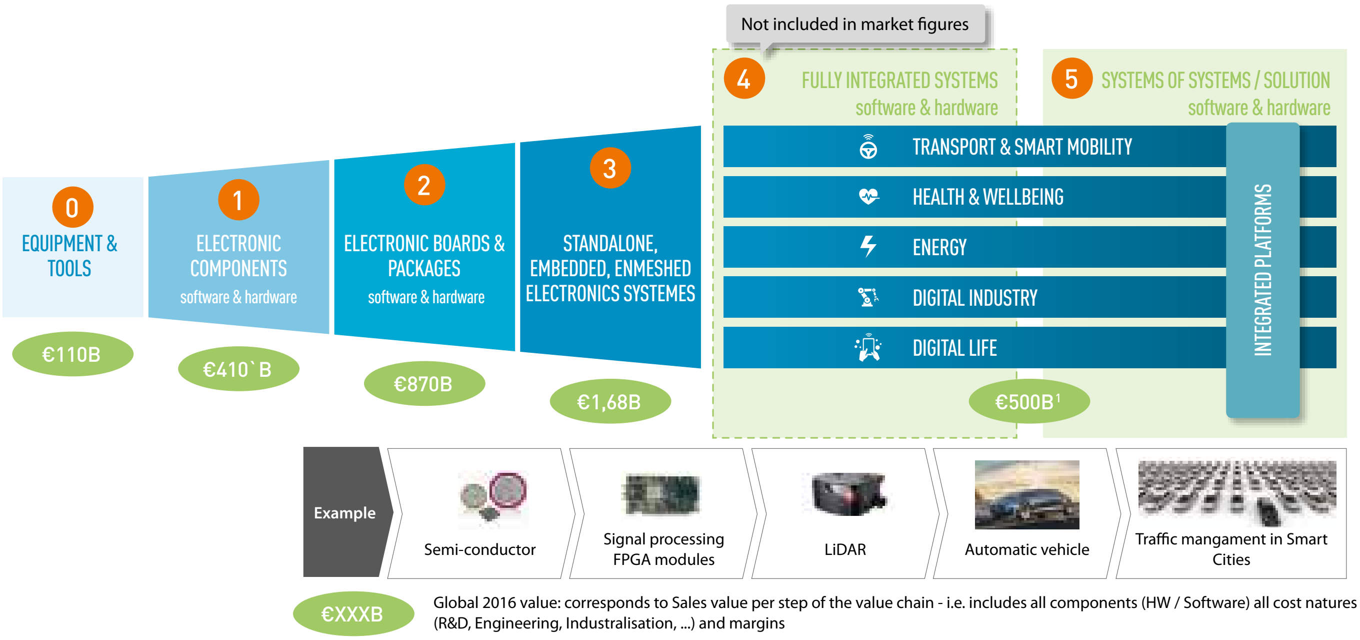
**Embedded & Cyber-Physical Systems are considered to cover software and hardware parts that are very hard to dissociate from one another. As such, all of the analyses and data shared in this report cover BOTH software and hardware challenges, market values and R&D investments.**

Looking more specifically at the Embedded & Cyber-Physical Systems market as a whole, value has been shifting down the value chain.

**Embedded & Cyber-Physical Systems can be broken up into 6 key value chain stages:**

0. Software, equipment & tools that are used to design, produce and validate E&CPS
1. Electronic components
2. Electronic boards & packaging
3. Embedded, enmeshed[2] electronic systems
4. Fully-integrated systems
5. Systems of Systems, applications and solutions

Steps 0 to 3 are usually not dedicated to one end-application, while steps 4 and 5 should be considered for main end-applications – **the 5 key end-applications identified by AENEAS, ARTEMIS-IA and EPoSS in the ECS-SRA [1] are: Transport & Smart Mobility, Health & Wellbeing, Energy, Digital Industry and Digital Life.**




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

**Figure 3:** *Global value chain in 2016 and worldwide market estimates[3]*

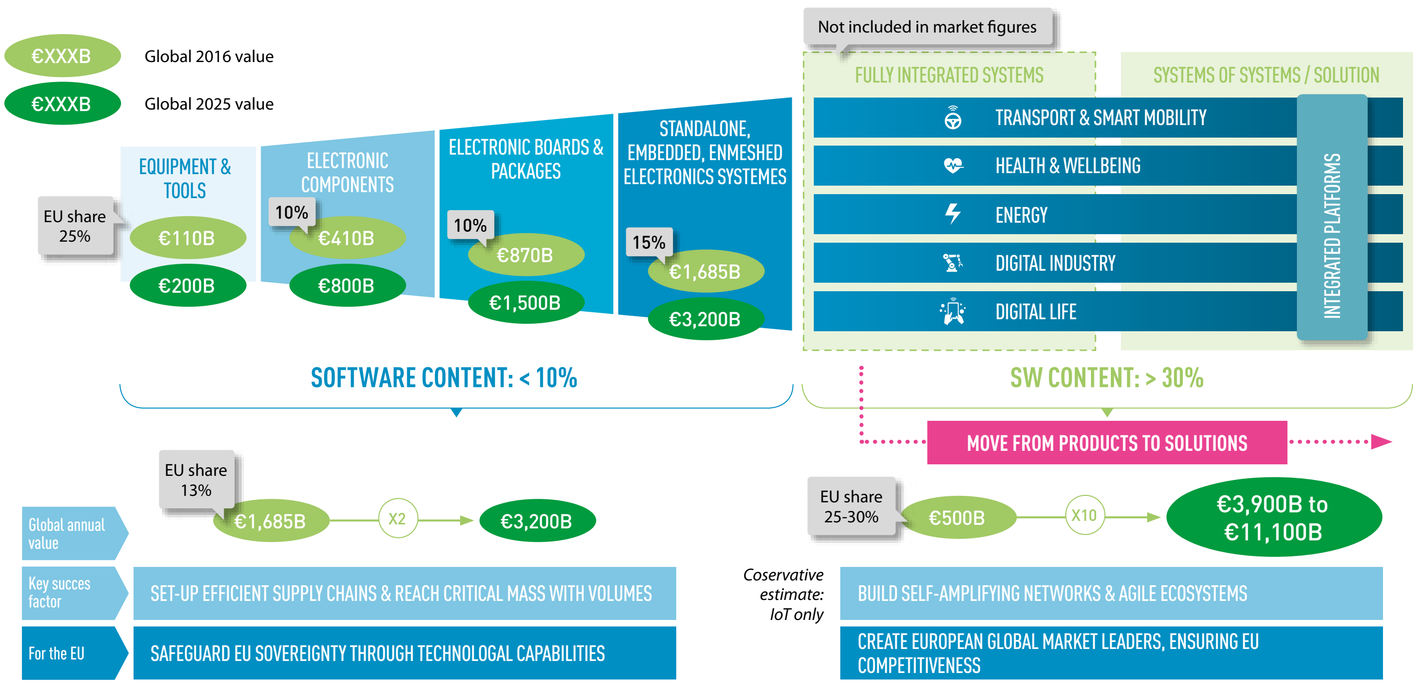
[2] *Enmeshed electronics: specific applications where electronics are integrated into other materials (e.g. smart textiles)*
[3] *Being 3 cosecutive steps of electronics integration, market values for steps 1, 2 and 3 are not additive i.e. market value for includes values for step 3 includes values of steps 1 and 2.*

**Today, value is mostly located upstream**, with stages 0 to 3 accounting for almost €1.7 t and step 5 estimated at c. €500 b in 2016. Over the next ten years, however, the value chain landscape is set to change dramatically: **value is expected to move downstream significantly, with a major shift from products towards solutions:**

- **The markets related to steps 0 to 3 are expected to almost double**, from €1.7 t in 2016 to €3.2 t in 2025. Value in this market is mostly driven by **hardware**, with only a small proportion of the total cost structure (<10%) linked to software.
- **The market related to stage 5 is expected to grow tenfold** over the same period, reaching between €3.9 and €11.1 t according to McKinsey. This step is **strongly driven by software content**, and the ability to capture this growth will be heavily dependent on (i) building software engineering and development capabilities and (ii) relying on **scalable business models and infrastructures** to operate as global platforms in Europe and beyond.

From an economic standpoint, this means that it is crucial for Europe to position itself on the fastest-growing segment of the value chain, so as to still matter in the E&CPS field of tomorrow's world. The starting position seems relatively good, with the EU's market share currently estimated at 13% of the markets for stages 0 to 3 and between 20% and 40% for stage 5. However, given the rapid, ongoing changes and the scale of growth expected for this last stage, cards are likely to be reshuffled and **it is in no way guaranteed that Europe's position in a solution-oriented market will become ten times larger than it is today.**

On top of this, maintaining Europe's position on the upstream segment of the value chain will require effort. Economies of scale are key to those stages of the value chain and technologies are also evolving quickly in this area. Controlling these stages is strategic, as suggested by the gigantic efforts being made by China to build a domestic semiconductor champion (over $100B) or South Korea's incentives to remain at the head of the technological race, for example.

