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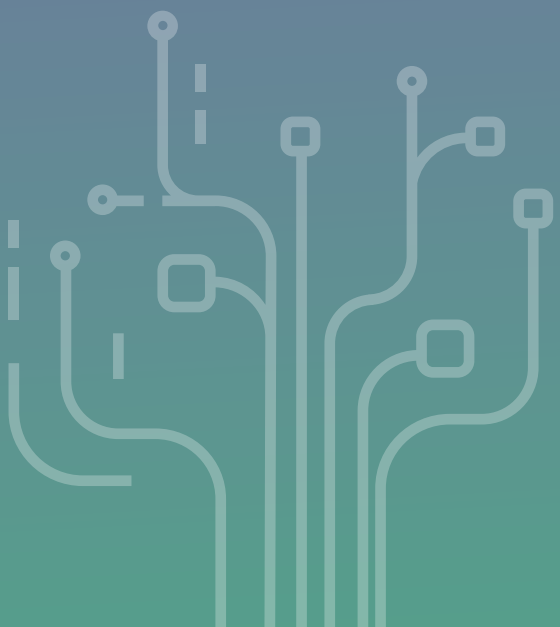
Study on the impact of ECSEL funded actions

Final Report

July 2020



This study is carried out for the **ECSEL Joint Undertaking** by:

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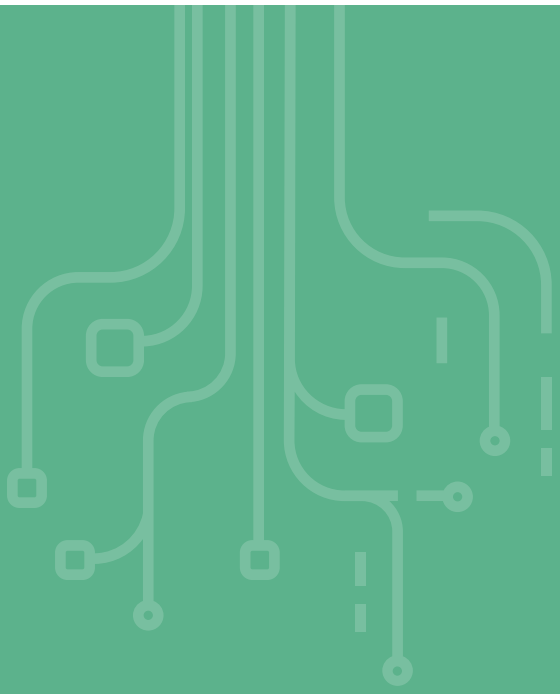

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Foreword

One of the key technological competencies of our times are the ECS-Electronic Components and Systems. ECS enable the digital transformation, allow us to generate opportunities and provide intelligent answers for the huge global societal challenges such as the climate crisis, more ecological mobility, as well as sustainable growth. This is a particular opportunity for Europe in a highly competitive global context. For exactly these reasons, a Joint Undertaking was set up to address ECSEL-the European Components and Systems for European Leadership.

In order to provide the necessary critical mass in Europe in a challenging global setting, the ECSEL Joint Undertaking was set up in 2014 as a public-private partnership between the European Union, Member States and Associated Countries to the Framework Programme Horizon 2020 and three industry associations. With its co-funding scheme, ECSEL aims at promoting collaborative research in electronic components and systems, supporting research teams and European industries to innovate at the leading edge in a highly competitive international context.

ECSEL manages a total budget of 5 B€ for the development of a strong and globally competitive ecosystem in the European Union. Since the programme's inception, 67 projects have been selected for funding. They cover a wide range of technologies and application areas where electronic components and systems deliver an essential value.

While entering in its last year of calls for proposals, and as the political debate on European research and innovation after 2020 is entering its core phase, an assessment of the impact of ECSEL funded actions appears relevant and necessary.

Following a decision by its Governing Board, ECSEL has commissioned a study to assess the impact of its funded actions. An independent consortium was selected after an open public procurement procedure. The present report is the outcome of this independent study by Deloitte and VVA, Valdani Vicari & Associati.

The report that you are about to read provides a synthetic view of the findings of the study. They reflect on a wide range of stakeholder interviews, desk research and participant network analysis. You will notably discover how the impacts of the ECSEL Joint Undertaking are very relevant for Europe, while it has been supporting excellent research and innovation contributing and enabling digitalization of the European industry and society, as well as providing solutions to tackle challenges in the areas of energy, mobility and healthcare.

I wish you a good reading!

June 2020
Dr. Sabine Herlitschka, *Chairperson of the ECSEL Governing Board*

Abstract

Electronic Components and Systems (ECS) are the core of the digital technologies and connected devices that are radically transforming our lives. As such, a thriving ECS industry represents a critical asset for global competitiveness and maintaining the innovativeness of key ECS players is a priority for all advanced economies, including for the European Union. With the ECS value chain experiencing profound changes, both in the geographies of production and in ways in which value is generated, the European Union, together with three industry associations and a large number of Member States and Associated Countries, has established the ECSEL Joint Undertaking with the objective of supporting European players in their research and innovation activities and helping them adapt to a fast changing environment.

This study looks at the impacts that the ECSEL programme and funded actions had on the innovativeness and competitiveness of the European ECS ecosystem and, more widely, on the European society as a whole. By looking these impacts, this analysis shows that the ECSEL programme has benefitted the European Union (EU) in two important ways. First, it has strengthened the overall R&I performance of the European ECS ecosystem which constitutes EU's main competitive advantage in this sector. By *providing a framework for collaboration in research and innovation activities*, it has helped establishing and reinforcing links between pivotal players and also integrating new stakeholders, including from other industrial sectors. This cross-sectorial dimension of the programme makes it particularly relevant for contributing to the digitalisation of industry and society in Europe and the advent of an Industry 4.0. Furthermore, by *strengthening and enriching* the ecosystem, the ECSEL programme has provided the roots for increasing innovativeness and competitiveness of the ECS industry and has created a wealth of opportunities for all stakeholders, including Small and Medium Enterprises (SMEs). Second, by *supporting the establishment of communities of interest around key application areas* (mobility and transport, health, energy and environment), the programme has helped the European Union in addressing key societal challenges such as reduction of CO2 emission or transformations linked to the ageing population.

The ECSEL programme thus helps tackling both European economic and societal objectives at the same time. Its key characteristics and notably the tripartite model, the type and size of projects funded and the multidisciplinary and cross-sectorial approach fostered constitute the main drivers of these positive impacts.

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Context: the role of ECSEL in a fast-changing Electronic Components and Systems market

1.1. Objective and structure of the study

The overall objective of this Study on the impact of ECSEL funded actions is to assess *"the impact of ECSEL Joint Undertaking since its creation in 2014, taking into account the legacy of ENIAC and ARTEMIS Joint Undertakings from the previous Framework Programme (FP7)"*. By evaluating the influence, effects and consequences of ECSEL funded actions, this study aims to provide *"evidence of what ECSEL has contributed to, what it has allowed to emerge or develop, what industrial take-up it has initiated, what impact it has had regarding national priorities and funding, how SMEs have benefited from the funding. It is also about identifying and measuring the leverage, the return on investment of funded projects within the ECS community and society at large."*[1] To address these objectives, the following analysis elaborates on the **major impacts** of ECSEL funded actions on the European Electronic Components and Systems (ECS) industry and value chain in Europe, and on their contribution to addressing European societal challenges at large.

In order to quantify and qualify these impacts of ECSEL funded actions as well as to substantiate the existence of drivers for them to materialise, the study relies on a very wide range of data collection activities and data sources, which are summarised in the Table below.

Table 1 - Data collection activities of the study

Online survey:	476 ***respondents*** *out of around **2100** project participants (**23%**, i.e. very significant and statistically representative sample)*
Interviews:	70 ***Interviews*** *with European, national and industry stakeholders, out of which **18** with project coordinators and project participants (covering ~**25%** of projects)*
*Case studies interviews with **26** participants from **8 ECSEL** projects:*	***Productive 4.0, Senate, WayToGo Fast, Reaction, InForMed, SCOTT, 3C Car, ENABLE S3***

In addition to data collection activities, the study team also carried out a project analysis covering all ECSEL funded actions, an analysis of the key features of the ECS market and a network analysis linking all projects participants to each other. By triangulating and

analysing the results obtained through these activities, this study found that **ECSEL funded actions have led to significant achievements both at the economic and societal level.** The present report includes the findings of the study and is structured as follows:

- Section 1 provides an introduction to the ECS market in Europe as well as to the ECSEL Joint Undertaking and its role in this context. It also briefly presents the theory of change approach adopted for the assignment and the list of identified impacts and related drivers and barriers.
- Section 2 describes how the ECSEL programme has helped establishing a strong ecosystem of ECS players which, in turn, helps sustaining the innovativeness and competitiveness of the European Union.
- Section 3 details the contribution of ECSEL funded actions for addressing societal challenges in the area of health, mobility and transport as well as energy and environment.
- Section 4 provides some conclusions and highlights the main findings of the study in terms of impacts of ECSEL.
- References are included in the Annexes.

1.2. The ECS market in Europe: from the origins until today

Electronic components and systems (ECS) are critical to enable the functioning of all electronic products and services. They are omnipresent as they "make things smart, turning technology into real, competitive added value."[2] The ECS industry can therefore not be defined by one specific product, technology or application: electronic components, the hardware, and software running on them make together an electronic system, which in turn is a standalone functional device. A system can also become a component of a larger system.[3] ECS make up parts of electronic devices that typically contain circuitry made primarily from semiconductor material. The ECS value chain covers *"equipment, materials, production technologies, packaging and assembly technologies, embedded software, architecture and design tools, modelling and models, libraries and complete functional blocks over the different levels of abstraction up to the level of Smart System Integration and to complex Cyber-Physical Systems or even Cyber-Physical Systems of Systems such as aircraft, cars, complex lithography systems and ECS manufacturing clusters."* Globally, the main markets for electronic components are automotive electronics, industrial electronics, data processing, consumer electronics, and communications. In terms of applications, i.e. system industry, the market can be divided into different segments, namely: environment and energy, mobility (automotive), aviation and aerospace, medical and healthcare, safety, defence, consumer, ICT, semiconductor industry and others.[4]

Europe has a long history of producing ECS. The European semiconductor industry dates from 1948, with the first germanium point-contact transistor. This solid-state component and soon circuits fuelled innovation, which opened up a broad variety of applications, stimulating the rapid expansion of the system houses. The combination of disruptive technologies such as transistors, integrated circuits (IC) and large-scale integration microprocessors (LSI) with incremental innovations, imprinted a characteristic dynamism in the electronics industry worldwide. Firms had to cope with ever-evolving technologies, rapid changes in products and processes, which in turn affected their competitive advantages, as well as lead and lag times[5]. Nevertheless, the European industry did not develop early a separate semiconductor industry, which stayed long as internal activities within system houses.[6] If the European ECS industry was deemed successful in earlier history, soon enough its slower technological advance caused Japan and the US to surpass it. By 1982, the semiconductor industry in the US was worth USD 7,525 million, in Japan USD 3,832 million and in Western Europe USD 2,436 million.[7] This decline could be attributed to several factors.[8] If Japan benefited from a focus on consumer electronics to gain an edge on the US, the European players continued to mainly serve the business areas of their parent system houses, more focused on industrial and automotive application sectors and having less growth potential for semiconductors. The maturity of the European integration was also not sufficient to provide the open market conditions for national champions to penetrate European-wide markets.

The European semiconductor industry experienced a further inflexion point at the beginning of 2000s. By then the European semiconductor business had moved to independent spin-offs from their former parent system houses, but with some lag compared to their US counterparts. The European electronics industry also stayed mostly focused on internal full control from design to manufacturing, limiting the emergence of the fabless industry, currently accounting for about 30% of the total of the worldwide revenues in semiconductors.[9] As in previous periods, the costs of R&D in conjunction with the increasing costs of building, owning and maintaining a manufacturing plant, and the escalating risks related to the fluctuating industry cycles, caused an important downturn in the industry, at the time of the burst of the Internet bubble.

In this context, Europe focused on the design of leading-edge technology, outsourcing the manufacture to Asian countries (fabless model), which offered important incentives such as land, lower taxes, cheaper labour, etc. In the next years, the underestimation of the importance of production for the economy, in particular at political level in various European countries, heavily deteriorated Europe's manufacturing base, with no large fabs being built in the last two decades. At the same time, the emergence of several powerhouses in the Asia Pacific region, tightened the competition.

In the meantime however, the European system companies have continued to strongly develop various industrial sectors. Their supply chains are not restricted to European semiconductor suppliers but rely on a much wider range of companies across the globe. They have maintained and grown a solid share of the worldwide market in their respective sectors. Nonetheless, the growing rivalry from other global powers translated into a risk that other major parts of the ECS value chain would migrate outside of Europe due to a smaller semiconductor incumbent base compared to most industrialised regions of the world, which would not only result in major losses in global market share but could also pose a threat to some of European fundamental values, such as data security and privacy, that may not be equally respected in the new scenario.[10] The situation prompted the EU to promote further public support, financing several initiatives and implementing a number of strategies aimed at strengthening the industry. The ARTEMIS and ENIAC Joint Undertakings (JUs) were immediate consequence of these efforts and the basis to the future establishment of the ECSEL JU. Some European countries jointly took action at the intergovernmental level by means of a sequence of Eureka initiatives[11] in the ECS areas. Also supported by the EU through the ECSEL JU, most Member States and several Associated Countries have shown their willingness to align their national strategies.

