INESC TEC Scientific Advisory Board Visit Report

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1. Introduction

Per the INESC TEC Statutes, the external monitoring, guidance, and evaluation of scientific activities shall be carried out by the Scientific Advisory Board (SAB) which shall regularly assess INESC TEC's overall operations and issue an opinion on INESC TEC's activity plans and activity reports. To fulfill its responsibility, the SAB conducted a visit on November 10 & 11, 2021 at INESC TEC Porto, Portugal. This report summarizes the SAB's findings and recommendations from said visit.

The INESC TEC Scientific Advisor Board (SAB) is composed of:

Dr. José Fortes (Chair)	University of Florida, USA.
Dr. Elsa Angelini	Imperial College London, England.
Dr. Anne-Marie Kermarrec	EPFL - L'Ecole Polytechnique Fédérale de Lausanne, Switzerland.
Dr. Masaru Kitsuregawa	National Institute of Informatics, Japan.
Dr. Edward Knightly	Rice University, USA.
Dr. Robert Lieberman	Lumoptix LLC, USA.
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Dr. Pere Ridao	Institut de Recerca en Visió Per Computador i Robòtica, Italy.
Dr. Tomás Gómez S. Román	Universidad Pontificia Comillas, Spain.
Dr. Bruno Siciliano	Università degli Studi di Napoli Federico II, Italy.
Dr. M. Grazia Speranza	Università degli Studi di Brescia, Italy.
Dr. Volker Stich	Aachen University of Technology, Germany.

All but Dr. Volker Stich and Dr. Bruno Siciliano participated in the visit. Dr. Masaru Kitsuregawa, Dr. M. Grazia Speranza and Dr. Mario Paolone attended parts of the visit remotely. Dr. Gerhard Gudergan from Aachen University of Technology participated in-person in representation of Dr. Volker Stich.

All the members who participated in the visit contributed to this report.

This report is divided into three major parts:

- Context and objectives of the visit
- Key findings and recommendations to the Board of Directors.
- Reports for individual scientific domains at INESC TEC.

2. Context and Objectives of the INESC TEC Site Visit

INESC TEC is a dynamic institution described in its Activity Plan 2021 as "a private, non-profit association dedicated to scientific research and technological development, technology transfer, advanced consulting and training, and pre-incubation of new technology-based companies." The primary focus of the SAB visit was to provide feedback on scientific research activities while secondarily considering the other INESC TEC activities which interplay with scientific work.

According to the Activity Plan 2021, the INESC TEC vision is "to be a relevant international player in Science and Technology in the domains of Computer Science, Industrial and Systems Engineering, Networked Intelligent Systems, and Power and Energy." and "The dual mission of INESC TEC is to excel in research and to seek its social and economic impact, with a unifying commitment to the scientific and technological aspiration of fostering pervasive intelligence". Also, according to the Activity Plan 2021, "Research at INESC TEC is undertaken by its 13 Research Centres, brought together in Clusters for strategy development and long-term planning of the institute's four scientific domains: Networked Intelligent Systems (NIS), Power and Energy (PE), Industrial and Systems Engineering (ISE) and Computer Science (CS)."

The last SAB visit took place in 2017. Since then, the membership of the SAB was reconstituted in 2020 with only five out of its current twelve members remaining from the previous SAB, a new Board of Directors (BoD) was put in place retaining five out of nine members of the previous BoD, and INESC TEC's organization has continued to evolve. The COVID pandemic limited the interactions between the SAB and INESC TEC to a 1-hour Zoom session on May of 2020. This year's visit provided a first opportunity for the renewed SAB to get acquainted with the new INESC TEC's organization, researchers, and leadership.

The two-day visit was structured to provide during the first day a high-level overview of INESC TEC followed by four parallel sessions with presentations of activities of each scientific domain followed by a plenary session presenting cross-domain interdisciplinary activities. During the second day, the SAB first convened in closed session and later reported its preliminary findings to the BoD and INESC TEC researchers. INESC TEC provided to the SAB the following documents:

- 2021 INESC TEC Activity Plan
- INESC TEC Overall Presentation
- ISE Domain Presentation
- PE Domain Presentation
- NIS Domain Presentation
- CS Domain Presentation
- INESC TEC Multidisciplinary Research Presentation
- SWOT Analysis and Questions for the SAB

This report presents the final version of the SAB's key findings and recommendations, its responses to questions asked by the BoD and its feedback on the activities of each scientific domain.

