NanoElectronics Roadmap for Europe: Identification and Dissemination

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1 Executive Summary

The goal of this deliverable is to compare and discuss possible harmonization directions, when possible, for the future of the European Nanoelectronics Roadmap developed within NEREID H2020 European project, as compared to the IEEE International Roadmap of Devices and Systems (IRDS). While the international dimension of IRDS appears to be larger, differences between the two can result from some of the European industrial priorities as well as from the longer-term academic vision that motivated the NEREID roadmap. On the other hand, IRDS is mainly devoted to computing systems while the NEREID Roadmap is also interested in many other electronic systems. In addition, the Roadmap for More than Moore technologies (sensors, power devices, components and circuits for energy harvesting and storage), which is a very important European strength, is only developed in NEREID.

The methodology adopted is based on analysis of structure, technical priorities and thematic keywords in the chapters of two roadmaps. The identified challenges and technology priorities are summarized in a table comparing NEREID chapters with similar chapters in IRDS.

Overall, the structure of the chapters of NEREID roadmap cover future technological challenges in a system-centric approach, including the functional components and their co-integration: nanoscale FETs, connectivity, smart sensors, smart energy and energy storage for autonomous systems but also the roadmapping of systems at a higher level (under smart systems). The system-centric approach is one of the strong points of NEREID and connects it better with More than Moore domain and with Internet of Things application platforms than in case of IRDS. NEREID also covers sustainability aspects of the European ecosystem (via manufacturability) that can be easily extended to international level. For the case of Beyond CMOS, the NEREID roadmap is more diverse and addresses research challenges providing quantitative information where available, or where it can be estimated. Thus, benchmarking and figures of merit are not addressed at the same level as in other chapters partly because the research is not a linear process and Europe has a very diverse and strong community in this field.

In the case of IRDS roadmap, the chapters are built in a more standalone manner and with more technical details than in NEREID, resulting from activities of many large teams of specialists. However, the impression is that the respective teams interact less than in NEREID and are strongly driven by the priorities of international leading industries even though the academic research is involved. The sections of IRDS show both overlap and differences with NEREID; they include many fields such as application benchmarking, beyond CMOS, More Moore, outside systems connectivity, emerging research materials, systems and architectures, packaging integration, lithography, metrology, yield, factory Integration, environment-safety and health.

The interactions between the two roadmaps have been positive and inspirational and the continuity in building them is considered crucial for the future success of the European nanoelectronics and future digital platforms. The observed combination of both harmonized on non-harmonized topics should be perceived as a motivating basis for more future interactions as well as the result of complementary strengths of Europe, USA and Asia.

NEREID Consortium thinks that **a future continuation of roadmapping is a key ingredient for the possible new European mechanism of missions**; a successful ''mission-based'' approach cannot be well formulated and planned without a strongly supporting roadmapping activity, which should be contextually compared at international level.

2 NEREID versus IRDS Roadmap

1. *Beyond CMOS*

The Beyond CMOS chapter surveys the potential of the emerging technologies, new state variables and computing paradigms to provide efficient approaches to information processing, either for distributed computation within the expanding Internet of Things, or to realize accelerators on CMOS platforms to increase the processing speed.

This chapter deals with "Non-conventional information processing approaches and devices", focusing on the technology aspects of emerging information processing methods, and their designs and architectures, concentrating on the potential of these new technologies for information processing and computing from the perspective of low energy processes. The interaction with the design and architectures (see System Design and Heterogeneous Integration) is recognised as crucial for Beyond CMOS technologies to address the emerging computation paradigms.

Both NEREID and IRDS have very comprehensive chapters on **Beyond CMOS**. In IRDS this rather follows the most recent trends in emerging technologies for computation, with benchmarking and validations in close relation with industrial platforms. From the Table below one can observe that: (i) similar approaches and choices are taken in the field of scaling of information processing (with priorities of energy efficient technologies and neuromorphic concepts), (ii) the NEREID roadmap includes a richer variety of potential concepts for long-term research in information processing such as quantum photonic, phonon, Brownian and nano-opto-mechanical computing while the IRDS roadmap stresses quantum computing, (iii) in terms of memories, where the industrial lead is rather in Asia and the US, NEREID focuses on spin-based memory under Beyond CMOS, considering their ability to achieve very low power) while a larger diversity of memory options is considered in the IRDS RM. The other types of memories are consider of a higher level of maturity (OxRAM, CBRAM, PCRAM, FeRAM) and are included in the Nanoscale FET chapter.

