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EXTERNAL PROFESSIONAL SERVICES FOR THE IMPLEMENTATION OF MAPPING AND FORESIGHT AS PART OF THE 'SCIENCE AND TECHNOLOGY FORESIGHT' PROJECT

Guidelines for Improving Strategic Documents in the Field of Science and Research Based on the Results of the Implementation of the Mapping and Foresight Pilot Exercise in the Energy and Sustainable Environment Thematic Priority Area

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1 Introduction

This document presents a part of the results of the activities carried out for the Ministry of Science and Education by a consortium consisting of the Institute for Development and International Relations and the Institute of Economics, Zagreb, to implement the mapping and foresight activities as part of the Science and Technology Foresight project (no. KK.01.1.1.03.0001). As such, the document is based on two previously produced documents: 'Analytical Report of the Conducted Scientific and Technological Mapping' and 'Study on the Development of the Energy and Sustainable Environment Priority Area: Science and Technology Foresight Pilot Exercise'.

The mapping and foresight activities carried out previously provided a more detailed insight into the quality situation of the research activities under the Energy and Sustainable Environment thematic priority area (TPA). In the mapping phase, the analyses of result data for institution participation in individual research programmes as well as survey data pointed towards the most important results achieved by researchers active in this TPA between 2011 and 2021. A SWOT analysis was also carried out to determine the key strengths, weaknesses, opportunities and threats for the strengthening of research capacities under the TPA. In the foresight phase, the obtained findings were expanded by implementing workshops with members of the working group and by carrying out additional surveys and interviews with a small number of selected researchers and representatives of the business sector. All of these findings were used to develop the guidelines for improving existing and future strategic documents in the field of science and research elaborated below.

The aim of this document is to draw up, based on the lessons learned from the Implementation of scientific and technological mapping and foresight project, a proposal for additional activities that can serve as a basis for updating existing measures or developing new ones laid down in the strategic documents relating to research capacity strengthening.

The development of scientific and technological capacities is currently governed by a number of strategic documents, the most relevant of which are:

- Strategy on Education, Science and Technology (adopted in 2014)
- Innovation Promotion Strategy of the Republic of Croatia 2014–2020 (2014)
- Smart Specialisation Strategy 2016–2020 (S3) (2015)
- Croatian Research Infrastructure Development Plan (2016)
- Croatian National Development Strategy 2030 (2021)
- National Recovery and Resilience Plan (2021).

This list of documents does not include the new Smart Specialisation Strategy 2021–2029 (S3) because the new S3 had not yet been adopted at the time of drafting this document. Once adopted, the thematic priority areas will be identified and they will form the basis for funding projects in the period 2021–2027.

At the moment, the National Recovery and Resilience Plan (NRRP) is the most important document elaborating on the key reform activities and investments in science and higher education. The importance of the NRRP, both for science and for other public policy areas, stems from the fact that the funds for the implementation of a range of reform activities and investments were provided in advance for the first time. However, the disbursement mechanism itself, under which the funds are disbursed according to the progress made in implementing reforms and investments, is equally important. This approach was adopted because it means that reform activities are significantly more likely to take place compared to

the situation before, when the adoption of strategic documents was not accompanied by funding and other necessary implementation mechanisms.

The second chapter provides a brief overview of the existing measures, i.e., the key actions set out in individual strategic documents. This is a way of highlighting that the existing documents contain a large number of measures that are still relevant. The third chapter describes the results of the implementation of the Science and Technology Foresight Pilot Exercise for the Energy and Sustainable Environment TPA. It summarises the results of the TOWS, PESTLE and DELFI analyses implementation and describes the key determinants of research capacity development scenarios under the TPA by 2026 and by 2035. The fourth chapter provides guidelines on improving the situation regarding the future development of research capacities under the TPA. These guidelines mainly include suggestions relating to the entire system of science and higher education, considering how the majority of the identified obstacles and opportunities for future development relate to the system as a whole. However, where possible, the guidelines are laid out in a way which reflects the needs for the development of research capacities under the TPA. This relates primarily to the proposed selection of priority research themes in the future.

2 Overview of key measures/priority areas of action of the strategic documents in the R&D area

The relevant measures and priority areas of action for the selected strategic documents are presented below.

1 Strategy on Education, Science and Technology – New Colours of Knowledge (2014) – Science and Technology Area	
OBJECTIVE 1 QUICK INITIALISATION OF CHANGE IN THE SYSTEM OF SCIENCE AND HIGHER EDUCATION	
	MEASURE 1.1 Introduce responsibility for R&D and competitive project funding in the programmes of all ministries, together with productive interdepartmental coordination to ensure the effective use of all state sources of R&D funding.
	MEASURE 1.2 Establish strategic management of higher education and science and initiate structural changes in the system of science and higher education through research transformation of public universities and through restructuring of public institutes.
	MEASURE 1.3 Improve the collection, processing, interpretation and publication of statistical and other RDI indicators.
OBJECTIVE 2 INTERNATIONALLY COMPETITIVE PUBLIC UNIVERSITIES AND PUBLIC RESEARCH INSTITUTES WITHIN CROATIAN HIGHER EDUCATION AND RESEARCH	
	MEASURE 2.1 Define the research mission of every public university and all its constituent units and of every public institute as a condition for transforming research, shaping research universities, and restructuring institutes.
	MEASURE 2.2 Strengthen the financial and managerial autonomy of public universities and public institutes as well as their accountability for the realisation of their research missions and social roles, while also strengthening the supervisory function of the founder through quality monitoring and mission fulfilment. Improve the international evaluation of public universities and institutes and establish mechanisms for impacts of evaluation results on institutional funding through programme agreements.