Today, the European semiconductor industry supports around 250,000 jobs directly. More than 800,000 people work on the integration of components into systems, applications and services across Europe, and more than 2.5 million are employed in the complete components value chain.[12] "By 2020, ECS will enable around 50% of European GDP due to its involvement in many sectors".[13] The current situation presents a wide range of investment possibilities for Europe to become an ECS world class powerhouse. The pace of technological breakthroughs and the new businesses paradigms pave the way not only for reinforcing EU's leadership in various fields, but also for developing new areas, building on Europe's strengths. According to AENEAS, ARTEMIS-IA and EPoSS[14] some key differentiators for the success of European systems are:

- *application-specific semiconductor technologies* ('More-than-Moore technologies') like RF, MEMS, and Power semiconductors, as well as the very low power CMOS technologies like Fully Depleted Silicon On Insulator (FDSOI) where European companies are world market leaders;
- the traditional European strength in *Cyber Physical Systems and the on-going revolution of the Ubiquitous Computing* that present an opportunity to position European actors as world-class leaders;
- *design of highly complex, efficient and reliable software solutions* operating from micro-controllers up to complex products such as aircraft, satellites, cars and trains, to cite a few;
- *highly miniaturised and tailored packaging and assembly technologies* to integrate the heterogeneous components of the ECS into a low-space, energy-efficient package;
- *a world-class equipment industry* which serves not only the local semiconductor industry but also manufacturers of high-volume standard products like microprocessors and/or memories that are produced mainly outside Europe but whose performance and reliability form the platforms of successful software implementations within any ECS.

Europe also houses competitive industry sectors in aeronautics and space, automotive, health and energy, which all critically rely on ECS. In addition to Europe having a distinctive competitive advantage, these sectors are forecasted to experience an expansive growth during the next years, as further detailed below.

1.3 The ECS sector's challenges in Europe and the role of the ECSEL Joint Undertaking

Despite the strengths described in the previous section and especially in terms of sectorial applications, to become an ECS world class powerhouse Europe faces some considerable challenges. European ECS industry performance has been improving since policy intervention was decided at the EU and national levels, resulting in a stronger interaction along the value chains between semiconductor suppliers and

system companies. However, European ECS players are still confronted with several issues mainly relating to *a) the continuous geographical value shift* from Western to Asian countries and *b) the rapid changes in the distribution of value along the value chain,* linked to the broader digitalization of industry and society.[15] Rapid digitalisation is transforming the ECS value chain and increasing the possible application and importance of ECS technologies. While historically the value in the ECS domain was mainly on traditional hardware, the world is currently experiencing a major shift from "products" to solutions and applications. The value of the hardware market is expected to double in 2025 compared to 2016 market figures. The systems of systems/applications market is expected to grow tenfold over the same period.[16] A key consequence of this shift is the increased relevance of the application domains for the wider success of the ECS industry in Europe. Effective R&I is a key differentiator for European industry and a fundamental condition for achieving European economic and societal objectives. The ECSEL Joint Undertaking (JU) was established as a way to address some of these challenges and to strengthen the European ECS ecosystem in its R&I efforts.

Transport and smart mobility

Europe is a frontrunner in the manufacturing of equipment and systems for the automotive sector. The industry is therefore in an advantageous position to steer technologies such as AI for autonomous driving, improvement of security and development of clean and sustainable cars. Rail and aerospace are also strategic fields to further develop. Transportation is of high socioeconomic relevance for Europe and maintaining the leadership will be critical for its prosperity.

Smart healthcare

An aging population coupled with rising labour costs and lifestyle changes is shifting the focus of healthcare from treatment to prevention. The cost pressure on the healthcare systems is also promoting the decentralisation of the services. As therapy moves from hospitals to home, the same or higher level of care is expected, while innovations help to optimise resources. The European ecosystem is heading the medical equipment fields, which has the potential to address these challenges delivering new applications and technologies.

Smart energy

The emergency of climate change and the increasing environmental awareness among citizens are prompting a shift towards sustainability. Consequently, the market for more energy efficiency solutions and technologies will expand, relying on ECS for an efficient, reliable, secure and intelligent use of energy along the whole energy value chain, from generation and storage to distribution and consumption. Renewable energy distribution and energy efficient manufacturing are also fields where Europe is a reference provider of sustainable technology.

Smart industry

The industrial control and factory automation market, and the additive manufacturing are projected to open a widerange of opportunities. The digitalisation of industry aims to optimise productivity, quality and flexibility, while the automation of repetitive tasks in the workflows will allow workers to focus on better suited jobs to human talents and capacities. This will require to enforce security as well as smart systems capable of analysing and processing information. Wireless sensors, connectivity, edge and cloud-based computing and integration solutions will be some of the technologies to integrate in the value chain. Sensors in particular will know an exponential growth over the next few years, with a 9.3% CAGR in between 2019 and 2025.[17] Europe is a front runner in manufacturing excellence. Its world-class enterprises focus on high-quality and personalised products and services, which could be provided at lower costs, while maintaining the quality design and functionality.

Smart society/life

Digital devices have already spread beyond what could have been imagined only a decade ago and they are now ubiquitous in our society. "The advent of new technologies like IoT (Internet of Things), 5G, AI (Artificial Intelligence) with DL (Deep Learning), VR (Virtual Reality) and AR (Augmented Reality), BCI, Robotics and the like will shape new ways of how people interact with the world and with each other".[18]
ECS play a pivotal role in ensuring that these technologies are available and safe for everybody to use,and that more intelligent, secure, privacy and user centred solutions can be developed to meet the increasing demands from citizens.

1.3.1 The ECSEL Joint Undertaking: objectives and role

The ECSEL JU is a key initiative of the European Commission under Horizon 2020[19] and constitutes the result of the merging of two previous JUs – ARTEMIS and ENIAC - established under the 7th Framework Programme (FP7). It has a number of objectives[20], identified based on the analysis of the abovementioned trends and challenges. Some of those were already the focus of the ARTEMIS and ENIAC JUs but required more long-term responses. The ECSEL JU is governed through a **tripartite model** *(see table 2)*, which in essence is a public-private partnership. Effective collaboration between the ECS industry representatives is a prerequisite for the programme to implement activities effectively, and as such, create the conditions for achieving the impacts expected at the start of the programme.

Table 2 - The ECSEL Tripartite members

Three associations (AENEAS, ARTEMIS Industry Association and EPoSS) representing the actors from the areas of micro-and nano-electronics, embedded/cyber-physical systems, and smart integrated systems, respectively;
The European Union (through the Commission's Directorate-General for Communications Networks, Content and Technology);
Member States and Associated Countries to the Framework Programme Horizon 2020 on a voluntary basis. The ECSEL Participating States are (both EU Member States and Countries Associated to H2020): Austria, Belgium, Bulgaria, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Israel, Italy, Lithuania, Latvia, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia, Turkey, United Kingdom and Switzerland.

In practice this means that the partners in the tripartite model need to compromise, and public authorities have to come up with solutions for co-funding projects. According to the way in which the programme management is set up, it is not possible for each country to solely support its national industry champions without collaboration and compromise that centres on agreeing on the highest ranked projects to co-fund.

A unique characteristic of ECSEL is also the **type of actions which are financially supported by the Joint Undertaking.** In line with Horizon 2020 and according to a "division of work" between the overall EU R&I framework programme and the work of the different Joint Undertakings established under its umbrella, ECSEL focuses particularly on large (more than 10 million euro) and close to market projects with higher Technology Readiness Levels (TRLs)[21]. TRL can be defined as the scale measuring the readiness of a given technology[22] and ECSEL focuses in particular on those technologies which are closer to full development and deployment. However, ECSEL can and "will address industrially relevant projects of any size at TRL 2-8 by engaging the whole ecosystem, including large, medium and small enterprises, and knowledge institutes, from countries and regions both more and less developed".[23] For large-scale projects, which require considerable investments, ECSEL projects can take a multi-funding approach, and combine ECSEL funds with other sources (e.g. the European Structural and Investment Funds, ESIF).[24] In this context, ECSEL supports three different types of actions and notably:

- **Innovation Action (IA):** these actions sustain capital intensive research and development investments and projects, pilot lines, demonstrators and applications and are aiming at bridging the gap to market (TRL 5-8).
- **Research and innovation Actions (RIA)**: these actions support initiatives which are aimed at generating new industrial knowledge or explore the feasibility of new methods, processes, products and solutions and are therefore farther from market implementation (TRL 3-4).

- **Lighthouse initiatives:** these initiatives are an entirely new concept developed by ECSEL "to signpost specific subjects of common European interest".[25] The idea is to use these initiatives as "umbrella" for facilitating cooperation and coordination between ECSEL projects and projects funded by other programmes (Eureka, National, etc.) working in the same domain and responding to a specific societal need. The ideas for establishing a lighthouse initiative can come from "bottom-up" meaning from consortia submitting proposals to ECSEL or from "top-down" meaning from the ECSEL Governance Board.

The ECSEL JU has funded *67 projects since its first call in 2014*. More than 2100 participants were involved in the calls for a total of 3.4 billion euro invested (1.6 billion from EU and national funding and 1.8 billion from in-kind contributions from industry and other project participants).

ECSEL in figures (2014-2018)[26]

Funded projects since 2014:	*67*
Participations:	*2100*
Individual research organisations and private companies:	*Above 1000*
European and national funding:	*1.6 B€*
R&I investment	*3.4 B€*
Lighthouse initiatives	*3*

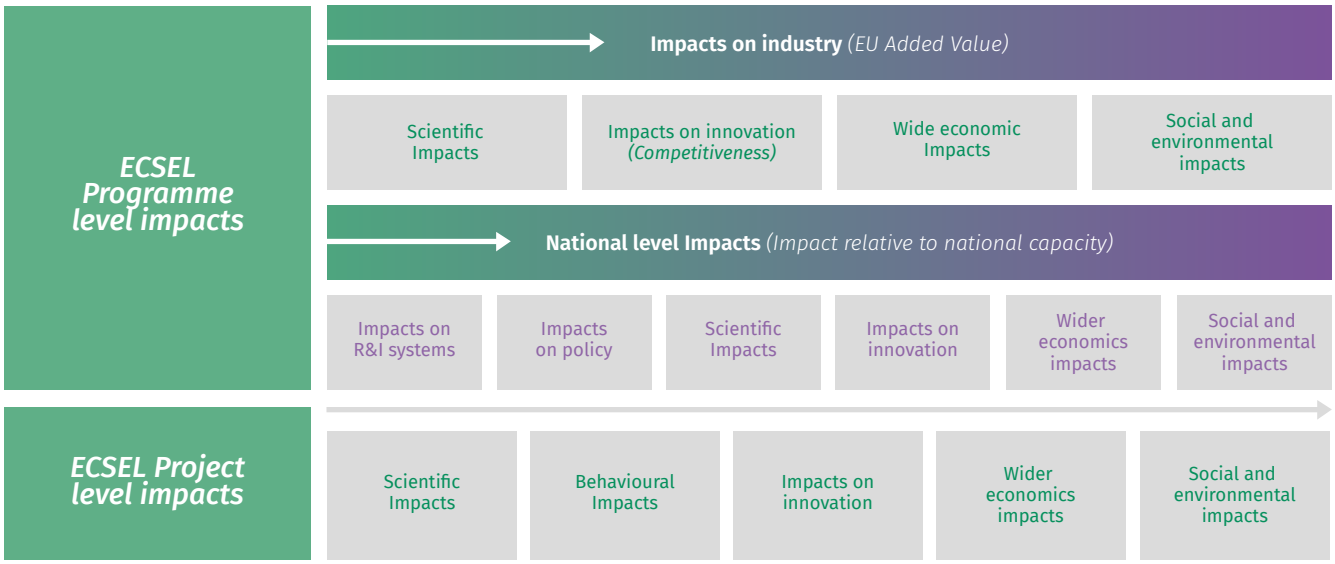
Most of the largest European companies, universities and Research and Technology Organisations (RTOs) active in ECS have been involved in one or more ECSEL projects. STMicroelectronics, Infineon and AVL GmbH for instance have participated in 23, 21 and 17 projects across different fields, respectively. All of them have involved various divisions and subsidiaries of their companies. For instance, five branches of STMicroelectronics participated in WAKeMeUp[27] and up to six subsidiaries of Infineon collaborated in iDev40[28]. Their participation in ECSEL has been consistent over the years, which can be interpreted as a sign of the benefits of the JU. This is especially relevant if considered that these companies have annual revenues over EUR 1 bn and spend large amounts in R&D, funding their own innovation centres and research personnel. RTOs such as Fraunhofer, TNO and VTT have also extensively leveraged the programme for their R&I activities (36, 17 and 20 projects respectively). Amongst the 2100 participations, universities are also well represented and constitute around 20% of the total. SMEs (Small and Medium Enterprises) also have a relatively prominent position. In 2014, 2015 and 2016 SME participation reached 30%, 28% and 24% respectively.[29]

1.3.2. ECSEL's expected impacts

As a research and innovation programme aimed at "contributing to the development of a strong and globally competitive electronics components and systems industry in the European Union"[30], ECSEL ought to be designed in a way that effectively makes the most of the opportunities of the ECS sectors in Europe (e.g. the EU competitive advantage in the automotive sector) and which also best tackles the challenges which exist (e.g. the high levels of global competition). In addition to providing a long-term societal return on investment of public budgets (EU and national), the programme design should create *impact for all public and private organisations* with an active interest in ECSEL. This study has explored to what extent the design, organisation, and activities of ECSEL are conducive to producing the kinds of **impacts** it aims to create – to what extent the programme has inherent organisational and behavioural **'drivers'** to support the creation of desired impacts, and conversely, to what extent there may be **'barriers'** to impact creation within the programme and its activities. This section focuses on the description of the identified impacts while the next section further describes the drivers and barriers to impact which could be found.

The figure below, based on the elements included in the ECSEL Council Regulation, distinguishes between *three 'levels' of impact* as well as different kinds of impact attributable to ECSEL directly or indirectly. This overarching framework of impacts served as a guidance for the data collection activities.

Figure 1 - Three levels impact framework



Source: study team elaboration based on feedback from the ECSEL JU Steering Group, an ad hoc group created to support the study team

The three levels have the following characteristics:

- **Impacts on industry.** Many if not all the long-term impacts that the programme aims to achieve are types of impacts which can be expected to benefit industry since they mainly concern **innovation and wider economic effects.** However, there is also an important societal dimension since the innovations developed (at least partly) as a result of the programme are expected to **benefit the wider society through e.g. new health technologies, development of clean and smart mobility solutions, etc.**
- **National level impacts.** National level impacts are created through project participation of i.e. RTOs, private companies and universities, which then apply **knowledge and skills** derived from the ECSEL projects back into their national ecosystems. There is also another national level type of impact, namely a perceived **increased efficiency and effectiveness on R&I policymaking** linked to the concept of 'pooling of resources', i.e. focusing human and financial efforts on key areas and sectors, and thereby avoiding fragmented R&I support which risks lowering impact. The study findings point to a number of EPS that have strengthened their R&I abilities as a result of the programme.
- **Project level impacts.** These are the types of impacts that can be directly traced to project level activities and to project outputs (e.g. IPR, new technologies, processes and applications, ultimately leading to new products or services in the marketplace). The online survey of ECSEL participants and the case studies provide evidence on how, and to what extent, impacts are created as a

direct or indirect result of project participation.