Challenges	***NEREID***	***IRDS***
	Technological Focus	
Scaling of information processing	**Neuromorphic computing** **Energy efficient steep-slope devices**	**Neuromorphic,** **Novel architectures,** **Device technology using charges (small slope switches)**
Longer term alternative state/hybrid state variables	**Spinwaves/Magnonics** **Quantum photonics** Phonon, Brownian and nano-opto-mechanical computing	Spin, magnon, phonon, photon, electro-phonon, photon-superconducting qubit, photon-magnon **Quantum computing**
Volatile and nonvolatile memories	**Spintronics**	**Beyond CMOS chapter:** **Resistive memories (PCRAM, ReRAM, MRAM)**

Note: The text in **orange** points out to *different* technological options while the text in **blue** points to *common* technological options (= harmonized). This color code will be used later in all the tables of this chapter.

2. Advance logic and connectivity

2.1 Nanoscale FETs

The historical trend in micro/nano-electronics over the last 40 years has been to increase both speed and density by scaling down the size of electronic devices, together with reduced energy dissipation per binary transition, and to develop many novel functionalities for future electronic systems. We are facing today dramatic challenges for More Moore and More than Moore applications: substantial increase of energy consumption and heating which can jeopardize future IC integration and performance, reduced performance due to limitation in traditional high conductivity metal/low k dielectric interconnects, limit of optical lithography and heterogeneous integration of new functionalities for future nanosystems.

With respect to the challenge of reduction of the static and dynamic power of future high performance/ultra low power terascale integration and autonomous nanosystems, new materials, ultimate processing technologies and novel device architectures (FDSOI, FinFET, Nanowire FET, Carbon NanoTube FET, Negative Capacitance FET, Non-charge-based Memories, 3D integration) are mandatory for different applications using ultimate CMOS, as well as new circuit design techniques, architectures and embedded software.

In the **More Moore** part there is excellent agreement between the two roadmaps. NEREID is promoting more the FD SOI and considers already the negative-capacitance FET as part of Nanoscale FET platform, NEREID include last generation memories (OxRAM, CBRAM, MRAM, PCRAM, FeRAM, FeFET) in this chapter while IRDS considers these candidates as part of Beyond CMOS. On the other hand, in the **Lithography** chapter from IRDS the potential pattering challenges of complex 3D structures are covered also in NEREID but they are more visibly highlighted in IRDS.

Challenges	*NEREID*	*IRDS*
	Technological Focus	
Power scaling	**FDSOI** **FinFET** **NCFET**	**More Moore chapter:** Steep subthreshold slope devices
Novel architectures for improving performance	**Nanowires** **FinFET** **CNTFET** **3D sequential integration**	**More Moore chapter:** **Horizontal & Vertical GAA NW** **3D stacking** **Co-integration of CMOS and beyond CMOS** **Lithography chapter:** **patterning challenges related to cost, yield, defectivity and optimization of complex 3D structures.**
Memories	OxRAM CBRAM MRAM PCRAM FeRAM (FeFET)	**Included in Beyond CMOS chapter**
Modeling simulations tools	**Included in NEREID**	
Characterization tools	**Included in NEREID**	**Metrology**