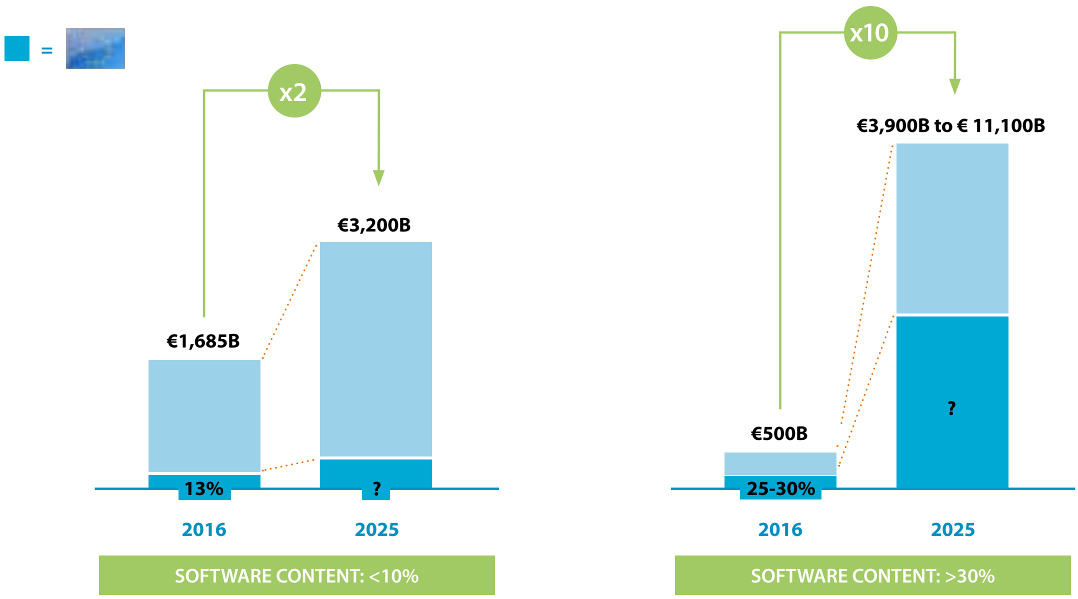



Note: rounded figures. (1): 2025 estimate value potential for the Internet of Things, not the full potential for ECS end-applications.
Source: Decision, IDC, MGI, Advancy research & analysis

**Figure 4:** *Global and European value chain 2016-2025*

## FIRST STEPS OF THE VALUE CHAIN: STEPS 0 - 3 GLOBAL VALUE 2016-2025, €B AND % OF TOTAL

## LAST STEP OF THE VALUE CHAIN: STEP 5 - 3 ZOOM ON IoT MARKET 2016-2025, €B AND % OF TOTAL




Source: Decision, MGI, IDC, Advancy researcg & analysis

**Figure 5:** *Embedded & Cyber-Physical Systems market 2016-2025 and EU market share*

2.3

# OBJECTIVES FOR EUROPE TO SUCCEED

**The EU can successfully tackle the challenges of shifting value (both geographically and along the value chain) and technological advances if it meets 5 key objectives:**

I. **Creating jobs:** create the jobs of tomorrow with new, value-added skills.

II. **Building leaders:** support European companies in building a successful ecosystem of applications and solutions; become global market leaders in Transportation, Health & Wellbeing, Energy, Digital Life, Digital Industry, etc.

III. **Protecting sovereignty:** protect the European electronic components value chain players by making sure that European sovereignty is developed/maintained for non-standard strategic technologies/components.

IV. **Preparing for convergence:** prepare to drive the convergence between applications to help materialise the vision of this new industrial revolution (e.g. Energy/Transportation, etc.).

V. **Increasing research efficiency and proximity to industry:** build closer links between research and applications to support European industry in remaining competitive, increase efficiency, attract volumes and protect distinguished innovations and Intellectual Property, especially for strategic applications.

CHAPTER 3

# RELEVANCE OF THE ECS-SRA*

## 3.1

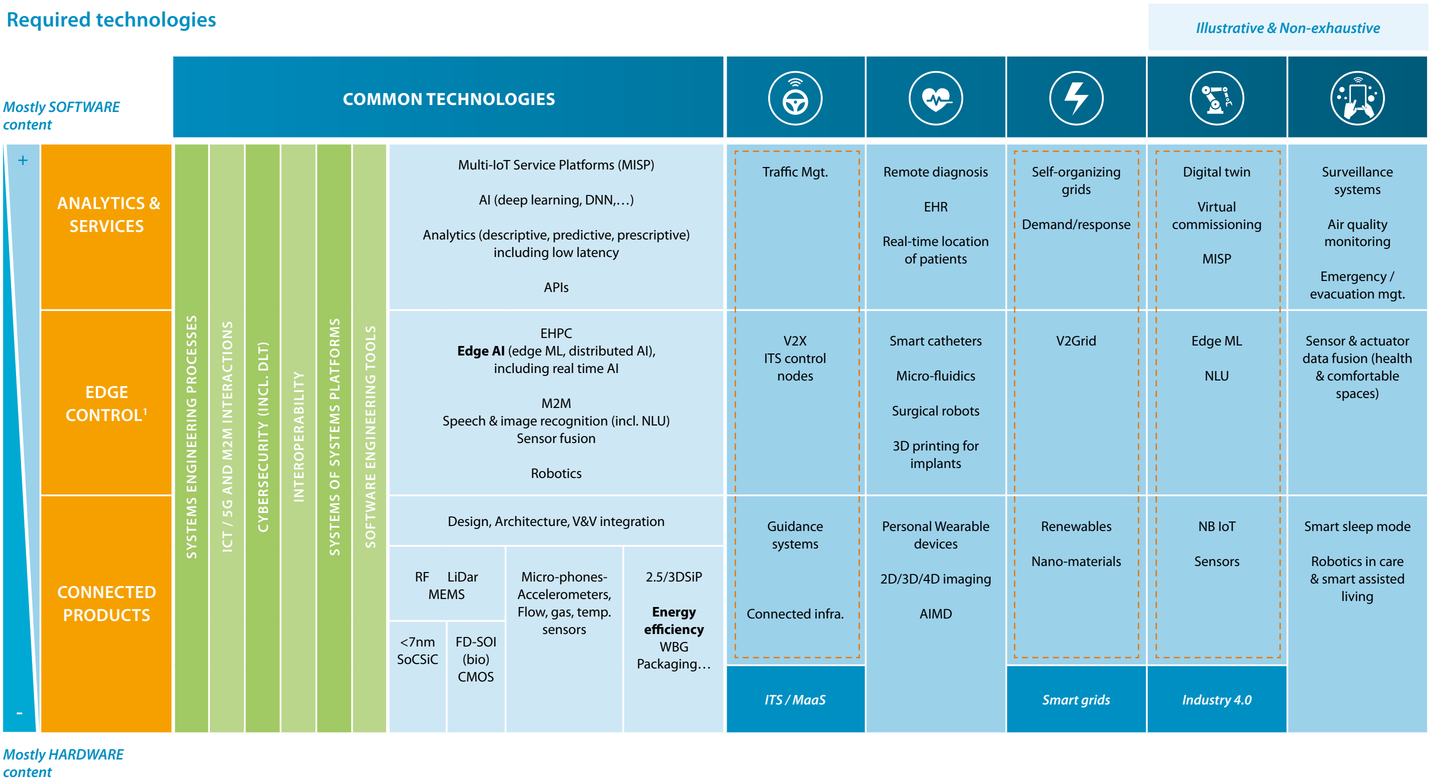
## KEY TECHNOLOGIES TO SUCCEED IN THE NEW INDUSTRIAL REVOLUTION

As mentioned previously, several new technologies are expected to affect all stages of the Electronic Components & Systems value chain. These technologies can be split across two axes:

- **Their position in the Embedded & Cyber-Physical Systems architecture**, being either part of the Physical world (connected product, control automation), of the Cyber world (e.g. embedded software technologies, SoS integration platforms, simulation & digital twins, analytics & services that are embraced by the six technology domains) or at the interface and overlap between both worlds.
- **The final application**, with some technologies being commonly used in several final applications, of course.

From left to right, the applications considered in this example cover (i) Transport & Smart Mobility, (ii) Health & Wellbeing, (iii) Energy, (iv) Digital Industry and (v) Digital Life.

* *The ECS-SRA is downloadable at www.artemis-ia.eu*




[1] An edge control is any piece of hardware that controls data flow at the between the CPS and the network. Serving as network entry (or exit) points : transmission, routing, processing, monitoring, filtering, translation, computing and storage of data. - Source: ECS SRA, Advancy research & analysis

**Figure 6:** *Illustrative and non-exhaustive sample of technologies, as presented in the 2018 ECS-SRA (see glossary for abbreviation)*

These common technologies are key facilitators or enablers in the development of solutions for final application:

- **Analytics[4] & services: software-intensive and AI-powered systems**
  - **SoS integration platforms** are essential for interoperability and seamless communication between different providers. As such, they are a prerequisite to the development of a General-Purpose Technology platform (GPT) that combines several providers whose products must be able to easily connect to each other. These platforms play a fundamental role in the integration of Systems of Systems (SoS).
  - **Embedded Artificial Intelligence (AI) and data analytics** are essential to the development of autonomous ECS. These will play a role, for example, in automated mobility (automatically detecting anomalies in healthcare through deep learning) and preventive and predictive maintenance in the digital industry.
  - **Interoperability: interoperability standard interfaces (both HW and SW),** will be critical in reaping the benefits of Machine Learning/AI, particularly when it comes to new GPU/CPU environments. These are the underpinnings of the cloud and IoT revolution, as they ensure speed, ease and portability of data that is exchanged across distributed systems.