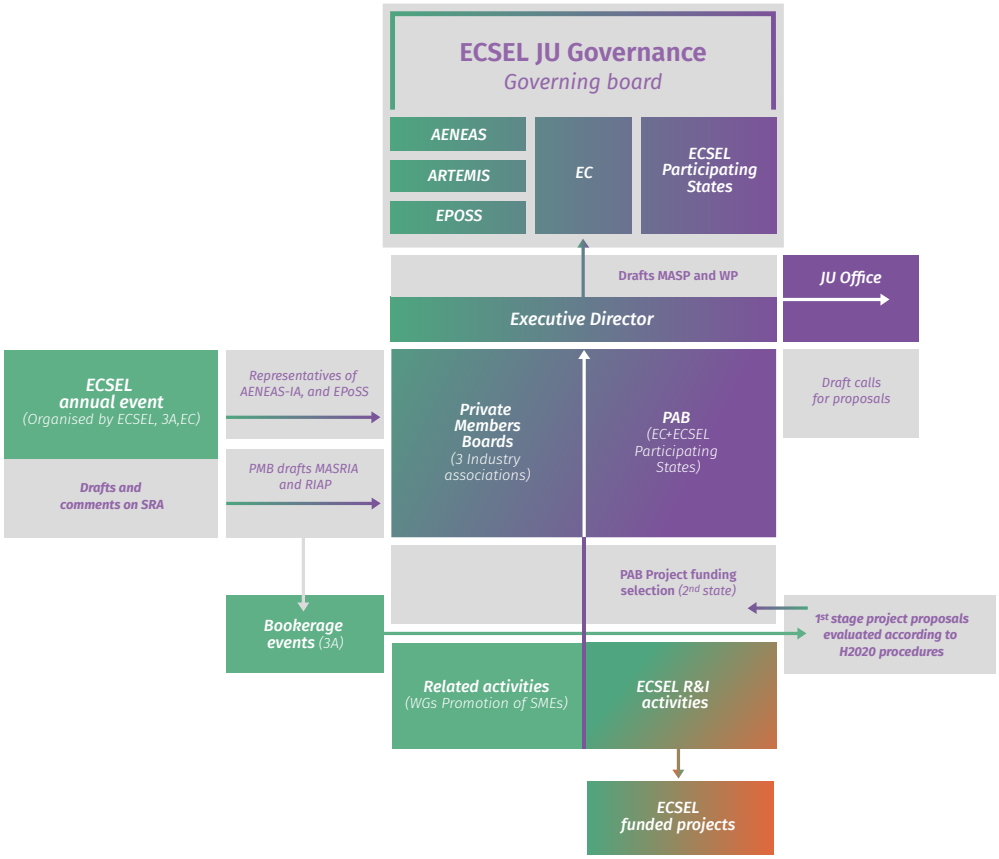
As ECSEL is in effect a merger and continuation of the two preceding ENIAC and ARTEMIS Joint Undertakings, which ran from 2008 to 2013, impacts observable under ECSEL may have originated from one of its predecessors. For example, both the ARTEMIS-JU and ENIAC-JU spent real and sustainable efforts building a European community in their respective fields, hence it should be recognised that ECSEL impacts should be partly attributed to the foundations laid by its predecessors. The current Multi Annual Strategic Plan (MASP) also partly stems from scientific knowledge acquired during the years 2008-2013. Other impacts observed may be attributed solely to ECSEL where new activities were established under this programme.

1.3.3. Drivers and barriers to creating impacts

Drivers and barriers for impacts for the ECSEL funded actions must be sought in the way the programme functions, the types of action it supports and the types of cooperation instruments it has established to implement its underpinning tripartite model. From a theory of change perspective, it is also important to understand "interlinkages" which are relations between key features of an intervention showing where impacts are expected to happen.[31]

The functioning and governance model of the current ECSEL programme as well as its main interlinkages can be visually depicted as follows:

Figure 2 - ECSEL modus operandi



Source: study team based on programme documentation and Steering Group guidance

This particular configuration contains processes, practices and behaviour which may ultimately have a positive or negative effect on the creation of programme and project level impacts.

The programme level management is characterised by the tripartite model under the ECSEL JU Governing board. The roles of the industry associations, the ECSEL Participating States and the European Commission are outlined in the figure above. At the programme level, the members of the Governing Board need to collaborate, both within the respective PAB and PMB boards but also

between the boards. The ECSEL Governing Board steers the strategic orientation and supervises the implementation of decisions and activities. This study suggests that the ECSEL *programme management is overall effective* in bringing together the parties and in facilitating their collaboration and can be considered as a *driver for impact*. There is also an overall consensus that the programme has built on the work of its predecessors in fostering a mutual understanding and creating ways of working together in what is a commercially sensitive set of markets. That is, ECSEL Participating States are able to co-fund very large multinational projects at fairly high Technology Readiness Levels which are also commercially sensitive. A **considerable degree of trust** has therefore been established. There are other implications of the JU model.

The tripartite governance mode makes the JUs somewhat different from other EU funding instruments that are managed by public bodies (e.g. the Commission or Executive Agencies), which gives them more of an ability to take risks and innovate (although the ECSEL JU is still bound by operational rules such as reporting and financial rules, in particular the Financial Regulation of the EU). The risk-taking ability has been highlighted as an advantage since 'riskier' investments in ambitious projects appear to have paid off in successful project implementation. Thirdly, the Multi Annual Strategic Research and Innovation Agenda (MASRIA) and Multi-Annual Strategic Plan (MASP) are considered important documents for consolidating funding priorities and focusing them on areas in which (broadly) Europe has an existing or potential competitive advantage. This common focus is important since the ECS sectors are 'blurred' and there are ongoing discussions on what the programme scope might be in the future. Although the MASP provides a sort of top-down direction, ECSEL could be described as a bottom-up programme insofar as the relatively open calls for proposals aim to capture new ideas from the R&I community itself (allowing the market to innovate). The MASRIA, being the main input for the is developed at the programme level by the three stakeholder associations and the wider ECS community.

The project level activities are dominated by the projects funded by ECSEL but other activities like working group activities, and matchmaking events organised by the Associations fall under this label. The matchmaking/brokerage events form an important activity in the extensive consortium building required by project participants. ECSEL projects are large (although a large project team is not a requirement, most current ECSEL funded projects are made up of consortia with 30 or more member organisations) and allow for combined funding from national and regional authorities, and from the EU via Horizon 2020.[32] Specifically, at the project level, a great number of public and private actors from multiple countries are collaborating on R&I activities. This in practice entails collaboration in R&I across the value chain and involving firms and organisations who may be competitors on the ECS market. This is considered a key driver by the wider ECS community. In this sense, partnerships need a high level of trust and integrity to work effectively. Participants must see the mutual benefits of the cooperation. These may not be immediate but rather include long-term and high-level impacts such as a strengthened European ECS market (in parts of the value chain) compared to that of competitors like the US or China. These collaborative characteristics are very important drivers of the programme since both EPS representatives as well as industry and research performers may be reluctant to work together. However, they are also easily overlooked – or not measured – since it is difficult for evaluators to quantify behavioural changes. Previous studies[33] of ECSEL have indicated that industry does not necessarily participate in ECSEL for the funding available but rather to build on their networks (which can also be used outside of ECSEL). This is also a conclusion of this study. **ECSEL thus provides an opportunity for creating contacts and to develop best practices for working across value chain. However, from many project participants' perspective, some shortcomings in the co-funding mechanism can be a potential barrier for participation.** Specifically, the different administrative and monitoring requirements set by the ECSEL Participating States, which risk delays in funding pay-outs, were raised as a concern by project participants, many of which had experienced delays in implementation as a result of a lack of streamlining by the national funding bodies involved.

The national R&I system of each EPS, e.g. the level of sophistication and specialisation of the national ECS R&I sector in each EPS also affects participation. For example, the role, size and focus of national actors such as RTOs – and the level of involvement in international activities such as ECSEL – may be a significant factor towards creating impact at national level. RTOs are key actors in implementing national and regional R&I strategies since they tend to operate at a higher TRL than universities and since they tend to collaborate with many different public and private partners within a given country. However, it is difficult to provide comprehensive evidence in this regard. There are examples of countries that have consistently high ECSEL participation rates. Some of these naturally collaborate internationally; hence their frequent ECSEL participation is not surprising. Other Participating States claim to have a certain affinity to the programme and perceive that participation has supported the growth of their national ECS abilities, through e.g. the creation of an ECS dedicated RTO as a result of ECSEL, examples of spinoffs which have grown into considerable companies, or through increased public and private investment as a direct consequence of ECSEL.

2

Putting the European Union at the forefront of innovation and digitalisation in ECS

The European ECS ecosystem has strongly benefited from the policy support provided at the European and national levels and especially for maintaining high levels of cooperation, innovativeness and growth within this sector. Today, the ECSEL programme not only strengthens the positive impacts already achieved thanks to its preceding programmes ARTEMIS and ENIAC but it also takes one step further by providing a more encompassing vision on the role of the ECS industry as driver for economic and societal innovation.

2.1. Fostering a culture of R&I collaboration and partnership within and beyond the ECS domain

The ECSEL programme has significant positive effects on the collaboration and behaviours of ECS players at the business, academic and also public sector's level. With important industry actors participating on a recurring basis in ECSEL funded actions, the programme manages to increase the overall levels of cooperation not only within this domain but also with other sectors and value chains. As such, **the main impact of the programme consists in supporting the establishment of a strong and rich ECS ecosystem in Europe, gathering businesses (both large companies and Small and Medium Enterprises - SMEs), academia and public sector stakeholders.** The existence of a vibrant ECS ecosystem is a pre-condition for the European Union to remain an innovative society and economy.

2.1.1. ECSEL strengthens cooperation between public and private ECS R&I performers in Europe

Ensuring a strong cooperation between actors in the ECS value chain is critical for the European Union due to the specific characteristics of this industry domain which is:

- highly globalized and strongly subject to economies of scale ("critical mass"), therefore escaping the power of intervention of single organisations/countries;
- and of strategic importance as a basis for many other industries.

This strategic relevance contributes towards a willingness from industry and countries to trade potential competitive advantages for a more inclusive approach to R&I, which involves higher levels of knowledge sharing. In this context, the ECSEL programme contributes to reinforce existing collaborative behaviours and it **further strengthens cooperation between public and private ECS R&I performers in Europe.** First, project participants generally *expect* increased collaboration as a result from their participation in ECSEL projects. A vast majority of them anticipate the possibility to increase their organisation's network and to become part/continue to be part of the European ECS ecosystem as the main benefit linked to ECSEL actions. Three participants out of four also expect to cooperate more easily and effectively with organisations based in other countries. Improved cooperation in R&I, therefore, is at the core of organisations' motivations for participating in ECSEL funded actions.

More importantly however, **increased cooperation with other organisations is seen as the single most important *realised benefit* linked to participation in ECSEL projects** both in the short and in the long term:

- On the *short term*, a significant majority of participants agrees that developing new relationships with other organisations in the same or new research fields is the most important benefit of ECSEL.
- On the *medium* to long term, this remains the second most highlighted benefit, after increasing their organisations' innovation potential.

Furthermore, the collaboration and the establishment of new relationships are also amongst the *top three impacts* of ECSEL both in the short and in the long term. This suggests that the types of relations, supported by the projects, are valued by the ecosystem and not only resume to project exchanges.

Key characteristics of the relations established under the ECSEL programme:

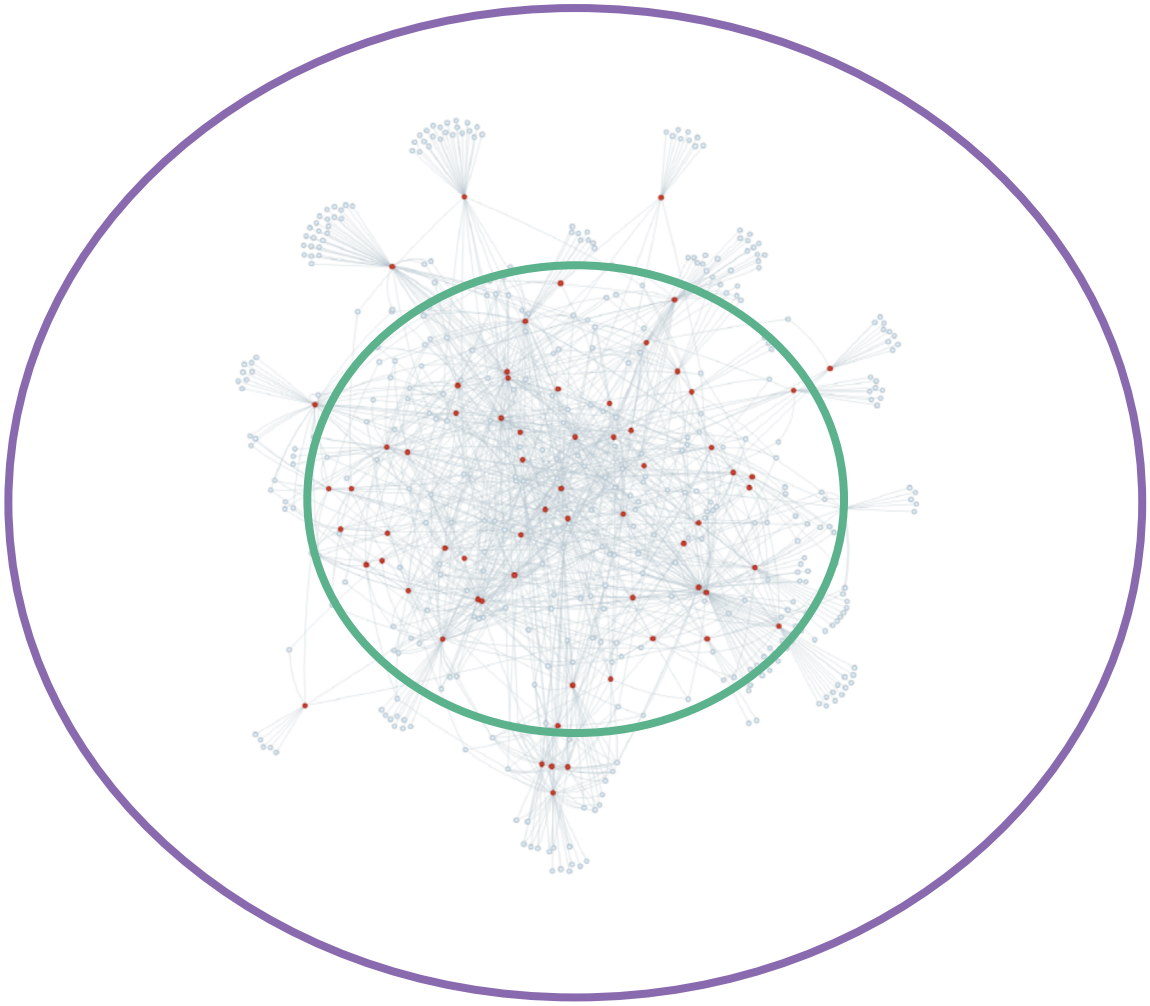
- ECSEL funded projects are seen by stakeholders as a platform for getting to know key players and for establishing relationships with them. From this perspective, **ECSEL constitutes a very practical access point for entering the European ECS ecosystem, especially for Small and Medium Enterprises (SMEs).**
- The cooperation between the participants that ECSEL helps establishing very often goes beyond the time and scope of the projects themselves: there are many instances in which an **ECSEL project set the grounds for more stable forms of collaboration, either in the R&D domain or in other forms** (i.e. through new contracts between buyers and suppliers);
- **ECSEL projects create communities of interests** which, on the long run, results in strategic partnerships and change the R&D and commercial approaches of ECS players.