2.2 *Connectivity*

The connectivity functions are everywhere, making the link between all other electronic functions. From the sensors and actuators to the processors and microcontrollers, from the sensor nodes to the gateways, from the gateways to the cells from the cells to the data centers, and all over the world. Inside each of these units, the connectivity links the computers to the memories, the core of multicores in high performance computing applications, and the peripheral devices to the central computing units.
The connectivity functions can be differentiated depending on the range and the nature. The nature of such function are wireless (in radio frequency mmW, THz bands, or visible light), or wireline (in copper or optical fiber). The range of such functions can be sorted out depending on the distance, the ultra-short range, is in the µm to cm distance; the short range is under 100 m, while the long range covers distances over 100 m.
Presently the largest connectivity market activity is dedicated to data communications, especially for cellular (WAN), WLAN, WPAN, NFC, and incoming WSN and IoT communications.
In the data communication field, three main directions are followed, using the link distance criteria: (i) the outdoor and cellular for example 5G and future generations. (ii) the indoor communication mainly represented today by the WiFi links, and (iii) "in devices" communications, which is not visible to the consumer.
IRDS structured a dedicated chapter on **Outside Systems Connectivity**, which mostly covers challenges of high-end wireless technologies, optical technologies and wireline applications. They also anticipate Virtual Reality technology needs. The chapters of **More Moore** and **Emerging Research Materials** cover reliable alternatives to Cu-interconnects. NEREID has very comprehensive roadmapping on **wireless communications technologies at all scales**, including photonic technologies and anticipating the challenges of 5G where Europe has leading activities.

Challenges	***NEREID***	***IRDS***
	Technological Output	
Ultra low power /energy efficiency requirements	**Outdoor wireless: IoT Long range** **Indoor wireless: WSN, WLAN** **Device to device: NFC, RFID**	
High end technologies (high speed, power, BW, mmWave)	**5G wireless** **5G wireline** **Photonics communications (medium power)** **Die to die, package to package (high frequency)**	**Systems and Architecture chapter – *Mobile*** BW and **display for video, augmented reality, communication and computation** **Outside Systems Connectivity chapter: cancellation of 5G mm wave noise, conversion of electrical and photonic signals**
Wireline applications	**Outdoor: Optical fibers** **Indoor: WLAN, WSN, Data center short range (copper, optical fiber)**	**Outside Systems Connectivity chapter: Reduction of latency of communication between CPUs and memory in data centers specially due to routing**
Localization (wireless)	**Radar, UWB, ultrasound**	
In package/Device photonics wireline applications	**Die to die (Cu links, photonics/active interposer, flip chipped copper)** **Module to module (optical waveguide, multifiber)**	**More Moore & Emerging Research Materials chapters: alternatives to Cu-interconnects with low resistance, good reliability and electromagnetic**

	Active cable (optical guide/fiber, plastic mmWave)	performance at the nanoscale **Outside Systems Connectivity chapter:** agreement on optical technology standards

3. *Functional Diversification*

3.1 Smart Sensors

Global challenges for today's technology concern more sustainable, ICT-enabled strategies for *healthcare, energy and environment.* The role of edge-of-the cloud devices and of the generated big data are expected to drive the creation of new ecosystems and include 11% of the world economy by 2030. In addition, the technology is moving from simple sensing to *smart sensing* in almost every object, enabling new classes of services and applications.

The exercise of performing a smart sensor roadmap was initiated in Europe and is broad, complex and diversified because sensing technologies are very diverse and not driven just by scaling and costs, such was the case of CMOS. Europe played a pioneering role in understanding and predicting the exponential growth and importance of smart sensors to support edge of the cloud applications in the future economy. Firstly, by the FET Flagship initiative Guardian Angels for a Smarter Life in 2011 and followed by the so called 'Trillion of sensors planet' proposed by some industries. **NEREID is leading this part of roadmpaiing at international level and proposes a very comprehensive and detailed analysis, with choices of technologies that are meeting particular needs in healthcare and automotive.** Indeeed, among many domains for smart sensor applications, NEREID has chosen to focus on two main fields: (i) *healthcare* and (ii) *automotive*, as application drivers of strategic importance for Europe. These two fields have a high relevance for European industry and research. In addition, the challenges of most of these sensors are similar and relevant for industrial segments such as consumer electronics (MEMS accelerometers, magnetic, chemical and gyroscopes), industrial (image sensors), infrastructures (air quality gas sensors) or defense (LiDAR sensors). Overall, connected objects (as part of Internet of Things, IoT), big data, software and algorithms, zero-power or self-powered sensors, sensor fusion, wireless sensor networks and system-in-package are all important topics for a more complete sensor roadmap.