	MEASURE 2.3 Set up a system of evaluation of researchers, research and research institutions that will establish and foster research excellence, international visibility, cooperation and collaboration with the research result beneficiaries, as well as the societal relevance of research.
	MEASURE 2.4 Introduce peer review in the processes of selection and academic promotion of university teaching staff and researchers.
	MEASURE 2.5 Set up doctoral schools at the university institutional level, international joint doctoral studies and national doctoral studies with a research component of at least 80% on the basis of existing quality doctoral studies.
	MEASURE 2.6 Improve the preparation and implementation of national research projects in order for their contents and results to contribute to the quality, relevance and rationality of research, as well as to the achievement of strategic objectives.
	MEASURE 2.7 Set up national centres of research excellence to bring together researchers and research resources and bring them together with their European counterparts.
OBJECTIVE 3 ENVIRONMENT WHICH ENABLES AND ENCOURAGES INTERACTION AND TRANSFER MECHANISMS OF COLLABORATION BETWEEN RESEARCHERS AND INNOVATIVE ECONOMY AND SOCIAL ACTIVITIES	
	MEASURE 3.1 Strengthen the cooperation between public universities and public institutes on one side and the business sector and social activities on the other side, in particular relating to R&D, through joint projects, joint mentoring of doctoral and master students, funding for doctoral research, and setting up businesses based on research results. Establish mechanisms for the transfer of knowledge, technology, innovation and intellectual property into the economic sector, in addition to mechanisms for the transfer of the needs for technological solutions and demands to address specific problems in the industry, economy and social activities into public universities and public institutes.
	MEASURE 3.2 Strengthen the cooperation between public undertakings, utility companies and state institutions and universities and research institutes on R&D related to societal challenges.
	MEASURE 3.3 Strengthen the mobility of human resources in research, including the recruitment of students who have completed bachelor, master or doctoral studies, and the recruitment or temporary stay of researchers from public universities and public institutes in the business sector. Double the number of PhDs in the economic sector, with support for the recruitment of PhDs in the industry and support for business for PhDs establishing innovative businesses.
	MEASURE 3.4 Set up innovative co-funding schemes for doctoral studies and doctoral candidates, with the aim of strengthening cooperation with the economic sector and addressing current societal challenges.
	MEASURE 3.5 Under the competitiveness clusters, foster international cooperation, the participation of Croatian partners in international research projects, and the joint participation of universities, research institutes and the economic sector in international and national tenders.
	MEASURE 3.6 For socially necessary commercial activities not carried out by other market operators, institutions within the system of science and higher education should set up limited liability companies they own and transfer such activities into them.
OBJECTIVE 4 UNIVERSITIES, COLLEGES AND RESEARCH INSTITUTES INVOLVED IN SMART SPECIALISATION PROCESSES AND RELATED TECHNOLOGICAL DEVELOPMENT GUIDELINES	
	MEASURE 4.1 Include universities, colleges and research institutes as institutions in the smart specialisation processes. Include the definition and analysis of industrial value chains and value networks in the priority area evaluation criteria.
	MEASURE 4.2 Prepare technological development guidelines as part of the smart specialisation process and as part of the process of defining priority economic activities and related production

	in Croatia, taking into account the European and global technological standards for the period 2014 –2020.
OBJECTIVE 5 NATIONAL RESEARCH AND INNOVATION INFRASTRUCTURES WITH PUBLIC ACCESS, WITH INTEGRATION INTO AND CONNECTION WITH EUROPEAN INFRASTRUCTURES	
	MEASURE 5.1 Establish a transparent system for evaluating infrastructure project proposals, equipment procurement project proposals, and proposals for projects that provide for the use of foreign or international infrastructures, and implement this system when making investment decisions.
	MEASURE 5.2 Build an advanced common e-infrastructure of Croatian education and research area.
	MEASURE 5.3 Set up a system of open access to existing and new public research infrastructure and equipment procured through public funding. Establish data services, including digital repositories, to enable the effective collection and processing of research results and to ensure their continued and reliable preservation and access, including open access to research and expert information generated from public funding. COMPETENCE: Ministry of Science and Education; National Council for Science, Higher Education and Technological Development
	MEASURE 5.4 Set up a system and provide competitive mechanisms for equipping existing and new laboratories, either standalone or through centres of excellence, based on transparent evaluation using the criteria set out in Measure 5.1.
OBJECTIVE 6 R&D INVESTMENT GROWTH THROUGH IMPROVING THE PUBLIC FUNDING SYSTEM AND FOSTERING R&D INVESTMENTS OF THE BUSINESS AND SOCIAL SECTORS	
	MEASURE 6.4 Increase budget allocations for competitive research programmes and projects to 0.15% GDP minimum.
	MEASURE 6.5 Facilitate innovative economy investment in RDI, including joint research projects with public universities and institutes.