3. Findings and Recommendations to the Board of Directors

3.1 Key Findings

3.1.1 Excellent Overall State of INESC TEC

The SAB was impressed by INESC TEC's large scale, healthy financial conditions, privileged geo-economic position and high performance for several metrics. INESC TEC synergistically assists and receives support from industry and people in northern Portugal whose GDP per capita matches 85% of Portugal's and 65% of European Union's. INESC TEC is recognized within Portugal as a key source of scientific and technological expertise to address national challenges. It has also become a desirable partner in international projects, particularly in the European context. In terms of human resources, INESC TEC's size at approximately 846 staff members (including about 332 permanent researchers) makes it one of the largest institutes in Europe. It also allows INESC TEC to have an extensive R&D portfolio covering multiple disciplines and enabling many successful interdisciplinary projects. INESC TEC has also engaged in long-lived international partnerships and projects with prestigious institutions from, for example, Europe, USA, and Brazil. The ongoing collaboration programs with CMU, MIT and UT Austin are particularly noteworthy. INESC TEC's annual expenditure of 18 million Euros is impressive. The expenditure growth appears to be sustained over time, with significant increases from 2014 to 2017 and from 2017 to 2020. INESC TEC investment in scientific infrastructures has increased by an order of magnitude since 2017.

3.1.2 Unique Successful INESC TEC Profile

INESC TEC is unique (in a good way) because its activities occur at all TRL levels, reflecting and enabling the translation of scientific discoveries into prototypes, products and services that are used by industry or originate start-ups, ultimately having a positive economic impact. The aligned combination of scientific domains and technology platforms (the so-called TEC4s) provides bidirectional pathways between science contributions and technology innovations in support of market and societal needs. The presence of basic research at INESC TEC gives to technology developers instant access to "consultants" who are world-class scientific experts. At the same time, the connection to "real-world" problems provides fertile ground for the discovery of new science. INESC TEC funding has achieved a good balance between low-TRL grants and high-TRL activities which appear to be equal contributors. Science funding brings in approximately 50 % of the total institutional budget. This diversified portfolio bodes well for the long-term sustainability of INESC TEC and its ability to adapt to changes in funding trends and economy downturns.

3.1.3 Impactful INESC TEC Contributions

INESC TEC's operationalization of its managed science model has proven in the recent past to be increasingly effective, as shown in 2020 by more than 715 scientific

publications (including 397 papers in indexed journals), 18 patent families and 4 active spin-offs (excluding past spin-offs which are now successful companies in which INESC TEC is no longer active). Overall, there is strong evidence of impactful contributions at all levels: academic, technology transfer, economic and public good.

3.1.4 Unique Timely Interdisciplinary Projects

Several INESC TEC large interdisciplinary projects clearly illustrate the benefits of its unique profile and differentiate INESC TEC from organizations that are mostly academic or mostly technological. Four such projects highlighted in the visit – CORAL, INTERCONNECT, VCardID and EU-SCORES – show how INESC TEC can have technical leadership positions at the national and international levels, and build large multidisciplinary teams as needed to address complex scientific and societal challenges.

3.1.5 Academic Levels of Scientific Productivity

In the context of INESC TEC's unique profile as an institute dedicated to both science and technology, the scientific productivity of its researchers matches many academic institutions that are mostly focused on science. With an annual production of 715 publications by 352 Full-Time-Equivalent (FTE) researchers, scientific paper productivity stands just under 2.1 publications per researcher, a rate also observed in engineering departments of many universities[1].

3.2 Key Recommendations to the Board of Directors

3.2.1 Improve Identification and Description of Strategic Objectives

The SAB recommends more clarity in the characterization of strategic objectives for INESC TEC in general, and for its scientific activities in particular.