Challenges	***NEREID***	***IRDS***
	Technological Focus	
Sensors for navigation and car's basic system performance	**Motion sensors (MEMS gyroscopes, accelerometers)** **Pressure sensors**	Not addressed
Advanced drive assistance systems (ADAS): Sensors for autonomous cars	**Image sensors (CCD, CMOS, SPD, BSI)** **LiDAR** **Infrared Detectors (microbolometers, pyroelectric, thermopiles, thermodiodes)** **Long/Medium-Short range Radars (Si, SiGe)**	Not addressed
Pollution/Air quality environmental monitoring: Gas Sensors	**MOS** **MOS-CMOS** **MEMS Micro hotplates**	**Systems and Architectures chapter –** ***IoT*** **Low power sensing, computing and**

	CMOS imagers Optical IR sensors MEMS, Spectroscopy Polymer, CNT-based Moisture absorbing materials Quantum dots, NWs, Nanomaterials Particulate Matter PM2.5 PM10	communication, automatic network configuration and security
Physiological Signal monitoring - Wearables	Patches, Tatoos ISFET, FinFET, Graphene, NWs	**Systems and Architectures chapter – *IoT*** Low power sensing, computing and communication, automatic network configuration and security Packaging Integration Chapter: reliable substrates for wearable electronics (bendable, washable) **Environment, Safety, and Health chapter**
Implantable Sensors - Bionics	Wireless power supply Hermetical packaging Long term sensitibity/stability	**Packaging Integration Chapter:** Bio-compatible systems for miniaturized implants Environment, Safety, and Health chapter
Molecular Diagnosis	Label free FET SC NW Capacitive CMOS Imagers	Environment, Safety, and Health chapter

3.2 Smart Energy

Power devices based on wide bandgap semiconductors (WBS), like GaN, SiC, are poised to play an important role in future power electronics systems. WBS has a high breakdown strength and, in the case of GaN, allows for fabrication of high electron mobility lateral transistors, for which the electron mobility is not degraded as would be the case for traditional silicon MOSFETs. These facts combined allow the fabrication of devices which have orders of magnitude better trade-off between the specific on-resistance of the devices and the breakdown voltage.

The roadmap for devices has been set up along three tracks, the first considers the GaN based devices starting from materials towards integration. The second track is related to the evolution of SiC (again from materials to applications). Finally future material systems (AlN, Diamond, Ga2O3) are considered which could offer benefits over the actual WBS in certain domains.

Challenges	***NEREID***	***IRDS***
	Technological Focus	
GaN devices and substrates	GaN-bulk substrate GaN-on-Si substrate Normally OFF devices, Vertical devices On-chip integration	Not addressed

	Ohmic contacts **Gate architectures**	
SiC-based substrates	**Thick epi-layer with low defect density and high V** **Trench power devices with high gate oxide reliability** **Bipolar devices** **Solid state circuit breakers** **Advanced passivation for high V and 3D integration** **Self-aligned processes for high manufacturability** **Wafer thinning and bonding**	Not addressed
Alternative Wideband Semiconductors	**AlN native substrate** **Ga_2O_3 substrate** **Diamond**	Not addressed

3.2.1 *Energy for Autonomous Systems*

As the communicating systems market is booming, the role of energy harvesting (EH) will be growing. Indeed, the number of connected devices is planned to increase by a huge factor of 200, while the number of mobile phones is just planned to increase by a factor 3. Connected devices are going to be used more and more in several fields such as healthcare, wearables, home automation, etc. The Internet of Things (IoT) market grows considerably leading also to the boom of the connected devices, and so highlighting the importance of energy needed to supply them in view of the limitations of current battery technology. In this particular case, we are focusing on small connected devices with low power consumption below a few mW (or even a few tens of µW).
Different wasted energy sources can be exploited and converted into electricity: sun or artificial light, heat, mechanical movements and vibrations... Moreover this converted energy needs to be used and transferred wisely to sensors, microcontrollers or other electronic components included in the system. Thus power management circuitry becomes also an essential element.
Several promising technologies for EH and power management circuits include photovoltaic cells for outdoor/indoor light EH, mechanical EH based on two concepts: piezoelectric materials and electrostatic energy conversion, and finally the power management circuits. **NEREID uniquely started the roadmapping for energy harvesting and management for autonomous systems**. The only overlap in harmony with IRDS concerns the battery technologies where IRDDS has activities on technologies for increased battery capacities focused on mobile technologies.