[4] *Analytics designate the large dataset-based analyses that allow us to extract value from data. Among the most common types of analytics, we find (i) descriptive, (ii) predictive and (iii) prescriptive analytics.*

- **Edge control: Embedded Intelligence**
  - **Embedded (or Edge) High-Performance Computing (EHPC):** 'edge' refers to computing infrastructure that exists close to the sources of data, such as industrial machines (e.g. wind turbines, magnetic resonance (MR) scanners, undersea blowout preventers) and time series databases that aggregate data from a variety of equipment and sensors. These devices typically reside separately from the centralised computing that is available in the cloud. Embedded (or Edge) High-Performance Computing (EHPC) enables many other technologies and allows them to be deployed on a wide scale in small devices. This EHPC must be able to increase performance at acceptable costs.
  - **Edge AI** is central to most AI-enabled applications (such as autonomous driving) as it allows AI algorithms to be processed locally on a hardware device. This permits the independent AI processing of data and decision-making even without an Internet connection.
  - **Machine-to-machine** is a crucial technological building block, as it will enable autonomous driving (communication between vehicles or between vehicles and infrastructure) and has key applications in the Digital Industry.
  - **Speech & image recognition** is at the heart of several solutions in Mobility, such as Human Machine Interfaces (HMIs), Digital Life (e.g. the home) or even Healthcare (e.g. EHRs).
  - **Sensors fusion** will empower the autonomy of kinetic objects. It does this by allowing accurate environmental recognition through the uncertainty reduction linked to each sensor (often with heterogeneous parameters) and by including a priori knowledge of the environment (e.g. through historical values or human input of third-party information, such as mapping in the case of autonomous vehicles).
  - **Robotics, control & real-time simulation** are to play a key role not only in Digital Industry but also in Digital Life care, smart-assisted living environments and even patient treatment assistance.

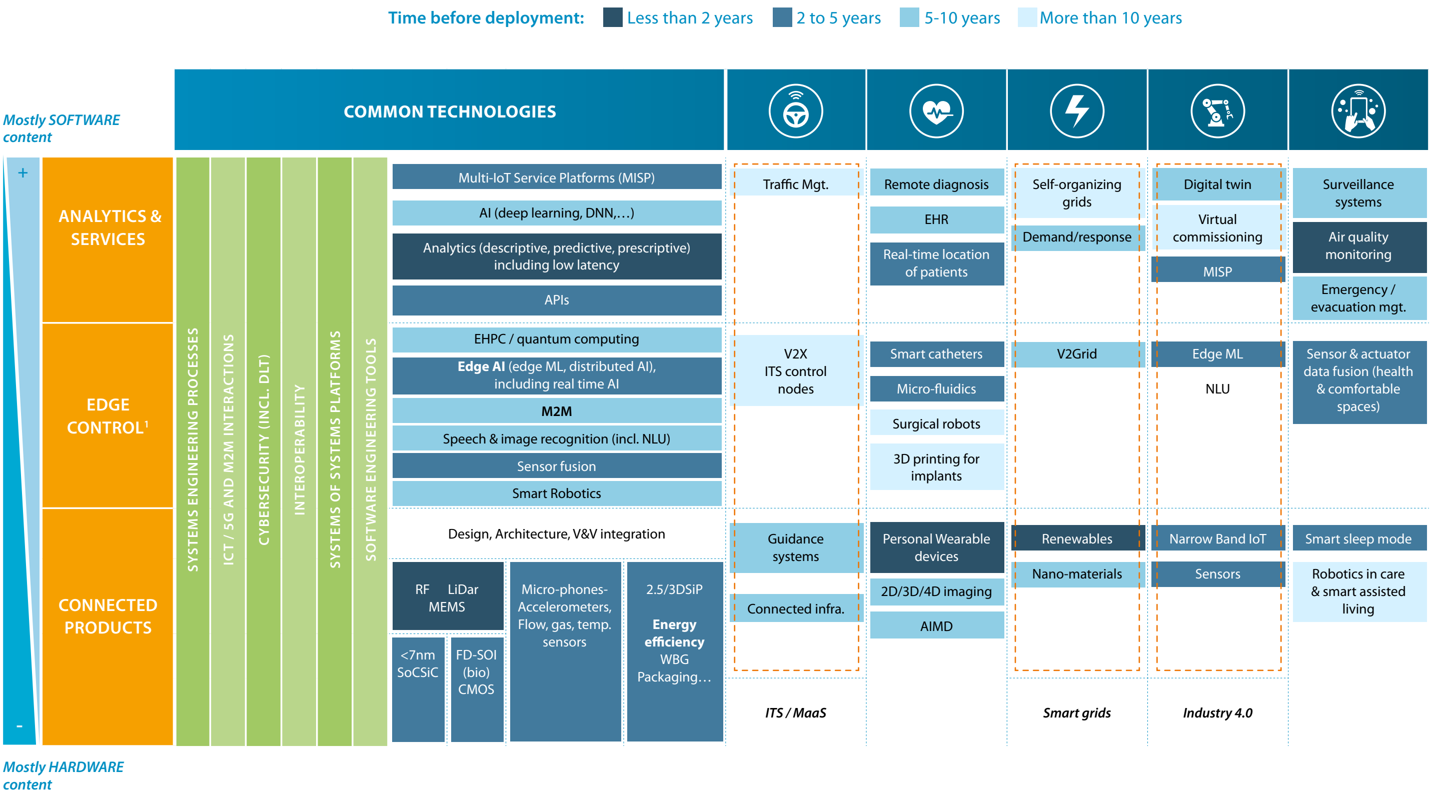
- **Connected products / IoT and SoS**
  - **The need for improved embedded software capabilities is paramount:**
    - **Architecture:** there are strong challenges in revisiting the architecture of existing integrated products (e.g. automotive vehicles) to gain efficiency and (cyber)security.
    - **Verification & validation:** strong integration challenges and interactions exist between increasingly complex components.
    - **Design:** we need to move to more agile, flexible and trustable design methods (agile development, continuous integration).
    - **Interoperability:** the effectiveness of solutions must be ensured from the component level to the System of Systems level.

  - **The improvement of embedded HW is equally important, with several key challenges:**
    - **Next-generation computing capabilities:** "More Moore" (SoC) and "More than Moore" (SiP), FD SOI, CMOS, Photonics, EHPC, New GPU / CPU, <7nm.
    - **Sensors & actuators:** MEMS, RF, LiDaR, microphones, flow, gas, temperature sensors.
    - **Energy efficiency:** yield, heat and mechanical stress to be addressed through Wideband Gap material and innovative packaging (2.5 / 3D, SiP).
    - **Communication:** radio-frequency chips that are compatible with a variety of protocols.
    - **Industrialisation & manufacturing:** pilot lines, robust industrialisation processes and integrated logistics.

In addition, six 'foundational technologies' are required and will serve as cornerstones of this vision, allowing the construction of reliable, safe and trustworthy E&CPS, Systems and Systems of Systems.

- **Systems Engineering processes:** methods & tools, quality assurance, testing, validation & verification techniques and methods on all levels of the systems hierarchy – these processes are strongly dependent on software technologies and on software engineering processes & tools.
- **Information and Communication Technologies:** 5G, NB-IoT, LoRaWAN and other M2M protocols.
- **Cybersecurity:** ensuring the safety and security of people and goods in each application, with the involvement of European states in defining powerful, coordinated strategies. In this context, **Distributed Ledger Technologies** could play a part by allowing for flexible, secure information exchanges across Systems of Systems.
- **Interoperability:** a key element for inherently controlling diversity in Systems of Systems and for avoiding a fragmentation or explosion of complexity.
- **Systems of Systems integration platforms:** CPS ecosystems require secure and efficient platforms that are capable of orchestrating and managing the complexity and heterogeneity of the ecosystem throughout its entire lifecycle.
- **Software engineering tools:** these ensure efficient and cost-effective connected products engineering along the entire supply chain and across the product's lifetime.

The ECS landscape is evolving rapidly and European players must act quickly to stay in the race: several key technologies that are required to succeed in this new industrial revolution are expected to be deployed in less than five years (SoS integration platforms, edge AI, sensor fusion, model predictive control, real-time simulation, predictive maintenance, automation & robotics, virtual reality, augmented reality, etc.). In other words, these technologies are already at the top of R&D agendas.