For example, the current statement of INESC TEC's vision in its Activity Plan 2021 aims for a somewhat vague institutional status ("relevant international player") regarding its generic scientific domains instead of specific objectives to which INESC TEC aims to contribute. The SAB recommends that an effort be made to identify both a 5-year and a 10-year vision, as that will help the institution focus its internal activities and sharpen the external perception of its scientific and societal roles. Currently, within each scientific domain, the list of scientific challenges appears as an inventory of what is being done. However, what is desirable as a vision is to have a set of strategic objectives and priorities to guide the future activities of researchers in the domain. The SAB understands that INESC TEC activities are bottom-up in the sense that they are initiated by researchers in the 13 distinct centers and laboratories, often in response to external

[1] INESC TEC's formula for the number (337) of core FTE researchers is (0.5× #Academic Staff) + (1.0 × #R&D Employees) + (0.3 × #Grant Holders) where #Academic Staff = 169, #R&D Employees = 152 and #Grant Holders = 334. The number of FTE (core and non-core) researchers is 352 which is computed as the number of core FTE researchers plus (0.2 × #Affiliated Researchers) where #Affilated Researchers = 77.

solicitations. Nevertheless, in order for INESC TEC to be more than the sum of its constituent centers, it needs to also have an institutional vision that aims at large-scale interdisciplinary initiatives (such as those mentioned in 3.1.4) across multiple domains addressing specific objectives. The Activity Plan 2021 mentions the role of "clusters for strategy development and long-term planning of the institute's four scientific domains" but the SAB saw little evidence of the outcomes of this approach. By considering 5-year and 10-year horizons, INESC TEC can properly account for and avoid short term constraints in its thinking, respectively. For example, grand-challenge initiatives that exceed the scale and scope of those possible within 5 years could be envisioned in a 10-year period.

Similarly, the current statement of INESC TEC's mission should convey more clearly the purposeful actions that INESC TEC will take to contribute to the achievement of its vision. The second half of the following current wording "to excel in research and to seek its social and economic impact, with a unifying commitment to the scientific and technological aspiration of fostering pervasive intelligence" has unclear different meanings for different readers. Clear vision and mission descriptions directly impact how INESC TEC should be assessed since the appropriate metrics should track how well INESC TEC is fulfilling its mission and contributing to its vision.

3.2.2 Improve Scientific Production

The SAB recommends the continuation of efforts aimed at increasing both the number and the quality of scientific publications with the goal of matching the top percentile of peer institutions. This requires INESC TEC to identify its national and international peers who are also likely to be its competitors for scientific projects and contributions. The SAB was pleased to see INESC TEC's emphasis on good venues for scientific publications and presentations. INESC TEC can build on this emerging culture of good publication practices to set targets in line with scientific production metrics of top performers.

The SAB was impressed by the open-science and open-data policies and practices adopted by INESC TEC with leadership and logistics provided by the CS domain and INESC TEC's information technology services. These practices enhance the visibility of INESC TEC science products (datasets, publications, and software) to the broad scientific community and the general public, thus contributing to the scientific prestige of INESC TEC. Consideration should be given to the tracking of the numbers of contributions to open data/science spaces/repositories to be used as metrics that can complement other measures of INESC TEC's scientific performance. The SAB also noted positively that several INESC TEC projects and publications explicitly deal with data governance and management. Collectively, the open data and science projects and practices are well aligned with the scientific objectives and regulations of funding agencies in Europe and elsewhere, contributing to the competitiveness of INESC TEC in obtaining research funding.

3.2.3 Grow Competencies Strategically

INESC TEC has extensive human resources which include partial-time faculty from several universities, PhD students and full-time R&D employees. In terms of FTE employment, INESC TEC has 337 core FTE researchers of which 168 have PhD degrees. The SAB recommends future evolution of the workforce to occur in a strategic manner which was not apparent from the presentations. Specifically, new researchers should be recruited to fill existing expertise gaps needed for INESC TEC to pursue strategic research opportunities. This alignment of hiring choices and strategic directions is particularly important for full-time R&D employees who must contribute to secure their own funding. A clear career path that is related to strategic objectives is important for both the success of full-time researchers and the continued success of INESC TEC. Therefore, the strategic plan of INESC TEC should explicitly include the identification of the competencies that it needs to develop via hiring, partnerships, and employee training. This strategic hiring plan should include proactive means of increasing gender and cultural diversity, along with the needed monitoring to assess effectiveness of the mechanisms used for outreach and recruitment.