Challenges	*NEREID*	*IRDS*
	Technological Focus	
Improve efficiency with reduced surface/volume	**<u>Mechanical EH:</u>** **-Electrostatic transduction (new materials: Fluorin polymers)** **-Piezoelectric transduction (develop packaging)** **<u>Thermal EH:</u> Improve efficiency of thermal to electricity**	

	transformation near room temperature.	
Improve scalable technology at low cost (and minimum energy)	Mechanical EH: Electrostatic Higher energy density Thermal EH: SiGe based solution (bulk and thin films)	**Systems and Architectures chapter –** IoT efficient EH autonomous systems using multiple sources, energy storage and management
Increase reliability/ stability vs. time	Mechanical EH: Electrotatic stable layers with time, polymers.	
Improve Performance	Electret materials: charge leakage reduction Porous piezoelectric material PV cell output power density: (Si, SC compounds, etc.)	
Flexible at low cost	Photovoltaic EH: Thin-film PV cells (perovskite, organic, DSSC, etc.)	
Green solutions	Thermal EH: not based on Bi2Te3. Nanostructure materials SiGe-based. Mechanical EH: -Piezoelectric transduction: Lead less piezoelectric materials (composites, nanocomposites, etc.)	
Micro power management	Battery less start-up from fully discharge state Fully integrated batteries, converters and miniaturization of magnetic compounds	**Systems and Architecture chapter** – Mobile increase battery capacity

4. *System Design and Heterogeneous Integration*

Building a roadmap for System Design and Heterogeneous Integration is a tough challenge, because of the variety of applications involved, demanding for very different requirements, sometimes even contrasting in terms of values, limits and importance. Several roadmapping attempts have been done in the past. The first example is the 2007 revision of ITRS43 where some quantitative Figures of Merit (FoM) were given in terms of percentage of improvement over standards or targets. In the following ITRS revisions (200944 and 201145), quantitative FoMs have been replaced by bar charts, related to the topic's development status with respect to the time horizon.

It is therefore justified to consider a new approach for roadmapping System Design and System Level Applications, which goes beyond the simple inclusion of static numerical tables. The NEREID approach is to build a general *Top-Down* description of the requirements (a hierarchical map) that has to be met in a *Bottom-Up* process, with concepts, methods, values and expectations strictly related to the application of reference.

The **Packaging Integration** chapter of IRDS is well harmonized with the **NEREID System Design and Heterogeneous Integration**. Parts of the chapter on **Emerging Research Material** are also in good agreement with the heterogeneous integration of this chapter (Ubiquitous/Pervasive concept) covering the integration of emerging materials (bio-compatible, flexible electronic) in CMOS platforms. Similarly, the **Factory Integration** chapter from IRDS tackles the environmental issues, which are covered in the same Ubiquitous/Pervasive concept. On the other hand, IRDS has particularly strong roadmapping activities on Application Benchmarking, including the Big Data Analytics and the Cloud.

Challenges	***NEREID***	***IRDS***
	Technological Output	
Functionalities	**Integration in Systems of Sensing capability, Computing/ storage capabilities, Interfaces /Communication, Learning capabilities, Autonomy**	**Packaging Integration Chapter:** **Efficient integration of electronic and optical components** **Application Benchmarking chapter** – ***Big Data Analytics:*** **improvement in algorithms, memory BW, lower latency and higher BW of the global network** -***Cloud*** **High BW memory and large socket thermal power dissipation using improved packaging and cooling**
Physicality's	**Energy/power, Response time Form factor**	**Metrology chapter**
Criticalities & opportunities	**Manufacturability, Cost Compatibility/Standardization System level reliability Quality of Service (QoS)**	**Factory Integration chapter**
Design paradigms	**HW/SW Co-design Reconfigurability/Flexibility Artificial intelligent, Bio-inspired, Neuromorphic computing Energy aware & energy driven**	**Packaging Integration Chapter:** Bio-compatible systems for implants, integration of cooling systems for quantum computing **Application Benchmarking chapter** – ***Feature recognition:*** DNN HW with digital or analog computation, low power high BW and extremely area efficient A/D converters
Design activities	**MultiPhysical Domain Modelling MultiParametric Analysis Optimization, Prototyping Constraints aware design Network Synthesis**	**Some parts in Metrology chapter**
Energy autonomy	**Low power architecture, long-lifetime storage, battery integration**	**Systems and Architecture chapter** – ***Mobile*** low power **consumption**
Connectivity	**Low-cost power-efficient Antenna massive multiple frequency, multiple antenna M-MIMO**	**Outside Systems Connectivity chapter:** Reconfigurable and high efficiency directional MIMO antenna with circuits of reconfigure and synchronize signals
Sensor integration	**Adaptive intelligent data**	**Systems and Architectures**

