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

Study on the Development of the Energy and Sustainable Environment Priority Area

Science and Technology Foresight Pilot Exercise

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Foreword

The production of foresight studies is very rare in Croatia, both by the academic community and by public policy makers. We are therefore particularly grateful to the Ministry of Science and Education for initiating the drafting of this document and hope that similar practices will also be implemented by other state bodies.

The successful production of this document would not be possible without the continuous and committed communication with the Ministry of Science and Education team. We would therefore like to thank Hrvoje Meštrić, Amalija Babić, Anita Šimić and Alen Rubčić for their full support and excellent cooperation.

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We hope that it will serve as a useful compass for further work in the field of foresight and that Croatia will catch up with the practices of many other Member States of the European Union.

The authors

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List of Acronyms

AEs — alkaline electrolysers
AEMEs — electrolysers with an anion exchange membrane
CO_2 — carbon dioxide
COST — European Cooperation in Science and Technology
DC — direct current
CBS — Croatian Bureau of Statistics
EERA — European Energy Research Alliance
EES — electrical energy system
EIT — European Institute of Technology
EC — European Commission
ERC — European Research Council
ESI — European Structural and Investment
ESIF — European Structural and Investment Fund
ETIPs — European Technology and Innovation Platforms
EU — European Union
FESB — Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split
PV — photovoltaic
FSB — Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb
EPEEF — Environmental Protection and Energy Efficiency Fund
GIS — geographic information system
GWEC — Global Wind Energy Council
HEP — Hrvatska elektroprivreda, Croatian national energy company
CCE — Croatian Chamber of Economy
CSF — Croatian Science Foundation
HVDC — high-voltage direct current
ICT — information and communication technology
IEA — International Energy Agency
IPCC — Intergovernmental Panel on Climate Change
RBI — Ruđer Bošković Institute
RDI — research, development and innovation
IT — information technology
ITOP — Integrated Territorial Programme 2021–2027
JANAF — Adria oil pipeline
JRC — Joint Research Centre
MENA — Middle East and North Africa Region
MVDC — medium-voltage direct current
MZO — Ministry of Science and Education
NN — Narodne novine, the official gazette
NRRP — National Recovery and Resilience Plan
RES — renewable energy source
PCC —Programme Competitiveness and Cohesion
PEC — photoelectrochemical
PEMEs — electrolysers with a proton exchange membrane
SET Plan — European Strategic Energy Technology Plan
RGN — Faculty of Mining, Geology and Petroleum Engineering
RH — Republic of Croatia
RITEH — University of Rijeka, Faculty of Engineering
USA — United States of America
CFCA — Central Finance and Contracting Agency for European Union programmes and projects

SETIS — SET Plan Information System
SOEs — solid oxide electrolysers
SRCE — University Computing Centre of the University of Zagreb
TIC — Thematic Innovation Council
TPA — thematic priority area
UK — United Kingdom
UN — United Nations
RIs — research institutions

1. Introduction

The ‘Science and Technology Foresight’ project is implemented by the Ministry of Science and Education (MZO) in cooperation with a partner, the University Computing Centre of the University of Zagreb (SRCE), with the primary focus of improving the institutional framework for planning, monitoring and implementing research, development and innovation policies and increasing the awareness of the research and business communities of the knowledge, resources and strategic choices of individual scientific institutions in the public research system.

Within the part of the project entitled ‘*Implementation of Scientific and Technological Mapping and Foresight*’, carried out by the Institute for Development and International Relations and the Institute of Economics, Zagreb, the mapping activities were followed by a **science and technology foresight pilot exercise** within thematic priority area (TPA) of the Croatian Smart Specialisation Strategy (RH) 2016–2020 — *Energy and Sustainable Environment*.

The main objective of the science and technology foresight process is the identification of the areas with the highest growth potential and a description of the structural advantages and obstacles to the further development of the RDI system in the area concerned. This pilot exercise is also the basis for formulating the recommendations and guidelines for the adoption and review of strategic documents relating to the *Energy and Sustainable Environment* TPA. Furthermore, its implementation helps to better direct investments in science and technology, which should consequently contribute to the faster development of new products, services and processes of high added value. Finally, the implementation of a foresight pilot exercise makes it possible to more effectively align the development and investment priorities with regards to science and technology in the Republic of Croatia with key strategic documents of the European Union (EU), such as the European Green Deal.

2. Contents of the Science and Technology Foresight and its Methods

2.1. Content, time period and geographical scope of the study

The subject matter of the science and technology foresight within the Energy and Sustainable Environment TPA includes foresight regarding the following topics:

- the development of human resources (needs/opportunities);
- technology development (global trends, domestic opportunities and preferred directions);
- the development of innovation and its application in the economic sector;
- enhancing of Croatia’s participation in EU framework programmes, its internationalisation and inclusion in the European Research Area and bilateral as well as multilateral cooperation; and
- the alignment and synergy of research activities with EU strategic priorities.

The time frame of the foresight according to the project task is a period between 5 and 15 years. For the purposes of the pilot exercise, the time frame is split into the medium-term period lasting until 2026 and the long-term period lasting until 2035.

The geographical scope of the foresight implies that the application of the science and technology foresight methodology takes into account the geographical distribution of individual topics and development potential. The starting point are the results of the mapping, showing the differences in capacities of regional research centres (Zagreb, Rijeka, Split and Osijek).

The Mapping and Foresight Working Group, formed by the MZO and comprised of the representatives of relevant state bodies (the Ministry of Science and Education and the Ministry of Economy and Sustainable Development) and scientific institutions, as well as the representatives from the economic sector and of economic associations (the Croatian Chamber of Economy or CCE), participates to a great extent in shaping the scenario parameters, based on the TOWS and PESTLE analyses conducted. Additional experts, including the representatives of the Thematic Innovation Council (TIC) for Energy and Sustainable Environment, were involved in carrying out the DELFI analysis.

2.2 Methods used for preparation of scenarios

The TOWS analysis (meaning threats, opportunities, weaknesses and strengths) is an elaboration of the SWOT analysis based on a baseline assessment of threats and opportunities in the environment, which is used to assess the strengths and weaknesses of the system that can be influenced and managed. The TOWS analysis is a tool used to move from the analysis and assessment of the situation onto the design of future objectives related to the areas under observation (Armand et al., 2007; Weichrich, 1999). Based on the results of the mapping, the research team prepared a draft of the TOWS analysis, which was then discussed and refined at the workshop with the members of the Working Group.

The PESTLE analysis (meaning political, economic, social, technological, legal and environmental factors) is a method of identifying the key external factors that influence the development of a given area or entity. If deemed necessary, the PESTLE analysis may be broadened to include one or more additional factors, or any of the mentioned six factors may be omitted from the analysis. The aim of the PESTLE analysis is to get a clearer picture of the key factors, that is, the prerequisites that influence the successful development of research capacities within the analysed TPA. The results of the PESTLE analysis, combined with the results of the SWOT analysis, are used to obtain an expanded overview of the key internal and external factors of the development of the analysed TPA. The PESTLE analysis was carried out at the same workshop where the TOWS analysis was carried out previously.

Subsequently, the **DELFI method** was used, which is a technique for reconciling the views of the participating TPA experts on specific topics. In the present case, the objective of using the DELFI method is to align as much as possible the views of experts on the key factors determining the development of the TPA and on the identification of more detailed research topics with the highest growth potential in the next 5 to 15 years. In addition to internal factors, the importance of external factors previously identified with the PESTLE analysis, factors which can significantly influence the dynamics and direction of the development of the TPA, was subject to special assessment. In addition to the members of the Working Group, the DELFI research included additional experts who were recognised during the implementation of the mapping as particularly successful researchers and entrepreneurs within the framework of the TPA. A more detailed description of the application of the DELFI method is given in chapter 3.2.

3. Results of the TOWS, PESTLE and DELFI Analyses

3.1. The TOWS and PESTLE Analyses

3.1.1. The TOWS Analysis

The TOWS analysis of the Energy and Sustainable Environment TPA has shown that the sector faces numerous vulnerabilities and external threats but also includes certain strengths and opportunities, and has highlighted the connections and interrelationships between the elements of the matrix that can be a lever for further development in the scientific field.

The **opportunities identified** in the external environment for the Energy and Sustainable Environment TPA include primarily the **energy crisis**, which represents an opportunity to strengthen research activities aimed at energy self-sufficiency and an opportunity to accelerate decarbonisation and digitalisation. **The fight against climate change and the accelerated transition to green energy** point to an increasing need for additional professional and scientific services linked to **renewable energy sources** (RES). The increase in the **commercialisation of systems for RES use** also drives an increase in research, development and innovation (RDI) investment.

The increase in agri-food production costs is an opportunity for scientific **research into the water-food-energy system links** and strengthening local supply chains, which stimulates companies' further interest in technological solutions that reduce energy costs. There is also a growing interest in **exploring the potential of the sea in the field of energy and in preserving marine ecosystems**. The new **Act on Higher Education and Scientific Activity** will create a new results-based funding framework and further stimulate the development of research capacities and cooperation with the economic sector, supported by **substantial EU funding intended for research activities**.

The threats to the further development of scientific research in the Energy and Sustainable Environment TPA are primarily linked to **the difficulty in recruiting young researchers** due to better working conditions and faster career progress in the business sector. Furthermore, the **lack of awareness among the broader professional public of the professional and scientific capacities of the public research sector** and the **propensity of the public and business sectors to seek cheap and fast solutions** that undermine the potential of the collaboration between the economic and scientific sectors also pose a threat. **There is also a lack of continuity of funding for scientific research and a lack of systematic public policy** and the need to strengthen **competence and capacities in public bodies** involved in funding and monitoring the implementation of research projects. Competence is essential primarily with regards to a better understanding of the specificities of implementing research projects.

The threats to the further development of scientific research in the Energy and Sustainable Environment TPA are primarily linked to **the difficulty in recruiting young researchers** due to better working conditions and faster career progress in the business sector. Furthermore, the **lack of awareness among the broader professional public of the professional and scientific**

capacities of the public research sector and the **propensity of the public and business sectors to seek cheap and fast solutions** that undermine the potential of the collaboration between the economic and scientific sectors also pose a threat. **There is also no continuity of funding for scientific research and a lack of systematic public policy** and **competence in public bodies** involved in funding and monitoring the implementation of research projects (CFCA).

The key forces for the development of the Energy and Sustainable Environment TPA are the **existing scientific and professional expertise** and **excellent researchers** with internationally recognised **publications** and **know-how in the preparation and implementation of research projects**. **The long-term cooperation established with scientific institutions in Croatia and abroad** is also a strength.

One weakness in the development of the Energy and Sustainable Environment TPA are **teaching responsibilities that are excessively restricting researchers**, which reduce their ability to commit to research projects to a greater extent. In addition, the weaknesses and constraints of the research sector are linked to the **organisation of research work**, **low-quality selection process for choosing research staff** and relatively **poor advancement opportunities in comparison to the economic sector**. There is still a visible **lack of international experience** in a large number of researchers, notably due to**insufficient networking** and participation in international research teams and a **lack of experience in project preparation and implementation.** There is also **less participation in the development of new products, processes and designs** in the Energy and Sustainable Environment TPA as well as a poorer **commercialisation of innovation**. This is mainly due to the **lack of cooperation and incompatibility of the research topics and practices at research institutions with the needs of the economic sector**. **Unsystematic public financial incentives are also insufficient, and there is insufficient interest and willingness of the economic and public sectors to cooperate and invest in R&D.** As a result, the development of new technologies is insufficient and the use of types of intellectual property through patents, trademarks and industrial designs is infrequent.

At the level of public policy, **national strategic development documents place too much emphasis on the use of existing methods and/or technologies as opposed to innovative solutions for addressing societal challenges**. As a result, the public research sector **reacts slowly to the needs of the economic sector**, and overall RDI capacities in the Republic of Croatia have fewer opportunities to cooperate with the economic sector than RDI institutions abroad. Another still present aspect of the system is **how old the laboratory equipment is and the inefficient ways of managing it** (the insufficient availability of the existing equipment to the wider scientific community, high prices of equipment, high costs of use and maintenance, insufficient professional staff, especially non-scientific staff, to work with the equipment, etc.). Finally, there is **a lack of systematic evaluation of the results of research projects** in relation to the funds received, i.e., the 'value for money' assessment.

In order to **further enhance recognised internal strengths, seize opportunities and mitigate threats in the environment** within the Energy and Sustainable Environment TPA, it is necessary to carry out systematic and continuous **mapping of the needs of the economic sector for the services of the research sector**. This would improve the understanding of the needs of the economic sector and increase the opportunities of the research sector to provide the necessary expertise.

The **availability of R&D and/or high-skill activities that can be provided by public scientific institutions should be continuously supported and financially stimulated** to suit the needs of the economic sector, in particular SMEs, **for example through a model for awarding vouchers to entrepreneurs for contracting such services.**

In addition, **strengthening organisational, human resources and technical support to public scientific institutions** will make it possible to increase the efficiency of research work and to steer the support and funding of research topics and groups **towards scientific excellence**. **The prerequisites for such an approach** are clear excellence criteria, skills for working on projects and management competence, as well as the strengthening of research cooperation projects in the country. Therefore, some of the **key potential activities for achieving scientific excellence** within the Energy and Sustainable Environment TPA in the future are:

- introducing a system for rewarding/fostering scientific excellence in all research institutions, including increasing incentives for top researchers;
- ensuring that the funds allocated to universities for scientific excellence actually end up at the disposal of the best researchers;
- strengthening the skills for working on projects and management skills of young excellent scientists;
- further strengthening the infrastructure for the work of successful, i.e. already established teams (e.g. by allocating young scientists to teams with a long-standing tradition of excellence); and
- providing incentives for networking at the domestic and international levels, participating in EU framework programmes and the internationalisation of research.