3.2.4 Seek to Establish Scientific Breakthroughs

Recognizing the unique position of INESC TEC as a successful institution in bridging from fundamental research to fully deployed solutions, the SAB recommends to INESC TEC to target grand interdisciplinary challenges that have the potential for scientific breakthroughs in addition to designing state-of-the-art solutions to hard but small-scale problems. INESC TEC's strategic vision could include solutions to grand challenges related to, for example, clean energy, environment, population health and wellbeing, aging, misinformation, or disaster resilience. The SAB felt that the existing research and development capacity of INESC TEC along with large projects already tackling wide-impact technological problems (e.g., Interconnect and EU-SCORES in the domain of Energy) position it well to have higher and larger technical ambitions. In practice, the mission of INESC TEC includes everything from basic science to near-final engineering. In this environment, it is important to acknowledge that true scientific breakthroughs usually come from projects that entail significant risk. "Stretch goals" should be established and tied to major research initiatives (such as grand challenges), but staff must be made to feel secure that even a 50% success rate in achieving these goals is a major accomplishment and will be rewarded.

4. Feedback on Individual Scientific Domains

4.1 Computer Systems

4.1.1 Overall Impression

Clearly, the Computer Systems (CS) domain is at the forefront of research in Portugal and includes highly qualified and internationally recognized researchers. The presentation

of the CS domain provided the SAB with a good overview of the ongoing CS activities at INESC TEC. The SAB greatly appreciated the fact that, in addition to the main presenter, the researchers were themselves called to discuss their activities during the session. This style of presentation led to fruitful interaction between the SAB members and the researchers. Integrating into the formal presentation a few slides stating researchers' names and their universities would have enabled the SAB to become acquainted with the researchers and to better assess the collaborations among INESC TEC groups from different universities.

4.1.2 Scientific Results and Impact

The research conducted in the CS domain at INESC TEC is timely, the researchers are highly competent and are well-aware of the national and international competition. The challenges they focus on are well identified and the research contributions have excellent scientific level in the areas of machine learning, computer graphics, sustainable IT, dependable information systems, and trustworthy computing. The research group has strong international collaborations (MIT/CMU/etc.) and there is a balanced coverage between AI and systems research. More specifically, the works on HPC and Software-defined storage provide support for AI algorithms and address the bottlenecks of distributed computing. There is a very clear and original positioning of research in distributed systems. Finally, the formal-method approach for privacy-preserving ML is novel and promising.

The publication record is very good with a clear drive towards high quality. It should be noted that huge efforts are put in conducting experiments, collecting data, and generating the material needed to perform and publish system-oriented research, notoriously known to require much more time than theoretical work.

The SAB observed a strong participation of INESC TEC CS researchers in interdisciplinary projects and collaborative EU projects. The numerous company-supported grants are important for young researchers to acquire experience in working on practical problems. The number of large-scale projects is one of the most important indicators to measure the activity and vitality of the organization.

Strong efforts are put towards societal contributions such as the COVID contact tracing app which quick implantation is quite impressive. Also impressive is the CS domain output in terms of transfers of technology and startups.

4.1.3 Recommendations for the Future

It was brought to the SAB's attention that there is a growing difficulty in attracting faculty and PhD students. Building up a strong INESC TEC doctoral school could increase the attractiveness of INESC TEC. The alumni network could also be leveraged to promote the PhD program. The benefits of the institute, such as potential for engaging in technology transfer, startup opportunities along with basic research and a supportive environment should be clearly advertised. Finally, a company-university model (where students simultaneously work in industry and carry out graduate studies) should also be

considered as a possible way to capture students who would otherwise never consider graduate studies because they wish to join industry.

The SAB observed an opportunity-driven approach to research that could easily be complemented with a long-term vision at the level of the domain.

The SAB appreciated and was impressed by its interactions with the young CS researchers. INESC TEC should leverage their knowledge and enthusiasm by engaging with them in identifying CS domain strategies, helping them advance their careers and get promoted.

The fact that the number of publications has been going down is explained by the desire to publish at higher quality conferences and journals. Clear identification of the venues and metrics of success could clarify the targets.