	acquisition **MultiParametric Sensing**	**chapter –** *IoT* Low power sensing, computing and communication, automatic network configuration and security
Reliability, functional safety & security	Lifetime, verification & testing **Harsh environment**	**Packaging Integration chapter: reliable interconnects and bio-compatible miniaturized bendable-washable systems** **Systems and Architecture chapter – *Cyber physical systems* HW and SW reliability, security**
Ubiquitous/pervasive	**Low cost manufacturing for heterogeneous integration, miniaturization, eco-friendly and recyclable materials**	**Emerging Research Materials chapter: Integration on CMOS Platforms, with flexible electronics and of biocompatible functional materials.** **Factory Integration chapter: tackles environmental issues like material recycling, substitution and global regulations** **Environment, Safety, and Health chapter**

5. Equipment and Manufacturing Science

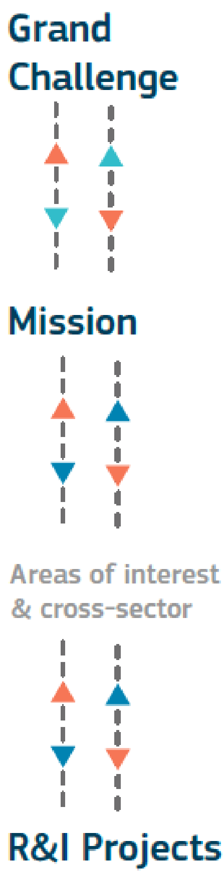
NEREID's approach to create a comprehensive "NanoElectronics Roadmap for Europe" is quite a challenge, in particular for Equipment and Manufacturing Science, where all other topics of the roadmap, e.g. Beyond CMOS, Nanoscale FET etc., have to be considered from equipment, materials and manufacturing perspective. At present it is mainly concentrating on equipment and materials, but does also reflect some manufacturing related things as well. It approaches also when the corresponding equipment and materials have to be available on the market for the different technologies.

IRDS has a chapter in **Emerging Research Materials**, which maps the Moore More manufacturing materials requirements while the **Yield** and the **Factory Integration** chapters from IRDS cover the productivity, automation and yield that appear in our manufacturing science concept. **NEREID uniquely covers manufacturability for both More Moore and More than Moore,** the last one is specific to NEREID and includes the components in relation to Functional diversification. NEREID believes that there will be unique opportunities for manufacturing in More than Moore, motivated by the Smart Systems and future massive use of sensor nodes in IoT.

Challenges	***NEREID***	***IRDS***
	Technological Output	
Moore More	**Manufacturing for Nanoscale FET CMOS (Si, SiGe, III/V, FDSOI, FinFET, NW, 3D sequential) Emerging Devices Beyond CMOS (tunnelling FET conventional and 2D materials, from charge based to spin based)**	**Emerging Research Materials Chapter: alternative materials in the field of 3D monolithic and vertical integration of high mobility and steep subthreshold transistors (III-V, Ge, 2D, CNT, Complex metal oxides, etc) to replace CMOS.**

	Interconnects (advance low-k to airgap, Cu based, beyond Cu)	Emerging non-charge-based memories, Ferromagnetic, Multiferroic, Complex Oxides to replace DRAM/SRAM/NVM CNT novel interlayer dielectrics e.g. Metal Organic Framework and Carbon Organic Framework to replace Cu.
More than Moore	Manufacturing for sensors (multiparameter, autonomous, new materials, SiP) Energy (GaN, SiC)	
Manufacturing Science	ESH Productivity Automation Yield	**Factory Integration chapter:** cost-effective, leading-edge factory Yield: covering next generation inspection technologies to discriminate defects as speed SEM, near-field scanning optical microscopy, interferometry, scanning capacitance microscopy and e-beam. In-line characterization and analysis