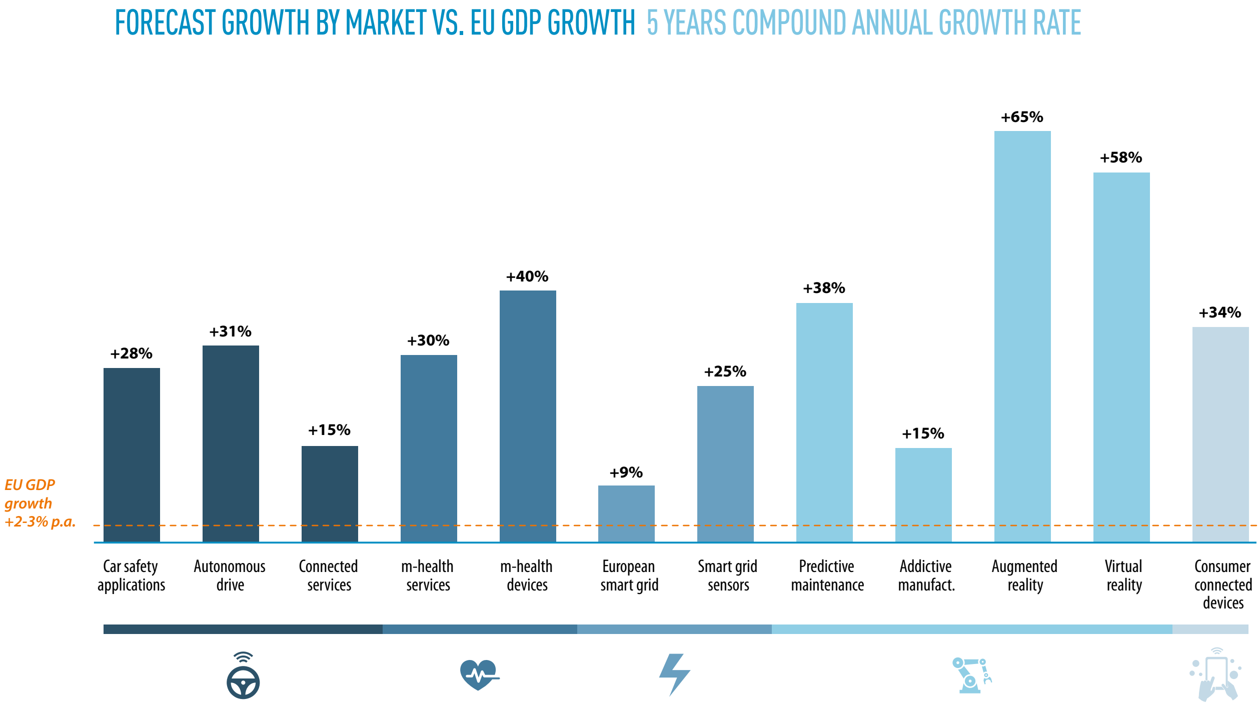

¹ An edge control is any piece of hardware that controls data flow at the between the CPS and the network. Serving as network entry (or exit) points : transmission, routing, processing, monitoring, filtering, translation, computing and storage of data. - Source: ECS SRA, Advancy research & analysis

**Figure 7:** *Time before deployment of required technologies for the illustrative and non-exhaustive sample of technologies, as presented in the 2018 ECS-SRA*

# 3.2

# ECS-SRA ON KEY APPLICATIONS

The market growth potential of key applications (i.e. Transport & Smart Mobility, Healthcare & Wellbeing, Energy, Digital Industry and Digital Life) is huge and can be a significant growth driver for the EU in years to come, should it manage to play a leading role in the emergence of these new markets.




Sources: Goldstein Research "Smart HEalthcare" - 2018, International Energy Agency " Energy efficiency" - 2017, Frost & Sullivan "European Samrt Grid" - 2016, Bloomberg New Energy Finance "Global storage market" - 2017, IHS "Smart Grid Sensors" - 2015, BIS Research "Global augmented and virtual reality" - 2016, Gartner (IoT) - 2017, MGI "The Internet of THings: mapping the value beyond the hype" - 2015

**Figure 8:** *Market growth forecasts*

1. **Transport & Smart Mobility:** the ECS-SRA underlines the key technologies needed to find this application's solutions, such as technological blocks to **develop clean, affordable and sustainable propulsion, and Mobility as a Service (MaaS)** that includes managing interactions between humans and vehicles (V2X communication), traffic management, guidance systems, etc.

   Revenues related to autonomous driving and connected cars are expected to boom, with **safety applications** (e.g. automatic collision detection/prevention) expected to reach USD 58 billion (up from USD 18 billion in 2017), **autonomous driving** (e.g. distance/park/motorway assistant, pilot, traffic sign detection/recognition) set to reach USD 55 billion (up from USD 14 billion in 2017) and **connected services** expected to reach USD 43 billion in 2022 (up from USD 21 billion in 2017).

2. **Healthcare & Wellbeing: successfully providing the same level of care in an appropriate, efficient and cost-effective way by, for example, decentralising healthcare** (out of hospitals and into our homes and daily life) or **developing connected health.** The technologies required to do so are being pushed forward in the ECS-SRA.
Healthcare is already key to European economies: c. 10% of the EU's gross domestic product is spent on it. 10% of this, in turn, is spent on medical technologies, a market that historically grew at 4.6% per annum. The growth forecast for these new technologies is on a different scale: the **global mHealth services and devices markets are expected to grow, respectively, by almost 30% and 40% per annum over the next 5 years,** according to Goldstein Research.

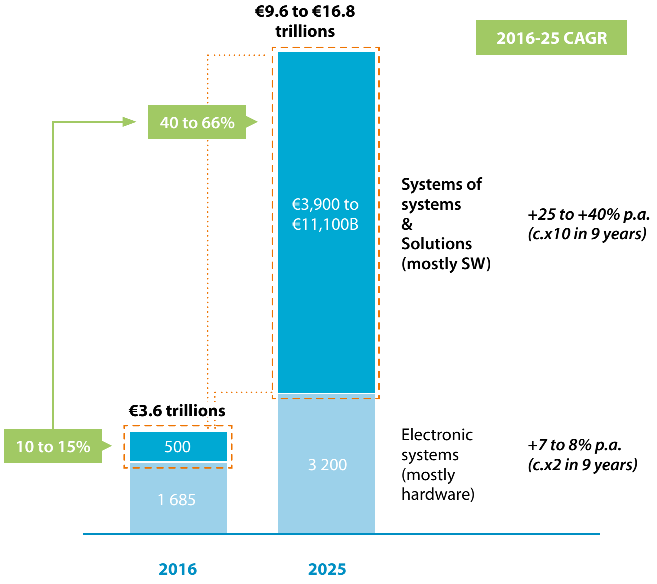
3. **Energy: ensuring sustainable power, managing energy efficiently and reducing energy consumption** are flagged as the key challenges to be tackled. The ECS-SRA underlines several priority R&D&I areas relating to solutions and the value chain.
Huge value is to be attained by rising to those challenges. According to the International Energy Agency (IEA), thanks to the decline in global energy intensity (amount of primary energy demand needed to produce one unit of gross domestic product), **energy productivity savings of approximately USD 2.2 trillion were generated in 2016** – as a point of reference, this is equivalent to twice the size of the Australian economy.
**The European smart grid market is expected to grow by 9% per annum between 2015 and 2025, reaching almost €30 billion** according to a study by Frost & Sullivan. As a smaller illustration of how this changing environment is boosting growth, the **smart grid sensors market is expected to more than triple by 2021**, according to IHS. Energy storage also has strong growth prospects, with global storage capacity expected to reach 11.3 gigawatts by 2020 (up from less than 4 gigawatts in 2017), according to Bloomberg New Energy Finance.

4. **Digital Industry:** the dedicated ECS-SRA chapter has set out the R&D&I areas required to succeed in this field, e.g. the development of digital twins, implementation of AI and machine learning, generalisation of condition monitoring and development of digital platforms.
The expected growth related to Digital Industry is tremendous. **Predictive maintenance is expected to grow by 38% per annum between 2017 and 2022, reaching USD 11 billion**. The **additive manufacturing (3D printing) market, for example, is predicted to grow by 15% per annum between 2015 and 2025**, reaching over USD 20 billion according to Frost & Sullivan. Regarding **augmented and virtual reality**, BIS Research predicts that these markets will globally reach c. USD 200 billion and USD 40 billion by 2025, i.e. a compound annual growth of 65% between 2018 and 2025.

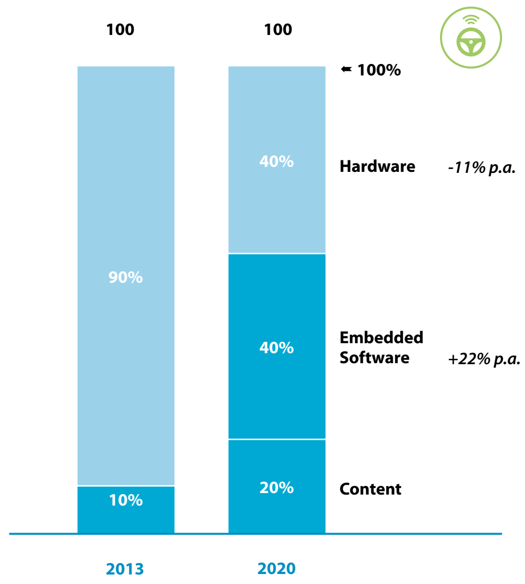
5. **Digital Life:** the objectives laid out by the ECS-SRA aim to improve our digital lives, ensuring safety, security, good health and comfortableness while developing sustainable spaces (public, professional, private or personal spaces).
Gartner forecasts the number of consumer IoT devices to reach 12,863 billion in 2020, i.e. a growth of c. 35% per annum. **Internet of Things (IoT) at home,** from chore automation devices and smart appliances to security and energy management applications and solutions, are expected to reach between **USD 200 and 350 billion by 2025.**

Within each of these applications, Software & Solutions will significantly outgrow hardware and electronic parts. This value migration constitutes a major opportunity for European players to capture growth in the long-term.