4.2 Industrial and Systems Engineering

4.2.1 Overall Impression

The SAB was impressed by the Industrial Systems and Engineering (ISE) domain's significant research capability with a more-than-adequate level of output. The overall research approach is well suited to solve current and future challenges, which are characterized by ever-increasing level of complexity. In this context, the domain's work on design science strengthens its innovation-oriented and engineering-driven research.

The SAB was also positively impressed by the ISE's research group in terms of its experience and competencies. In particular, the experience of researchers contributes to the maintaining of a high level of quality and further developing an outstanding capability for the future. However, in terms of building strong competencies for the future, there is also a point that should be given special attention: the number of PhDs has decreased significantly over the reporting period of the last 4 years. The development of a strategy against this trend should be considered seriously, as the number of PhDs determines the future research capacity for the INESC TEC ISE domain.

IP protection, commercialization and patents have been appropriately addressed. Furthermore, there is a clear capability in technology transfer. It might be useful to develop more specific dissemination and transfer plans. Beyond involvement with the industrial data space consortium, more involvement in international standardization bodies could be considered to enhance the dissemination and transfer of scientific results.

Based on the presentations and discussions, it was unfortunately not clear how feedback loops from companies or industry in general are implemented. The establishment of expert groups, working groups and committees could be a suitable means of achieving this. Furthermore, it remained unclear how the different groups are collectively working to achieve a specific societal impact. Similarly, based on the information exchanged, it

remained unclear how outreach to STEM education and public is or will be achieved in the future.

4.2.2 Scientific Results and Impact

In general, the ISE research group is very impressive in terms of its scientific results and publications. However, due to the uniqueness of INESC TEC as an institution, it remains a challenge to make an ultimately objective classification. For purposes of self-assessment as well as for continuing improvement, it would be very helpful for INESC TEC or the ISE domain to identify a peer entity for benchmarking purposes. This would make it easier to comparatively assess the real performance of the ISE domain and would likely stimulate performance improvements.

To promote research and publication efforts, it could be helpful to create appropriate incentives for PhD students to publish during their time-limited PhD program. Appropriate models could be created at a higher, institutional level for this purpose.

In general, the ISE scientific themes presented to the SAB are appropriate as they build the foundation to solve current and future complex problems. All centers within the ISE domain have submitted ambitious roadmaps outlining the topics of future activities. This is a good start to the thinking towards the necessary actions and implementation plans. However, these were not shown to the SAB or were not transparently presented in a form that truly supports the execution of such roadmaps. It is recommended that appropriated implementation plans be made for further improvement. This could include activities that are explicitly dedicated to make the future objectives happen.

4.2.3 Recommendations for the Future

While the SAB was positively impressed by the ISE research challenges and results, the following recommendations aim to help the different ISE centers to be in an even better position in the future. To leverage and enhance the existing potential, a more explicit focus for each center might be very helpful. A recommendation is to define a clear scientific and research-oriented vision for each center which makes explicit in which domain and field of expertise each center sees itself in a top-position in a realistic number of years. In addition, each team should reconsider which unique capabilities will differentiate it from others in the future. It would be helpful for each team to evaluate its output against comparable benchmark institutions to support a more objective performance-based ranking.

The INESC TEC's organization has been very supportive of graduate students. However, there seems to be a need to enhance its attractiveness to PhD candidates as their number has been decreasing significantly. An appropriate approach should be implemented at the institutional level. Along with an increase in the number of PhD students, consideration should be given to their grouping in clusters, which would encourage the exchange of ideas and the sharing of tools and resources. This would enhance the scientific capacity and increase the quality and depth of research outputs.

At the strategic level, it is further recommended to consider the most important challenges being faced in society and economy into the overall ISE research strategy. These are challenges related to climate change, aging population, and others. There is a great opportunity for the ISE domain to build a unique position by addressing these challenges in combination with its existing strengths.