2 Innovation Promotion Strategy of the Republic of Croatia 2014–2020	
Thematic pillar I: Development of the Croatian innovation system and the legislative and fiscal framework to foster innovation	
	I.1 Improving the operation of the national innovation system
	I.2 Developing and strengthening the innovation value chain
	I.3 Establishing the legislative framework to foster innovation
	I.4 Establishing the fiscal framework to foster innovation
Thematic pillar II: Strengthening the innovation potential of the economy	
	II.1 Supporting the start-up and growth of innovative SMEs
	II.2 Supporting business investments by SMEs in RTD&I
	II.3 Supporting business investments by large undertakings in RTD&I
	II.4 Facilitating access to funding for innovative businesses
	II.5 Attracting foreign direct investments in high-tech sectors and emerging industries
Thematic pillar III: Promotion of cooperation and circulation of knowledge between business, public and research sectors	
	III.1 Fostering interactions between industry and research institutions
	III.2 Tackling societal challenges through innovation
Thematic pillar IV: Strengthening human resources in innovation and creation of an attractive environment for world-class researchers	

	IV.1 Promoting the development of new skills needed for RTD&I
	IV.2 Providing business support to undertakings in RTD&I
	IV.3 Fostering the building of a system based on research excellence and internationalisation

3 Smart Specialisation Strategy 2016–2020 (S3)	
Specific strategic goals:	
Specific strategic goal 1: Increasing the capacity of research organisations to carry out cutting-edge research that meets the needs of the economy	
Specific strategic goal 2: Overcoming the fragmentation of the innovation value chain and bridging the gap between research organisations and the business sector	
Specific strategic goal 3: Modernising and diversifying Croatian economy through business sector investments in research, development and innovation	
Specific strategic goal 4: Upgrading the global value chain and encouraging the internationalisation of Croatian economy	
Specific strategic goal 5: Engaging in partnership work for tackling societal challenges	
Specific strategic goal 6: Developing smart skills – improving the qualifications of the existing and new workforce for smart specialisation	
Thematic priority areas and sub-areas:	
1 Health and quality of life	
	Pharmaceuticals and biopharmaceuticals, medical equipment and devices
	Health services and new methods of preventive medicine and diagnostics
2 Energy and sustainable environment	
	2.1 Energy technologies, systems and equipment
	2.2 Environmentally friendly technologies, equipment and advanced materials
3 Transport and mobility	
	3.1 Manufacture of high value-added parts and systems for road and rail vehicles
	3.2 Environmentally friendly transport solutions
	3.3 Intelligent transport systems and logistics
4 Security	
	4.1 Cybersecurity
	4.2 Defence technologies and dual-use products
	4.3 Mine action programme
5 Food and bioeconomy	
	5.1 Sustainable food production and processing
	5.2 Sustainable wood production and processing

4 Croatian Research Infrastructure Development Plan (2026)
This document does not contain any measures developed specifically for research infrastructure development. However, Annex 1 of the document sets out the funding available for investment in research infrastructure. In addition, Annex 2 provides a list of project proposals for research infrastructure to be financed through the European Regional Development Fund, and Annex 3 provides a list of centres of research excellence founded in 2014 and 2015.

5 Croatian National Development Strategy 2030 (2021)	
Strategic goal 1 'Competitive and innovative economy'	
Public policy priority area: Science and technology development	
Policy implementation priorities in the science and technology area:	
1.	Reforming the system of science and the academic research sector to meet global standards of excellence and innovation
2.	Developing research capacities, with a focus on human resources in STEM
3.	Strengthening research excellence and fostering open science through investments in research infrastructures and internationally significant research projects
4.	Supporting R&D activities in research and business sectors
5.	Ensuring conditions for the creation of innovation and the transfer of knowledge and technologies to business ventures in Croatia
6.	Continued support for the innovation system to ensure its strengthening and sustainability through funding programmes for RTD&I, in particular in ICT, AI and robotics, biotechnology and green technologies
7.	Digital transformation in research

6 National Recovery and Resilience Plan 2021–2026 (2021)	
Component 3 Education, science and research	
C3.2 Research and innovation capacity building	
Reforms	
C3.2 R1	Reforming the public research sector and strengthening its capacities for R&D
C3.2 R2	Creating a framework for attracting students and researchers to STEM and ICT
C3.2 R3	Improving the effectiveness of public RDI investments
Investments	
C3.2 R1-I1	Developing a system of programme agreements to fund universities and research institutes focused on innovation, research and development
C3.2 R1-I2	Strengthening the institutional capacities of universities and research institutes for innovation
C3.2 R2-I1	Developing an enabling model for the career progression of researchers and for conducting cutting-edge research in STEM and ICT
C3.2 R2-I2	Investing in research and technology infrastructure in STEM and ICT
C3.2 R3-I1	Introducing a more functional programming framework for RDI project funding

Comment on the relevance of strategic documents

This outline of the key measures in the strategic documents for research and development points to the existence of a wide range of themes that are important for the strengthening of scientific and technological capacities in Croatia. Most of the measures appear to be still relevant, including those found in slightly older documents such as the 2015 Strategy on Education, Science and Technology or the 2014 Innovation Promotion Strategy. This confirms that little progress was made in implementing the strategic documents in the years following their adoption, and it is therefore not surprising that the NRRP includes

a number of measures very similar to those proposed in earlier strategic documents. The Smart Specialisation Strategy 2016–2020 (S3) should be examined separately. The S3 is the first strategic document to identify thematic priority areas (TPAs), providing a basis for theme-oriented RDI investment funding through the Operational Programme Competitiveness and Cohesion 2014–2020. In addition to identifying the thematic areas and sub-areas, the S3 also contains a list of indicative themes for RDI under each sub-area, which allows for a rather high level of channelling funding towards fewer pre-selected themes of interest. Available data on S3 implementation indicates that implementation was supported by very generous funding from the ESI Funds and through a large number of instruments[1]. However, a more complete assessment of the S3 implementation results, and in particular of the performance of the investments in individual TPAs and STPAs, will only be possible once the implementation is formally completed, after 2023. The new S3 is currently being finalised. The new document will identify new investment TPAs. The Croatian Research Infrastructure Development Plan does not provide concrete measures but rather relies on the investments planned in other strategic documents, primarily in the Smart Specialisation Strategy. It would be desirable for the new plan to be significantly more specific in terms of channelling investments towards specific forms of research infrastructure.