## ECS ANNUAL GLOBAL MARKET VALUE BY VALUE CHAIN STEP 2016-2025, BILLION EUROS



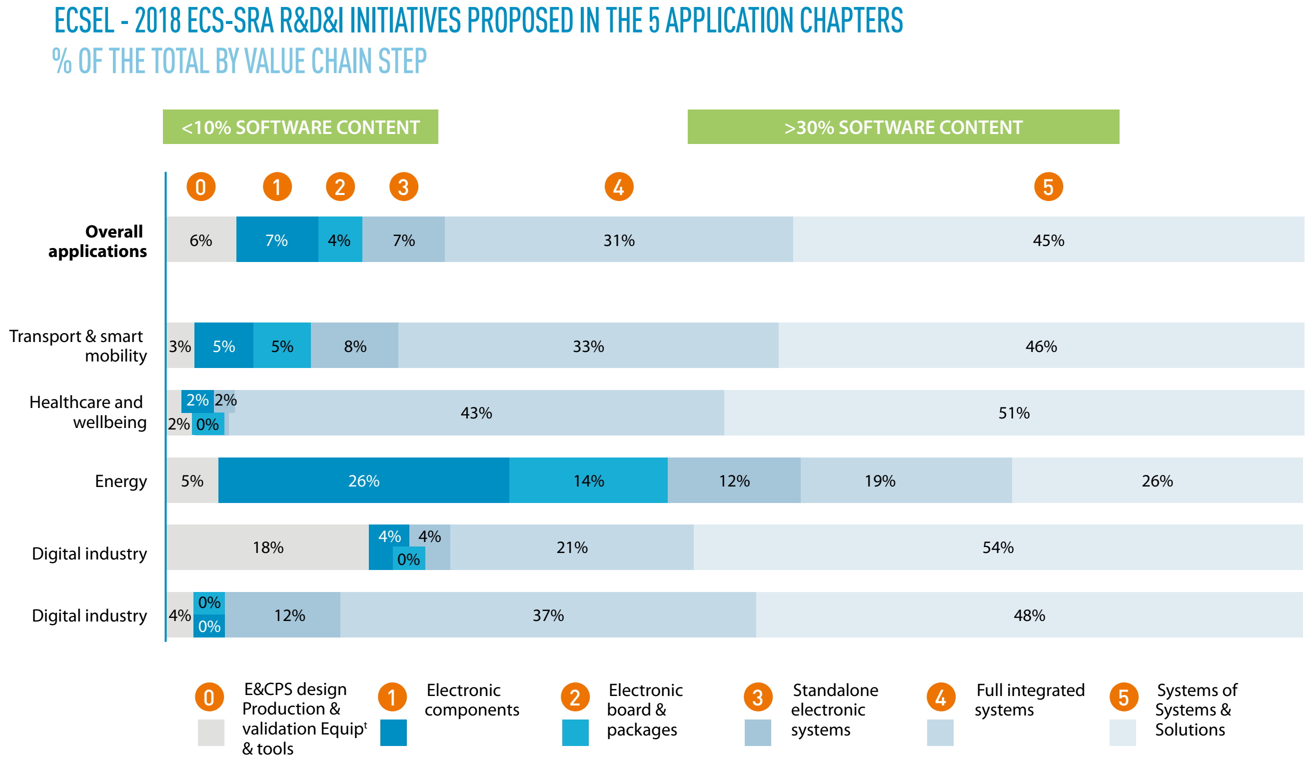

## EXAMPLE OF VALUE SHIFT FOR AUTOMOTIVE APPLICATION 2013-2020, % OF CONTENT PER VEHICLE




Source: IMF, Decision, MGI, IDC, Morgan Stanley Advancy analysias

**Figure 9:** *Value migration towards software and solutions – incl. example for Automotive*

Of these key applications, **the ECS-SRA puts emphasis on products and solutions**, which amount to **31% and 45% of the priority Research & Development & Innovation (R&D&I) areas** respectively. By doing so, it identifies and addresses how we can make the best of these business and social challenges, **allowing Europe to capture its fair share of the fast-growing markets at the last stages of the value chain.**




Note: Excluding enablers - Source: ECS-SRA 2018 project list, Advancy analysis & hypotheses

**Figure 10:** *Value chain mapping of ECS-SRA applications in high-priority R&D&I areas. Percentages represent the proportion of projects proposed in ECSEL ECS-SRA, mapped across the value chain*

ECSEL has set the foundation for this evolution. With a strong focus on the first stages of the value chain, it has allowed the ecosystem to begin preparing for future challenges. In particular, ECS-SRA 2018 has significantly shifted the focus towards Systems and Solutions, realigning it with future market trends and societal challenges. **ECSEL would gain in impact by broadening its member base to include more end-application players and by focusing on European companies.** These are key to tomorrow's world, given the shift in the value chain described previously and because they drive a large part of the innovation process.

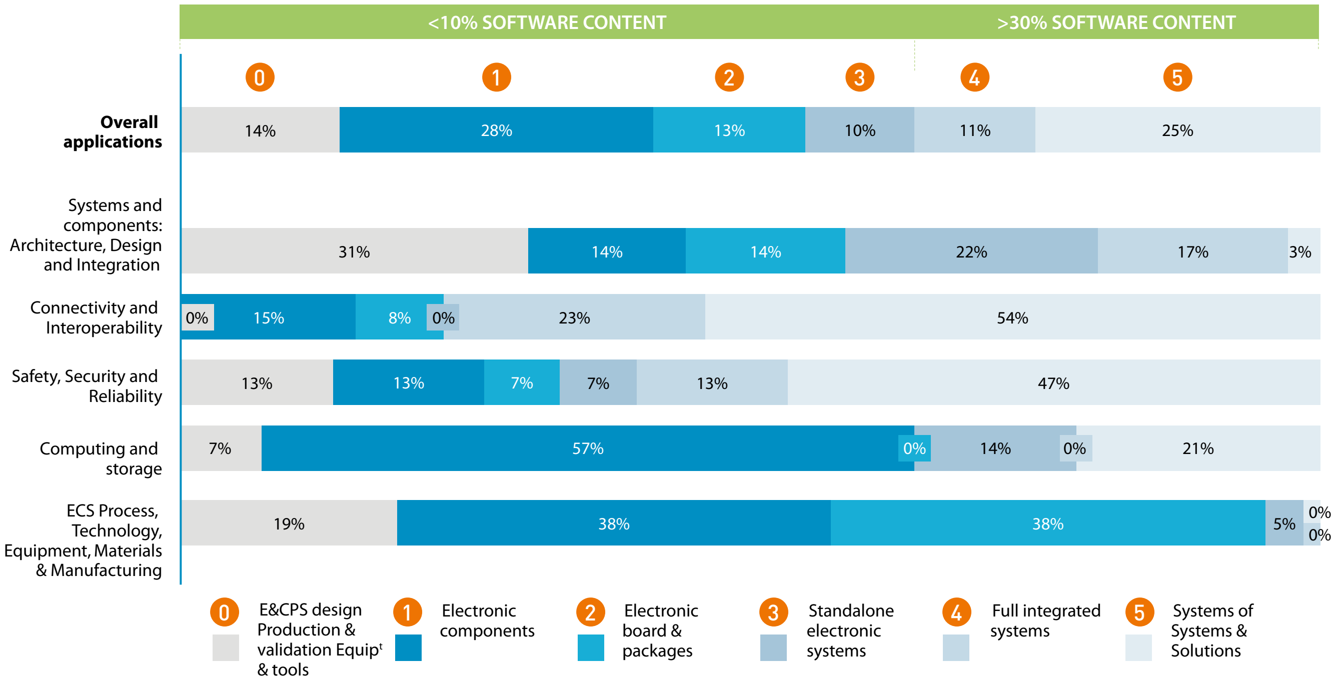
# 3.3

# ECS-SRA ON COMMON TECHNOLOGIES

The ECS-SRA underlines the key enablers of the General-Purpose Technology platform (described in the opening context section of this report):

1. **Efficient application, architecture, design & integ ration capabilities**.
2. **Interoperability & value delivery**, which will require seamless integration of different technologies – both hardware and software – through semantic interoperability and heterogeneous integration.
3. **Security & reliability of Embedded & Cyber-Physical Systems**, achievable through improved software technologies, e.g. Distributed Ledger Technologies, encryption technologies and authorisation & authentication technologies.
4. **Performant-affordable, integrated and intelligent components and embedded systems**, which will be realised (among others things) through advances in **energy efficiency**. This is made possible thanks to: energy efficient building blocks (CPU, memory, potentially based on 3D silicon technologies); extensive usage of accelerated computing technologies (e.g. GPU, FPGA) to complement general purpose processes; and domain-specific integration, such as SiP (System-in-Package) or SoC (System-on-Chip). Additionally, the ECS-SRA anticipates and identifies new **disruptive technologies** that are already high-priority R&D&I areas: quantum, neuromorphic, spintronic and optical computing, to name a few.

## ECSEL - 2018 ECS-SRA R&D&I INITIATIVES PROPOSED IN THE 5 APPLICATION CHAPTERS
## % OF THE TOTAL BY VALUE CHAIN STEP




Note: Excluding enablers - Source: ECS-SRA 2018 project list, Advancy analysis & hypotheses

**Figure 11:** *Value chain mapping of ECS capabilities in high-priority R&D&I areas, as per ECS-SRA document structure (excluding 'enablers')*

# CHAPTER 4
# INTERNATIONAL BENCHMARKS

The ECS-SRA largely addresses most of the technological areas on which Europe must focus its Research & Development & Innovation efforts in years to come. It also gives insights into Europe's relative strengths and weaknesses versus the Rest of the World. Furthermore, to gain a full understanding of how the EU fares versus the Rest of the World, the expected level of government support for ECS is presented hereafter. This highlights what seems to be a difference in scale between other governments' support and the EU's support, with the EU lagging behind.