<u>An external opportunity to mitigate weaknesses</u> within the Energy and Sustainable Environment TPA is the **global challenge of energy sufficiency and climate change in the future**, as well as increasing interest in RESs and environmental conservation. Areas that have not been sufficiently explored so far, such as the storage of renewable energy using hydrogen, determining the availability of marine and river energy (temperature and flows) for use, geothermal measurements and the like, are particularly interesting.

Public funding of scientific research should be linked to the **needs of the economic sector,** and cooperation between this sector and public scientific institutions should be one of the criteria **for programme funding** for universities and public scientific institutes.

Some of the potentially important **sources of funding** for strengthening the research capacities for the development of the Energy and Sustainable Environment TPA are:

- state scholarship schemes that should ensure that the best students are awarded internships working on research projects;
- research vouchers for SMEs; and
- public-private, public-public (e.g., cooperation with local and regional government) and public-civil partnership projects as an innovative model for R&D funding.

Finally, overcoming weaknesses and avoiding or mitigating threats is possible through the **internationalisation of research, attracting foreign researchers and students and the strengthening of knowledge and skills in the field of innovation commercialisation**.

Table 1 — TOWS analysis of research institutions within the Energy and Sustainable Environment TPA

TOWS matrix S-O connection — How to enhance strengths by seizing opportunities? S-T connection — How to mitigate threats using strengths? W-O connection — What external opportunities are there that we can use to mitigate our weaknesses? W-T connection — How to overcome vulnerabilities and avoid/mitigate threats?	**Weaknesses (W)**	**Strengths (S)**
	• Too many teaching responsibilities restricting the ability to commit to research projects to a greater extent • Limited capacity of the research sector due to organisational weaknesses, a low-quality selection process for choosing research staff (linked to, among other factors, to the low mobility of researchers) and relatively poor advancement opportunities in comparison to the economic sector • Insufficient international experience of a large number of researchers, primarily in the context of project implementation • Less participation in the development of new products, processes and designs and poorer commercialisation of innovation, partly linked to the profiles and functioning of RIs being insufficiently aligned with the needs of the economic sector as well as to insufficient financial incentives and, on the other hand, to a relatively poor understanding of the research process and the insufficient readiness of the economic sector (or at least of a good portion of the sector) to invest in R&D • Insufficient development of new technologies, linked in particular to insufficient investment in this segment of RI activities • Infrequent use of any form of intellectual property (patents, trademarks or industrial designs) • Old laboratory equipment is (insufficient funds to acquire new equipment) and the ways of managing it • Insufficient availability of laboratory equipment to carry out R&D (due to the lack of equipment, lack of qualified equipment operators or high cost of using the equipment) • Lack of professional staff, especially non-scientific staff, who should be involved in the management of the equipment used for research • Insufficient advanced knowledge and skills	• Renown of several institutions in terms of the provision of different types of expertise • Expertise of excellent researchers as well as the recognition of their scientific publications and knowledge in terms of attracting research projects • Expertise of project-oriented researchers in terms of attracting projects • Possibility of further career advancement for young, currently less productive researchers • Established long-term cooperation with scientific institutions in Croatia and abroad

	• The public scientific sector responds to the needs of the economic sector too slowly (lack of rapid reaction capacity) • Overall RDI capacities limit opportunities for cooperation with the economic sector in comparison to RDI institutions abroad • Lack of attention given in national strategic documents to innovative solutions for addressing societal challenges (too high a focus on the use of existing methods/technologies) • Lack of systematic evaluations of the results of research projects against funds received (the 'value for money' assessment)	
External opportunities (O)	**What external opportunities are there that we can use to mitigate our weaknesses?**	**How to enhance strengths by seizing opportunities?**
• The energy crisis as an opportunity to strengthen research activities aimed at achieving energy self-sufficiency • Increased agri-food production costs stimulate further interest of companies in technological solutions that reduce energy costs • The new Act on Higher Education and Scientific Activity, which will ensure additional incentives for the development of research capacities and cooperation with the economic sector • Significant EU funding secured to fund research activities • The energy crisis as an opportunity for accelerated decarbonisation and digitalisation • The comparative advantages of green energy in terms of future development • Strengthening the need for additional highly professional and scientific services linked to RESs	• Use the increased interest in RESs to increase investment in measuring/mapping the underlying data needed to activate new RES capacities, especially in areas that have not been sufficiently explored so far (e.g. the storage of energy from RESs using hydrogen, sea and river temperatures and flows, geothermal measurements, etc.) • Include the cooperation with the economic sector as a criterion for programme funding for universities and public research institutes • Align state scholarship schemes with the internship needs/opportunities of and for the best students within research projects • Mapping and targeted fostering/funding of research by topic at individual hubs (not only in Zagreb) • Sector integration and the development/encouragement of research collaboration regarding different topics (inclusion of humanities and social sciences) • Improve the procurement of research equipment from national sources and EU structural funds, as Horizon does not fund projects without adequate equipment at their disposal	• Continuously support and financially strengthen approaches to procurement for R&D or highly professional activities that can be provided by public scientific organisations to suit the needs of SMEs (e.g. through a model for awarding vouchers to entrepreneurs for contracting such services) • Carry out systematic and continuous mapping of the needs of the private sector for the services of the research sector in order to improve the understanding of the needs of the economic sector and the ability of the research sector to provide the necessary expertise • Strengthen the professional/technical support to faculties and institutes to achieve the most effective research possible • Allocate support and funding to excellent researchers at specific hubs and for specific topics throughout Croatia • Significantly improve the fostering of excellent researchers according to clear criteria • Strengthen the expertise of working on projects and management skills of young researchers in particular • Strengthen research collaboration projects in the country

• The increasingly commercial character of systems for making use of renewable energy sources will benefit RDI investments in this field • Strengthening local supply chains opens up further opportunities to carry out scientific research • The transfer of technology within the water-food-energy system • A range of options for exploring the potential of the sea for energy purposes and for the conservation of marine ecosystems	• Develop own capacities to produce high-quality project proposals for Horizon and other calls for proposals, but also make use of already existing external capacities (such as renowned international consultants) where necessary	
External threats (T)	**How to overcome vulnerabilities and avoid/mitigate threats?**	**How to mitigate threats using strengths?**
• Difficulties in retaining young talent because of better working conditions in the business sector • The impatience of young researchers in wanting to achieve personal success as soon as possible (which normally happens more slowly in the public research sector) • When it comes to cooperation with the economic sector, too much importance is given to patenting while disregarding the importance of highly expert work and its contribution to improving the competitiveness of the sector • Lack of awareness among beneficiaries (from both the public and business sector) of the professional and scientific capacities of the public research sector • Tendency of the public and business sectors to seek cheap/fast solutions,	• Strengthen internal financial and other incentives from scientific organisations for researchers collaborating with the economic sector (faster advancement and so on) • Internationalisation of research and attracting foreign researchers and students • Strengthening of knowledge and skills in the fields of innovation commercialisation, working on projects (project preparation and implementation) and management skills • Attempt public-private partnership research projects (especially in terms of cooperation with large cities)	• Ensure scientific excellence, e.g. by introducing a system of rewarding/fostering scientific excellence at all research institutions (including increasing incentives for top researchers in environments where internal incentives already exist) • Ensure that the funds allocated to universities for scientific excellence actually end up at the disposal of the best researchers • Strengthening the management competence of excellent young scientists • Strengthening the infrastructure for the work of successful, i.e. already established teams • Securing new talent and allocating young scientists to teams with a lot of research experience and a long-standing tradition of excellence

which reduces the potential and benefits they could yield from collaborating with the public research sector • Insufficient skills within the state bodies involved in funding and monitoring the implementation of research projects (CFCA) • Incoherent policies and an absence of continuity in terms of research and funding policies		

3.1.2. The PESTLE Analysis

The PESTLE analysis (meaning political, economic, social, technological, legal and environmental factors) is a method of identifying the key external factors that influence the development of a given area or entity. The PESTLE analysis further elaborates on the TOWS analysis and presents the most important external factors affecting the TPA, the relative importance of selected political, social, technological, legal and environmental factors, as well as the direction of their changes in the future.

The **most important political factor** for the development of the Energy and Sustainable Environment TPA, which is considered essential by 50% of the study participants, very important by 40% of the study participants and important by 10% of the study participants is the **energy crisis** that increases the interest of the public and private sectors in investing in R&D in the field of RESs. The development trend of this factor is positive. **The lack of knowledge and interest of political decision makers** about public-private partnership opportunities in the field of R&D and the current research funding model, which does not sufficiently encourage collaboration with the scientific sector and does not ensure a sufficient concentration of resources is considered essential by 30% of the study participants, very important by 60% of the study participants and important by 10% of the study participants. All these factors show a negative trend.

The **energy crisis** also shows a negative trend in the sense that it can have a negative impact on public sector investment because of new, unforeseen costs that have to be funded by the budget. This factor is considered essential by 30% of the study participants, very important by 50% of the study participants and important by 20% of the study participants. **The absence of a clear scientific sector development strategy and clear scientific sector development priorities** in the Republic of Croatia are considered essential by 20% of the study participants, very important by 40% of the study participants and important by 40% of the study participants. This factor has a negative trend.

Unlike the strategic framework in the Republic of Croatia, **the relevant public policies related to scientific research at the EU level** show a positive trend, and this factor is considered very important by 30% of the study participants, important by 60% of the study participants and not very important by 10% of the study participants. The **ability to recruit scientists from abroad** (administrative issues with obtaining work permits) was assessed as the least significant political factor, and was considered very important by 10% of the study participants, important by 60% of the study participants and not very important by 30% of the study participants. This factor has a negative trend.

Additional political factors identified in the PESTLE analysis as important for the development of the Energy and Sustainable Environment TPA are:

- the absence of cooperation between key stakeholders, i.e., development decision makers, the academic community, the economic sector, civil society and media, in making and monitoring the implementation of strategic decisions;

- insufficient public debate on strategic issues and insufficient involvement of the academic community in strategic decision making;
- the absence of cross-departmental cooperation, especially to support scientists in applying for EU projects, particularly Horizon Europe, which requires having industry partners, in a context where industry partners are reluctant or unwilling to be part of a consortium when applying for such projects;
- the need to develop a clear strategic framework and programme document ensuring systematic longer-term funding for priority research; and
- the need to strengthen the resilience of the entire science and research system to geopolitical and energy challenges, inflation and potential recession.

The most important **economic factor** influencing the scientific and technological development within the Energy and Sustainable Environment TPA are the **limited salaries in the research sector,** which hinder attracting and raising the standard of researchers. This factor is considered essential by 50% of the study participants, very important by 40% of the study participants and important by 10% of the study participants, and it shows a negative trend. The factors of the **unfavourable structure of the Croatian economic sector** (too little investment in R&D) and of its low **innovation capacity**, which are considered essential by 30% of the study participants, very important by 40% of the study participants and important by 30% of the study participants, also have a negative trend.

The poor reputation of the scientific community in the private sector is a factor with a negative trend. It is considered essential by 10% of the study participants, very important by 60% of the study participants, important by 20% of the study participants and insignificant by 10% of the study participants. The **price competitiveness of the services within the Croatian public scientific sector** in comparison to competitors in developed EU countries is a factor with a positive trend, considered essential by 10% of the study participants, very important by 20% of the study participants, important by 60% of the study participants and not very important by 10% of the study participants. **The green and digital development agenda** is also a factor of the development of TPA with a positive trend, considered very important by 60% of the study participants, important by 30% of the study participants and not very important by 10% of the study participants.

Almost half of the participants of the study consider **the lack of awareness among entrepreneurs of the opportunities for cooperating with public scientific institutions** to be a very important economic factor with a negative trend. **Inflation and macroeconomic stability** are considered a very important factor by 40% of the study participants, important by 40% of the study participants and not very important by 20% of the study participants. The factor considered the least important are the **low costs of living for foreign researchers** coming from developed EU Member States, the US and other parts of the world (considered very important by 20% of the study participants, important by 10% of the study participants, not very important by 50% of the study participants and insignificant by 20% of the study participants), and it shows a positive trend.

The PESTLE analysis also proposed the following economic factors of the development of the Energy and Sustainable Environment TPA:

- the return of industry and manufacturing to the EU;
- the disruption of global trade supply chains, the energy crisis and making better use of tax policies to achieve strategic objectives;
- the opening up of new markets in Asia, Africa and South America;
- poor awareness of the scientific community of the objectives of the business sector;
- increasing the available resources of public institutions and government finances in key strategic areas;
- national support to scientists in submitting EU projects; and
- devising better purposes for resources from funds used to support the achievement of strategic national development objectives (e.g., funds from the Environmental Protection and Energy Efficiency Fund, or EPEEF, the Croatian Science Foundation, or CSF, etc.).

The most important social factor of the development of the Energy and Sustainable Environment TPA, which is considered essential by 20% of the study participants, very important by 30% of the study participants, important by 30% of the study participants and not very important by 20% of the study participants, is the **increasing internationalisation of science and education**. This factor has a positive trend. The factor of **the lack of entrepreneurial spirit in society (risk aversion)** has a negative trend and is considered essential by 20% of the study participants, very important by 20% of the study participants, important by 40% of the study participants, not very important by 10% of the study participants and insignificant by 10% of the study participants. **The departure of young educated staff to other countries** is a factor that has a negative trend and is considered essential by 10% of the study participants, very important by 60% of the study participants, important by 10% of the study participants and not very important by 20% of the study participants.