[1] See, for example, HAMAG-BICRO (2021) *Izvješće o provedbi "Strategije pametne specijalizacije Republike Hrvatske za razdoblje od 2016. do 2020. godine" u razdoblju 2016. – 2019.* (*Report on the implementation of the Smart Specialisation Strategy of the Republic of Croatia 2016–2020 in the period from 2016 to 2019.)*

3 Key findings from the implementation of the Scientific and Technological Mapping and Foresight Pilot Exercise for the Energy and Sustainable Environment TPA

The scientific and technological foresight pilot exercise under the TPA from the Smart Specialisation Strategy of the Republic of Croatia 2016–2020, the *Energy and sustainable environment TPA,* pointed towards the research themes with the highest growth potential and to the key opportunities and obstacles to the further development of the RDI system. The results of research in this regard can serve as a basis for the future alignment of investments in science and technology in Croatia with key EU strategic documents, such as the European Green Deal, as well as a basis for the development of future national strategic documents for science and technology. The foresight pilot exercise was carried out for the medium term until 2026 and for the long term until 2035.

The assessment of the research system development was based on several key elements: human resources development (needs/possibilities), technology development (global trends, EU policies, national abilities and desirable directions), innovation development and applications in economy, participation of the Republic of Croatia in EU Framework Programmes (internationalisation, participation in the European Research Area, bilateral and multilateral cooperation), and alignment of research activities with the strategic priorities of the EU. The key settings for the development of the scenarios were prepared on the basis of the SWOT, TOWS, PESTLE and DELFI analyses, which determined the views of the survey participants involved.

The key strengths for the development of the Energy and Sustainable Environment TPA are the existing experienced experts and researchers and a range of internationally excellent researchers with knowledge and experience in preparing and implementing high-quality research projects. Well-developed long-term scientific cooperation with national and foreign institutions is another strength. As regards the **opportunities for the future development of scientific and technological potential** under the TPA in Croatia, the current energy crisis certainly represents an important opportunity to further strengthen the research activities aimed at energy self-sufficiency, as well as an opportunity to accelerate decarbonisation and digitalisation. Increasing investments in the systems for the use of renewable energy sources (RES) are expected in the coming years, and these will also lead to an increase in investments in the related RDI activities. The rising costs of agri-food industries resulting from the energy crisis are an additional incentive for research into the water-food-energy system connections as well as for strengthening local supply chains both in energy and in food. There is also a growing interest in exploring the potential of the sea for energy purposes and in the related conservation of marine eco-systems. **One of the key weaknesses** for the further development of research capacities are the substantial teaching responsibilities of researchers, which prevent them from dedicating themselves to research projects more. Moreover, the recruitment of research staff is not competitive enough, and career development opportunities are relatively sparse compared to the economic sector. A large number of researchers still lack international experience and networking, they are not part of international research teams, and lack the know-how needed for preparing and implementing projects. In addition, the results in terms of developing new products, processes and designs are relatively poor. Despite improvements made over the recent years, largely thanks to funding from a variety of EU programmes, cooperation between research institutions and the economic sector remains weak. In addition, public funding incentives for such cooperation are insufficient and non-systematic, and both private and public undertakings show

insufficient interest and willingness to cooperate with researchers or invest in research. With regard to public policies, there is a lack of systematic searches for innovative solutions for tackling societal challenges. This is the reason that the entire public research sector is slow to react to the needs of the economy and society as a whole. One characteristic of the system is also the lack of research infrastructure, the age of existing research infrastructure, and the inefficient infrastructure management (insufficient availability of existing equipment to the wider research community, high prices of equipment, high use and maintenance costs, not enough qualified staff to work on the equipment, etc.). Finally, there is a lack of systematic evaluations of the results of research projects in relation to the funds received, i.e. a value-for-money assessment, which would serve as a basis for funding decisions about new investments in the research sector. **The key threats** to the further development of research capacities are primarily linked to the difficulty of recruiting young researchers, which is the result of better working conditions and faster career development available to them in the business sector. Another threat is the lack of awareness among the professional public about the professional and research capacities of the public research sector, as well as the propensity of the public and business sectors to seek fast and cheap solutions that undermine the potential of collaborations between economy and science. Further aggravating factors are the lack of funding continuity for research as well as the lack of understanding of the specific issues that accompany the implementation of research projects by the authorities involved in funding and controlling their implementation.

The most important actions for overcoming these weaknesses and avoiding or reducing threats, and for achieving research excellence in the Energy and Sustainable Environment TPA in the future, are:

- introducing a system of rewarding/fostering research excellence in all research institutions, including increasing incentives for top researchers;
- ensuring that the funds allocated to universities for research excellence really end up with the best researchers;
- strengthening project work skills and management competencies of excellent young scientists;
- strengthening knowledge and skills in commercialisation of innovation;
- attracting foreign researchers and students;
- further strengthening the infrastructure for the work of successful, well-established research groups; and
- providing incentives for networking at the national and international level, participation in EU Framework Programmes and internationalisation of research.