## 4.1
## EU STRENGTHS AND WEAKNESSES ON END-APPLICATIONS VERSUS THE REST OF THE WORLD

**The EU stands out and is leading the changes in Transport & Smart Mobility, Energy and Digital Industry.** It brings together EU MNCs, start-ups and leaders with strong societal stakes in these critical industrial fields. This situation calls for even higher and more sustained R&D&I investments in these fields to contain the constantly increasing international competition.

On the contrary, **Europe is not a leader in some of its historical strongholds, such as Health & Wellbeing** – here, the US has a leading position and Asia (mostly China and Japan) are strongly positioned to benefit from the future growth opportunities of autonomous vehicles or V2X infrastructures. **Similarly, the US is set to become the leader in Digital Life,** having the largest market share while the EU remains a follower.

**The EU's positioning in Digital Life suggests grim prospects** as it does not have any domestic IT giants, which are the key players for driving change in this segment. Additionally, limited cloud capabilities and a lack of VC culture both hinder Europe's ability to develop itself.

The table below summarises the positioning of the EU, US, PRC, Japan and South Korea on these 5 applications.

| | | | | |
|---|---|---|---|---|
| Historically leading but being challenged on electrification, V2X infrastructure | Strong IT giants increasingly investing the transport space, speech recognition, V2X regulation progressing | Leading in powertrain electrification & speech recognition, #1 potential market globally | Leading on powertrain electrification & good V2X infrastructure already set up for full scale testing | Good positioning on powertrain electrification & good positioning on speech recognition |
| Strong historical players in medical, some players in new segments but EU not expected to lead | Leading on AIMD, expected to retain the highest market share in the digital health market | Strong emerging players in diagnostic imaging and digital health | Some historical players, current surveys show low adoption potential for connected health devices in Japan | Samsung emerging in diagnostic imaging and digital health |
| Strong position across value chain, particularly u pstream, leading role in standardisation | Currently very limited political will on this topic | Weak today but strong political will and investments to make China a leader in alternative energies | Leading in smart grid / smar communities | Good positions on smart grids |
| Strong on digital monitoring, edge but lagging behind on AI, IoT platform & cloud | Strong on AI, cloud, digital twins, condition monitoring | Ambitious targets (Made in CHina 2025) & investments in AI & smart manufacturing | Already among the most advanced manufacturing sector in the world | Smart manufacturing pushed by the private large groups and the government |
| Nog segment dominated by the EU: no IT giant, limited on cloud and speech recognition, limited VC culture | Strong on smartphones, home automation | IoT considered a strategic industry for CHina | Levaraging its strangth in robots, ambitious ongoing projects for smart cities | IoT pushed by electronic manufacturers (Samsung, LG) and telcos |

**Positioning** Very strong Strong Average Weak

Source: ECS-SRA 2018, Advancy research & analysis

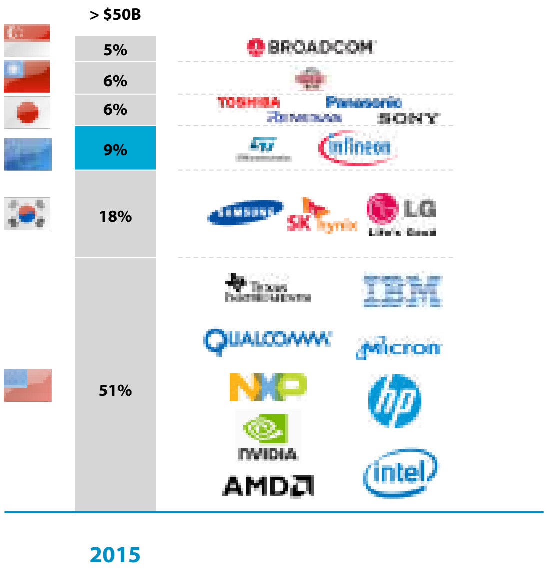
**Figure 12:** *International benchmarks by application*

# 4.2

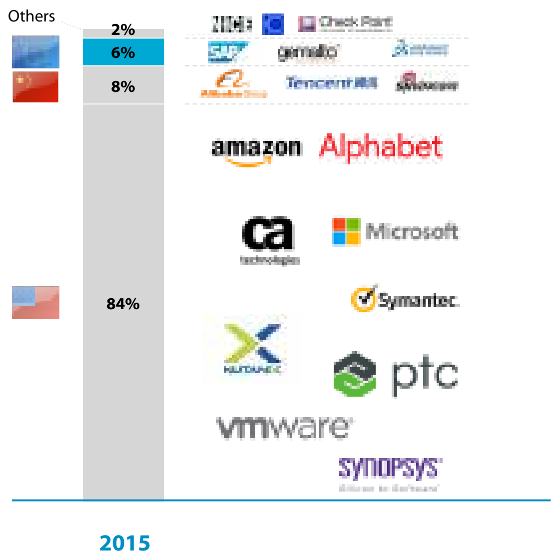
# LEVEL OF PRIVATE ECS R&D

**European private sector R&D in ECS seems to be lagging behind other countries, in both hardware and software technologies related to Embedded & Cyber-Physical Systems.** For example, in the semiconductor industry, Europe's R&D spending is well below the USA and South Korea and only slightly above Taiwan and Japan. In the software industry (application and system software), the situation is very similar.

## TOP SEMICONDUCTOR PLAYERS RESEARCH AND DEVELOPMENT 2015, % OF TOP PLAYERS TOTAL R&D SPEND




## TOP SOFTWARE PLAYERS RESEARCH AND DEVELOPMENT 2015, % OF R%D SPEND IN TOP 1000 PLAYERS IN APPLICATION & SYSTEMS




Source: IC Insights, Annual Report, Advancy analysis, Strategy & Top 1000 innovators survey

**Figure 13:** *Private R&D, the example for hardware (semiconductors) and software*

## 4.3

# LEVEL OF PUBLIC SUPPORT TO ECS R&D

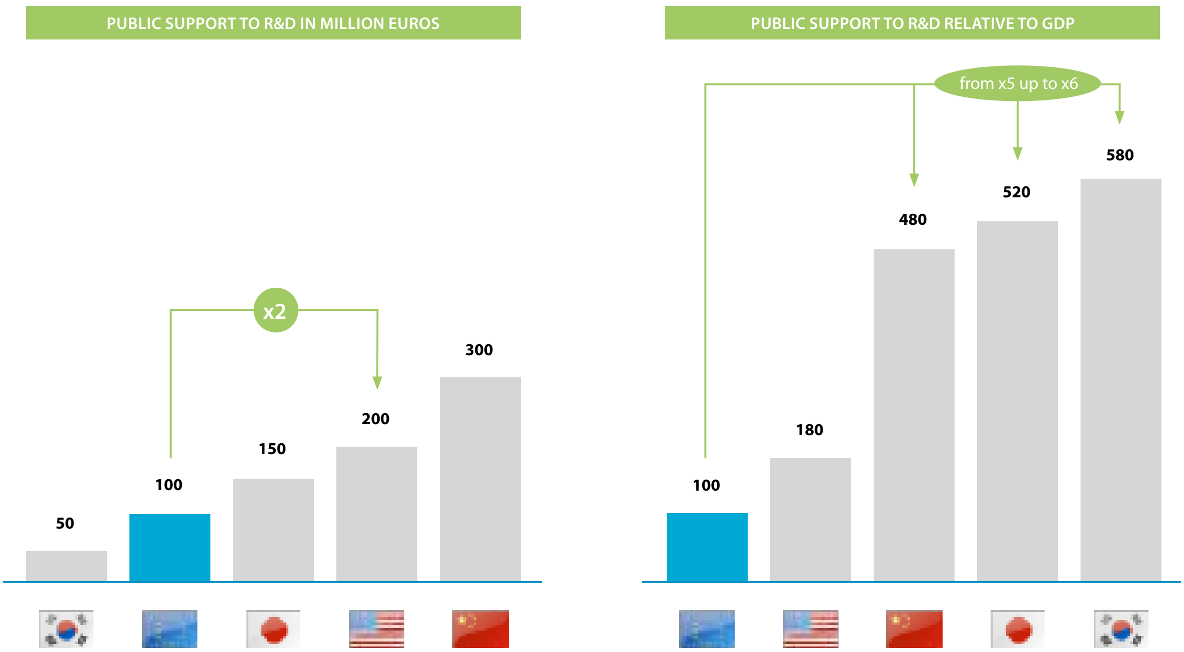
**Methodology & scope:** although it is difficult to ensure both the exhaustiveness and full comparability (scope, duration, etc.) of public support in different areas of the world, which may have different mechanisms and levels of public disclosure of expenses, the following analysis aims to compare the levels of government support to R&D in the ECS industry. We have chosen to:

- focus on direct financial support from governments to R&D, and as a result have chosen to;
- exclude fiscal and tax incentives, funds dedicated to supporting the industry's external growth (e.g. China's National Integrated Circuit Fund, mostly focused on helping the industry through M&A) and the advantageous financing facilities of banks.