4.3 Networked Intelligent Systems

4.3.1 Overall Impression

The SAB noted several strengths in the Networked Intelligent Systems (NIS) domain, namely:

- Strategic problem selection is driven by societal impact and areas enabling disruptive innovation.
- Strong experimental capabilities are available.
- The IP portfolio (inventions, licensing, spin-offs, etc.) is diverse and strong.
- NIS has access to high quality and unique data sets and domain experts.
- There are strong connections to ultimate consumers of research.
- There are large interdisciplinary teams with outstanding in-house breadth.
- Projects have impressive outcomes that take research from the chalk board to working systems to spin-offs for ambitious problems. Examples include the projects vCardID, UNEXMIN and GeoRobotics.
- Consistently publishing in good-quality journals, and organizing top-level conferences in relevant fields, particularly in optics/photonics, is a notable strength, and provides opportunities for both international collaborations and recruitment in the NIS domain.

4.3.2 Scientific Results and Impact

The SAB's assessment of the scientific results and impact of the NIS domain is discussed below for each of the four research challenges identified by the NIS group.

Context-aware communication systems

The SAB found the NIS work under this challenge to be strong in several regards. The work is focused on excellent forward-looking and high-impact research areas which include

- Adapting over orders-of-magnitude of spectrum - microwave to VLC.
- Reconfigurable Intelligent Surfaces in THz which go beyond non-specular reflection to sensing, positioning, and embedding in the environment.
- Networks on a mission which are characterized by being dynamic and deployed to serve a greater purpose such as sensing for disaster recovery.
- Challenging scenarios which enable unique experiments and data, and leverage INESC TEC's unique capabilities.

However, the SAB also observed that there is a need to ensure critical mass per area for high impact, international visibility, and publications.

Novel perception tools

Perception tools are at the root of Networked Intelligent Systems – without sensors and proper "front-end processing" there would be no information for a networked system to process; no basis would exist for making intelligent decisions and analyses. INESC TEC's great strength in sensor research and development is its well-balanced optical sensor program, with a multi-year track record of inventing and delivering technologies for physical, chemical, biological, and medical applications. The ability to aggregate and process data from these sensors, together with other information (e.g., MRI images and electronic sensors) has led to impressive results that can help lead to a "sensor fusion" based understanding of environments, systems, and even organisms. This progress in applying novel perception tools to solve real-world problems has been greatly accelerated by INESC TEC researchers' excellent relations with collaborators and "customers," whether medical doctors, mining engineers, or others. This has produced important results in fields as diverse as neurological research and civil/industrial engineering. Many of the sensors being developed at INESC TEC have incrementally improved upon the state-of-the art, outperforming results from international competitors, but no revolutionary breakthrough in sensor technology appears to be on the horizon as yet. Because the SAB did not actually get to visit laboratories during this meeting, it is unclear whether facilities are adequate for the expanded participation by new students and researchers that would lead to such breakthroughs.

Beyond human vision

The SAB found the NIS work under this challenge to be strong in several regards. The work has a unique breadth of application domains (general computer vision, medical imaging, forensics, multimedia, autonomous vehicle, underwater perception). It has the necessary access to robots, sensors and medical data via university hospitals. It also has a unique position in "real-world" learning and applications. However, the SAB is concerned with the fragmentation of capacity in too many research directions and the clear appreciation of the tradeoff between efforts and costs versus benefits of pursuing patenting of software and code.

Autonomous robotics systems

This research challenge, in particular the area related to marine robotics, is well aligned with the European objectives to achieve sustainable oceans and a sustainable blue economy. Marine and maritime research and innovation are essential to understand the marine environment. This requires the development, improvement, and utilization of observation systems to collect data from our sea basins using fixed and mobile platforms. Among the strengths related to this challenge, INESC TEC is equipped with excellent infrastructures and has unique experimental capabilities (experimental boat, research AUVs, USVs and UAVs, water tank, etc.). Moreover, it has a strong team which has demonstrated an excellent capability to create and lead international projects

successfully. “Platforms and operations” is probably the most singular research line of the team. The capability for designing, implementing, and operating marine robots identifies the team internationally. A remarkable example is the UNEXMIN project, which led to a singular robot development and, later, to a spin-off company.

4.3.3 Recommendations for the Future

The SAB identified both challenge-specific and cross-cutting recommendations.

For *context-aware communication systems*, the domain should undertake efforts that jointly address security with communications and sensing. It should also grow in-house experimental capabilities in emerging areas.