Performing a network and project analysis confirmed the behavioural impact of ECSEL and shows that the ECSEL ecosystem is composed of:

- a number of "core" organisations (red nodes included in the green circle), which are connected to an extremely high number of other players via several projects (red nodes);
- some more peripheral players (included in the bigger blue circle) which are involved only in one specific project (red nodes) and therefore connected only to a limited number of project participants.

The centrality analysis shows in particular that there are *40 core organisations*, located in 16 different ECSEL Participating States, representing 40% of the project costs and taking part in the quasi totality of ECSEL projects.

Figure 3 - Final Network Analysis carried out by the project team with all ECSEL projects



Source: study team based on ECSEL data

Whilst the 40 core organisations are the most central in the ECSEL programme's ecosystem, the majority of other organisations is also strongly interconnected. This suggests that, **although there is a core of 'repeat collaborators' in ECSEL, they seem not to be isolated from the wider network of participating organisations, i.e. they do not monopolise the support but rather function as core partners that may facilitate contact with others in the network.** Two thirds of the participants in the ECSEL funded projects have participated only once. This underlines the openness of the programme when it comes to gather the right competencies in the projects.

The "core" organisations therefore show a capacity to bring new players and stakeholders under ECSEL and at the centre of the network. At the same time, many organisations funded through ECSEL projects already had pre-existing relationships with at least one other ECSEL partner prior to their collaboration within the framework of the programme. Therefore, the programme is also a vehicle to formally structure existing cooperation. Two-thirds of the survey respondents participated in one or more ECSEL projects thanks to a suggestion by organisations with whom the respondent already had pre-existing relationships with, while one-third of the respondents state that the idea for collaborative research stems from having participated in previous ECSEL funded research.

This positive impact of ECSEL on the ECS ecosystem is linked to key features of the programme, some of which characterise many Joint Undertakings but are particularly important in the ECS context:

1) Complementarity in skills and value chain expertise (available under the programme): ECSEL projects, much thanks to their size, are made up of R&I performers and companies that contribute with different strengths throughout the project cycle phases. Research organisations are naturally strong in the early phases, supporting conceptualisation activities and undertaking exploratory research to find solutions, while large enterprises tend to take a most active role in higher TRL phases and SMEs often participate in testing activities. Of course, the overall composition, roles, responsibilities and added value of different types of organisations working together are specific to each project, however as a general rule, **ECSEL projects tend to follow a basic 'recipe' for problem solving which has proven very successful. A core ingredient in this recipe tends to be the role of reputable and sizeable RTOs, which are highly valued by enterprises.** While the complementarity of skills is not a unique characteristic of ECSEL, the **size of its funded actions** and the extent to which collaboration happens within its ecosystem strengthen this feature and result in greater behavioural impacts for the stakeholders involved. Furthermore, it can be argued that the characteristics of the ECS domain in terms of ecosystem (also thanks to ECSEL) constitute a fertile ground for this positive outcome to emerge.

2) Multidisciplinarity/Cross-sectoriality: in addition to fostering cooperation across the value chain and between different categories of stakeholders, ECSEL projects generally attract participants from other sectors, some of which are traditionally close/reliant on ECS.

This is due to due ubiquity of ECS in modern industry, which makes this sector pivotal for many others, but it also follows a clear Strategic Research Agenda indicating that ECSEL should help "ensuring the availability of ECS for key markets". Although it is nowadays clear that innovation happens at the crossroad between sectors and that sectorial silos are breaking down, stakeholders believe that there are few funding programmes of this size and scope allowing this extent of cross-sectorial collaboration. ECSEL offers to ECS players the possibility of gaining more in-depth knowledge about the requirements of their sectorial customers and, vice versa, to customers the possibility to express their needs and build solutions together with their suppliers. ECSEL hence provides a framework in which research allows sectorial customization of ECS to happen and this is considered to be very rare even at the national level. As such, ECSEL was even mentioned as a good practice by a recent national industry report which called for more cross-sectorial programme of this size to be put in place. ECSEL projects thus have become a *platform for knowledge exchange* between core ECS sectors and wider high-tech sectors that are dependent on the technologies produced by the former.

- The ***SCOTT*[34] *project***, for example, brought together organisations with expertise varying from aeronautics to rail, and from health to smart infrastructure.
- Another example is the ***AutoDrive***[35] project that has gathered the "critical mass" required to improve the current technology of automated driving by bringing together Europe's leading semiconductor companies, suppliers, research institutes and Original Equipment Manufacturers (OEMs).
- Through the ***AMASS project***[36], experts on software and hardware systems have been linked with leading companies varying from space to the automotive industry.

As a result, the ECS ecosystem becomes stronger and richer and this allows to better address emerging challenges related to, for instance, automated driving, energy, IoT. Multidisciplinarity/cross-sectoriality as such are key characteristics of the ECS domain which constitutes key enabling industry for the different sectors. Within the ECSEL programme, these features are strongly encouraged and valued by stakeholders, especially when compared to other research programmes.

3) Collaboration on a pre-competitive platform: it is not frequent for two competitors to collaborate on the research and development of innovative solutions benefitting both. This however happens in the context of ECS as "R&I partnerships" between competitors or semi-competitors are sometimes established to cater for important investment needs which would not be realised otherwise and to gather around the table the few organisations which are capable of innovating in a certain domain. ECSEL funded actions contribute to enabling competitors to work together in R&I and find solutions for their

common challenges. Although this is not a given in all projects, examples show very positive results. The size of the European ECS ecosystem also makes this collaboration needed occasionally: nonetheless, the impact of the trust and appeal of ECSEL projects in gathering competitors around the table should not be underestimated. Furthermore, pivotal players sometimes recognise that "European" solutions need to be found to address certain challenges and that this implies for them to work together in R&I with their direct competitors.

2.1.2. Reinforcing the dialogue between national authorities, European institutions and the industry

The behavioural impacts of ECSEL also concern the dialogue between national authorities, the European Commission and EU level industry associations. Interaction between these stakeholders predominantly occurs through cooperation at the programme level and cooperation is formalised through the interaction in the ECSEL JU Governing Board, in which the three industry associations (AENEAS, ARTEMIS-IA and EPoSS), the European Commission and the ECSEL Participating States (EPS) are represented.

EPS and industry's representatives regard favourably the cooperation established under the umbrella of ECSEL: overall, the relationship is seen as constructive and bringing benefits for all concerned parties through improved coordination between actors and a decision-making process steered by common industry priorities and needs. **The capacity of the programme to mobilise a greater budget by pooling resources from all the parties involved is underlined as a key benefit**, both by EPS and industry representatives and by project participants. Furthermore, the latter also believe that ECSEL helped to align EPS strategies towards the ECS industry, which is one of the objectives of the programme. In fact, **a strong majority of respondents agrees** that ECSEL has been successful in building dialogue and cooperation between EPS and in coordinating their actions, at least to some extent. This achievement is particularly important given the challenge at stake: the members of the Governing Board all agree on the need to build a common European front, drawing on each individual country's strengths and industrial profile, to be able to compete internationally. However, exploring synergies and finding complementarities is only possible if all actors collaborate within a sustainable framework. **The tripartite model provides Participating States with a common playing field based on shared rules, ensuring the decisions on budget and projects, as well as the R&I cooperation between players, which sometimes happen to be competitors in the market, are as transparent and fair as possible.**

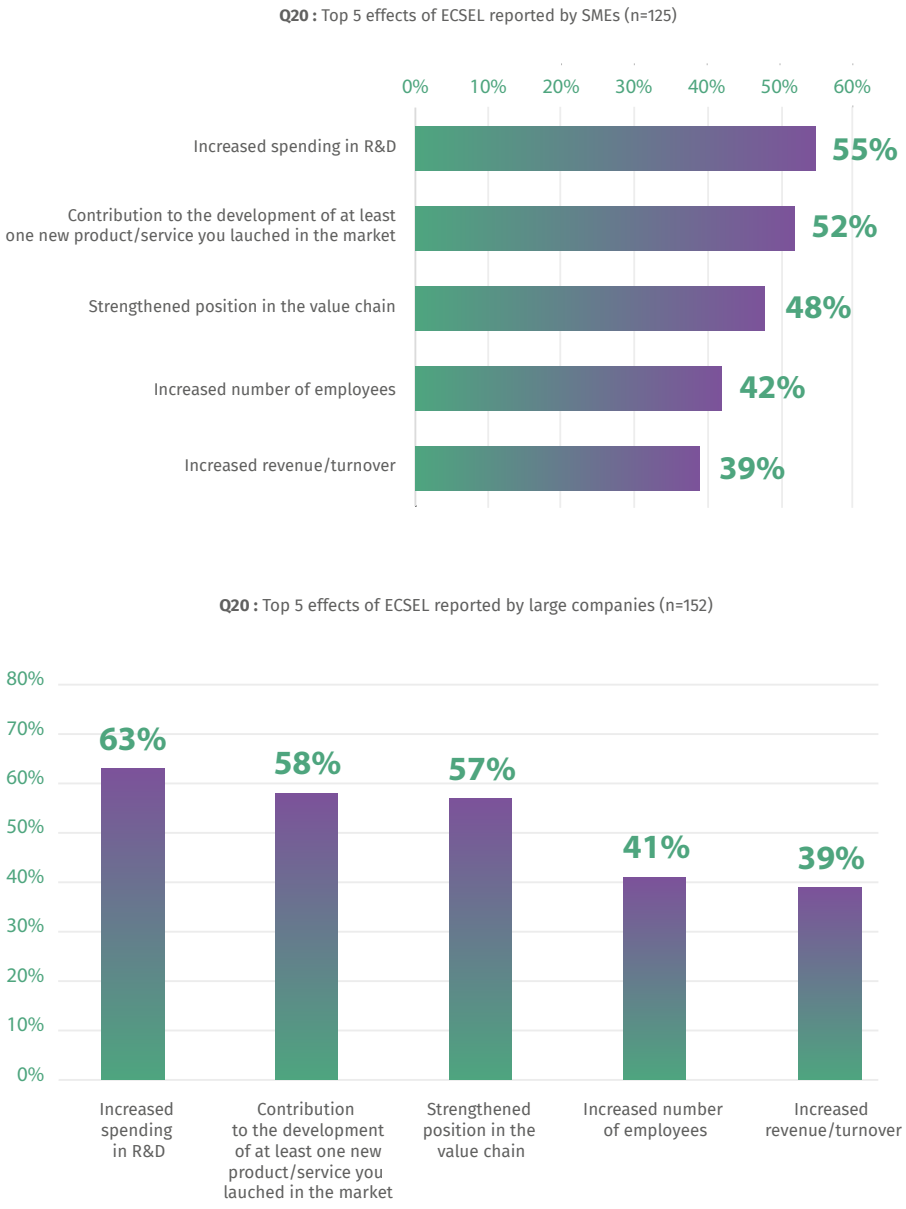
The strategic value of the ECSEL JU is thus unquestionable. The projects funded by the JU are ambitious to a degree that would make it nearly impossible for a country to carry out a similar initiative on its own. The impacts resulting from such projects are also considered to have European level relevance. For all these reasons, ECSEL funded actions have also a direct effect on EPS and EU industry stakeholders as they provide a number of incentives for cooperation which, in turn, results in enhanced dialogue and alignment, thus leading to greater project impacts.

2.1.3. Strengthening the integration of SMEs in R&I activities and in the ECS value chain

SMEs are very important players for maintaining a sustainable ECS ecosystem, but they sometimes struggle to participate in large R&I programmes at the European level, due in particular to administrative burden and lack of resources for participating in time consuming calls for projects. In 2018, the ECSEL JU launched several activities aiming at better understanding SMEs' needs and improving their experiences in the programme. Despite the challenges highlighted in the past and the fact that, today, ECSEL funded projects are still considered by some as a rather close environment with high entry barriers[37], those SMEs managing to "conquer" *this environment experience very high returns on investments (ROI) and therefore strong incentives to participate in ECSEL funded projects exist for them.*

According to this study, the top five benefits for SMEs participating in ECSEL projects are: **1)** the increase in R&D spending, **2)** the contribution to the development of new products, **3)** a strengthened position in the value chain, **4)** an increased number of employees and **5)** an increased turnover.