Society's growing awareness of the need for sustainable waste management increases interest in new technological solutions, especially in the agri-food industry. This factor has a positive trend. It is considered essential by 10% of the study participants, very important by 50% of the study participants, important by 30% of the study participants and not very important by 10% of the study participants. **The openness of young researchers to mobility (training in other countries)** is also a factor with a positive trend, considered essential by 10% of the study participants, very important by 30% of the study participants and important by 10% of the study participants. The factor of **insufficient research/innovative spirit in society**, including **society's low willingness to embrace innovation**, has a negative trend and is considered essential by 10% of the study participants, very important by 40% of the study participants, important by 40% of the study participants and insignificant by 10% of the study participants.

As the least significant factor of the development of the Energy and Sustainable Environment TPA, the study participants highlighted the **openness and awareness of young people to and of the importance of topics related to RESs and the environment,** which has a positive trend, and is considered very important by 60% of the study participants and important by 40% of the study participants.

As part of the PESTLE analysis, the following social factors relevant to the development of the Energy and Sustainable Environment TPA were also proposed:

- the definition of the public mission (purpose) of research institutions;
- the development of a culture of trust (high-trust institutions managed disruptions and the remote work of staff better);
- insufficient entrepreneurial spirit in the research community;
- media influence on public opinion and decision making, in particular in the field of energy and sustainable development;
- the increase in transparency of the work of the public sector in the Energy and Sustainable Environment TPA and different technological solutions; and
- the use of refugee crises to strengthen human resources in the scientific sector in Croatia.

The most significant **technological factor** of the development of the Energy and Sustainable Environment TPA is the **poorly developed production of technological equipment** in the Republic of Croatia, which slows down the development of RDI capacities. It is a factor with a negative trend, considered essential by 20% of the study participants, very important by 50% of the study participants, important by 10% of the study participants and not very important by 20% of the study participants. **Insufficient research infrastructure** is also a factor with a negative trend. It is considered essential by 20% of the study participants, very important by 40% of the study participants, important by 20% of the study participants and not very important by 20% of the study participants. **The use of new technologies** (e.g., the Internet of Things, big data technology, etc.) is a factor with a positive trend considered essential by 20% of the study participants, very important by 20% of the study participants and important by 60% of the study participants.

The **increase in equipment certification standards/costs and the high equipment maintenance costs for public scientific institutions** were cited as the least significant technological factor, and it is a factor with a negative trend. It is considered essential by 10% of the study participants, very important by 20% of the study participants, important by 60% of the study participants and not as important by 10% of the study participants.

The PESTLE analysis **proposed additional technological factors** of the development of the Energy and Sustainable Environment TPA:

- the high fragmentation of technological capacities at scientific institutions;
- insufficient knowledge for the application of key technologies;
- poor opportunities for the transfer of knowledge and a high need for the transfer of knowledge and technologies developed through research cooperation and EU projects;
- introducing and standardising the monitoring and measuring of progress; and
- sector integration (electricity, heat, gas, transport, water, drainage, waste management, etc.).

The most important **legal factor are the insufficient tax incentives for investment in R&D**. This factor has a negative impact and is considered essential by 40% of the study participants, very important by 30% of the study participants and important by 30% of the study participants. The legislative framework is an obstacle to the recruitment of foreign researchers as well. It is considered very important by a percentage as high as 40% of the study participants, important by 30% of the study participants, not very important by 20% of the study participants and insignificant by 10% of the study participants.

As part of the PESTLE analysis, two additional factors related to legislation that affect the development of the Energy and Sustainable Environment TPA were proposed:

- laws not being enforceable because of various shortcomings (regulations, terminology or insufficient cross-departmental cooperation); and
- poor alignment of EU science and research policies and the Croatian context.

The most important factor of the **environmental aspect** is **climate change**, which reinforces the need to increase investment in R&D, and it is a factor with a positive trend, considered essential by 50% of the study participants, very important by 30% of the study participants and important by 20% of the study participants. The factor of **favourable natural conditions for the use of geothermal, hydrothermal and aerothermal heat sources** also has a positive trend and is considered essential by 10% of the study participants, very important by 60% of the study participants and important by 30% of the study participants. **The cleanliness of the sea** as an important research area is a factor with a positive trend, and is considered essential by 10% of the study participants, very important by 50% of the study participants, important by 30% of the study participants and not very important by 10% of the study participants. Finally, the factor of the **quality of life in cities** as an important research area is a factor with a positive trend, and is considered essential by 10% of the study participants, very important by 30% of the study participants, important by 50% of the study participants and not very important by 10% of the study participants.

As part of the PESTLE analysis, additional environmental factors assessed as significant for the development of research capacities under the Energy and Sustainable Environment TPA were proposed:

- climate change concerns have prompted investment in green technologies to grow;
- great potential for harnessing all RESs (geothermal energy, wind and solar energy, hydropower, biomass and marine energy) to produce electrical energy, thermal energy, cooling energy, biofuels and synthetic fuels;
- the link between water, energy and food security;
- harnessing the potential of the sea for the development of energy systems, transport, aquaculture, mariculture, fisheries, tourism, culture, etc.; and
- the Republic of Croatia as a hub for the transport of energy and goods as well as the transit of people.

Table 2 — The PESTLE Analysis

Aspect of the environment	External factors influencing the scientific and technological development of the TPA	Relative importance of factors (E, VI, IM, NVI or IN)	Positive/ negative trend
Political	– The energy crisis that increases the interest of the public and private sectors in investing in R&D in the field of RESs	50% E, 40% VI, 10% IM	Pos. (+)
	– Lack of knowledge and interest of policy makers about public-private partnership opportunities in the field of R&D	30% E, 60% VI, 10% IM	Neg. (–)
	– The current research funding model does not sufficiently encourage the collaboration between the scientific and economic sectors and does not ensure a sufficient concentration of resources (there is a lack of a critical mass of investment needed to achieve more significant results in a smaller number of areas)	30% E, 60% VI, 10% IM	Neg. (–)
	– The energy crisis that can have a negative impact on public sector investment because of new, unforeseen costs that have to be funded by the budget	30% E, 50% VI, 20% IM	Neg. (–)
	– Absence of a clear scientific sector development strategy and of clear priorities in the Republic of Croatia	20% E, 40% VI, 40% IM	Neg. (–)
	– Established incentivising public policies at the EU level	30% VI, 60% IM, 10% NVI	Pos. (+)
	– The ability to recruit scientists from abroad (administrative issues with obtaining work permits)	10% VI, 60% IM, 30% NVI	Neg. (–)
	INDIVIDUAL SUGGESTIONS FOR ADDITIONAL FACTORS: 1) Awareness of political actors about serving the community being a key role — E 2) Absence of cooperation between key stakeholders (government, the academic community, the economic sector, civil society and media) in strategic decision making, producing strategic documents and programming funds — E 3) Defence investments as a result of war in the environment as well as inflation arising from the same cause — VI 4) Economic consequences of the Republic of Croatia adapting to the growing danger of war in the environment — VI 5) Meritocracy in political decision making — VI 6) Insufficient public debate on strategic issues and law making — VI 7) Insufficiently taking into account the attitudes of the academic community in strategic decision making — VI 8) Absence of cross-departmental cooperation — IM 9) Support to scientists in applying for EU projects, particularly Horizon Europe, which requires having industry partners, in a context where industry partners are reluctant or unwilling to be part of a consortium when applying for such projects — IM		
Economic	– Capped salaries in the research sector hinder attracting and raising the standard of researchers	50% E, 40% VI, 10% IM	Neg. (–)

	– The unfavourable structure of the Croatian economic sector (too little investment in R&D)	30% E, 40% VI, 30% IM	Neg. (–)
	– Low innovation capacity of the economic sector	30% E, 40% VI, 30% IM	Neg. (–)
	– Negative perception of the scientific sector by the business sector	10% E, 60% VI, 20% IM, 10% IN	Neg. (–)
	– Price competitiveness of the services within the Croatian public scientific sector in comparison to competitors in the more developed EU Member States	10% E, 20% VI, 60% IM, 10% NVI	Pos. (+)
	– The green and digital development agenda	60% VI, 30% IM, 10% NVI	Pos. (+)
	– Lack of awareness among entrepreneurs of the opportunities for cooperating with the public scientific sector	50% VI, 50% IM	Neg. (–)
	– Inflation that is challenging macroeconomic stability	40% VI, 40% IM, 20% NVI	Neg. (–)
	– Low costs of living for foreign researchers coming from the more developed EU Member States, the US, etc.	20% VI, 10% IM, 50% NVI, 20% IN	Pos. (+)
	INDIVIDUAL SUGGESTIONS FOR ADDITIONAL FACTORS: 1) The return of industry and manufacturing to the EU — E 2) Poor awareness of the scientific community of the needs of the business sector — E 3) Disruptions of global trade supply chains — VI 4) The energy crisis — VI 5) Making better use of tax policies to achieve strategic objectives — VI 6) Opening up of new markets in Asia, Africa and South America — IM 7) Increasing the available resources of public institutions and government finances in key strategic areas — IM 8) Support to scientists in submitting EU projects at the MZO level — IM 9) Better devising and replenishing of funds used for strategic objectives (e.g. EPEEF funds, CSF funds, etc.) — IM 10) Major impact of tourism on the competitiveness of other sectors — NVI		
Technological	– Poorly developed production of technological equipment in the Republic of Croatia, which slows down the development of RDI capacities	20% E, 50% VI, 10% IM, 20% NVI	Neg. (–)
	– Insufficient research infrastructure in the private sector	20% E, 40% VI, 20% IM, 20% NVI	Neg. (–)
	– Use of new and advanced technologies in R&D (e.g. big data technology, new materials, etc.)	20% E, 20% VI, 60% IM	Pos. (+)
	– The ever-growing increase in equipment certification standards/costs increases maintenance costs for public scientific institutions	10% E, 20% VI, 60% IM, 10% NVI	Neg. (–)
	INDIVIDUAL SUGGESTIONS FOR ADDITIONAL FACTORS: 1) Unnecessarily high fragmentation of technological capacities at scientific institutions — E 2) Insufficient knowledge for the application of key technologies and poor opportunities for the transfer of knowledge — E		

	3) Standardisation and introduction of different indices to measure technological progress — VI 4) Application of tools to aid in strategic decision making and planning — IM 6) Sector integration (electricity, heat, gas, transport, water, drainage, waste management, etc.) — IM		
Social	– Insufficient entrepreneurial spirit in society (risk aversion)	20% E, 20% VI, 40% IM, 10% NVI, 10% IN	Neg. (−)
	– Increasing internationalisation of higher education	20% E, 30% VI, 30% IM, 20% NVI	Pos. (+)
	– Departure of young people to other countries reduces the pool for recruitment into RDI institutions	10% E, 60% VI, 10% IM, 20% NVI	Neg. (−)
	– Society's growing awareness of the need to properly manage by-products/biowaste increases interest in new technological solutions, especially in the agri-food industry	10% E, 50% VI, 30% IM, 10% NVI	Pos. (+)
	– Openness of young researchers to mobility (training in other countries)	10% E, 30% VI, 60% IM	Pos. (+)
	– Insufficient research/innovative spirit in society (including society's low willingness to embrace innovation)	10% E, 40% VI, 40% IM, 10% IN	Neg. (−)
	– Openness and awareness of young people to and of the importance of these topics (RESs and the environment)	60% VI, 40% IM	Pos. (+)
	INDIVIDUAL SUGGESTIONS FOR ADDITIONAL FACTORS: 1) A growing emphasis on management of institutions based on a clear purpose (mission-based institutions), as institutions guided by a clear and focused purpose are more flexible and able to adapt to new circumstances — E 2) Creative vision, as institutions that saw the pandemic as an opportunity rather than a hindrance were able to identify new areas for growth and research — E 3) A culture of trust, as high-trust institutions managed disruptions and the remote work of staff better — E 4) Insufficient entrepreneurial spirit in the research community — VI 5) The democratisation of relations between stakeholders in different sectors, e.g. energy or environment protection — VI 6) Influence of different media on public opinion, decision making, elections, etc. — VI 7) Increasing the transparency of stakeholders' actions through the use of digital technologies — IM 8) Use of refugee crises as opportunities for at least a partial demographic renewal — IM		
Legal	– Insufficient tax incentives for investment in R&D	40% E, 30% VI, 30% IM	Neg. (−)
	– Continuous neglect of the importance of the collaboration between researchers and the economic sector in the system of advancement in the scientific field	20% E, 60% VI, 20% IM	Neg. (−)
	– Restrictions and obstacles to the recruitment of foreign researchers	40% VI, 30% IM, 20% NVI, 10% IN	Neg. (−)
	INDIVIDUAL SUGGESTIONS FOR ADDITIONAL FACTORS:		

	1) Laws are not enforceable because of various shortcomings (low-quality regulations, questionable terminology or insufficient cross-departmental cooperation in the planning and implementation of legislative acts) — E 2) Poor ability to adapt EU policies to the Croatian context — IM		
Environmental	– Climate change reinforces the need to increase investment in R&D	50% E, 30% VI, 20% IM	Pos. (+)
	– Favourable natural conditions for the use of geothermal, hydrothermal and aerothermal heat sources (via heat pumps)	10% E, 60% VI, 30% IM	Pos. (+)
	– The cleanliness of the sea as an important research area	10% E, 50% VI, 30% IM, 10% NVI	Pos. (+)
	– The quality of life in cities as an important research area	10% E, 30% VI, 50% IM, 10% NVI	Pos. (+)
	INDIVIDUAL SUGGESTIONS FOR ADDITIONAL FACTORS: 1) Great potential of the Republic of Croatia for harnessing all RESs (geothermal energy, wind and solar energy, hydropower, biomass and marine energy) to produce electrical energy, thermal energy, cooling energy, biofuels and synthetic fuels — E 2) The water-food-energy system links (a broader analysis of the role of energy in the context of water and food security) — VI 3) Blue economy (the general use of the potential of the sea for the development of energy systems, transport, aquaculture, mariculture, fisheries, tourism, culture, etc.) — IM 4) The Republic of Croatia as a hub for the transport of energy and goods as well as the transit of people — IM		

E = essential, VI = very important, IM = important, NVI = not very important and IN = insignificant

In conclusion, the results of the **PESTLE analysis** helped to identify both positive and negative **factors in the environment that are potentially relevant for the development of research capacities under** the Energy and Sustainable Environment TPA. It is a large number of factors stemming from different domains, from the political domain to the economic and environmental domains. The results obtained were then used as a starting point.