For *novel perception tools*, it is recommended that the NIS domain maintains and strengthens its focus on optical sensors. Other types of sensors will be important to developing systems that create new insights by combining data from “orthogonal technologies” – an important goal. However, the temptation to work on “everything else” (e.g., nanoelectronics sensors and MEMS – microelectromechanical system – sensors) in addition to optical sensors should be avoided. There are certainly many new opportunities in the optical domain that should be pursued. INESC TEC’s nascent program in quantum technology holds great promise; a similar exploratory program in “topological physics” should be considered. Both will benefit from the institute’s very solid grounding in optical science. The focus on the development of photonic integrated circuit “optical chips” both as sensor platforms and as a mean of significantly miniaturizing and reducing the cost of optical sensor interrogation should be increased. Similarly, the use of optical metamaterials in sensor designs could be strengthened.

For *beyond human vision*, the domain should go multimodal and expand linkage of vision algorithms with sensors. It could also think of going beyond “vision” for pattern recognition tasks, and fusing extended-spectral-range (e.g., non-visible wavelength and/or hyperspectral) data with conventional imagery.

For *autonomous robotics systems*, although the list of research topics related to the challenge is adequate and relevant to advance the state of the art, there is a risk of fragmenting the research due to the high number of target topics. A suggestion would be to promote the most promising topics, focusing the research to foster international leadership in these areas. One of the areas with high potential may derive from the inherent interdisciplinary nature of the institution. This may lead to high impact contributions, making the NIS domain very singular. Some of these areas of interdisciplinarity were already identified in the presentations by the researchers, including “Photonic solutions for extreme sensing (underwater)” and “Interferometric sensing for sea applications”.

Cross-cutting recommendations include:

- Focus on fewer research topics to become international leaders in these areas.
- Get support to reinforce your access to high-quality impactful data in some areas.

- Consider open-source sharing of codes and models for large-scale impact and visibility.
- Synergize the sub-application domains of innovative AI models being developed.
- Publications should be more strongly emphasized as key project outcomes as they provide a foundation for impact by archiving project accomplishments and providing a roadmap for other researchers to build on INESC-TEC's results.
- Calibrate future efforts to aim for scientific publications in Science, Nature and high-impact clinical journals where applicable.

4.4 Power and Energy

4.4.1 Overall Impression

The scientific domain Power and Energy (PE) is organized around five research challenges which are aligned with the mainstream drivers leading the transformation of the power system, namely: decarbonization, digitalization and decentralization with distributed energy resources.

In the last years, INESC TEC has been on an effective trajectory of substantial involvement in projects financed by the European Union (EU), demonstrating that the scientific production of the PE domain is well aligned with actual European R&D programs. It is worth noting that most of those projects are characterized by a high TRL, with important funding for demonstrators. Strategically, PE should think on how to take advantage of this position on EU financed projects to co-finance further basic science research in the selected areas.

A strength of the PE scientific domain is an important number of promising young researchers who not only are leading research tasks and assuming management responsibilities in projects but also have high scientific potential.

On the other hand, a weakness of the presentation made to the SAB is related to the way scientific production was presented. The metric based on the number (i.e., volume) of indexed publications was the main selected indicator. However, this metric alone can bias the assessment of the impact of the research activities as well as their quality. This aspect is considered a major shortcoming. The SAB suggests the identification by the PE domain of a few scientific breakthroughs (in the form of either scientific publications or technical innovations developed with industry partners) and discussing them thoroughly in the presentation.

4.4.2 Scientific Results and Impact

The scientific results and impact are examined below for each of the five research challenges.

Massive renewable sources (RES) integration through power-electronic based interfaces

This is one of the research areas where the PE domain can be considered a leader within the European Union. The adequacy of the research is in line with the main challenges proposed in EU energy legislation regarding, for instance, the implementation of flexibility markets incorporating distributed resources and energy communities with active customers that both consume and generate or store energy. The impact of this research is confirmed through relevant scientific publications and technological transfer through research projects with industries and institutions. In addition, some of the main senior researchers in the area provide advice on institutional issues to the Portuguese administration, government, and energy regulators.

This research area has a very good combination of senior and young researchers who are highly visible and leaders in their fields. The scientific capacity is ensured and reinforced by a multidisciplinary combination of technical, economic, and regulatory knowledge, together with very good experimental facilities (i.e., the smart grid and electric vehicle lab), and a good number of PhD students.