Figure 4 - Top 5 benefits of ECSEL for SMEs and by large companies respectively



Source: study team tabulation based on the project participants' survey results, 2019

While the top three effects (on R&D spending, on product/service development and integration in the value chain) are the same for both SMEs and large enterprises and confirm the impact of the programme as producer of innovation and of collaboration opportunities, it appears that the *increase in number of employees and the increased revenue/turnover* are **more important impacts for SMEs than for large companies**. The evidence gathered throughout the study confirms this finding: SMEs often consider the first ECSEL project they participate in as a possibility to display their capabilities, develop new products/services and become part of the ecosystem. However, if the SME performs well, this opens the possibility for the company not only to carry out highly innovative R&D activities with key players but also to **gain them as new customers / business allies**. Larger companies are often positively surprised by the expertise brought by SMEs and frequently take them on board for follow up projects under ECSEL and in the context of other business opportunities. Therefore, SMEs participating

in ECSEL not only obtain new knowledge and new contacts with key players, but they also benefit from direct effects in terms of competitiveness.

As mentioned in the ARTEMIS Magazine in 2018, "the prospects for SMEs are therefore clear: collaborative R&D constitutes an opportunity to learn about industry leaders' requirements, gain access to standards as they are developed, to secure a position at the forefront of technological advances as early adopters of the outcomes or as components suppliers.[38] Challenges still exist however and it is difficult for SMEs which are not yet connected to one of the central 40 players to be on boarded in ECSEL funded projects. Nonetheless, there are several examples of SMEs which have gained a better position in the value chain thanks to their participation in the ECSEL programme. For these reasons, it can be argued that ECSEL has an impact on SMEs' integration in the value chain although the magnitude of this impact remains limited in terms of number of companies concerned.

2.2. Increasing the innovativeness, scientific excellence and competitiveness of the EU ECS ecosystem

Market data suggests that the ECS players invest on average in between 10 to 20% of their total revenue per year in research and development and ECSEL project participants are no exception; amongst the for-profit participants a majority spends in between 6 and 20% per year in R&D activities and, for the non-profit organisations, the percentage increases to between 61% and 100% (this category includes mainly universities and RTOs). The latest ECS Strategic Research Agenda mentions that R&D investments in the areas of lithography, imaging, deposition and assembly technologies have been quite stable over time even when the market showed quite extreme volatility (+/- 30% yearly).[39]

ECSEL funded actions have a **very significant track record in terms of impacts on innovativeness and scientific excellence of the ecosystem and contribute to maintaining high level of R&D investments**. To understand the very positive impact of ECSEL, it is important to remind that: **a)** R&I and innovation activities in the ECS domain are characterised by high levels of costs[40] which also lead to **b)** collaborative approaches and partnerships being often established between industry players to carry out cutting edge research more effectively.[41] ECSEL strengthens investments in R&D in the domain and reinforces the collaborative approach chosen by stakeholders thus perfectly fulfilling the ecosystem's needs. For these reasons, ECS players have largely integrated the use of this funding programme in their R&D strategies.

Figure 5 - ECSEL's role in R&D strategies of the main players

Source: study team tabulation based on the project participants' survey results, 2019

A vast majority of RTOs and research institutes operating in the domain is particularly oriented towards leveraging ECSEL funding for their R&I activities and around 75% of large companies also attributes a particular role to ECSEL in their strategies. The importance of ECSEL in organisations' strategies decreases for SMEs, universities and private research institutes. However, overall, **three out of four respondents suggested that ECSEL plays a role in their strategic approach to research and development.** Project participants tend to agree that ECSEL is an important tool for them to carry out R&D activities and especially when these involve large scale and multi country projects, for which ECSEL is one of the preferred mechanisms. In this context, a significant number of project participants go as far as to say that **for collaboration at the European level on large and close to market projects there is no good alternative to ECSEL.**

Furthermore, the overwhelming majority of survey participants agrees that, **by supporting large scale R&I collaboration between stakeholders, ECSEL funded actions have also helped developing and maintaining a strong competitive ECS industry in Europe.** In the absence of ECSEL R&I support, the European ECS industry would have suffered more from the challenges linked to geographical shift to Asian countries and changes in the distribution of value along the value chain. **Without ECSEL and its predecessors ARTEMIS and ENIAC, the European ECS ecosystem of research and innovation players would not look as vibrant as it looks today.**

In this R&D context, there are three main impacts that can be closely associated with ECSEL funded actions:
1) increased R&D spending,
2) increased innovativeness of the ecosystem, and, directly linked to these two impacts,
3) increased growth and competitiveness of ECS players.

2.2.1. Increasing R&D spending in the EU

The results of the survey carried out with project participants suggest that **the main effect of ECSEL on the participating organisations consists in increasing their R&D spending.** Although it is difficult to put an exact figure on this increase[42], **two thirds** of respondents stated that this is the *most important effect* of the ECSEL programme on them. When looking at a more granular level and considering the differences between types of organisations, it can be found that this remains the single most important effect for all of them ranging from large companies (63%) to SMEs (55%). In addition to the public funding provided for R&D, there are **two main reasons why ECSEL drives increased R&D spending across all organisations** and these can be summarised by two keywords: **trust and risk taking.** It is widely acknowledged that ECSEL projects build on high level of trust between players and that this trust concerns not only the relations between them but also the relevance and innovativeness of the outcomes produced in these projects. Stakeholders in fact tend to have positive expectations towards ECSEL funded actions in terms of innovation and excellence, because they trust the other players involved *(see also Section 2.1 - Fostering a culture of R&I collaboration)* and ECSEL's ways of functioning.

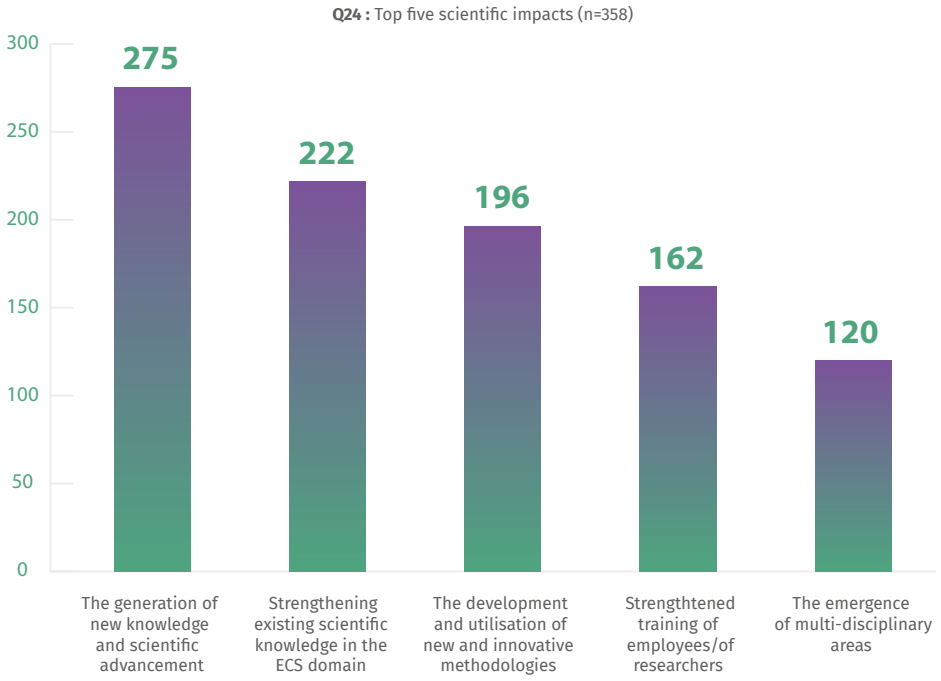
Trust in the ecosystem of ECSEL and the validity of its projects provides a fertile ground for taking risks. In business terms, taking risk might mean pooling together more resources and investing higher amounts of money in potentially innovative projects on which the return on investment is not initially clear. ECSEL is considered as a safe environment for doing so, where organisations can rely on trusted relations with each other and on the support of the ECSEL JU. Compared to other funding programmes at the EU and national levels, ECSEL sometimes accepts to fund more "risky" projects which would not necessarily qualify elsewhere due to their characteristics or the characteristics of their participants. Examples on how this happened in the past have led to very positive and innovative outcomes. Therefore, ECSEL JU's reputation as "risk-taker" also helps with the increase in R&D spending from project participants. Additionally, the tripartite model contributes to the establishment of trust and provides a sense of support and direction to the community which is then enabled to take more risks. There are several examples of projects in which private players invest in the ECSEL framework because they felt it was sufficient to guarantee a positive return, based on their previous experience with these projects and this ecosystem. In this respect, the continuity of some research areas under ECSEL also helped stakeholders to become more confident with the programme and increase the money they allocate to it.

Concerning SMEs and start-ups, it is often argued that large programmes such as H2020 are difficult to access due to the administrative requirements they entail. While this holds true for ECSEL as also indicated in the ECSEL mid-term evaluation[43], interviewees suggested that **the programme has driven up R&D spending for SMEs** as it offers something more than other funding schemes: it provides SMEs not only with the occasion to carry out cutting edge research but also and especially with new business opportunities and the possibility of finding their place in the ECS ecosystem overall. For these reasons, and especially to gain access to the core of the European ECS ecosystem, SMEs are also willing to take more risks and allocate more money to R&D in order to be able to participate in these projects.

2.2.2. Supporting and increasing the overall innovativeness of the ecosystem

Compared to other research programmes, **one of the specificities of ECSEL consists in the fact that it contributes not only to raising the research and innovative capacity of a limited number of key players (which are more successful in accessing the funding[44]) but also to increasing the overall innovativeness of the ECS ecosystem in Europe.** New knowledge, generated by many organisations, reaches a higher number of players within the domain due to the strengths and characteristics of the ECS ecosystem under ECSEL.

Figure 6 - Top 5 scientific impacts



Source: study team tabulation based on the project participants' survey results, 2019

The importance of the knowledge generation potential of ECSEL emerged strongly from the survey analysis, **and it is also confirmed by the impressive number of publications developed under each ECSEL funded action,** going up to hundreds in the lifecycle of the projects. These do not only include journal publications but also successful books used in university curricula.[45] For an industry driven research programme, such a significant number of publications means that it generates not only project specific and concrete knowledge but that it also produces new knowledge and scientific advancement which is relevant for the entire ecosystem. In this respect, it was often argued that ECSEL projects work not only on (generally) innovative initiatives but also and especially on "cutting-edge" and "game-changing" R&I areas which heavily benefits European players[46] This does not only translate in publications but also in many other highly innovative and scientifically valid outcomes such as frameworks for instance **(i.e. Arrowhead[47])** or even blockchain based standards **(i.e. Productive 4.0[48])**. Additionally, from an innovation standpoint, ECSEL has been at the heart of the development and deployment of many cutting-edge ideas *(and also pilot lines)* including the establishment of a semantic web for ECS and the refinement of FDSOI technologies. These two examples in particular testify the transformative nature of some of the

innovations developed under ECSEL and the potential to impact ECS industry to a tremendous extent once fully taken up.

What is striking and more peculiar about ECSEL however is not only its extensive contribution to overall scientific excellence and innovation, but rather why this happens and why it impacts the entire ecosystem and not only a few "lucky" players. Thanks to ECSEL funded projects in fact, the entire ECS industry becomes more innovative as knowledge and innovations are shared amongst many and not restricted to a few. This is due to two crucial characteristics of the programme and notably:

- **The collaborative approach to research and innovation it supports:** ECSEL contributes to creating an ECS vibrant ecosystem of players which remains stable over time while being able to continuously include new emerging stakeholders. The existence of such an ecosystem and of hundreds of connections between players entails huge potential for scientific and innovation spill overs and dissemination of knowledge. In fact, projects' scientific and innovative outcomes do not remain closed in the scope of the projects, but they are transferred from one project to another thanks to participants but also to the many communication and dissemination activities which ECSEL funded actions foresee. In this respect, the importance of communication and dissemination activities increased over time and very good practices can be identified amongst ECSEL projects. Furthermore, some of the most important scientific and innovative outputs of the last few years have been made freely accessible to non-project participants even before the end of the project. This contributed to increasing scientific spill-over effects and sharing of knowledge and also to cross-fertilise between ongoing projects and new proposed ideas.
- **The continuity of research which has been ensured since ARTEMIS and ENIAC:** ECSEL contributes to high levels of knowledge sharing and scientific excellence as it offers the possibility of having "continuous" research in some key domains. Although this is not an entirely unique feature of ECSEL, success chances of proposals are higher under ECSEL (compared to H2020 for instance).[49] Knowing that EPS support research streams that are relevant to them and building on these higher success rates, several projects which were initiated under ARTEMIS and ENIAC generated follow-up projects under ECSEL as new research ideas stemmed from the initial work. This creates sorts of "generations" of projects which contribute to a process of incremental knowledge acquisition, leading from an initial idea to very concrete results in the space of 2-3 projects, a continuity which is highly appreciated by project participants. At the same time, this continuity also reinforces the spill-over effect mentioned above as, in general, new players are involved in each new project and therefore knowledge is spread further and further. This phenomenon is surely neither new nor entirely unique to ECSEL: however, the way ECSEL functions, focusing on few relevant application domains relevant to societal challenges, ensures higher levels of certainty for stakeholders innovating in the related domains hence enhancing continuity and providing a framework for high levels of knowledge generation.

2.2.3. Nurturing R&I collaboration as a driver for growth and competitiveness

The overwhelming majority of participants agrees that ECSEL funded actions have helped to a large orvery large extent to developing and maintaining a strong competitive ECS industry in Europe. It was often stated that ECSEL projects and EU level intervention are "necessary" to maintain the competitiveness of the ecosystem. Some even argue that ECSEL plays a role similar to "angel funds" in terms of sustaining the ecosystem's competitiveness, due to the size of its projects and its capacity to encourage industrial and public sector players to take some risks. Overall, stakeholders believe that, in the absence of ECSEL, the European ECS industry would have suffered more from the challenges linked to the geographical shift to Asian countries and changes in the distribution of value along the value chain. Without ECSEL and its predecessors ARTEMIS and ENIAC, the European ECS ecosystem would not look as vibrant as it looks today.