The PESTLE analysis confirmed the opportunities and threats in the TOWS analysis and added a clear future direction to them. It also identified the key factors affecting the future development of the scientific and technological capacities under the TPA. One **positive direction** is represented by the **political factor** that is the ongoing energy crisis, as it increases the interest of the public and private sector in investing in R&D in RES. EU public policies concerning the green and digital agenda are also an important positive factor. Regarding the **economic factors**, the price competitiveness of the Croatian research sector services compared to the competitors in developed EU countries and the low living costs for foreign researchers in Croatia also have a **positive direction**. The most important **social factor with a positive direction** is the increasing internationalisation of science and education and the openness of young researchers to mobility (training in other countries), as well as the growing awareness in society of the importance of topics relating to the sustainability of overall socio-economic development. The most significant **technological factor with a positive direction** is the application of new horizontal technologies such as

the Internet of Things (IoT), big data, artificial intelligence (AI) and others. Different **environmental factors with a positive impact** on the development of scientific and technological capacities are also present: the increasing severity of climate change reinforces the need to increase investment in R&D, and the natural conditions in Croatia are favourable for researching geothermal, hydrothermal and aerothermal energy sources.

Above all, the **negative direction** for the future development of the TPA is represented by **political factors**: lack of knowledge, experience and interest among decision makers regarding the possibilities of public-private partnerships in R&D, a science funding scheme that does not encourage cooperation between researchers, absence of a consistent science development policy with unclear research priorities, and difficulties in recruiting researchers (especially from abroad) and retaining them. In addition, the energy crisis can also have a negative impact if the new costs for the national and EU budgets result in a (temporary) reduction in investment in R&D. Regarding the important **economic factors with a negative direction**, the following are identified: unfavourable structure of the Croatian economy (high-tech sector is less developed), low innovation capacity of the economy, constrained wages in the public research sector, poor reputation of the research community in the private sector, low awareness among entrepreneurs about the opportunities for collaboration with the research institutions, and finally, inflation and macroeconomic (in)stability. The most important **social factors with a negative direction** are the lack of entrepreneurial spirit in society (willingness to take risks), low willingness to embrace innovation and the departure of educated young professionals to other countries. The most important **technological factors with a negative direction** are the poorly developed production of technological equipment in Croatia, which slows down the development of RDI capacities, the still insufficient research infrastructure, and the high costs of maintaining equipment for public research institutions. Particularly important **legislative factors with a negative impact** are the numerous shortcomings of the current legislative framework governing the system of science and higher education, in particular regarding the promotion of research-excellent individuals and institutions, the lack of sufficiently attractive tax incentives for investing in research, and the administrative barriers to hiring foreign researchers.

The DELFI analysis further verified and expanded the findings of the TOWS and PESTLE analyses. The survey method was used to identify the attitudes of researchers regarding the innovation and research potential under the Energy and Sustainable Environment TPA in the next 5 to 15 years. **Of the eleven proposed research themes**, the following have the **highest potential to deliver excellent research results in the medium term** (next five years)**:**

- development of energy storage technology, equipment and devices;
- development of technology, systems, equipment and devices for producing energy from RES;
- development of electric vehicle charging infrastructure systems and devices; and
- development of heating/cooling technology, systems, equipment and appliances.

Development of energy storage technology, equipment and devices, development of technology, systems, equipment and devices for producing energy from RES, development of electric vehicle charging infrastructure systems and devices and development of heating/cooling technologies, systems, equipment and appliances are also themes with the highest potential in the long term (next 15 years). Other themes with high potential in the long-term include the development of waste management systems and equipment, development of environmental technologies, development of technology,

systems, equipment and devices for producing energy from RES, and development of hydrogen production and storage technologies.

Most of the proposed research themes were assessed as having a high potential to generate innovation in the long term. The highest rated themes were: development of technology, systems, equipment and devices for producing energy from RES; development of electric vehicle charging infrastructure systems and devices; development of energy storage technology, equipment and devices; and development of waste management systems and equipment and environmental technologies. Other themes also demonstrate important research and innovation potential in the medium and especially in the long term. The only theme with a considerably low potential to generate innovation is the development of technology, systems, equipment and devices for the production of nuclear energy. In addition to the eleven initially proposed themes, several additional ones were identified. These additional themes have significant potential to strengthen research excellence and increase innovation, mostly related to the application of digital technologies in the field of energy.

The results of the survey show that the estimated potential of each theme is different compared to the findings from the mapping phase in connection with the number of newly developed technologies by theme in the period 2011–2021. According to those findings, almost two thirds of the newly developed technologies are recorded within only two themes. In short, the gap between the assessed potential and the realisation of this potential in the form of developing new technologies under the TPA remains rather wide, and further efforts are needed to reduce it.

The results emerging from the TOWS, PESTLE and DELFI methods were used as a starting point for the development of TPA scenarios by 2026 and by 2035. According to the methodology set out above, two scenarios, a baseline scenario and an accelerated development scenario, were developed for each of the key areas of capacity strengthening:

- funding science and research;
- human resources development;
- research infrastructure quality;
- cooperation with the economic sector.

In the area of funding the development of scientific and technological capacities, significant investments in research capacities are expected in the period up to 2026. In the baseline scenario, the analysed factors (total size of funding available, funding criteria and continuity of funding) are expected to improve slightly in the medium term. A moderate improvement is expected in terms of the size of available funding, which is mainly linked to the implementation of the NRRP, while the funding criteria and ensuring the continuity of funding are expected to remain unchanged. In the period up to 2035, the availability of funding is expected to improve, owing to the resources available from the ESIF programmes for 2021 – 2027 and 2028 –2034. At EU level, the growing policy support for accelerating the development of new technologies to reduce the EU's dependence on fossil fuels plays an important role in the size of the available funding.