3.2. The DELFI Analysis

The following are the key results of the survey that aimed to identify researchers' attitudes towards the future development of research potential under the Energy and Sustainable Environment TPA. The results of a previously conducted mapping of scientific and technological potential, the results of a workshop with the members of the Working Group and the results of a survey carried out immediately after the workshop all had an important role in the preparation of the survey questionnaire. The results of previously implemented activities helped to identify the key factors of the development of research potential thus far, which were then included in the survey questions about the future development of the TPA. The results of the DELFI analysis are primarily based on responses collected through the survey by experts active in the Energy and Sustainable Environment TPA. The findings of the survey were subsequently discussed with the experts from the Working Group as well as a wider group of experts on the topic, on the basis of which these findings were revised or verified, thus establishing the starting points for the development of a scenario analysis of the development of the TPA and the final prioritisation of research topics.

3.2.1. Basic Data on the Survey

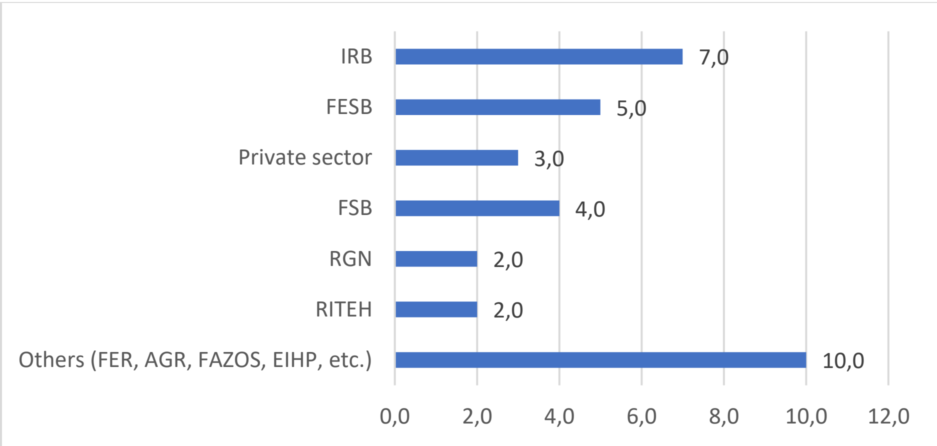
The questionnaire was made using the SurveyMonkey software tool and was addressed to the target respondents as an online questionnaire. The full text of the questionnaire can be found in Appendix 3. The data collection lasted from 2 May to 19 May 2022. Prior to sending the questionnaire, a pilot survey was done with three scientists to assess the clarity, completeness and relevance of the survey questions.

Following an introductory part with general information on the survey, Chapter 2 presents the results of the processing of the respondents' views. Specifically, the analysis covers the following areas:

- the likelihood of achieving specific outcomes that would potentially significantly contribute to strengthening scientific excellence under the TPA;
- the likelihood of achieving specific outcomes that would potentially significantly contribute to strengthening the cooperation with the economic sector under the TPA;
- the relevance of specific research topics for strengthening scientific excellence and the cooperation with the economic sector under the TPA in the next 5 to 15 years;
- the relevance of specific research programmes, such as Horizon Europe and others, for strengthening scientific excellence and the cooperation with the economic sector;
- the relevance of certain factors for further improving scientific excellence and the cooperation with the economic sector under the TPA;
- the expectations for future research excellence under the TPA in the next 5 to 15 years; and
- the expectations for future cooperation with the economic sector under the TPA in the next 5 to 15 years.

The most important conclusions of the analysis are set out in Chapter 3. A total of 33 respondents filled out the questionnaire, 31 of which completed the questionnaire in full and two of which completed it partially. The respondents can be tentatively divided into three groups based on inclusion criteria: the first is made up of the members of the Mapping and Foresight Working Group, the second is made up of selected members of the Energy and Sustainable Environment TIC, and the third group consists of researchers included in the research based on the recommendations of the members of the Working Group and members of the TIC. The members of the TIC involved in the research were selected based on an assessment of their personal involvement, that is, the involvement of the institutions where they worked, in the implementation of research activities. This selection of respondents, in accordance with the previously established methodology for the implementation of the Science and Technology Foresight Pilot Exercise, aims to gather the opinions of respondents with the greatest possible degree of understanding of the research aspects of the TPA. Given the composition of the TIC, which also includes representatives from the private sector, the survey was completed by three council members, representatives from the private sector. In order to further improve the results of the research, additional researchers, who were assessed as being able to contribute to the quality of the research, were included on the basis of the recommendations of the members of the Working Group and the representatives of the TIC. The following figure shows the distribution of respondents by place of work.

Figure 1 — Respondents by place of work, *n* = 33



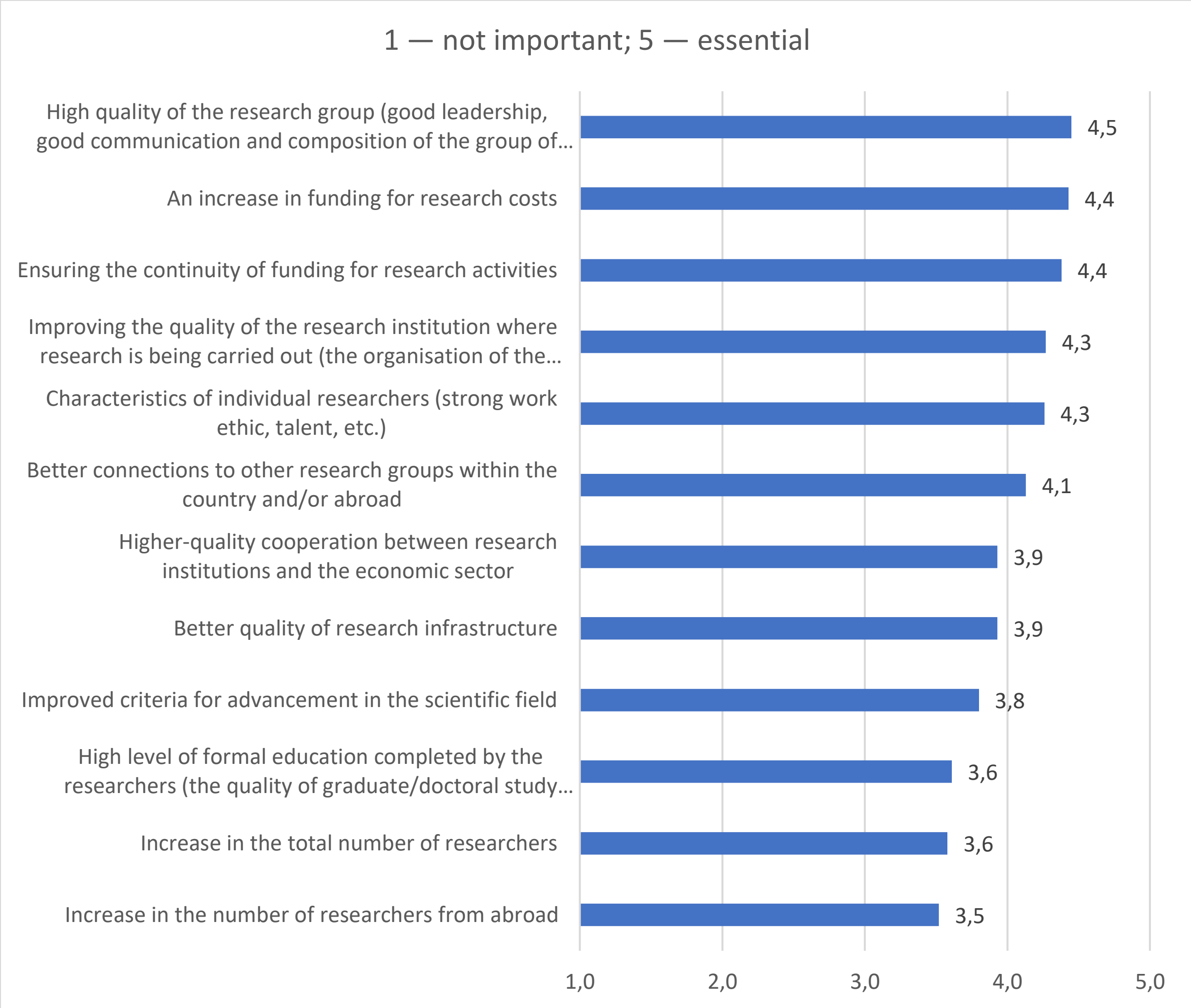
Most of the respondents were from the RBI (7), followed by the FESB (5), FSB (4), the private sector (3), RGN (2) and RITEH (2). Other institutions were represented individually (10 in total). The diversity of the institutions from which the respondents came is a good basis for gaining comprehensive insight into the future development of research potential under the TPA, given the scope that it covers. In terms of the location of the respondents' place of work, most of them came from the Zagreb area (21), Split area (6) and Rijeka area (2). The remaining four locations were represented by one respondent (Osijek, Slavonski Brod, Varaždin and Sisak).

3.2.2. Survey Results

3.2.2.1. Key Factors of Increasing Scientific Excellence and Cooperation with the Business Sector

The following figure illustrates the assessment of the importance of individual factors for further improving scientific excellence under the Energy and Sustainable Environment TPA. Research excellence implies an increase in the number of scientific papers published in prestigious scientific publications, number of citations and attention garnered. The list of factors was largely compiled on the basis of a previously conducted workshop with the members of the Mapping and Foresight Working Group and a survey following the workshop.

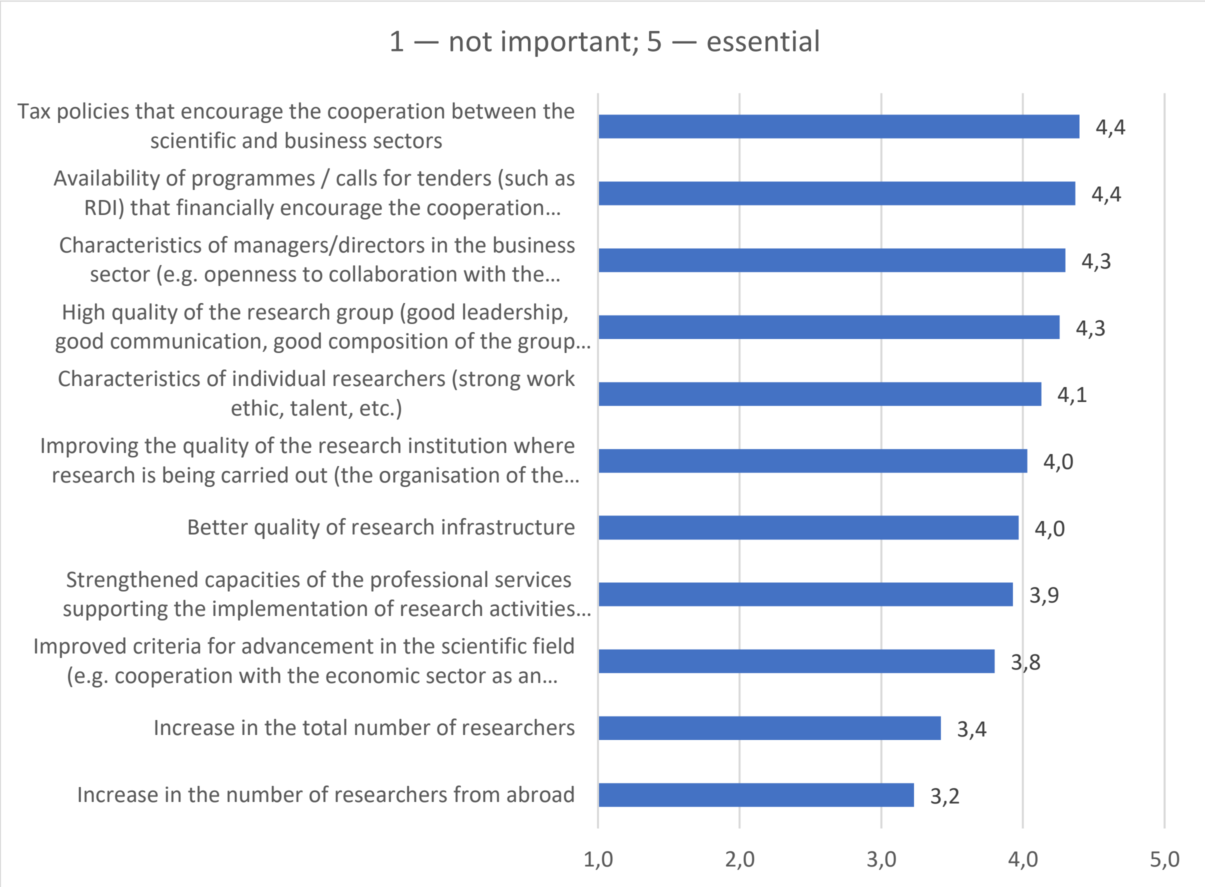
Figure 2 — Assessment of the importance of factors for further improving scientific excellence under the Energy and Sustainable Environment TPA, *n* = 31



The respondents prioritised the quality of the research group, meaning good leadership, good communication and good composition of the group of collaborators, as well as other related factors. Additionally, very high values of importance were assigned to the following factors: an increase in funding for research costs, ensuring continuity of funding for research activities, strengthening the quality of the research institution, the quality of individual researchers and better connections to other research groups within the country and/or abroad. Interestingly, according to the respondents' assessment, factors related to funding play a key role for future development, even though the available resources for strengthening the capacities of research institutions have significantly increased in recent years.