By increasing R&I spending and supporting the innovativeness of the ECS ecosystem, the ECSEL programme hence contributes to the competitiveness and growth of the ECS private sector players which constitute around 60% of project participants. Amongst them, **strengthened competitiveness** is experienced by **almost one participant out of two** and is generally explained by the fact that, by supporting R&I efforts, *ECSEL helps organisations increasing efficiency and productivity, thereby increasing turnover and market shares and improving human resource capacities.*

Efficiency and productivity gains linked to R&I activities are very often generated by ECSEL funded projects and, in many instances, official key performing indicators (KPI) are established to monitor these gains. In a few cases, efficiency gains were estimated to go

up to 50% for participating organisations but, more frequently, efficiency and productivity gains seem to be in the range of 10-30%, which has nonetheless a considerable impact on organisations' performances. These gains are generally reached because ECSEL funded actions allow piloting of production lines, integration of digitalized systems for production management, improvement of prior modelling, etc.

- The ***3Ccar project***[50] is expected to produce a gain in productivity estimated in-between 10-20% corresponding to around 10.5 million euro spared by organisations participating in the research.
- The ***MegaM@Rt***[51] ***project*** expects a 15% improvement in production costs driven by a reduction of 40% of the time needed to develop specifications[52].

Other similar examples and interesting figures can be found in projects' documentations and constitute strong evidence supporting the impact that ECSEL funded actions have on efficiency and productivity of the ECS industry. Amongst the project level benefits of ECSEL funded actions, *efficiency and productivity gains are the most widespread and those on which there is the strongest consensus.*

The increased **turnover** generated by the launch on the market of one or more products/services developed through research performed under ECSEL funded projects is another indirect impact of the programme recognised by the project participants. Stakeholders provided many examples of increased turnover (i.e. "up to 2mio euro for the launch of 4 new products", "several million euro" after the deployment of a new production line or even "doubling turnover" over a period of a few years thanks to the technology developed under the project). Some participants struggle to follow up on project results after the end of the actions and once the new products for instance are commercialised and become part of a wider product offering of their organisation. Despite lack of quantitative evidence, the development of new/improved products under ECSEL very often has an *indirect impact on companies' turnover* as it brings to increased sales and penetration of new markets. The trend break analysis of the turnover of a few specific companies confirmed this statement and ECSEL impact visits by the public authorities in different Member States also offer a number of examples substantiating this finding.

The indirect impact of ECSEL on organisations' **market shares** is difficult to quantify but ECSEL funded projects tend to have an indirect impact on European companies' market shares due to two elements in particular:

- The support for *cutting edge technologies* (such as Fully Depleted Silicon On Insulator – FDSOI) which are true "European success" and lead to emergence of new market segments. With respect to this and concerning FDSOI in particular, it must be noted here that this market is growing at a CAGR of 43.37% for the period 2019-2023 and that important leaders for the future development of this technology are based in Europe. **By supporting research projects on FDSOI, ECSEL indirectly enables European players to maintain and grow their market shares in this domain.** However, the application of this technology is not limited to Europe as South korean companies for instance are using the FDSOI technology for the components in smartphones. ECSEL's support for very innovative projects and pilot lines in thearea of power electronics (see Section 3.1 of this report) also contributes to provide new market opportunities for European players and thus has a potential effect on their market shares in this domain.
- The generation of *new business opportunities and the facilitation of contacts between buyers and suppliers* which benefits particularly SMEs. The latter constitutes a key characteristics of the ECSEL funded projects and some interviewees argued that this programme constitutes a *European "marketplace"* where capabilities of European producers can be shown and products needs can be discussed. This often leads to the generation of new business opportunities for the participants, which in turn has an impact on their turnover first and then on their market shares.

Concerning **employment impacts,** nearly half of the respondents confirmed that participation in ECSEL projects resulted for them in an increased number of employees and in strengthening human resource capacity. This means that participation in ECSEL *funded projects has a job creation effect for almost one organisation out of two.* For some of these organisations, participating in ECSEL funded projects had impressive or rather transformative employment effects.

- One organisation created 550 jobs in Europe over a 3 years period for exploiting the results of an ECSEL funded project.
- For another organisation, the number of FTEs more than doubled towards the end and immediately after the end of the project (from 45 to 102 FTEs).

Stakeholders from universities and research centres also highlighted the importance of ECSEL projects in terms of employment, but more from a human resource capacity perspective. Universities and research centres use these projects to further train their researchers and provide them with an industrial "concrete" understanding which would not be easy to acquire otherwise and which also appeals to "new" researchers. This means that the number of relevant researchers' profiles increases and that they become even more attractive for the industry; this helps addressing the question of scarcity of talents in the ECS R&D domain. While some interviewees underlined that these jobs are mostly highly qualified jobs and that production is still performed most often outside Europe, there was a strong agreement on the fact that ECSEL funded projects help maintaining jobs in Europe and strengthening human resource capacity.

Finally, **establishment of spin-off companies** can also be considered as a possible effect linked to participation in ECSEL funded projects, although rarer, and this also contributes to maintaining the ECS ecosystem in Europe competitive.

- Recently, a spin-off company was established to exploit the outcomes of the ***Productive 4.0***[53] ***project*** concerning the use of blockchain for security layers.
- Other spin-off companies are currently being set up, for instance under the ***InForMed project***[54]**.**

2.3. Ensuring a rapid digitalisation of industry and society

The phenomenon of digitalisation (touching both industry and society) accelerated in the past few years and its impact on the European Union is exponential. For the European ECS industry, the rapid digitalisation is an opportunity intertwined with other market challenges and requires an important effort to ensure the take up and exploitation of new technological solutions. From this perspective, the ECS production processes and business models need to be adapted to the emergence of connected devices (i.e. IoT) and other technologies (i.e. Business to Business data sharing platforms) in order for Europe to reap the benefits of digitalisation.

For citizens and the wider society, the challenges and opportunities are different but equally important; they revolve around the question of managing the digital spaces we live in to ensure they are secure, comfortable, healthy, anticipating (meaning that they can provide us with the right solution at the right time) and sustainable. **Today, the ECSEL programme is paving the way for the successful digitalisation of both EU industry and society.** By supporting fundamental projects in the area of digital industry and by enabling the development of key solutions for the Digital Life's challenges, ECSEL establishes the R&I ground for the digitalisation of Europe.

2.3.1. Accelerating the shift to Digital Industry and the adoption of connected devices amongst businesses

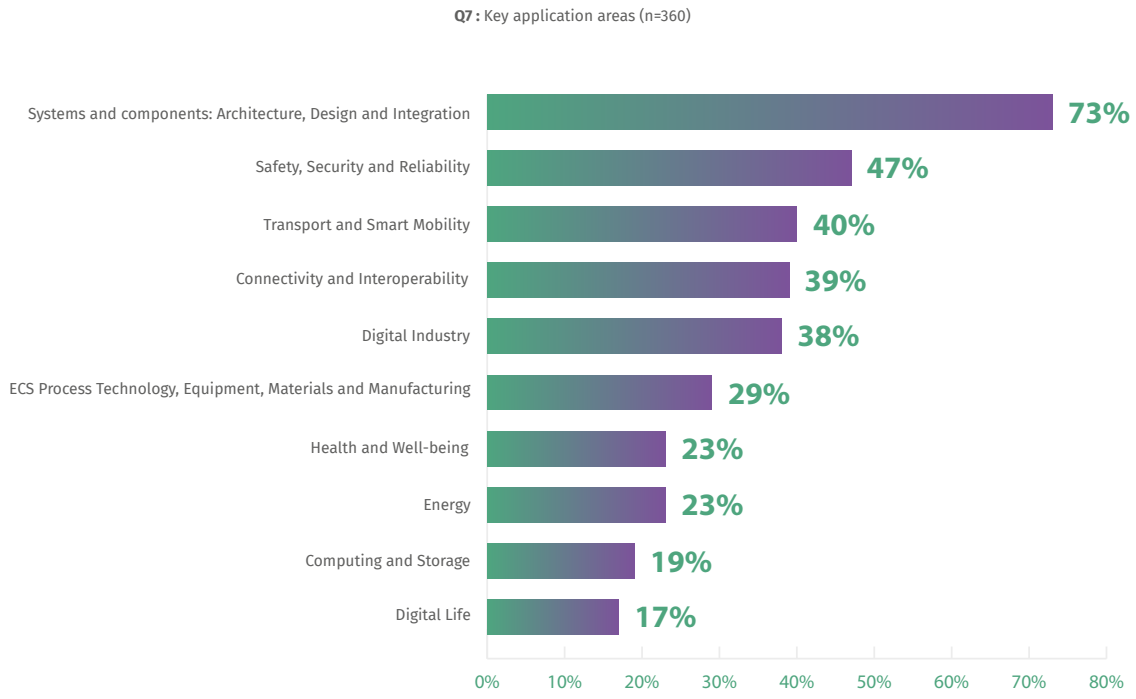
In terms of *industry digitalisation*, ECSEL is particularly sustaining the European ECS ecosystem in the process of take up of IoT systems and further in the value chain shift towards a more application-based economy. In particular, it supports **digital industry** by contributing to the development of key horizontal components and systems that can accelerate the digitalisation of the ECS industry overall, and by strengthening sector specific solutions, which reinforce Europe's assets whilst enhancing application domains where the current ECS ecosystem is weaker. To do so, ECSEL JU funds ambitious industry-wide projects and establishment of cutting-edge pilot lines, thus benefitting the overall ecosystem through the provision of essential components for Industry 4.0, and by bringing together ECS and stakeholders from the specific application sectors to foster innovation.

Stakeholders strongly agree that projects such as Productive 4.0[55] or Arrowhead[56] and its successor Arrowhead Tools help developing "building blocks" and key components and systems for the ECS industry of the future. These can be of various types, but they all share some characteristics:

- Due to their complexity and costs, they cannot be developed by one or a small group of players but rather require large consortia and international collaboration, as well as to be tested in practice and piloted as far as possible as stakeholders need to see practical results;
- They address transversal challenges to the industry (i.e. security of communications between machines or optimisation of the supply chain) and to all ECSEL Participating States, making them relevant for the quasi totality of players in the domain;
- Given their transformative power, they can revolutionise the functioning of the industry when widely integrated (i.e. the Framework and Digital Platform developed under Productive 4.0);
- They need to be made available and widely spread as they can help maintaining EU competitiveness on a global stage, for instance the development and adoption of standards can benefit initial players when these become the reference at international level.

The characteristics of these key components underline the importance of the ECSEL JU, as it can ensure large and international consortia, helps pooling significant resources, funds testing and pilot lines in different domains and allows taking risks and "outside the box" thinking. Furthermore, ECSEL projects are based on the principle of open innovation and knowledge sharing and therefore their outcomes are made available to the wider industry during and after the projects themselves. Consequently, ECSEL acts as an "incubator" for industry-wide innovative solutions that can help the European ECS industry remain at the forefront of Industry 4.0. The development of these horizontal components for applications is often considered more relevant for the industry than the work on sector specific application areas.

Figure 7 - Key application and technology areas as mentioned in the MASP



Source: study team tabulation based on the project participants' survey results, 2019

2.3.2. Ensuring European Citizens benefit from a safe and fulfilling Digital Life

The impact of ECSEL is not restricted to the digitalisation of industry: on the contrary, the programme has a significant impact on European citizens' **Digital Life, Europe's technological sovereignty** [57] and on the wider digitalisation of society. Challenges in this domain concern the availability of ECS components for connected devices as well as the safety, sustainability and comfort of the increasingly digital spaces we inhabit, whether they are public, professional, private or personal spaces. Widespread use of sensors and IoT devices also creates "anticipating" spaces, which can offer the right service at the right moment. Around one quarter of ECSEL projects work on all of these digital life challenges, seeking to make sure that relevant ECS technologies are available in an effort to build smart, safe digital spaces. These projects focus on a wide array of applications, such as smart cities (i.e. smart lighting, air quality monitoring), smart buildings and emergency management in various contexts but also on horizontal challenges such as miniaturisation of components of devices or data privacy and cybersecurity.

Examples of ECSEL projects focusing on applications for Digital Life

- The ***InForMed*[58] *project*** has supported new solutions relevant for the Digital Life domain. Among those, smart dressings allowing patients to leave the hospital earlier and coming back to the hospital only for punctual appointments when the dressing needs to be changed.
- The ***ENABLE-S*[59] *project*** works on the use of highly automated cyber physical systems (ACPS) in automated driving, helping handicapped or elderly people to gain mobility and independence while ensuring the security of the vehicle.
- The ***SCOTT*[60] *project*** focuses on the development of IoT solutions in various fields and has developed a safe and secure electronic monitoring system for elderly care. The systems helps to track the location of the person and in the event of an incident, it sends an alert to the caregiver's mobile phone, who can assess the alert and accept it so as to be granted access to the person's in need room or home.

Concerning the more horizontal challenges addressed by ECSEL funded projects in this domain, the progress made in the area of lithography, components packaging and FDSOI technologies must be particularly highlighted. Many ECSEL funded projects (and ENIAC projects) focus on enabling European players to keep on Moore's law projection and continue reducing the size of chips and transistors so that they can make their way into many more connected devices (including wearables and other every day life's devices). In this context, the development of technologies for advanced packaging, the work on FDSOI technologies as well as the establishment of new lithography solutions under ECSEL all represent key stepping stones for the industry to go towards 7nm and 3nm products and manufacturing capabilities. These technologies in fact are required for making further miniaturisation of transistors and components technically possible and therefore contribute to their usage in a wider range of connected devices.

Examples of ECSEL projects providing horizontal solutions for Digital Life

- The ***SeNaTe***[61] project worked towards enabling the production of the 7nm technology node. Extreme Ultraviolet (EUV) technology is the next step in lithography and an essential part to create shorter wavelengths needed to be able to reduce the size of chips. The ***SeNaTe project*** developed a lithography scanner based on EUV technology to achieve the 7nm module patterning specification. This constituted a very important European success on the road towards the continuation of Moore's law.
- The ***WayToGo Fast***[62] project aimed at establishing a European ecosystem for production of Fully Depleted Silicon On Insulator (FDSOI) technologies. This technology helps addressing one of the major shortcomings concerning the application of Moore's law: the more the transistor's size is scaled down the higher is the dispersion of energy and the loss of control over the electric flux. This means that reducing traditional transistor size can imply energy waste and loss of control over the behaviour of the transistor itself. FDSOI based transistors do not significantly differ in their aspect ratio from traditional transistors and they can be produced with limited modifications to the manufacturing processes. However, they enable better control over the behaviour of the transistors and reduce considerable energy waste (see also Section 3.1 of this report). Furthermore, they allow a better performance of the transistors in case of low voltage. FDSOI technologies constitute another European R&D success for tackling the challenges of Moore's law.
- The recently launched ***Applause***[63] project works on building advanced packaging solutions for photonics, optics and electronics in order to develop new tools, methods and processes for high volume mass manufacturing of electrical and optical components. The use cases developed under this project are multiple and concern for instance: 1) substantially smaller 3D integrated ambient light sensor for mobile and wearable applications, 2) a high performance, low cost, uncooled thermal IR sensor for automotive and surveillance applications and 3) miniaturized cardiac implants with advanced monitoring capabilities.