A similar development in terms of availability of funding is expected under the accelerated development scenario, with a slightly greater increase in funding available through the CSF as a result of higher total public investments in R&D. Unlike in the baseline scenario, the funding criteria and the continuity of funding are expected to improve moderately over the medium term and significantly over the long term,

primarily in connection with better project selection procedures and improved long-term funding planning.

In the area of human resources development, the need for labour is expected to increase primarily based on the increased system funding. In the baseline scenario, most of the analysed factors (quality of research groups, criteria for promotion in science, cooperation with other research groups in Croatia and abroad and quality of formal training completed, number of researchers) are expected to remain unchanged by 2026 and slightly improve by 2035. The only exception is the number of researchers, which is expected to stagnate until 2035 and then decrease slightly as a result of negative demographic trends and increasing competition from the private sector which offers increasingly better working conditions for young researchers.

In the accelerated development scenario, slight improvements are expected for all factors except for the number of researchers by the end of 2026. In general, in the period up to 2035, moderate or significant improvements are expected, except for the number of researchers, where only a slight improvement is expected. In the accelerated development scenario, the key drivers of positive change are reforms of the scientific-technological policy and improvements in the internal regulations and procedures of research institutions that support positive changes. The slight increase in the number of researchers in the period up to 2035 is mainly due to increasingly attractive working conditions for young researchers.

In the baseline scenario, the evolution of the key factors influencing the **quality of research infrastructure** as an important determinant of research excellence overall – availability of physical infrastructure (facilities, equipment, etc.), equipment use organisation, logistical support in preparing and implementing projects, physical infrastructure maintenance funding, and an effective framework to foster the protection of the intellectual property of researchers/institutions – remains broadly unchanged until 2026, with researchers still experiencing difficulties in organising the use of equipment and funding equipment maintenance, as well as having poor logistical support for research teams. The availability of research equipment will be improved primarily thanks to funding through the NRRP and through other programmes (co-)funded by the EU. However, the overall investments will be slightly lower than potentially possible due to absorption capacity difficulties, labour shortages and insufficient motivation among researchers to apply for projects. To conclude, infrastructure availability is expected to improve moderately up to 2035 owing to increased investments from programmes funded by the EU.

The accelerated development scenario implies a slight improvement of the situation in terms of availability and maintenance funding for physical infrastructure by 2026, while equipment use organisation and logistical support in preparing and implementing projects is expected to improve moderately. Significant improvements across all factors are expected in the period up to 2035. The differences between the scenarios are based on significant improvements to the normative/financial framework at central level concerning the equipment use organisation, logistical support in preparing and implementing projects, and equipment maintenance funding, as well as on the many distinct efforts of individual research institutions under the accelerated development scenario. In addition, a significant difference is the creation of an enabling framework for intellectual property protection for research organisations, which will stimulate researchers to develop new innovations. In the accelerated development scenario, a significant improvement of the current situation is expected already by 2026, and this improvement is expected to continue growing in the period up to 2035. On the other hand, in the baseline scenario, the situation regarding the protection of intellectual property remains unchanged.

The development of cooperation with the economic sector was analysed through the evolution of factors relating to tax incentives for investments in R&D, public calls fostering cooperation with the economic sector, and internal policies of research organisations fostering cooperation with the economic sector. In the baseline scenario, development based on the use of EU programme grants is expected by 2035, with the results of cooperation being limited due to a number of obstacles that continue to hinder or slow down the cooperation itself. In particular, these problems are connected with insufficient motivation among the public sector researchers to get involved with these kinds of projects due to significant administrative burdens, lack of material incentives, and the inadequacy of the overall institutional environment for research. Research institutions still lack a clear vision of the development of their relationships with the economic sector, and there is still a significant information asymmetry between the public and private sectors in understanding opportunities for cooperation.

On the other hand, in the accelerated development scenario, the legislative framework is expected to be supplemented and thus enable a slight improvement by 2026 in terms of the direct impact of regulation on strengthening cooperation with the economic sector (e.g., through tax advantages or exceptions). This improvement is expected to become moderate by 2035. With regard to improving the criteria which foster cooperation with the economic sector, a moderate improvement is expected in the medium term, and a significant improvement in the long term. With regard to the financial impact of the public calls, a moderate improvement is expected by 2026, mainly due to NRRP funding. This impact is expected to increase significantly by 2035, mainly due to ESIF funding and, to a lesser extent, the contributions of the Horizon Europe and CSF programmes.

The evolution of these factors in both scenarios should be continuously monitored and evaluated. The chapter devoted to performance indicators proposes the key indicators for monitoring the development of the TPA in the future. It focuses on research excellence indicators and impact indicators of economy development. Data sources already exist for a substantial part of the indicators and these are updated regularly. For a minor part of the indicators, data collection processes need to be set up.

4 Guidelines for improving the capacity strengthening measures in R&D, with a particular focus on the Energy and Sustainable Environment TPA

These guidelines represent one of the results from the implementation of the project of scientific and technological potential development mapping and foresight in the Energy and Sustainable Environment TPA. In this regard, the recommendations in these guidelines reflect previous research findings resulting from the analysis of a number of primary and secondary sources. Primary sources include the results of the survey carried out as part of the potential mapping phase, the results of the workshops with the MZO Mapping and Foresight Working Group, as well as the results from additional surveys and interviews with a small number of experts who are active in the TPA. Secondary sources relate primarily to the analysis of key national and EU strategic documents carried out during scenario elaboration in the TPA development foresight phase. Individual interviews with experts active in the TPA were especially important for the development of these guidelines. The interviews made it possible to check earlier findings relevant for strengthening research capacities, and they provided insight into the potential additional improvement activities. In total, seventeen interviews with experts listed in the appendix were held between July and September 2022.