The lowest scores were recorded for factors such as an increase in the number of researchers from abroad, an increase in the total number of researchers and a high level of formal education completed by the researchers. However, these factors were also technically given rather high scores that are labelled 'very important' in the qualitative categories of the survey. Interestingly, improved criteria for advancement in the scientific field, although assessed as very important, are a factor that falls in the bottom part of the list of factors in terms of importance. When it comes to cooperation with the business sector, the results were relatively similar, with some differences as regards the choice of the factors themselves.

Figure 3 — Assessment of the importance of factors for strengthening the cooperation with the business sector, n = 31



The factors standing out as the most important were tax policies that encourage the cooperation between the scientific and economic sectors, the availability of programmes / calls for tenders that financially encourage the cooperation between the scientific and business sectors, the quality of managers/directors in the business sector (e.g. openness to collaboration with the scientific sector) and high quality of the research group. All these factors were given scores averaging above 4.3. The next group of factors by importance includes the quality of individual researchers, improving the quality of the research institutions, the improved quality of the research infrastructure, the strengthened capacities of the professional services supporting the implementation of research activities and improved criteria for advancement in the scientific field, where the cooperation with the economic sector is an important criterion. The increase in the total number of researchers and the increase in the number of researchers from abroad, although still significant, are the factors assigned the lowest importance in terms of strengthening the cooperation with the business sector.

Similarly as with the factors of improving scientific excellence, the respondents highlighted in particular the importance of financial factors. In addition, the factors of the quality of individual researchers and of the representatives of the business sector received very high importance ratings. On the other hand, the matter of the number of researchers (or lack thereof) was not perceived by most of the respondents as a very important factor of strengthening the relationship between the scientific and business sectors.

3.2.2.2. Likelihood of Achieving Outcomes with a Positive Impact on the Future Development of Research Potential

This part of the study examined the respondents' views on the likelihood of achieving specific outcomes of particular importance for the future development of research potential under the Energy and Sustainable Environment TPA. The aim was to obtain a more detailed basis for developing scenarios for the future development of the TPA. The outcomes were largely defined based on the previously obtained results of the implementation of the PESTLE/TOWS workshop and the survey that followed it. The outcomes are divided into two groups. The first group concerns higher participation of domestic researchers in relevant EU programmes such as Horizon Europe, while the second group is about strengthening the cooperation between the research and business communities.

The scores were based on assigning numerical values to categorical variables, where the lowest probability (category 'Almost impossible') had a value of 1 and the highest probability ('Almost certain') had a value of 5.

Table 3 — Quantitative values of individual categories of respondents' responses in terms of the probability of achieving outcomes

Category	Numerical value
Almost impossible (probability of achievement lower than 10%)	1
Unlikely (10%–30%)	2
Somewhat likely (30%–60%)	3
Likely (60%–90%)	4
Almost certain (probability > 90%)	5

The following table shows respondents' ratings regarding the achievement of certain outcomes that encourage higher participation of domestic researchers in EU programmes such as Horizon Europe, COST and others. The aim was to identify, according to respondents, which of the favourable outcomes has the highest chance of being achieved in the next 5 to 15 years.

Table 4 — Assessment of the probability of achieving outcomes that encourage higher participation in relevant EU programmes (1 — almost impossible; 5 — almost certain), *n* = 33

Outcomes	In the next 5 years	In the next 15 years
Almost all research institutions adopt their own policies to strengthen encouraging scientific teams to prepare project proposals for calls within Horizon Europe and other EU programmes	3.2	3.9

The reform of the science and higher education system leads to a significant increase in successful participation in EU programmes through increased financial and other support for demonstrably successful research teams	3.1	3.8
Research institutions have significantly improved infrastructure, leading to increased opportunities to apply to calls within Horizon Europe and other EU programmes	3.0	3.7
Most research institutions have developed project management competence and provide strong logistical support to researchers in applying to calls within Horizon Europe and other EU programmes	2.7	3.7
The reform of the science and higher education system leads to a significant increase in successful participation in EU programmes through reducing the fragmentation of research capacities, fostering stronger inter-institutional cooperation and through a higher degree of internationalisation	3.0	3.6
Most research institutions have effective intellectual property policies that encourage researchers to submit research project proposals (notably those with high commercial potential)	2.4	3.3
Average value of achieving outcomes	2.9	3.7

The results obtained show that the respondents **consider that there is a moderate probability of achieving most outcomes in the next 5 years** (the average score of all outcomes was 2.9). The outcome considered the most likely to be achieved was *'Almost all research institutions adopt their own policies to strengthen encouraging scientific teams to prepare project proposals for calls within Horizon Europe and other EU programmes'.* On the other hand, the one considered the least likely to be achieved was *'Most research institutions have developed, in the next 5 years, effective intellectual property policies that encourage researchers to submit research project proposals'* (notably those with strong commercial potential).

The probability of achieving favourable outcomes is slightly higher when looking at the 15-year period (the average rating of all outcomes is 3.7), i.e. they are at the boundary between the moderate probability of achievement and likely achievement. Nevertheless, the increase in the rated likelihood of achieving the outcomes is not significantly higher compared to the medium-term, which shows that respondents have some reservations regarding the achievement of favourable outcomes, even in the next 15 years. The biggest increase in likelihood of achievement is for the outcome regarding most research institutions having developed project management competence and providing strong logistical support to researchers in applying to calls within Horizon Europe and other EU programmes. On the other hand, the smallest increase is for the outcome regarding the reform of the science and higher education system leading to a significant increase in successful participation in EU programmes through reducing the fragmentation of research capacities, fostering stronger inter-institutional cooperation and through a higher degree of internationalisation. In their comments, several respondents stressed the importance of linking advancement in the scientific field and financial incentives to the implementation of research projects funded through EU programmes. Very similar but slightly lower values were recorded for respondents' estimates regarding expectations about the likelihood of achieving outcomes to do with encouraging stronger cooperation with the economic sector.

Table 5 — Assessment of the probability of achieving outcomes that encourage stronger cooperation with the economic sector (1 — almost impossible; 5 — almost certain), *n* = 32

Outcomes	In the next 5 years	In the next 15 years
Increasing political interest in decarbonisation and increasing energy independence leads to a strong increase in funding for research activities with a particular focus on their commercialisation	3.1	3.7
A strong increase in technologically advanced industrial manufacturing within the TPA leads to a significantly increased demand for research activities by the economic sector	2.9	3.7
The reform of the science and higher education system leads to a significant increase in incentives for the cooperation between the science and economic sectors through new funding criteria for research institutions and advancement in the scientific field	2.9	3.5
The growing number of examples of successful commercialisation of research projects leads to a strong increase in the business sector's interest in collaborating with research institutions	2.9	3.5
Research institutions have significantly improved infrastructure, leading to improved cooperation with the business community	2.8	3.4
Most research institutions have developed project management competence and provide strong logistical support to researchers to collaborate with the business community	2.5	3.3
Most research institutions have effective intellectual property policies in place that encourage researchers to commercialise innovative solutions	2.5	3.2
Average value of achieving outcomes	2.8	3.5

Respondents consider that there is a moderate possibility of achieving the described outcomes in the next 5 years (the average rating of all outcomes is 2.8). Looking at the period of the next 15 years, respondents expectedly gave a slightly higher rating of the likelihood of achievement, at the boundary between a moderate possibility of achievement and likely achievement (average rating of 3.5). Individually, the **outcome rated as most likely to be achieved is *'Increasing political interest in decarbonisation and increasing energy independence leads to a strong increase in funding for research activities with a particular focus on their commercialisation'*** (with an average rating of 3.1 and 3,7 respectively). On the other hand, the **outcome rated as the least likely to be achieved is the outcome *'Most research institutions have effective intellectual property policies in place that encourage researchers to commercialise innovative solutions'*** (with an average rating of 2.5 and 3.2, respectively). Similarly to the first group of outcomes, the differences in average values between the 5-year and 15-year periods were relatively small.

In their comments, some of the respondents highlighted the problem of insufficient financial and other incentives for the cooperation between the scientific and economic sectors. The introduction of additional financial incentives for researchers working with the economic sector, the introduction of so-called strategic, higher-value scientific projects, involving compulsory cooperation with the economic sector, and the inclusion of cooperation with the economic sector as one of the criteria for advancement were proposed as potential mechanisms that would increase the motivation of scientists to cooperate with the economic sector. The mandatory monitoring of the results of cooperation projects and the use of the results of project evaluations as a starting point for funding decisions for the new cycle of projects for collaboration between the scientific and economic sectors was also proposed.

3.2.2.3. Expectations Regarding the Overall Dynamics of Scientific Excellence and Cooperation with the Business Sector

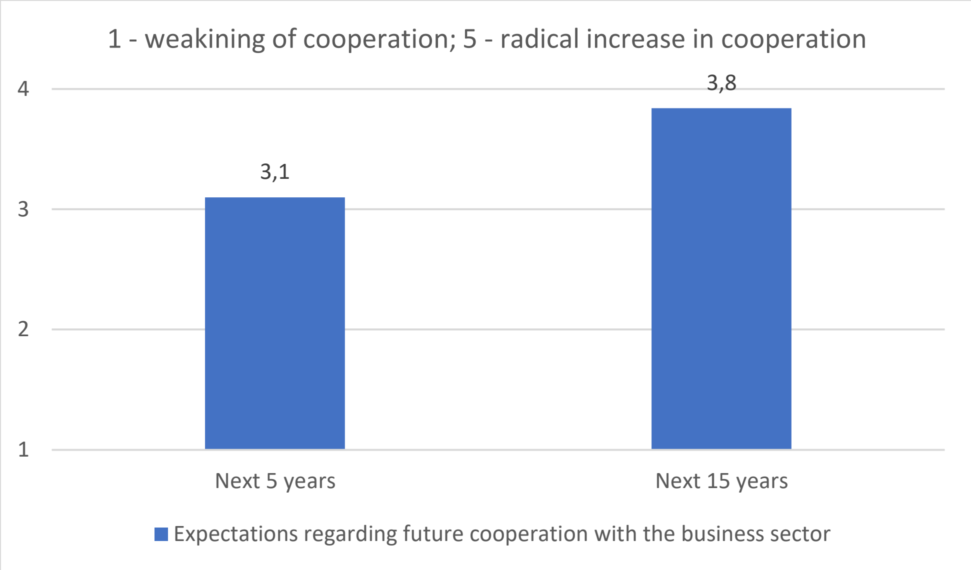
In the final part of the survey, the respondents were asked to rate their expectations of the trends regarding scientific excellence and collaboration between the research community and the business sector within the next five and fifteen years, respectively. The following table shows the quantitative and qualitative categories of scientific excellence and cooperation with the business sector ratings.

Table 6 — Categories of respondents' responses about their expectations regarding scientific excellence and strengthening the cooperation with the economic sector in the future

Qualitative rating of scientific excellence	Qualitative rating of the cooperation with the business sector	Numerical value
I expect the level of research excellence to be lower	**I expect less cooperation between the scientific and business sectors**	1
I expect the level of research excellence to remain at the current level	**I expect the current level of cooperation to persist**	2
I expect a slight increase in the level of research excellence	**I expect a slight increase in the level of cooperation**	3
I expect a significant increase in the level of research excellence	**I expect a significant increase in cooperation**	4
I expect a dramatic increase in the level of research excellence	**I expect a dramatic increase in cooperation**	5

The views of the respondents are shown in the following figure. The respondents had positive expectations regarding the improvement of the level of research excellence and of the cooperation with the business sector. The respondents expected on average a slight increase in the level of research excellence under the Energy and Sustainable Environment TPA in the next 5 years, and they expected a significant increase in the level of research excellence in the next 15 years.

Figure 4 — Expectations regarding the future level of research excellence and collaboration with the business sector, n = 31



On average, the respondents expressed only slightly lower expectations regarding the future collaboration of the (public) research sector with the business sector, with a significant increase in the quality of cooperation expected in the long term, i.e., over the next 15 years. The respondents reported that they expected a slight increase in the level of cooperation with the business sector over the next 5 years, and they expected a significant increase in cooperation over the next 15 years.

3.2.2.4. The Potential of Specific Research Topics for Achieving Future Research Excellence and Innovation Development

This section looked at researchers' views on the potential of specific topics for achieving future research excellence of domestic research institutions and innovation development under the Energy and Sustainable Environment TPA. **Future research excellence** is defined as the performance of domestic researchers in terms of the number of papers published, number of citations and attention garnered, as well as their participation in European Research Council (ERC) projects and Marie Skłodowska-Curie Actions in the next 5 to 15 years. For example, if the respondents estimated that researchers would significantly increase the level of scientific excellence within a given topic, then that topic was rated as one with high or very high potential. **Innovation development** refers to the development of new products/services, processes or designs as a result of development and research activities.

The list of research topics was developed on the basis of different strategic documents at the EU and national levels.[1] Eleven research topics were identified in total:

- Topic 1: development of technologies, systems, equipment and devices for the generation of electrical and thermal energy from RESs

[1] Of the EU documents, European Commission (2021) and European Commission (2021a) reports were used, and of the national documents, the Smart Specialisation Strategy 2016–2020 and a draft of the new Smart Specialisation Strategy 2021–2029 were used.