As these examples suggest, many ECSEL funded innovations in the area of Digital Life are relevant in the health, energy, and environmental sectors and follow an application-based logic. For instance, many anticipating devices in the future will be "wearables" and several ECSEL projects are further investigating the ECS needs and requirements for this type of devices, especially in the health sector. However, the ECSEL programme also supports projects whose benefits go well beyond individual sectorial applications: the work on miniaturisation of transistors, the development of better ECS packaging solutions and the efforts made for the continuation of Moore's law are all pivotal for the diffusion of connected devices across sectors.

Overall, there is a wide range of projects tackling Digital Life's challenges under the ECSEL programmes and, due to the importance of these challenges for our quality of life and for a broader diffusion of sensors technologies, many more are likely to be started in the near future. As suggested by all the evidence, the ECSEL programme is greatly contributing to the digitalisation of industry and society and more particularly to the successful take up of connected devices, by making sure that these technologies are not only available, but also safe and efficient for everybody to use. This is especially important as the integration and normalisation of IoT devices in the daily lives of European citizens is highly dependent on these being relevant and trustworthy.

3

Fostering research and innovation for addressing European societal challenges

The ECSEL Joint Undertaking programme contributes positively to addressing European societal challenges in the areas of mobility, health, energy and environment by providing an overarching framework for cooperation between ECS and other sectors' players and by channelling research and innovation around key issues. Through its programme and project level activities, the ECSEL JU not only helps pursuing the wider societal objectives of the European Union, but it also has a direct and positive impact on European citizens' lives.

3.1. Supporting Europe's journey towards the achievement of its ambitious energy and environmental objectives

3.1.1. Energy and environment: key priorities for European Union's businesses

According to a recent report from the International Energy Agency (IEA), "industrial energy productivity (industrial value added per unit of energy used) has risen in most regions (including the EU) since 2000 due to the deployment of state-of-the-art technologies", also funded by an increasing number of public research and innovation programmes.[64] Worldwide, the ECS sector has been essential in the development of semiconductor-based innovative technologies consuming less energy, and their use contributed to improving overall energy efficiency levels by 14% on average between 2000 and 2015.[65] In Europe, although "firms have significantly reduced their energy intensity, for most industries the reduction was not large enough to offset the price increase". Therefore, despite increased attention paid to energy and environment and investments in these areas, addressing energy challenges remains a crucial European challenge.

The ECS sector in Europe is at the same time quite exposed to energy costs (also due to the high levels of competition it suffers from) and represents a possible driver for change, given the ubiquity of ECS technologies.[66] For these reasons, the ECSEL JU has considered energy as one of its major application domains and it has pushed for a market-pull-supply-drive strategy for smart energy in ECS, aimed at addressing three major challenges: 1- Ensuring sustainable power generation and energy conversion; 2- Achieving efficient community energy management; and 3- Reducing energy consumption.

Currently, around one fifth of ECSEL funded projects is relevant from the perspective of energy and environment and the **ECSEL programme has already contributed to making major progress in addressing energy and environmental challenges.** This mission will become even more important in the future considering the emphasis that the new European Commission has put on implementing a European Green Deal and the growing importance of technologies such as edge computing and Artificial Intelligence, which all require energy efficient solutions.[67]

3.1. 2. Supporting the establishment and take up of energy saving electronic and systems

Energy and environment applications are very important for one third of ECSEL project participants and **the programme has already substantially contributed to the development of different technologies and solutions, by funding several game changing projects in the domain** and especially in the areas of lattera) power electronics and b) low-power electronics. Especially for the further development of future energy systems, the efficiency of electric power conversion is of extreme importance. It holds great potential to reduce critical conversion losses on the renewable energy's way to the end use equipment. Wide-bandgap materials like Galliumnitride and Siliconcarbide can help to further increase the power conversion efficiency. These new materials outperform Silicon-based power semiconductors enabling smaller, lighter and more efficient power electronics. The ECSEL program, with its possibilities to form big consortia along the entire value chain, enabled joint research work on the new wide-bandgap materials in several projects like PowerBase[68] and UltimateGaN[69] . While PowerBase particularly addressed a Galliumnitride pilotline and showed up with the first European fully industrial qualified Galliumnitride Power devices, UltimateGaN lays the foundation to overcome the challenges of the future Galliumnitride roadmap with research on GaN technologies, devices and applications. The development and commercialisation of GaN technologies present multiple advantages from an energy perspective; these technologies in fact significantly reduce energy losses (for up to 50% according to the project's calculations)[70] and they are heavily used for energy intense applications (such as data centers and within the automotive industry). The energy reduction effect combined with the spread of applications produce a very positive impact for the industry overall. ECSEL's investment in GaN technologies allowed European ECS players to even set new benchmarks and thresholds for what is considered a good efficiency level for electronic components and systems (from 90% before the PowerBase project to 97% today[71]).

In the context of low power electronics, a significant number of ECSEL projects have investigated how the ECS industry could cater for the need of less energy consuming components and systems, thus helping meet societal goals. This led, for instance, to the development of the previously mentioned FDSOI technologies, which represent one of the possible technical solutions to the challenges brought by Moore's law. In fact, in the past decades, transistors have exponentially scaled down in size while increasing computational power, and this, in turn, leads to increasing challenges for transistors' performance and energy consumption. FDSOI technologies provide a solution for continuing to scale down transistors' size while maintaining under control energy leakages.

The many projects related to FDSOI, and especially the **WayToGo Fast**[72] and the **Ocean12**[73] projects, all have an important energy efficiency dimension and contribute to addressing energy and environmental challenges in two ways:

- FDSOI technologies consume up to 50% less energy than traditional bulk transistor technologies. Therefore, by supporting the improvement and commercialisation of these technologies, ECSEL projects help providing more energy friendly transistors to the market.
- FDSOI technologies are less disruptive in terms of production processes and require fewer substantial modifications to production plants than other transistors solutions: this means that less resources (including energy) will have to be spent in upgrading production facilities.

While the development of FDSOI and the role of ECSEL in it must be emphasised, the programme's contribution to the area of power electronics is equally important. This technology domain deals with the conversion and control of electrical energy through power semiconductor devices that operate in a switching mode, and this in turn creates innovative and competitive solutions for energy saving and CO2 reduction and sustainable environment through renewables integration and smart grid. As a result, power electronics play a significant role in addressing European societal challenges, as it provides clean and efficiency energy and smart, green and integrated transport.

This, in turn, highlights ECSEL's importance, as it has funded many projects involved in the manufacturing and supply of energy efficient components, modules and systems. For instance, in the case of the **R2POWER300**[74] project, which developed a 300mm pilot line for the generation of smart power and power discretes device technologies, and the **HiPERFORM**[75] project, which has introduced silicon carbide and gallium nitride in the power electronic circuits and charging infrastructure of electrified

vehicle in order to reduce energy consumption. In addition, the **CONNECT**[76] project also illustrates the positive impacts of ECSEL actions on energy and environment, as it focused on the development of efficient devices and components of the future smart grid and supported the enhanced integration of renewables and storage combined with intelligent management of the energy flow.

As these many examples suggest, the ECSEL programme already had a very significant and direct impact on energy challenges, particularly by enabling development and commercialisation of more efficient ECS technologies (whether GaN based or FDSOI) but also by contributing to laying down the future of smart grids. The ECSEL programme has helped ensure the pooling of resources in this area and maintaining the competitiveness of EU ECS players, in a context where cost of energy can affect their revenues and profits. Furthermore, ECS technologies are the basis for a number of sector-specific components and innovations, ranging from transport to health and digital industry. The§refore, the development of ECS energy-friendly solutions, which are then taken up and reused across sectors, can thus have significant impact on numerous other domains and generate energy reduction spill-over effects. As such, it is very difficult to quantify the energy saving impacts that technologies developed under ECSEL might have, due to their ubiquity, but it can be argued that supporting the development and take-up of energy efficiency ECS solutions is a pre-condition for meeting the EU ambitious energy and environmental objectives.

3.2. Fostering the future of transport and mobility

3.2.1. Mobility and transports: a pivotal domain for citizens and businesses

According to the ECSEL MASP 2019[77], Europe is currently facing four major challenges in the area of transport and mobility and these are:

1) *The development of clean, affordable and sustainable transport and the reduction of fossil fuel's consumption.* The awareness concerning environmental challenges and the need to reduce transport emissions is constantly increasing; finding environmentally friendly alternatives to conventional vehicles, such as electric vehicles (EVs), is high up on the agenda of European leaders and citizens. Overall, clean transport is an area in Europe where industrial and societal interests converge. Reducing CO2 emissions (of vehicles but also during the production processes) is an economic priority for European firms that need to adapt to more environmental exigent customers and to CO2 restrictions in many large cities. However, within the EU there seems to be a financing gap concerning the development of cleaner transport of in between €5.5bn and €13bn annually, according to the European Investment Bank.[78] This is mainly due to "the high level of risk and large capital requirements typical of road transport innovation".[79]

2) *The provision of secure connected, cooperative and automated mobility and transportation.* The automation and connectivity of vehicles (including cars, aircrafts, trucks, vessels, trains, off-road vehicles, satellites and drones) are both a major opportunity and a challenge from a societal perspective. In general, new technologies help increase safety of transport and mobility solutions. However, to work effectively and safely, these solutions cannot be developed and managed by one single player in the value chain; they require a variety of partners working together across sectors, from the telecom operator to the original equipment manufacturer and from the hardware providers to the software providers. This collaboration sometimes proves difficult to achieve.

3) *The management of interaction between humans and vehicles.* Ensuring humans and vehicles cooperate well is pivotal for the provision of safer transport through automation. Even though automation is increasing within all transport domains, there is still a need for these automated systems to coexist with humans and conventional vehicles. Furthermore, everyone in society (including the elderly and disabled) must be able to use these partly or entirely automated systems.[80]

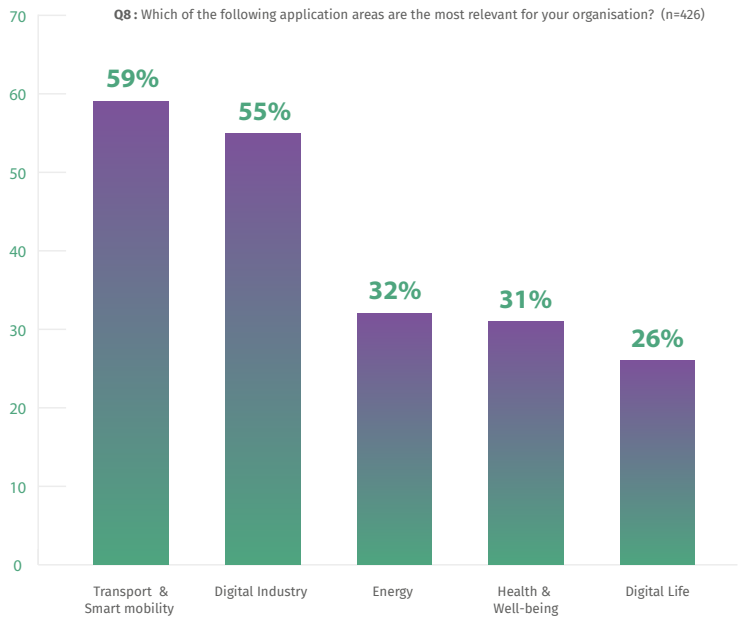
4) *The implementation of infrastructure and services for smart personal mobility and logistics.* This concerns the development of Mobility-as-a-Service (MaaS) alternatives to conventional mobility solutions.[81]
ECSEL already works on all these challenges: today, around 40% of ECSEL funded projects are relevant for Transport and Mobility. This number might even increase in the future, as this area is being considered by the project participants and the wider ECS ecosystem as a domain in which ECSEL can and must strive for high impact.[82]

3.2.2. Developing the ECS solutions required for the transport and mobility sector of the future

With over 11 million Europeans employed in services related to transport and logistics, mobility is a pivotal source of economic and societal prosperity in Europe, including from an ECS perspective, as both ECSEL's strategic research agenda and ECSEL project participants widely recognise.

To strengthen the programme's impact on this area, the Joint Undertaking has already established a Lighthouse initiative entirely dedicated to transport and mobility, under the umbrella of which different projects can exchange and coordinate. In this context, ECSEL funded actions already work towards addressing the key European mobility and transport challenges and notably by supporting:

Figure 8 - Relevant application areas (n=426)



Source: study team tabulation based on the project participants' survey results, 2019

- The development and take-up of *clean transport solutions;*
- The provision of *safer transports*;
- The development of safe *mechanisms for interaction between humans and vehicles;*
- The development and *take-up of Mobility-as-a-Service (MaaS) solutions.*

ECSEL funds many important projects supporting the European provision of **clean and affordable transports** and it *enables the development of new components for cleaner vehicles while also improving the vehicles'* production processes. Most of these projects have clear EU level ambitions and KPIs in terms of increasing availability of clean mobility options, such as an increased production of electric cars from 9% in 2020 to 27% in 2030 or increase in the electrical vehicle market by 50% to foster the EU players' competitiveness worldwide.[83] All of them include players from the automotive and transport sectors (i.e. automotive original equipment manufacturers) and involve concrete piloting of innovative solutions. ECSEL funded projects also directly enable the production of less polluting vehicles, taking into account the entire life cycle of the product. In fact, automation and digitalisation are key tools for reducing carbon footprint as they allow significant productivity gains. By developing state-of-the-art technologies

and ensuring their take up along the entire value chain, ECSEL projects help produce less CO2 when building Electric Vehicles and other types of vehicles. In general, more than one participant out of two believes that **ECSEL has a positive environmental impact** precisely due to the enhanced technical and scientific capacity that it enables, through the development and leveraging of "state-of-the-art" technology.