The guidelines were written to reflect, as far as possible, the materialisation of the accelerated scientific and technological capacities development scenario by 2026 and by 2035. In other words, the implementation of these guidelines should largely support the materialisation of this scenario, which is significantly more favourable for the future development of this TPA.

The guidelines address three different levels of action:

- The first part of the guidelines concerns the **actions of the bodies responsible for planning and implementing public policies** relating to R&D activities. This applies in particular to the MZO and to other national bodies such as the CSF, the National Council for Science, Higher Education and Technological Development, the Croatian Rectors' Conference, and others.
- The second part of the guidelines concerns actions that **strengthen capacities at the level of individual research institutions.**
- The third part of the guidelines deals with the **selection of relevant research themes under the Energy and Sustainable Environment TPA** in the future.

The three levels were set up to differentiate between the responsibilities for the development of the whole system, which are connected to the central level responsible for the legislative and overall strategic and financial system framework on the one hand, and, on the other hand, the responsibilities connected to the levels of the different research organisations or the University as important stakeholders in the process of developing scientific and technological capacities

I Guidelines for improving the national system of science and higher education:

a) Strategic and theme-oriented funding

1. Introduce theme-oriented CSF tenders to explore priority research themes within an individual S3 thematic area.
2. Identify cooperation between more research institutions (consolidation of research teams) and cooperation with the economic sector as necessary requirements for funding larger research projects in tenders relating to the S3 thematic areas.
3. Set up a funding system for strategic research projects with large funding amounts (e.g., at least EUR 3 million per project) and mandatory private partners.
4. Encourage research teams in the fields of science, technology, biomedicine and biotechnology to collaborate with research teams in the fields of humanities and social sciences to strengthen a transdisciplinary approach to key societal challenges (in particular in the Energy and Sustainable Environment TPA).

b) Selection, monitoring and evaluation of investments in research activities

1. Develop and link unique identifiers related to research projects (irrespective of the source of funding of the project), researchers and research institutions, so that a comprehensive monitoring base for research activities can be established.
2. Set up a continuous monitoring system to monitor results from individual research projects (irrespective of the source of funding) in an identical and comparable way with a common set of

underlying data: project duration, eligible costs, project participants, budget, scientific activity area, project description, planned and achieved performance indicators, S3 TPA (if applicable).

3. Continuously evaluate scientific and technological potential and periodically carry out future development foresight activities as an important part of the analytical framework for identifying priority research themes for funding.
4. Provide a system for selecting strategic research projects to facilitate funding for well-established research teams; the system should, to a certain extent, take the results/effects of previously funded projects into account.
5. Ensure adequate remuneration for research project evaluators (irrespective of the source of funding and the stage of the project under evaluation – application/implementation).
6. Strengthen the monitoring of the achieved research results during project implementation and reduce the administratively burdensome progress reporting that does not provide a clear picture of the project research performance progress.
7. Provide a system of ex-post evaluation of the effects of completed research projects with a greater financial value (e.g., above EUR 1 million).
8. In cooperation with the Ministry of Economy and Sustainable Development (MGOR), establish a single system for monitoring and evaluating innovation activities and activities of cooperation with the economic sector for research institutions.

c) Framework for research infrastructure management

1. Adopt a new national research infrastructure development plan aligned with the objectives and the thematic priority areas of the S3 and other strategic documents in the field of R&D.
2. Develop recommendations for research infrastructure management to ensure a standardised approach to the use and maintenance of equipment and other forms of infrastructure.

d) Human resources

1. Adopt a national framework for funding the costs of work on research projects that will establish the funding models for the engagement of existing and new staff in research institutions.
2. Increase the importance of cooperation with the economic sector in the requirements for academic promotions.
3. Provide financial and other incentives for the establishment of postgraduate specialist and doctoral programmes in cooperation with the economic sector and with a mandatory international component in areas corresponding to the S3 thematic areas.
4. Specifically encourage applicants to apply for projects establishing international doctoral programmes (for example, under the Marie Skłodowska-Curie Actions) in areas corresponding to the S3 thematic areas.
5. Develop a system of scholarships/funding for traineeships for excellent students on research projects.

e) Developing academic entrepreneurship and strengthening partnerships with the economic sector and the public sector

1. In cooperation with the MGOR, the MZO should develop national guidelines for the development of academic-entrepreneurial ecosystems to encourage and better guide the efforts of the University regarding the strengthening of academic entrepreneurship.
2. Develop national guidelines for intellectual property policies and the commercialisation of research institution technologies.
3. Draw up a national plan for the promotion of research capacities for the purposes of cooperating with the economic sector.
4. Launch the co-funding of multi-annual partnership research programmes between research institutions and large enterprises under the S3 TPAs.
5. Launch the co-funding of multi-annual partnership research programmes between research institutions and the public sector (regional and local governments, public institutions, etc.) within the individual S3 TPAs, with a focus on tackling societal challenges.