- Topic 2: development of nuclear power generation technology, systems, equipment and devices
- Topic 3: development of electrical energy transmission and distribution technologies, systems, equipment and devices
- Topic 4: development of energy storage technologies, equipment and devices
- Topic 5: development of hydrogen production technologies, systems and devices
- Topic 6: development of hydrogen storage technologies, systems and devices
- Topic 7: development of heating/cooling technologies, systems, equipment and devices
- Topic 8: development of waste management systems and equipment and of environmental technologies (anaerobic decomposition of biowaste, composting, material recovery from waste, capture and storage of landfill gas, etc.)
- Topic 9: development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings;
- Topic 10: development of electric vehicle charging infrastructure systems and devices;
- Topic 11: development of carbon capture and storage systems; and

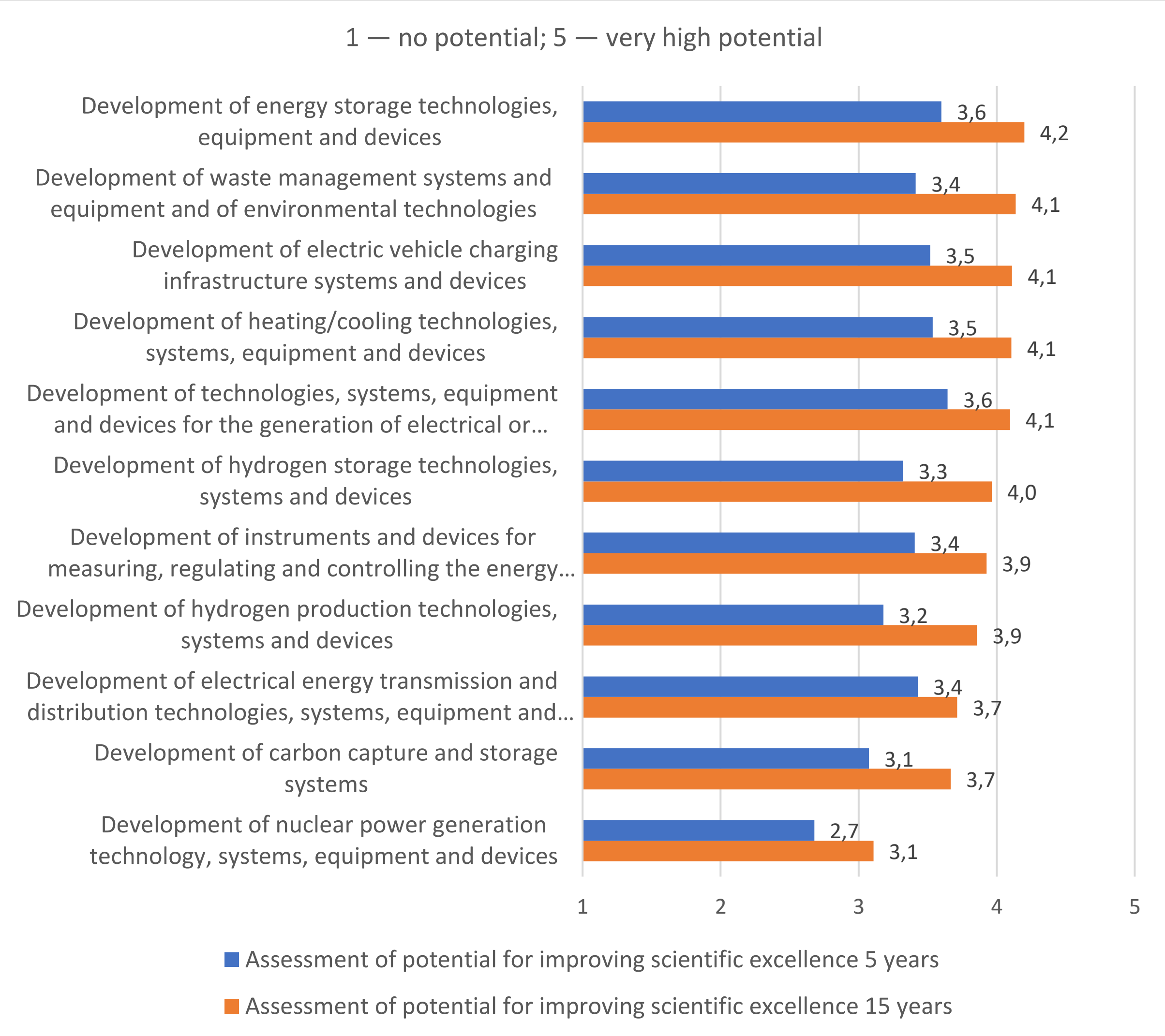
The scores were based on assigning numerical values to categorical variables, where the minimum probability of improving excellence (category 'No potential') had a value of 1 and the highest probability ('Very high potential') had a value of 5.

Table 7 — Quantitative values of individual categories of respondents' responses regarding the assessment of potential for improving scientific excellence

Category	Numerical value
No potential	1
Low potential	2
Moderate potential	3
High potential	4
Very high potential	5

The following figure shows respondents' ratings of the potential of the specific topics for improvement in scientific excellence over the next 5 to 15 years.

Figure 5 — Assessment of the potential of specific topics for improvement in scientific excellence under the TPA in the next 5 to 15 years, *n* = 32



The respondents rated the potential of most of the research topics for improvement in scientific excellence relatively similarly. Only the development of nuclear power generation technology, systems, equipment and devices was rated significantly lower than the other topics (2.7). Slightly lower ratings were also noted for the development of carbon capture and storage systems (3.1). Most of the topics with potential for improvement in scientific excellence over the next 5 years were given ratings between 3.4 and 3.6, which is the boundary between moderate and high potential. The topics rated as having the highest potential (rated 3.5 and above) were:

- development of energy storage technologies, equipment and devices; and
- development of technologies, systems, equipment and devices for the generation of energy from RESs;
- development of electric vehicle charging infrastructure systems and devices;
- development of heating/cooling technologies, systems, equipment and devices.

The development of waste management systems and equipment and of environmental technologies, the development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings and the development of electrical energy transmission and distribution technologies, systems, equipment and devices can also be highlighted (all three with a rating of 3.4).

For the long term, i.e. for the 15-year period, the highest rated topics (a rating of 4.0 and above) were:

- development of energy storage technologies, equipment and devices;
- development of waste management systems and equipment and of environmental technologies.
- development of electric vehicle charging infrastructure systems and devices;
- development of heating/cooling technologies, systems, equipment and devices;
- development of technologies, systems, equipment and devices for the generation of energy from RESs;
- development of hydrogen storage technologies, systems and devices.

However, other topics were also given relatively high ratings, with the exception of nuclear power. In terms of additional research topics with potential for improvement in scientific excellence, respondents suggested for consideration a high number of new topics that are listed in the following table.

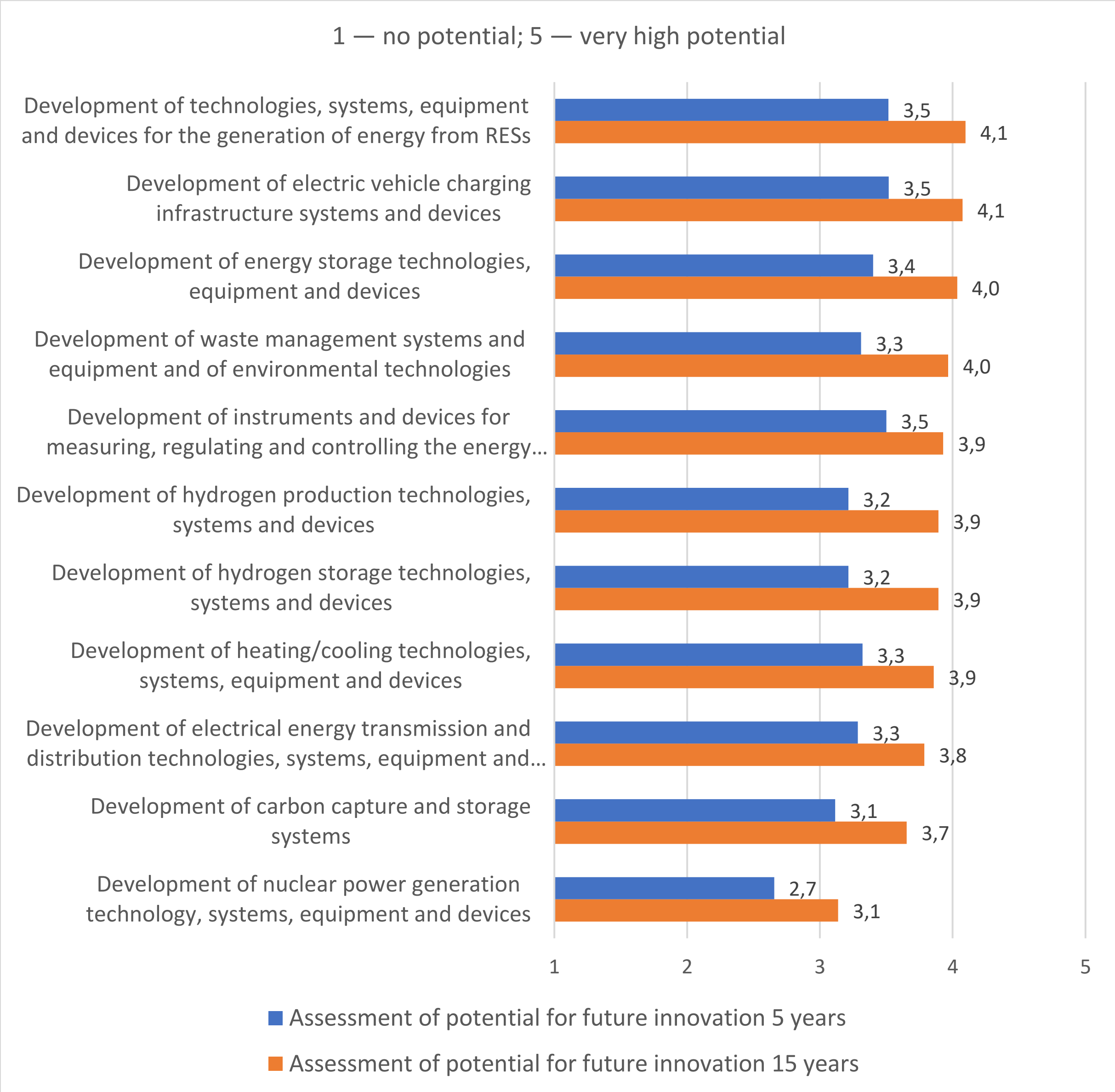
Table 8 — Suggestions and ratings of additional RDI topics for improving scientific excellence

Suggestions for additional RDI topics	Rating of potential	Arguments for recognising the importance of the topic
Research and development of geothermal energy use for the generation of electrical and thermal energy, exploration of geothermal energy potential, the development of equipment and the development of integration with other sectors	High for the 5-year period / very high for the 15-year period	By 2030, it will certainly be possible to achieve 100 to 200 MW of production capacity in geothermal power plants. The energy development strategy of the Republic of Croatia until 2030 cites 100 MW as the technical potential for electricity generation along with the exploration of new sites that is very likely already being carried out.
Research and development of solar heating plants with seasonal storage	Moderate for the 5-year period / very high for the 15-year period	Technology has shown major potential for replacing natural gas in district heating systems. Solar heating plants are garnering interest in a regional context and may boost the development of domestic industry. For example, there is plenty of aluminium processing in the Republic of Croatia, which can be used to produce bases or other parts of solar heat collectors, and there are also glass factories and insulation material factories.
Research and development of floating solar power plants	Moderate for the 5-year period / very high for the 15-year period	The use of floating photovoltaic (PV) modules is an increasingly considered solution regarding the hybrid management of systems based on hydropower and other variable RESs. Floating PV modules can be installed on the upper and/or lower reservoir, creating a hybrid model that offers the advantages of increasing efficiency in the use of land and water resources, reducing water evaporation, increasing the efficiency

		of PV modules because of cooling effects, using existing high-voltage infrastructure, etc.
Research and development of alternative propulsion systems in ships and related infrastructure	High for the 5-year period / very high for the 15-year period	Because of the tradition of shipbuilding in the Republic of Croatia, the shipbuilding sector can easily focus on the development and production of ships operating on clean/green power, which also involves certain infrastructure (electric chargers, hydrogen or ammonia charging stations, etc.).
Research and development of technologies, systems, equipment and devices for harnessing energy from the sea	High for the 5-year period / very high for the 15-year period	Marine and ocean research will intensify in the coming period, and marine energy offers great opportunities, in particular because it can be integrated into other activities related to the sea, such as aquaculture.
Research and development of technologies, equipment and devices for links in the water-food-energy nexus	High for the 5-year period / very high for the 15-year period	The links in the water-food-energy security system are an essential area for the circular economy and for the security of energy, water and food supply, especially in the event of major climate change.
Application of electric propulsion in road/maritime transport	High potential	-
Cascading use of biomass for biomaterials, biomolecules and bioenergy	-	-
Development of systems to improve and protect water, air and land	-	-

While some of the suggested topics can be classified under one of the 11 topics mentioned above (e.g. geothermal energy technologies are covered by topic 1, the development of technologies, systems, equipment and devices for the generation of electrical and thermal energy from RESs), the table includes all of the respondents' suggestions in order to preserve the completeness of the comments. The following figure shows respondents' ratings of the potential of specific topics for innovation development in the next 5 to 15 years.