*As a point of reference, the benchmarks presented below considers the annual amount in euros spent on R&D by the EU.*

**The EU is being outspent by the US, Japan and China, the latter on key policies which are focused on making the transition from being the world's factory to becoming a self-sufficient leader in innovation.** It could even be said, relatively speaking, that the EU is being outspent by South Korea. An example would be if we were to compare public efforts to support R&D, given the South Korea's gross domestic product.

### ANNUAL PUBLIC R&D SUPPORT INDEX 100 = EU 2016 ANNUAL AVERAGE




Source: World Bank, Advancy Analysis

**Figure 14:** *International benchmarks of public support to ECS R&D*

1. **China:**
   - **The 'Made in China 2025'** initiative aims to transform China into a 'manufacturing superpower' that dominates advanced industries (robotics, advanced IT, aviation, new energy vehicles, etc.) while increasing the domestic share of Chinese suppliers across the value chain. **Since 2014, $250 b in funding has been announced** to support strategic sectors (e.g. $100 b for the National Integrated Circuit Fund, $45 b in the China Development Bank's support for Made in China 2025, a $30 b venture capital fund for state-owned enterprise innovative technology and industrial upgrading, $22 b in credit lines for China Internet Investment Fund participants, a $22 b state-owned enterprise fund for strategic sectors, $15 b for the China Internet Investment Fund, a $6 b Emerging Industries Investment Fund, a $3 b Advanced Manufacturing Fund, etc.). This figure becomes even higher if we consider local government funding. Below are a few examples of specific themes of this 'Made in China 2025' plan, which are by no means exhaustive:
     - **High-performance computing:** China is set to surpass the US in 2020 with the fist exascale computer – China has invested over $1 b since 2009, built Sunway TaihuLight (the world's fastest supercomputer) and set ambitious targets in terms of the market share of Chinese firms by 2020.
     - **Cloud computing:** $7.7 b in financial support to develop the industry in the 12th Five-Year Plan and, in the 13th Five-Year Plan, an $177 b investment in infrastructure to build more than 90,000 km of high-speed fibre optic cables and two million 4G base stations.
     - **Industrial robotics:** there is significant local funding ($7 b+) in this area, and the central government is facilitating the acquisition of foreign companies (e.g. Kukea, Broetje). MIC2025 has set a target market share of 70% for Chinese companies in 2025 (versus 31% in 2016) and, in some specific sub-sectors, China is already a leader (e.g. commercial drones).

   - The PRC aims to become the **global leader in Artificial Intelligence by 2030** and has announced that **$150 b is to be invested by the government over the coming decade (compared to the €100 m to be invested by France)**. In addition, local governments have already pledged $7 b to reach this target and the private sector is already very strong on AI. Baidu, for example, is becoming the global leader in speech recognition (DeepVoice-converted text, an almost humanlike voice and over 400x times faster than Google's DeepMind).

     **Methodology & scope:** for the purposes of this benchmark, Made in China funding has been used, excluding the following items: National Integrated Circuit Fund ($100 b, mostly focused on helping the industry through M&A), the China Development Bank's support for Made in China 2025 ($45 b) and credit lines for China Internet Investment Fund participants ($22 b). The amounts included have been considered as if they were to be spent over a period of 10 years.

2. **USA: more than $4 b is spent annually via the NITRD** (Networking and Information Technology Research and Development) on high-end computing, cybersecurity, artificial intelligence, etc.

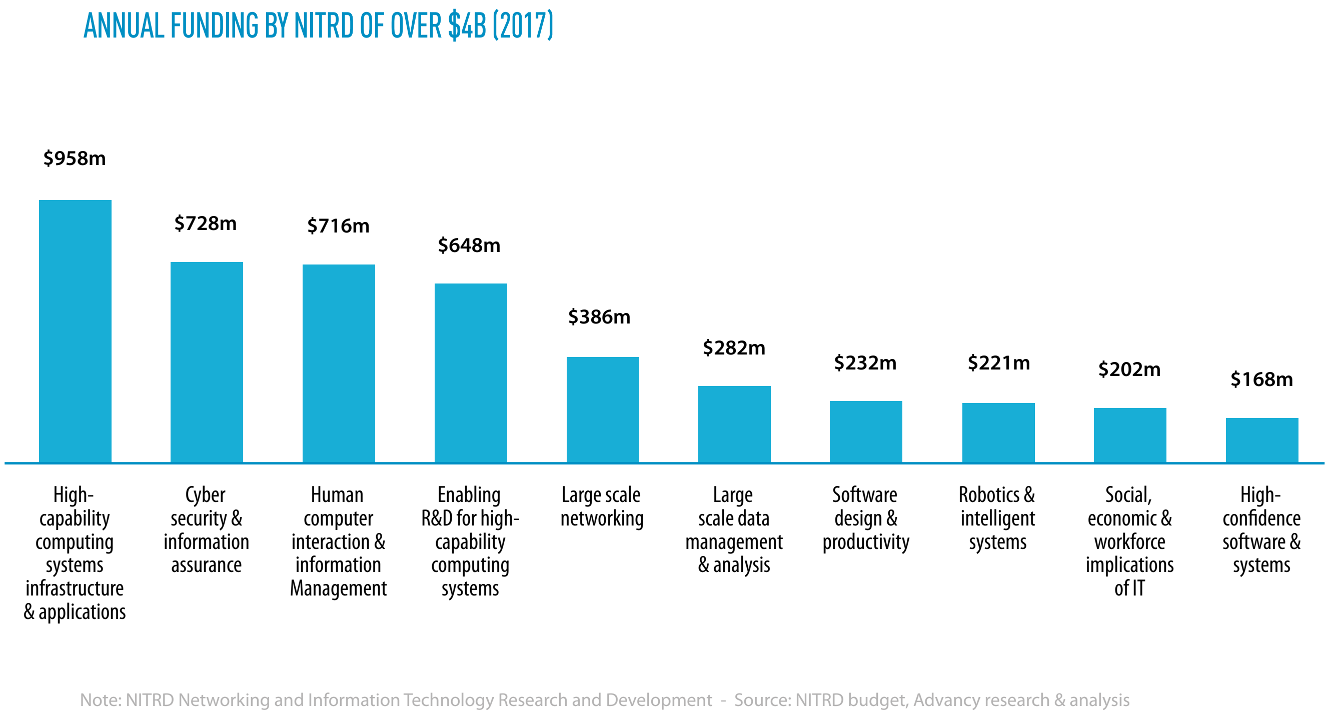



**Figure 15:** *US NITRD annual budget*

**Methodology & scope:** *the NITRD's budget is used in the benchmark in such a way that, regardless of any exclusions or additions, it includes approximately $0.9 b allocated to the Department of Defense. It must be noted that, outside of the NITRD, additional specific funding for ECS may exist within the DoD or other departments. These are not included in the benchmark presented, but would undoubtedly widen the gap with the EU.*

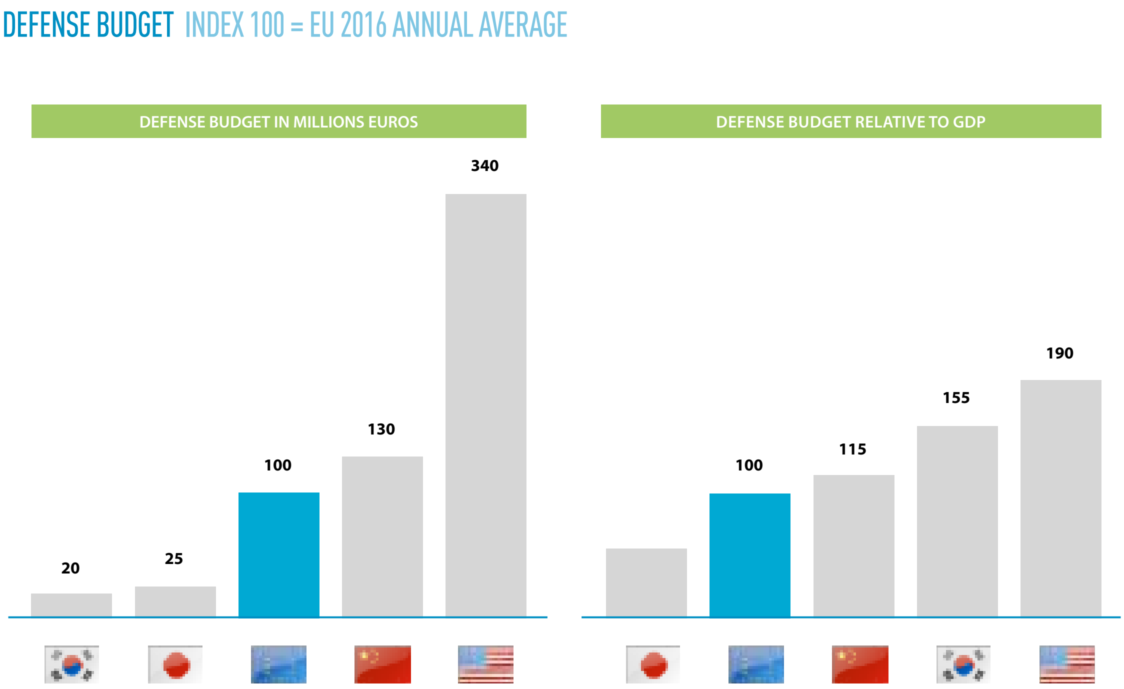
3. **Japan: the 5**th Science and Technology Plan, announced at the end of 2015, plans to build a **'super-smart society' (Society 5.0)**. To achieve this, the government is to spend €200 b between 2016 and 2020, focusing on cybersecurity, IoT system architecture technology, big data analytics, Artificial Intelligence, device technology, network innovation and edge computing. Funding is expected to go partly through Japan's funding agencies, particularly:
   - **JST** (Japan Science & Technology) - $1 b annual budget, responsible for implementing S&T policies
   - **NEDO** (New Energy and Industrial Technology Development) - **$1.3 b**
   - **AMED** (Agency for Medical Research and Development) - **$1.3 b**
   - **JSPS** (Japan Society for the Promotion of Science) - **$3.1 b annual budget** for fostering young researchers and awarding grants-in-aid for scientific research

**Methodology & scope:** due to the lack of clarity and disclosure on the scope of the spending R&D, the annual budgets of JST, NEDO and AMED have been used as the annual spend for the purposes of the benchmark. This is instead of the announced total amount, which may include costly items of a radically different nature (e.g. infrastructure upgrading).