3 NEREID versus other Roadmaps and as enabler of Future Mission-Oriented Programs of the European Commission



The NEREID Roadmap has the particularity to privilege focus from medium to long term time horizons for nanoeletronics, and can be considered as complementary to the ECSEL ECS-SRA (Electronic Components and Systems Strategic Research Agenda) as well as to ECSEL MASRIA, which are focusing on shorter terms and strongly driven by industry. From this point of view the NEREID roadmap offers clear added value to the European digital and technological research agendas.

In this deliverable, a comparison of the NEREID roadmap has been carried out versus IRDS, which is the most relevant in the nanoelectronics field and has a similar level of ambition as NEREID. However, the Consortium is aware that there are other roadmaps with which would be relevant to compare. Some of them are very focused, such as for instance the "International Technology Roadmap for Wide Bandgap Power Semiconductor", and the exercise of this deliverable was not supposed to go into this level of details per all the individualized domain roadmaps. Another important aspect of NEREID, is that it includes a dynamic evolution of the main figures of merit with the time horizon for most promising technologies, not included for example in the ECS SRA. It is worth noting that NEREID has some commonalities and is developing joint collaboration with the new International IRDS Roadmap especially in the fields of More Moore, Beyond CMOS and computing systems, but is also complementary to IRDS with very important NEREID activities in the More than Moore domain (e.g. Smart Sensors, Smart Energy, Energy Harvesting), which is a sound European competence, leading to a large diversity of electronic systems useful for many applications. In the More Moore field, there are also strong interests in Europe for specific activities dealing with very low power systems, leading to possible disruptive applications for instance for future IoT systems, or for application driven performance, e.g. high temperature operation for the automotive industry. Therefore, the NEREID Roadmap takes into account the specificity of the European industrial and academic landscape and can serve as input for future research programmes at European and National levels in order to join our efforts to overcome the main Nanoelectronic challenges and put the EU at the forefront of future technological developments.

Finally, one important aspect concerns the consideration given today and in the future in Europe to mission-oriented research. In the Mazzucato's report[5], it is mentioned that: *'Mission-oriented policies can be defined as systemic public policies that draw on frontier knowledge to attain specific goals or "big science deployed to meet big problems. Missions provide a solution, an opportunity, and an approach to address the numerous challenges that people face in their daily lives'.* These missions, in case they will be adopted and implemented, will better formulate the interface between R&I projects and challenge to achieve. They will require long term research but at the same time strong connections with well defined targets. Conducting a mission at long term will require technological roadmaps as the ones propose here by NEREID, to align and connect the best emerging technologies at various time horizons. Therefore, NEREID activities should be continued in the future to achieve such continuity and readiness of both the research communities and of industries to address such ambitious endeavours.

4 Conclusions

In this deliverable we analyzed the specificities and differences between the NEREID and the IRDS roadmaps, thus positioning the work performed in NEREID in an international context.

The interactions between the two roadmaps have been inspirational and provided international visibility to NEREID, with teams participating with specific inputs to IRDS RM. In reciprocity, members of IRDS have been invited in the advisory board of NEREID. NEREID is a system-centric roadmap that is better adapted to the European priorities in industry and R&D. Its uniqueness originates in its **excellent broad coverage on More than Moore technologies and their system applications** as well as in a **longer-term perspective for Beyond CMOS**, which is not necessarily anchored to the short-term industrial priorities**.**

It is worth noting that **without a future continuity, the NEREID effort will have less impact on European nanoelectronics and future digital platforms, despite his present relevance and success**. NEREID Consortium sees such a continuation of roadmapping as a key component for connecting into the new European mechanism of missions.

[5] MISSIONS - Mission-Oriented Research & Innovation in the European Union, A problem-solving approach to fuel innovation-led growth European Commission Directorate-General for Research and Innovation - A problem-solving approach to fuel innovation-led growth by Mariana MAZZUCATO, 2018.