Health assets under smart grid operation

This research challenge is organized around a new area with young researchers with promising initial results, but still in need of consolidation. The adequacy of the proposed research is strategic and in line with the main trends in digitalization. High levels of monitoring and big data would allow improving maintenance and useful lives of electrical infrastructure. The proposed approaches and research products present a very good combination of data driven and physical models.

As already stated, the research area is manly formed by young researchers who share knowledge in power systems and industrial and systems engineering. This combination provides higher synergies, and it is strategic for the consolidation of the research challenge. To ensure sufficient scientific capacity it is recommended to create a critical mass that includes additional future projects and a larger number of PhD students that collaborate in a more structured way.

Data-driven methodologies for energy systems

The scientific productivity in this research challenge is rich and similar to what is observed in other mainstream research institutions. The research strategy is in line with main trends in coupling power systems and digitalization technologies. It is suggested to have more evidence of applicability of the method in real applications. The quality of research products is good, both in publications and involvement in technology transfer with EU funding. The quality of researchers is high, with a good blend of young and senior researchers. In this area, the capacity to innovate is important, especially considering multi-disciplinary collaborations with the other domains at INESC TEC.

Large-scale modelling and optimization of energy systems

The scientific productivity in this area is extremely rich, as this is one of the mainstream sub-domains where the research competences of INESC TEC are acknowledged worldwide. The strategic adequacy of research is excellent, especially considering the coupling with EU industry needs. The quality of research products is excellent, with promising new breakthrough ideas on computational methods. The quality of senior researchers who are renowned worldwide is excellent. However, to improve the scientific capacity in the medium-term, a plan for recruiting new researchers should be established considering the aging of research staff.

Cybersecurity and IoT for electrical infrastructures

This research challenge is a new area with well identified research topics. Again, it is a strategic opportunity for INESC TEC, in line with the main trends in digitalization. In particular, for energy services and massive electrification of energy services in buildings and transport, proliferation of energy services platforms would open new scientific and technological challenges to ensure cybersecurity in critical energy infrastructures.
The quality of research products is still incipient, and some time is needed to consolidate these preliminary results. This research area is mainly dominated by young researchers who integrate knowledge coming from the power system domain and from the industrial and systems engineering domain of INESC TEC. As mentioned before for the research area of health condition, this research challenge must develop a critical mass that includes new future projects and a larger number of PhD students.

4.4.3 Recommendations for the Future

Despite the performance of the PE scientific domain being excellent, there are some recommendations for improving communication of scientific products and social impact.

A first recommendation is to improve the scientific production metrics. Publications that are truly scientific breakthroughs that have been transferred to industry, or generated IP exploited by the industry should be highlighted over others, emphasizing quality over only quantity.

A second recommendation is to improve the presentation and communication of impact on the society. Putting forward the past and existing collaborations with authorities active in the energy systems domain since the adoption of research outcomes by these entities is key due to the highly regulated nature of the power and energy domain. In addition, technological and knowledge transfer to companies and institutions should be better quantified by specific metrics and highlighted as one of the important results.

A final recommendation, in line with the general recommendation 3.2.3, but which is especially relevant for the PE scientific domain, is to ensure that young researchers, leading the new research challenges, follow an academic track with clear targets for impactful scientific results. This aspect is particularly important having in mind that these

researchers do not belong formally to the University and therefore their academic careers should be fully defined as researchers in INESC TEC.

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6. Signature Page

The Scientific Board Members

Dr. José Fortes (Chair) _____ Date _____

Dr. Elsa Angelini _____ Date _____

Dr. Anne-Marie Kermarrec _____ Date _____

Dr. Masaru Kitsuregawa _____ Date _____

Dr. Edward Knightly _____ Date _____

Dr. Robert Lieberman _____ Date _____

Dr. Mario Paolone _____ Date _____

Dr. Pere Ridao _____ Date _____

Dr. Tomás Gómez San Román _____ Date _____

Dr. Bruno Siciliano[2] _____ Date _____

Dr. M. Grazia Speranza _____ Date _____

Dr. Gerhard Gudergan[3] _____ Date _____

[2] Unable to participate in visit
[3] On behalf of Dr. Volker Stich