Figure 6 — Assessment of the potential of specific topics for innovation development in the next 5 to 15 years, *n* = 32



Respondents gave ratings similar to those regarding scientific excellence and, in most cases, assessed that the suggested topics had **moderate potential to generate innovation in the medium term** and **high potential to do so in the long term**. For the medium term, the following topics were the highest rated (rated 3.5 and above):

- development of electric vehicle charging infrastructure systems and devices;
- development of technologies, systems, equipment and devices for the generation of energy from RESs.
- development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings;

It should be pointed out that a number of additional topics were given only slightly lower ratings and that only the development of nuclear power generation technology, systems, equipment and devices was rated as having slightly lower innovation potential.

For the long term, the following topics were the highest rated (rated 4.0 and above):

- development of technologies, systems, equipment and devices for the generation of energy from RESs.
- development of electric vehicle charging infrastructure systems and devices;
- development of energy storage technologies, equipment and devices
- development of waste management systems and equipment and of environmental technologies; and

However, as in the case of the assessment of potential for the medium term, a number of other topics were also given relatively favourable ratings of long-term potential that was rated as between moderate and high. The respondents also suggested some additional topics with significant innovation development potential in the coming period, which are listed in the following table.

Table 9 — Suggestions and ratings of additional RDI topics with potential for innovation development

Suggestions for additional RDI topics	Rating of potential	Arguments for recognising the importance of the topic
Research and development of geothermal energy use systems for the generation of electrical and thermal energy, exploration of geothermal energy potential, the development of equipment and the development of integration with other sectors	Very high for the 5-year period / very high for the 15-year period	Knowledge transfer from oil and natural gas research for geothermal energy use can quickly lead to innovation
Research and development of solar heating plants with seasonal storage	Low for the 5-year period / very high for the 15-year period	The transfer of knowledge from other EU Member States to the domestic industry and research centres is needed
Research and development of floating solar power plants	Low for the 5-year period / very high for the 15-year period	The transfer of knowledge from other EU Member States to the domestic industry and research centres is needed
Research and development of alternative propulsion systems in ships and related infrastructure	High for the 5-year period / very high for the 15-year period	Using existing resources for innovation
Research and development of technologies, systems, equipment and devices for harnessing energy from the sea	High for the 5-year period / very high for the 15-year period	Using existing resources for innovation and knowledge transfer from other sectors present in the Republic of Croatia can ensure innovation
Research and development of technologies, equipment and devices for links in the water-food-energy system	High for the 5-year period / very high for the 15-year period	The necessary knowledge transfer, the use of existing resources for innovation and the transfer of knowledge from other sectors present in the Republic of Croatia can ensure innovation

RDI topics and the development of new technologies between 2011 and 2021 will be used;
In order to further consider the potential of the suggested eleven RDI topics in the context of previously achieved results, data on technologies developed by domestic research institutions in the Energy and Sustainable Environment TPA between 2011 and 2021 was analysed. The data was previously collected during the mapping phase. In total, data regarding 95 technologies was collected, and for 50 of those technologies, a link to the 11 RDI topics was identified. By categorising the data on newly developed technologies across all eleven RDI topics, it is easy to identify which topics were particularly successful in the previous period. However, this does not necessarily mean that the technology development pattern will remain the same in the coming period. The following table shows the number of the developed technologies by topic.

RDI topic	Number of new technologies developed between 2011 and 2021
Topic 1: development of technologies, systems, equipment and devices for the generation of electrical and thermal energy from RESs	12
Topic 2: development of nuclear power generation technology, systems, equipment and devices	1
Topic 3: development of electrical energy transmission and distribution technologies, systems, equipment and devices	0
Topic 4: development of energy storage technologies, equipment and devices	5
Topic 5: development of hydrogen production technologies, systems and devices	3
Topic 6: development of hydrogen storage technologies, systems and devices	0
Topic 7: development of heating/cooling technologies, systems, equipment and devices	5
Topic 8: development of waste management systems and equipment and of environmental technologies (anaerobic decomposition of biowaste, composting, material recovery from waste, capture and storage of landfill gas, etc.)	21
Topic 9: development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings;	3
Topic 10: development of electric vehicle charging infrastructure systems and devices;	0
Topic 11: development of carbon capture and storage systems; and	0
Total	50

The results show a fairly high concentration of technologies in two areas: topic 8, the development of waste management systems and equipment and of environmental technologies, is the category under which 42% of all developed technologies are classified, and topic 1, the development of technologies, systems, equipment and devices for the generation of energy from RESs, is the category under which a further 24% are classified. In other words, these two topics can be 'credited' with 66% of all developed technologies. Also of note are topic 4, the development of energy storage technologies, systems and devices, and topic 7, the development of heating/cooling technologies, systems, equipment and devices, accounting for 6% of all developed technologies. The remaining topics include fewer than three developed technologies, with no developed technologies identified for four of the topics. When comparing the results obtained with the ratings of the potential of the specific topics regarding scientific excellence and innovation, there is a significant

3.2.2.2. Importance of Advanced Technologies and Specific Programmes / Calls for Tenders for the Development of the Energy and Sustainable Environment TPA

Advanced technologies are recent technologies that have been identified as technologies that will significantly change the business and social environment at the global level, or are expected to do so. Advanced technologies and industrial value chains play a key role in the European Green Deal strategy, helping reduce the carbon footprint and accelerating the transition to clean technological solutions (EC, 2020). The list of advanced technologies selected for survey purposes was largely based on the 2021 EC report 'Advanced Technologies for Industry — Methodological Report'.[2]

The importance ratings were based on assigning numerical values to categorical variables, where the lowest probability (category 'Not important') had a value of 1 and the highest probability ('Essential') had a value of 5.

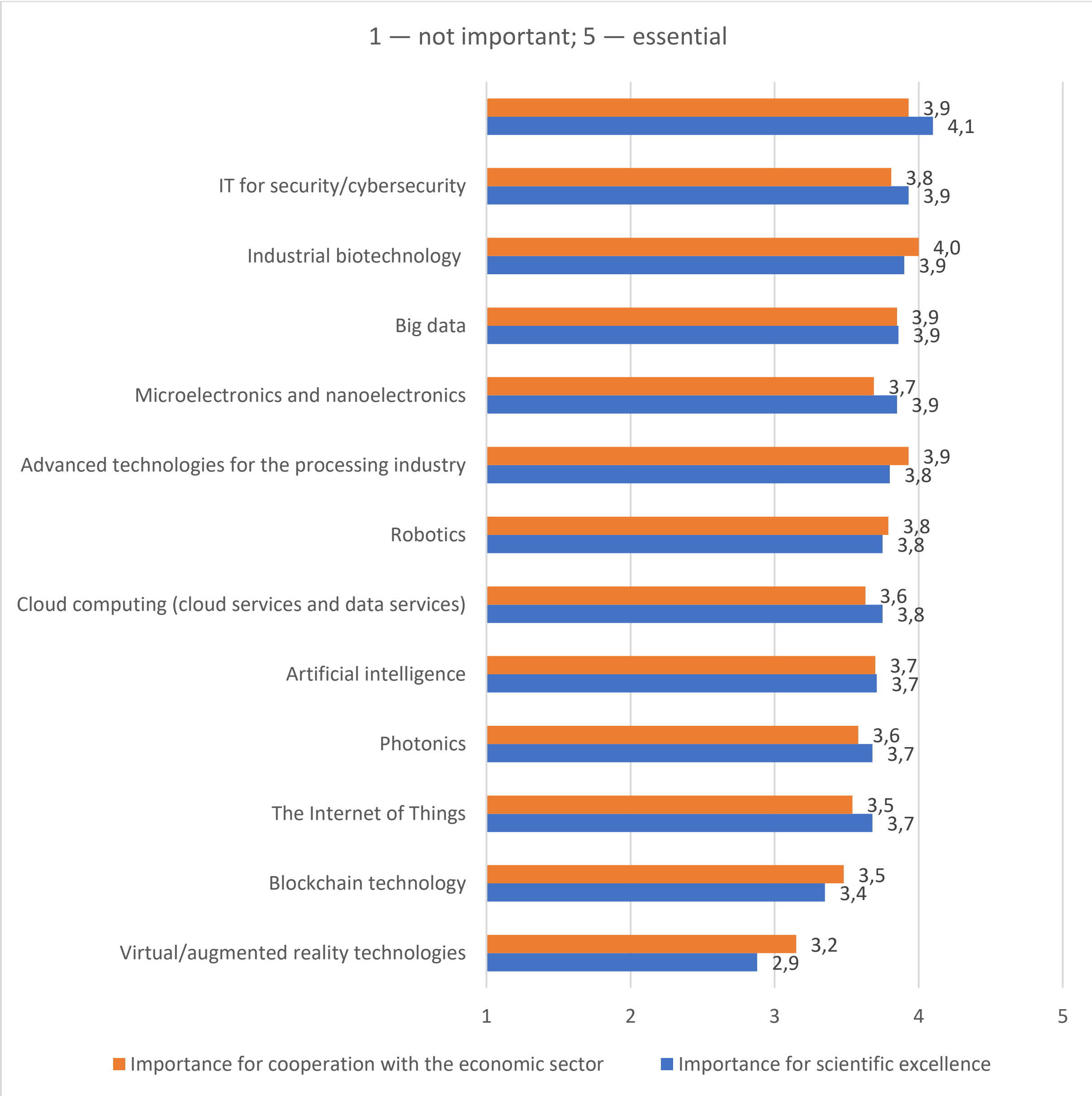
Table 10 — Categories of respondents' responses on the importance of advanced technologies for improving scientific excellence and strengthening cooperation with the economic sector

Category	Numerical value
Not important	1
Not very important	2
Important	3
Very important	4
Essential	5

The following figure shows the ratings of the importance of specific advanced technologies for improving research excellence and for increasing the cooperation between the scientific and business sectors in the Republic of Croatia under the Energy and Sustainable Environment TPA.

[2] Available at https://ati.ec.europa.eu/reports/eu-reports/advanced-technologies-industry-methodological-report

Figure 7 — Ratings of the importance of advanced technologies for improving research excellence and the cooperation between the scientific and business sectors, *n* = 31

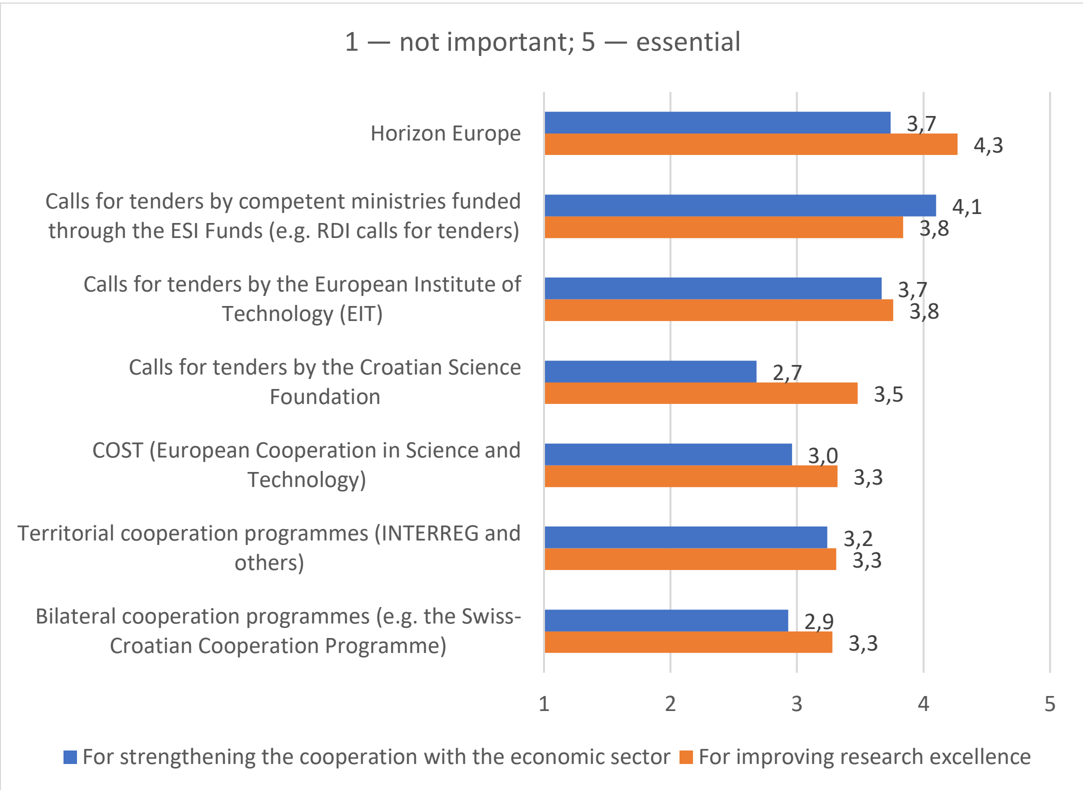


Most technologies received ratings ranging between 3.5 and 4.0, which would correspond to the 'Important' category. In other words, the respondents rated most of the advanced technologies as important for improving scientific excellence as well as for strengthening cooperation with the economic sector under the Energy and Sustainable Environment TPA. In terms of improving scientific excellence, the following technologies were rated as the three most important ones: advanced materials, IT for security and industrial biotechnology. In terms of strengthening cooperation with the economic sector, the three highest rated technologies were industrial biotechnology, advanced materials and advanced technologies for the processing industry. On the other hand, of the technologies that were given the lowest ratings, virtual/augmented reality technologies should be noted, as they are characterised by a slightly larger deviation than the other technologies. In terms of additional technologies important for the Energy and Sustainable Environment TPA, the respondents listed the following:

- GIS tools and their advanced use — important;
- meteorology, the advanced use of meteorological infrastructure, weather forecasts, data and tools — very important;
- digital twin technology — very important;
- quantum computing — not very important;
- drones — very important;
- 3D printing — very important;
- bioprinting — important;
- 5G and 6G networks — very important; and
- smart factories — no rating of importance.[3]

The following figure shows the ratings of the importance of specific programmes / calls for tenders for improving research excellence and the cooperation between the scientific and business sectors under the Energy and Sustainable Environment TPA. The aim is to identify which programmes / calls for tenders can have the greatest impact on the future development of research capacities.