4. **South Korea:** several initiatives have been launched to promote South Korea as a strong player in ECS, e.g. Manufacturing 3.0 in 2014 ($1 b), I-Korea 4.0 in 2017 ($2 b), support to semi-conductors ($2 b to potentially be announced) and an AI national program in 2018 ($2 b).

   **Methodology & scope:** all of the amounts announced have been included in the benchmark, considering that they were to be spent over 6 years (some programmes are based on 5 years, others over a longer period of time).

In addition to specific programmes to support ECS and ECS R&D, we can also consider the military budget, which includes R&D (e.g. 12% in the US, 8% in France) and can more or less directly result in non-military applications. The following analysis compares the defence budgets of top European countries (Europe, Germany, the United Kingdom and Italy) with other countries. **Here too, the results show that the EU is well below the US and China in absolute terms.**




Note: The EU figures consist of France, Italy, the UK and Germany. - Source: Advancy research & analysis

**Figure 16:** *International benchmark of defence budgets*

# 4.4

# RESEARCH AND INNOVATION ENVIRONMENT

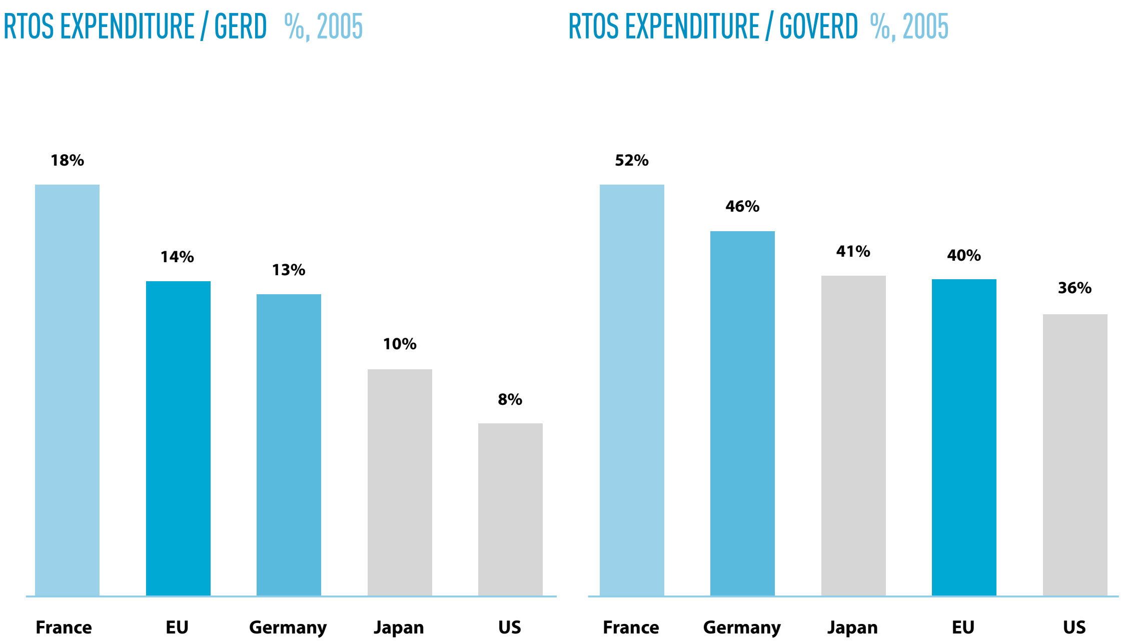
**RTOs (Research and Technology Organisations, e.g. Fraunhofer in Germany, TNO in the Netherlands, CEA in France or VTT in Finland), play a hybrid role between public/private and science/market innovations. This helps to bridge the gap between low TRLs (Technology Readiness Levels, TRL 1 to 4), which are generally the focus of universities, and higher TRLs (TRL 7 to 9), which are the focus of industrial players.** They are typically involved in three types of R&D&I activities:

1. Collaborating with universities on basic scientific knowledge, aiming to build expertise and technical capabilities in the long-term;
2. Working on competitive regional, national or European calls (such as ECSEL), usually on product development or the application of a new technology in a production process;
3. Providing services to the industry, directly working on market applications, i.e. existing products or processes.

**The funding of RTOs illustrates this triple focus well:** 29% comes from core government funding, 30% from competitive public and private income and 41% from contractual income from industry, according to a study by the EARTO.

As previously explained, the TRL of the key technologies required to succeed in this new industrial revolution are very heterogeneous: some are expected to be deployed in less than 2 years, while some might not reach the market within 10 years**. This heterogeneity makes organisations like RTOs all the more important, as they can play a pivotal role in passing on technology research from its early stages down to its late stages.**

**Historically, the European Union has strongly relied on the RTO model for public R&D,** with RTO expenditures accounting for an average of 40% of government R&D expenditure, going up to 46% for Germany and 51% for France. In contrast, the **USA relies less on such organisations and funnels significant funds to public R&D via its defence budget (over $80 b annually). Japan spends a similar proportion of government R&D on RTO but also relies strongly on its industry, as does South Korea (e.g. Samsung, LG).**




Source: World Bank, Advancy Analysis

**Figure 17:** *RTOs expenditures as a % of GERD (Gross Domestic Expenditure on R&D) and GOVERD (Government Expenditure on R&D)*

Clearly, there are different country models that rely to a lesser or greater degree on RTOs, on other public spending or on private players. **Although the RTOs are a key link between low and high TRLs, the EU must not focus itself solely on RTOs and neglect more mature technologies and applications, as these reach the market quicker and their development is driven mostly by industry.**

## CHAPTER 5

# MAIN CONCLUSIONS

The EU needs to ramp up R&D&I investments on hardware and software technologies for Embedded & Cyber-Physical Systems:

- **Embedded & Cyber-Physical Systems are at the centre of Europe's future competitiveness and will have long-lasting, positive societal and economic impacts.**
- **Europe needs to gear up investments** in this strategic area to consolidate its competitive advantage (e.g. in Transportation) or to catch-up with China, the US, South Korea and Japan.
- **The investments in software technologies should be on at least an equal footing with hardware technologies, considering the expected growth at the higher level of the value chain (Systems of Systems, applications and solutions).**
- **The ARTEMIS-IA community has a key role to play** as a tool for European R&D&I environments to capture the upcoming opportunities in a structured way.

These main conclusions are in line with the European Commission's vision for Horizon Europe, which will require:

- acceleration on strategic Embedded & Cyber-Physical Systems and their Electronics and process enablers, helping to remain in the race against strong competitors (the US, China) that are heavily investing to pre-empt these future economic and societal value spaces;
- more synergies/less siloes between Industry Associations;
- less overlaps in the themes covered;
- benefits for European society, research and businesses;
- a synergetic link between research and regulation by delivering actionable and distinctive standards that put Europe ahead on these topics.

# GLOSSARY

| | |
|---|---|
| **AI:** | Artificial Intelligence |
| **AIMD:** | Active Implantable Medical Device |
| **DNN:** | Deep Neural Network |
| **DLT:** | Distributed Ledger Technology |
| **E&CPS:** | Embedded Software & Cyber-Physical System |
| **ECS:** | Electronic Components & Systems |
| **EHR:** | Electronic Health Record |
| **EHPC:** | Embedded High-Performance Computing |
| **FD-SOI:** | Fully Depleted Silicon On Insulator |
| **GERD/GOVERD:** | Gross Domestic Expenditure on R&D/Government Expenditure on R&D |
| **GPT:** | General-Purpose Technology platform |
| **ICT:** | Information and Communications Technologies |
| **ITS:** | Intelligent Transport System |
| **IoT:** | Internet of Things |
| **LiDAR:** | Light Detection and Ranging |
| **MaaS:** | Mobility as a Service |
| **MEMS:** | Microelectromechanical System |
| **MISP:** | Multi-IoT Service Platform |
| **MNC:** | Multinational Company |
| **NB IoT:** | Narrow-Band Internet of Things |
| **NLU/NLP:** | Natural Language Understanding/Natural Language Processing |
| **R&D&I:** | Research, Development and Innovation |
| **RTO:** | Research and Technology Organisation |
| **SiC:** | Silicon Carbide |
| **SiP:** | Systems-in-Package |
| **SoC:** | System-on-Chip |
| **SME:** | Small and Medium-sized Enterprise |
| **TRL:** | Technology Readiness Level |
| **V2X:** | Vehicle-to-everything |
| **WBG:** | Wideband Gap |

ARTEMIS
Industry Association