II Guidelines for strengthening the capacities of individual research institutions active within the Energy and Sustainable Environment TPA

1. Clearly articulate the vision and mission of the institution and identify thematic research priorities in the medium term.
2. Adopt plans for the development and use of research equipment at the individual research institution level.
3. Adopt human resources development plans at the individual research institution level.
4. Develop and adopt internal intellectual property policies and research result commercialisation policies.
5. Adopt plans to strengthen project management competencies and provide adequate resources for their effective implementation.
6. Ensure the involvement of the private sector in the development of research priorities of research institutions in applied and experimental research.
7. Establish a permanent organisational unit within a research institution in charge of collaborating with the economic sector and developing academic entrepreneurship.
8. Set quantitative targets for the number of doctoral dissertations drafted in cooperation with the economic sector.
9. Set quantitative targets for the number of final and master theses developed in cooperation with the economic sector.

III Guidelines for the selection of priority research themes under the Energy and Sustainable Environment TPA

In accordance with the findings of the scientific and technological foresight study, the following research themes are prioritised under the TPA:

1. development of energy storage technology, equipment and devices;
2. development of technology, equipment and devices for the reduction of resource consumption, for the reduction of waste production, and for more efficient waste treatment;

3. development of technology, systems and equipment for the protection/sustainability of the environment;
4. development of solutions based on biomass and/or bio-based products;
5. development of electric vehicle charging infrastructure systems and devices;
6. development of technology, systems, and equipment for heating/cooling
7. development of technology, systems, equipment and devices for producing energy from RES;
8. development of smart grid technologies and digitisation of the energy system;
9. development of technology, systems and equipment for hydrogen production/storage;
10. development of instruments and devices for measuring, regulating and controlling the energy performance of buildings;
11. development of electricity transmission and distribution technology, systems, equipment and devices;
12. development of carbon capture and conservation systems;
13. development of technology, systems, equipment and devices for the production of nuclear energy.

For the listed themes, the MZO should, as the most important authority for the overall development of the system of science and higher education, ensure that the achieved research results are systematically monitored according to individual research themes. The achieved results should be taken into account when updating the list of priority themes in the future. In addition, the achieved results can serve as a starting point for deciding on the size of future funding for individual themes. The themes that prove their successful performance and justify the investments made should have a certain level of advantage in new funding. This way, in addition to the institutional and personal levels, the system of rewarding/stimulating successful performances can and should be extended to the level of research themes.

5 Conclusion

As outlined in the foresight study on the development of scientific and technological capacities in the Energy and Sustainable Environment TPA, research organisations have considerable resources at their disposal to strengthen their capacities to conduct state-of-the-art research and to cooperate with the economic sector in the period up to 2035. In addition, the current challenges of climate change, environmental conservation and energy sufficiency are key topics of interest for global development, which puts researchers and research institutions active in this TPA in a very favourable situation. However, the high amounts of available funds and the favourable broader social circumstances do not guarantee that the necessary steps forward in terms of strengthening the scientific and technological capacities will be made. It is enough to consult the findings from the mapping phase, which show very slow progress in absorbing the available European R&D funds in the 2014–2020 programming period. For that reason, it is necessary to take a number of steps to ensure a more favourable environment for the further strengthening of research excellence and for allowing research to make a greater contribution to tackling societal challenges, in particular with regard to strengthening the competitiveness of Croatian economy. In this regard, the proposed guidelines provide a way forward for actions in areas identified as important for strengthening the overall scientific and technological capacities. Even though these guidelines are

limited in scope and do not cover all the necessary activities, nor do they seek to do so, they would certainly increase the chances of the accelerated development scenario by 2035 materialising.

The proposed guidelines focus mainly on the development of the overall research system, and only to a small extent on capacity development within individual research institutions. This is because the identified barriers hindering the accelerated development of scientific and technological capacities are still present at the national level, i.e. system-wide. However, it is also very clear that significant room for improvement exists within each individual research institution.

Some of the guidelines identified during the project as key to the materialisation of the accelerated TPA development scenario have already been provided in relevant strategic documents (primarily in the Strategy for Education, Science and Technology) in a wider context. This only confirms a well-known fact: that, when it comes to the development of the research system, the key shortcoming or key challenge for policy makers remains the lack of effective implementation of the measures/activities already identified and established, while the development of potential additional measures in this regard is only a minor problem or challenge.

Appendix: List of experts who participated in individual interviews

1 Ankica Kovač, PhD, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb

2 Frano Barbir, PhD, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split

3 Tomislav Capuder, PhD, Faculty of Electrical Engineering and Computing, University of Zagreb

4 Ivan Tolj, PhD, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split

5 Ivan Marasović, PhD, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split

5 Goran Krajačić, PhD, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb

6 Tea Žakula, PhD, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb

7 Daniel Rolph Schneider, PhD, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb

8 Sibila Borojević Šoštarić, PhD, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb

8 Goran Pavlov, IRI Centar, Split

9 Božo Terzić, PhD, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split

10 Damir Jakus, PhD, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split

11 Branimir Pavković, PhD, Faculty of Engineering, University of Rijeka

12 Kristian Lenić, PhD, Faculty of Engineering, University of Rijeka

13 Marinko Stojkov, PhD, Faculty of Mechanical Engineering, University of Slavonski Brod

14 Robert Spajić, PhD, Faculty of Agrobiotechnical Sciences, University of Osijek

15 Ana Sunčana Smith, PhD, Ruđer Bošković Institute, Zagreb

16 Anet Režek Jambrak, PhD, Faculty of Food Technology and Biotechnology, University of Zagreb

17 Hrvoje Lovrić, HELB d.o.o.