Examples of ECSEL funded projects supporting the development of cleaner transport solutions and the improvement of vehicles' production processes

- The ***3Ccar***[84] project aims at providing integrated components for complexity control in affordable smart electrified cars;
- In addition, this same project is trying to democratise access to EVs by reducing the costs of these products and therefore their accessibility for citizens;
- The ***Ocean12***[85] project has developed a system allowing to use five times less power in the functioning of EVs;
- The ***IoSense***[86] project has developed a demonstrator that enables smart mobility. Such technology can be used to significantly decrease air pollution and emissions.
- ***AutoDrive***[87] is another example of a project which is targeting improvements in the area of automated driving and is therefore contributing towards Mission Zero. With a shift in focus from vehicle to mobility, the project targets to decrease the number of vehicles on the road and rather optimising their use.
- Through exploiting the methods developed within the ***Prystine***[88] project, large industrial players have been able to improve their industrial processes (e.g. losing less energy).

By sustaining the investments in clean transports and putting the spotlight on this domain through its programme's activities, ECSEL substantially contributes to addressing the financing gap identified at the EU level. Furthermore, by bringing the different projects under the umbrella of the ECS ecosystem (through the Mobility Lighthouse initiative), it also multiplies their possible impacts and fosters knowledge dissemination of results.

Besides supporting the development of cleaner transports, ECSEL funded projects also work on many aspects that are crucial for **safety and security of connected vehicles** and especially road transports. This is an area in which ECSEL funded projects are of high value: by enabling collaboration among different sectors and along the entire value chain, ECSEL supports the development of better safety and security solutions, truly building on the knowledge and experiences of all the partners of the ecosystem. While many projects concern the automotive sector, the programme goes beyond road transportation and it also funds projects in other transport and mobility areas.

- The ***ENABLE-S3***[89] project concentrates its efforts in the area of automated cyber-physical systems and increased safety in transportation by reducing human errors in automated driving.
- The ***RobustSENSE***[90] project focuses on the enhancement of sensor technologies to make them increasingly resilient to adverse conditions (such as limited visibility due to snow or excessive rain and fog). Where other sensor systems would shut down, these technological advancements make automated driving significantly safer and available to all parts of the population.
- The ***SWARMs***[91] project developed an integrated platform for sophisticated autonomous and remotely operated underwater vehicles. In the context of this project, human risk in offshore operations and activities such as deep-sea diving was significantly decreased by introducing solutions for unmanned operations with larger precision.

As the above examples show, ECSEL's contribution to security and safety of connected vehicles encompasses a multitude of transportation and application domains, due to the fact that ECS are the basis for any type of connected vehicle. This means that solutions developed as part of ECSEL do not only increase the reliability of specific products and applications (i.e. connected trucks or boats), but also have the potential to increase safety of mobility in Europe overall, as they can be taken up in different transport domains. ECSEL's work in this area therefore strengthens European leadership in the transport and mobility domain by making EU players competitive in the provision of safe solutions, while addressing key societal challenges in the future of mobility.
To address challenge of **vehicle-to-human communication**, ECSEL is funding projects which pave the way for commercialisation of cutting-edge Automated Cyber Physical Systems (ACPS).

Cyber Physical Systems (CPS) are "systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet".[92] Automated Cyber Physical Systems are CPS which also integrate Artificial Intelligence and work with more and more autonomy.

This advanced technology is created with the purpose of enabling humans to hand over part of their responsibilities to machines in order to improve safety. European companies benefit from a strong market position in complex electronic systems interacting with the physical world. In this context, ECSEL funded projects support research and innovation activities focused on automation of CPS (according to the European Commission ACPS 2030 vision[93]) and cover all the six levels of automated driving, ranging from level zero (no automation) to level five (fully autonomous car).
As per the other mobility challenges, the work carried out by ECSEL funded projects in terms of human-machine interaction and development of ACPS technologies is of great value from a societal perspective for two main reasons:

For example, the ***Prystine***[94] project is currently focusing on level 2-3 and aims at combining human vision with Radar and LiDAR technology to ensure enhanced perception of the cars' environment. The combination of these three elements enables a significantly more accurate view of the cars' surroundings.

- Solutions for human-machine interactions are relevant well beyond the mobility domain and have great potential for being reused in other areas in the future.
- Without developing trust in machines and connected vehicles, the take up of these technologies and the size of the related markets will remain more limited.

Therefore, **ECSEL projects currently help establish solutions which will shape the size and characteristics of automated and connected vehicles market.** ECSEL thus sustains the efforts of the ECS industry in a high potential domain and, by doing so, helps both the market to develop and the society to benefit from these market developments.

Finally, some of the ECSEL funded projects are currently working towards addressing other mobility and transport challenges, more related to the question of **Mobility-as-a-Service**. For instance, a recent project is trying to develop a cooperative traffic management system to help address other mobility challenges such as persistent problems of congestion and accessibility. Development of solutions to these challenges can support the shift towards Mobility-as-a-Service approach, which is also known for reducing CO2 impact and increasing the sustainability of human transportation.

3.3. Accompanying the transformation of the healthcare sector for care providers, patients and practitioners

3.3.1. The future of healthcare in Europe: several challenges ahead

A growing and aging population is putting a significant strain on the healthcare systems across the world. By 2030, the global population will have grown to 8.5 billion people, with some 1.3 billion aged over 65.[95] The demand for access to quality healthcare facilities and services will increase in parallel, jeopardising the sustainability of current health systems, as well as the quality and affordability of the care. Innovative approaches, research and technologies are in development, prompting substantial changes in the diagnosis and treatment of diseases, and shifting the focus from therapy to prevention and wellbeing.

ECS technologies play a key role in the development of sustainable and future looking healthcare solutions, by supporting the personalised delivery of healthcare, by smartening existing healthcare providers and by allowing the population to integrate behavioural changes to improve their health. Globally, the MedTech market is forecasted to reach USD 529.8 billion in 2022, growing by 5.2% per year (CAGR) between 2015 and 2022.[96] Europe has a robust healthcare ecosystem, where cooperation among companies, universities, RTOs and hospitals is very dynamic. This has favoured the emergence of solid value chains, encompassing strong industrial players, small companies and innovative start-ups. An average of 10% of gross domestic product (GDP) is spent on healthcare and around 1% of this amount corresponds to medical technologies, giving account of its current and future relevance for Europe.[97] However, Europe is also characterised by fragmented solutions, legislations, healthcare systems and markets, with limited cross-border cooperation. The strengthening of an EU level ECS-healthcare ecosystem is therefore a pre-condition for addressing present and future healthcare challenges.

3.3.2. Nurturing an ECS-Healthcare ecosystem of players and the development of key enabling technologies

The ECSEL funding programme has already led to innovations directly applicable into the healthcare field, as well as to other spill-over effects having the potential to positively contribute to a better quality of life for EU citizens. For one third of the survey respondents, health and wellbeing is one of the most relevant application areas for their organisation and half of the project participants believe that enhanced quality of life, health and well-being is a direct impact of ECSEL projects. This impact on health challenges is linked to several features and characteristics of the ECSEL programme. First, the ECSEL JU is supporting the **strengthening of an ECS-healthcare ecosystem** and the development of **key enabling technologies**. Fostering a closer cooperation between industry and academia within the ECS and healthcare domains, the projects funded under ECSEL have already developed new solutions in various fields that are helping and will help improve patient's wellbeing.

ENABLE-S3[98] focused on Image Guided Therapy systems, which are used in hospitals for a broad range of minimally invasive procedures. The systems use semi-autonomous robotic movements to assist the physician to manoeuvre a robot arm with an X-ray tube and X-ray detector around the patient to obtain optimal X-ray images, while avoiding collisions with patient, staff or devices in the operating room. Another project, ***POSITION-II***[99], focused on the development of the next generation of catheters for better diagnosis, building a pilot line and leveraging platform technologies which can be accessed by different re-users.

Given the relevance of healthcare-oriented projects for the society as a whole, the JU also established the Health.E lighthouse, aiming at accelerating innovation in medical devices and allow cross-fertilisation among projects. By providing coordination among different projects and enabling exchanges among them, this Lighthouse initiative will help consolidate the emerging ECS-healthcare ecosystem and therefore provide a platform for more projects and initiatives to be started in the future.

By funding ECS medical innovation, ECSEL also sustains the **restructuring of healthcare delivery systems, from supply-driven to patient-oriented.** Today, healthcare is provided when the condition already disturbs the life of the patient to an

important degree. This causes the systems to incur in cost-inefficient protocols, which could be improved by the combination of information sources and a higher precision of the different tests and instruments, for example by integrating imaging and AI. In the case of chronic diseases, the costs are determined by long-term pharmaceutical prescriptions and irregular treatments, while patient centric healthcare demands prevention, early diagnosis, and continuous care.

The ***InForMed***[100] project, is supporting the development of solutions for safer and more personalised treatments; automatic diagnosis of certain conditions; and, tools for minimally invasive procedures, among others. These instruments are highly sophisticated allowing for targeted treatments, eliminating the need of trial and error that sometimes is the only manner to find the correct therapy, and reducing the times for diagnostic and treatment. As a result, the healing process tends to be faster.

As this example suggests, the ECSEL programme is already producing concrete results that help improving patients' lives: more will be developed in the future when healthcare-oriented projects will reach a critical mass.

Finally, the outcome of ECSEL funded projects can help **engaging individuals more actively in their own health and wellbeing.** Chronic lifestyle diseases and those related to old age are on the rise. These conditions often need long-term monitoring of the patient's state and rehabilitation support. Early prevention measures and mechanisms to actively engage individuals, including vulnerable people, are becoming increasingly important. Digitalisation and uptake of ECS based solution provide the opportunity of bringing healthcare closer to citizens. The development of digital health ecosystems (comprising digital health platforms, ECS based health monitoring wearables and devices, mobile applications and online services) can empower individuals to monitor, manage, track and improve their own health. It can also help to collect data so as to early capture any disorder, enhancing the probability of fast and successful treatment, as well as to provide targeted solutions. By **developing components and platforms for wearables/implants, data analytics, Artificial Intelligence for precision medicine and personalised healthcare and wellbeing** ECSEL funded projects can improve access to healthcare, reducing inefficiencies.

- The ***SCOTT***[101] project developed an indoor localisation system for hospitals to support assisted living in elderly community care. This electronic monitoring system enables to alert a caregiver of an incident involving an elderly, either at home or in a care facility, decreasing the response time.
- In addition to the numerous smart medical devices produced, through the ***InForMed***[102] project, the ECSEL JU also helped establish a pilot line qualified for the testing, validation and manufacturing of micro fabricated medical devices, as well as a virtual test platform, which supports validation and usability tests with end users in an early phase. These respond to the need to accelerate the innovation process and place product in the markets earlier.

These developments make a higher efficacy and efficiency possible by reducing times, improving accuracy, and minimising risks. Furthermore, they also improve significantly work and life quality of the **healthcare personnel** by providing them with reliable tools, decreasing workload and optimising healthcare system resources. Therefore, ECSEL funded projects already benefit directly European citizens, both patients and healthcare professionals. There are other initiatives within ECSEL JU contributing indirectly to addressing health challenges: improving energy efficiency, reducing pollution and fostering a more sustainable and environmentally-friendly industry, all ultimately aim to provide healthier living conditions for the whole society. While ECSEL is already contributing to addressing some health challenges with the potential of having a positive impact on EU citizens, the ECS-health ecosystem is currently less developed than other application ecosystems under the programme (i.e. mobility). The interviews suggest that the full potential of the healthcare domain has not yet been exploited and, in the future, the Health.E Lighthouse initiative might support an increase in the number of projects and innovative outcomes coming from ECSEL.

4

Conclusions: ECSEL establishing the foundation for tomorrow's innovation

Since 2008, first ARTEMIS and ENIAC and then the ECSEL programme have **supported** to a very significant extent the **innovativeness and performance of the European R&I ECS ecosystem.** By building on the strengths of the ECS sector in terms of research and innovation and by providing a positive framework for trust building and risk taking, these programmes, and ECSEL in particular, have become instrumental for the ECS players and a key pillar of their R&I strategies. While the current ECS ecosystem might need strengthening in certain areas, it still constitutes the main competitive advantage of Europe on a global scale. For this reason, rather than simply having an impact on innovation outcomes, **the ECSEL JU clearly helped establishing the right condition or environment for innovation to happen, in the form of the ecosystem itself.** Its impact and effects on the innovativeness and competitiveness of the overall ECS value chain in Europe happen at the same time at the project level, through the development of innovative solutions and the increased competitiveness of project participants, and at the programme level, by putting in place the right conditions of trust and collaboration in which the ecosystem can strive and innovate.

However, the positive impact of ECSEL is not limited to the ECS ecosystem and the stakeholders composing it. ECSEL also pools public and private resources around key societal challenges and fosters innovation and research directly benefitting European citizens. This societal impact and these direct benefits for citizens are particularly strong in the mobility, health and energy and environment domains due to the current strategic focus of the programme and the existence of strong ECS-sectorial ecosystems in some of these areas (i.e. mobility). Across these domains, the programme and its funded actions allow to establish cooperation around key societal challenges, such as clean mobility or energy efficient industry, and to develop concrete solutions to those, some of which having incredible potential for the future of the ECS industry as well as for all other economic sectors.

These achievements can be explained mainly by some key features of ECSEL, which constitute the drivers for the materialisation of its impacts. These success factors are the tripartite model underpinning the functioning of the Joint Undertaking, the type and size of projects funded and the multidisciplinary and cross-sectorial approach which is encouraged under the programme. However, barriers for impact also emerged and notably relating to the administrative complexity and burden of the programme and the challenges in terms of cooperation linked to the tripartite model. Despite these barriers, both the programme, through the provision of a strategic vision and a framework for collaboration, and its funded projects, through the development of specific solutions, substantially contribute to addressing some of the key EU economic and societal challenges. In many instances, the importance and impact of the ECSEL programme is likely to increase in the future.

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