Figure 8 — Ratings of the importance of specific programmes / calls for tenders for improving research excellence and the cooperation between the scientific and business sectors, *n* = 31



[3] However, it should be noted that some of these additional technologies are already covered by the previous categorisation of advanced technologies. For example, according to the mentioned EC report on advanced technologies, 3D printing is part of advanced technologies in the processing industry, drones are already included under robotics and smart factories under the Internet of Things.

According to the respondents, the Horizon Europe programme has the greatest importance for improving scientific excellence (average rating of 4.3), followed by calls for tenders by competent ministries funded through the European Structural and Investment (ESI) Funds and calls by the European Institute of Technology (average rating of 3.8). On the other hand, bilateral cooperation programmes, territorial cooperation programmes and COST were given the lowest ratings (average rating of 3.3). However, even these had decent ratings (on average, they were qualitatively assessed as important). CSF calls for tenders received a mid-range rating, somewhere between important and very important, which seems somewhat below expectations given the relatively significant resources invested in the past period in projects specifically focused on research activities.[4]

In terms of the importance of programmes / calls for tenders for strengthening the cooperation between scientific institutions and the economic sector, the calls for tenders by ministries funded through the ESI Funds were rated the highest (average rating of 4.1), followed by calls from the Horizon Europe programme and the European Institute of Technology. On the other hand, CSF calls for tenders were given the lowest ratings (average rating of only 2.7), which clearly reflects the relatively poor contribution of the CSF to strengthening the cooperation between the public scientific sector and the business sector.

[4] According to the data collected during the mapping phase, the total value of funds granted through the CSF for the Energy and Sustainable Environment TPA between 2011 and 2021 was HRK 80.2 million.

3.2.3. Conclusion on the Results of the DELFI Analysis

The aim of the survey was to determine the views of experts regarding the development of research potential in the Energy and Sustainable Environment TPA in the next 5 to 15 years, with particular reference to the matter of cooperation between public research institutions and the business sector. As such, the results of the survey will serve to develop scenarios for the future development of the Energy and Sustainable Environment TPA and to develop guidelines for the review of strategic documents. The respondents assessed the potential for improving scientific excellence over the next five and fifteen years **of eleven suggested research topics**. **Most of the topics were given relatively similar ratings corresponding most closely to the category of moderate potential for the medium term.** The topics with the highest potential in the medium term were:

- development of energy storage technologies, equipment and devices; and
- development of technologies, systems, equipment and devices for the generation of energy from RESs;
- development of electric vehicle charging infrastructure systems and devices;
- development of heating/cooling technologies, systems, equipment and devices.

However, a number of additional topics were given only slightly lower ratings, with the exception of the development of nuclear power generation technology, systems, equipment and devices and the development of carbon capture and storage systems.

The ranking of topics for the long term, i.e., over the next fifteen years, was very similar, with the ratings of the potential for improving scientific excellence expectedly higher (most of the topics were rated as having high potential). The highest rated topics were:

- development of energy storage technologies, equipment and devices;
- development of waste management systems and equipment and of environmental technologies.
- development of electric vehicle charging infrastructure systems and devices;
- development of heating/cooling technologies, systems, equipment and devices;
- development of technologies, systems, equipment and devices for the generation of energy from RESs;
- development of hydrogen storage technologies, systems and devices.

The respondents gave very similar ratings for the potential to generate innovation for the medium and long term, respectively. Most of the suggested topics were rated as having **moderate potential for generating innovation in the medium term**, and **high potential to do so in the long term**. For the medium term, the respondents identified the highest potential for innovation in the following topics:

- development of electric vehicle charging infrastructure systems and devices;
- development of technologies, systems, equipment and devices for the generation of energy from RESs;
- development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings.

For the long term, the following topics were rated the highest:
- development of technologies, systems, equipment and devices for the generation of energy from RESs;
- development of electric vehicle charging infrastructure systems and devices;
- development of energy storage technologies, equipment and devices; and
- development of waste management systems and equipment and of environmental technologies.

It should be noted that a number of other topics were given only slightly lower ratings, i.e. that they were also rated as having important potential in the medium term, and especially in the long term. Only the development of nuclear power generation technology, systems, equipment and devices was rated as having a much lower potential for generating innovation. In addition to the suggested topics, the respondents also proposed several additional topics with significant potential for improving scientific excellence and increasing innovation. These were mainly topics focusing more closely on specific areas of the development of technologies for the generation of energy from RESs.

It is interesting to note that **the ratings of the potential of specific topics correspond only in part to the results achieved so far in terms of the development of new technologies.** More specifically, according to the data collected during the mapping phase, 66% of all technologies developed by domestic research institutions between 2011 and 2021 had to do with only two of the topics:

- development of waste management systems and equipment and of environmental technologies; and
- development of technologies, systems, equipment and devices for the generation of energy from RESs.

Assuming that the data collected on the technologies developed reflects an objective state of the achievement of research potential, such a result shows that the **gap between the potential and the achievement of this potential is still quite large in the Republic of Croatia**. The respondents also rated the importance of advanced technologies for improving scientific excellence as well as for strengthening the cooperation with the economic sector. In terms of improving scientific excellence, the following technologies were rated as the three most important ones:

- advanced materials; and
- IT for security; and
- industrial biotechnology.

In terms of strengthening the cooperation with the economic sector, the three highest-rated advanced technologies were:
- industrial biotechnology;
- advanced materials; and
- advanced technologies for the processing industry.

The remaining advanced technologies were given slightly lower but relatively similar ratings. A larger negative deviation was observed only for virtual/augmented reality technologies.

The assessment of the importance of specific programmes / calls for tenders for **improving scientific excellence has shown that the Horizon Europe programme has the highest importance**, followed by calls for tenders by competent ministries funded through the ESI Funds and calls by the European Institute of Technology (EIT). On the other hand, bilateral cooperation programmes, territorial cooperation programmes and COST were given the lowest ratings. **The ranking is slightly different when it comes to the importance of programmes / calls for tenders for strengthening the cooperation with the business sector.** In that regard, the **highest ratings were given to calls for tenders by ministries funded through the ESI Funds (e.g., the so-called RDI calls for tenders).** These were followed by Horizon Europe and EIT calls.

The respondents were also asked to assess **the importance of certain factors for further improving scientific excellence and the cooperation with the business sector.** They rated a large number of factors as very important, which only confirms that overall excellence is the result of the impact of many factors. Nevertheless, **the quality of the research group was rated as the most important factor of improving scientific excellence**. In addition, very high ratings were given to the increase in funding for research costs, ensuring continuity of funding for research activities, strengthening the quality of the research institution, the quality of individual researchers and better links to other research groups within the country and/or abroad. The lowest scores were recorded for factors such as an increase in the number of researchers from abroad, an increase in the total number of researchers and a high level of formal education completed by the researchers. However, these factors were also technically given rather high scores that are labelled 'very important' in the qualitative categories of the survey.

In terms of strengthening the cooperation with the business sector, the most important factor were tax policies that foster cooperation between the scientific and economic sectors. These were followed by the availability of programmes / calls for tenders financially incentivising cooperation between the scientific and business sectors, the quality of managers/directors in the business sector (e.g. openness to collaboration with the scientific sector) and high quality of the research group.

Increasing participation in relevant EU programmes such as Horizon Europe is one of the most important indicators of improving scientific excellence. However, in order to achieve this goal, it is necessary to achieve a number of changes that will serve to strengthen the capacity of domestic institutions to take part in EU programmes. **The respondents considered that there was a moderate likelihood (a probability of achievement between 30% and 60%) of achieving a range of favourable outcomes encouraging the stronger participation of domestic institutions in the relevant EU programmes in the medium term**, i.e., over the next five years. **For the long term (the next 15 years), the respondents were somewhat more optimistic, though not significantly.** In most cases, the ratings of achieving a favourable outcome fall somewhere between the moderate probability of achievement and likely achievement (probability > 60%).

The respondents reported the greatest optimism regarding the outcome 'Almost all research institutions adopt their own policies to strengthen encouraging scientific teams to prepare project proposals for calls within Horizon Europe and other EU programmes'. On the other hand, they were the most sceptical regarding the outcome 'Most research institutions have effective intellectual property policies that encourage researchers to submit research project proposals (notably those with high commercial potential)'.

They expressed only a slightly lower level of optimism regarding the achievement of certain outcomes fostering stronger cooperation with the business sector. **They expressed the highest level of optimism regarding the achievement of the outcome 'Increasing political interest in decarbonisation and increasing energy independence leads to a strong increase in funding for research activities with a particular focus on their commercialisation'.** On the other hand, the outcome rated as the least likely to be achieved was 'Most research institutions have effective intellectual property policies in place that encourage researchers to commercialise innovative solutions'. These differences suggest that the respondents had higher expectations regarding external factors of change than internal ones under the control of the research institutions themselves.

Finally, the respondents rated their overall expectations regarding the improvement of scientific excellence as well as the improvement of the cooperation with the business sector in the next 5 to 15 years. These expectations were moderate for the medium term. However, **for the long term, i.e., over the next fifteen years, the respondents expected a significant increase in research excellence and, to a slightly lesser extent, a significant improvement in collaboration with the business sector.**

Following further consultation on the results of the conducted survey with the members of the Working Group, the list of priority areas was somewhat broadened by adding a topic related to the development of smart grid technologies and the digitalisation of the energy system. Additionally, the topic 'development of waste management systems and equipment and of environmental technologies' was divided into two topics: (i) the development of technology, equipment and devices for reducing resource consumption, reducing waste generation and more efficient waste treatment and (ii) the development of environmental protection and/or sustainability technology, systems and equipment.

4. Scenario Development

Scenario analysis is a process of the strategic assessment of potential alternative futures and of the potential for the development of the economic sector based on innovation. Scenario analysis also provides a basis for formulating recommendations for investments and reforms in the scientific sector. Scenario analysis places particular emphasis on the impact of research and innovation on the economic sector and on their contribution to reducing and adapting to climate change as well as to achieving the green and digital transitions in the Republic of Croatia in line with the development objectives of the Croatian National Development Strategy 2030 and the objectives of the European Green Deal. Also, scenario analyses allow the identification of key development directions and critical points for achieving outcomes. Two scenarios were analysed — the **baseline scenario and the accelerated development scenario**, the key determinants of which are presented in Chapter 4.1. Thereafter, Chapters 4.2. and 4.3. describe the key outcomes of each scenario.

4.1. Scenario Parameters

The results of the TOWS, PESTLE and DELFI methods are the starting point for the development of scenarios of the development of the TPA by 2026 and 2035, respectively. This chapter elaborates on the basic parameters for each of the scenarios. The parameters relate to the following key areas:

- funding for science and research;
- Development of Human Resources
- development of infrastructure; and
- Cooperation with the Economic Sector

Five potential development directions are specified for each of these areas:

- slight deterioration (code −);
- unchanged status (code 0);
- slight improvement (code +);
- moderate improvement (code ++); and
- significant improvement (code +++).

The differences in the development directions are primarily the result of different policies and organisational measures that are key to creating an encouraging research environment, which consequently lead to an increase in the number of excellent researchers and to the strengthening of the cooperation with the economic sector.

4.1.1. Funding Research Activities and Absorption Capacity

The strong increase in the availability of funding for RDI activities following Croatia's accession to the EU is probably the single most important driver of positive change in the past period. Even larger financial investments in research capacities are expected in the next 10 or so years. This assumption is based on the data obtained so far concerning the funding for R&D

investments from various European sources in the coming period, be it programmes at the level of the Republic of Croatia or at the EU level. On the basis of this data, projections of the funds potentially available for RDI activities under the Energy and Sustainable Environment TPA have been produced for the period until 2026 and until 2035. These projections were made taking into account several important facts:

- only the funds from the National Recovery and Resilience Plan 2021 –2026 (NRRP)[5] have been officially confirmed so far;
- Programmes related to the use of the European Structural and Investment Funds (ESIF) between 2021 and 2027 are still under negotiation. For the purposes of this document, the data from the drafts of operational programmes published at www.strukturnifondovi.hr was used.
- In accordance with EU strategic documents, EU programmes (Horizon Europe and others) will be available to the TPA, but the opportunities for use will depend on the absorption capacity of Croatian scientists / research groups as there are no national funding quotas.

Projections of the funds available for RDI activities from the NRRP and the ESIF operational programmes for the period between 2021 and 2027 are shown in Table 9 below.

Table 11 — Potential funding for RDI activities from the NRRP and the ESIF programmes for the period between 2021 and 2027.

Programme	Total available for RDI activities (EUR)
National Recovery and Resilience Plan 2021-2026. (component C.3.2)	320,000,000
Programme Competitiveness and Cohesion 2021 and 2027. (specific objectives 1.i, 1.iii and 1.iv)	706,496,000
Integrated Territorial Programme 2021 and 2027. (specific objective 1.i)	330,000,000
Total	**1,356,496,000**

Source: NRRP, draft PCC (April 2022), draft ITOP (April 2022)

Note: the data on the funds available under the PCC and ITOP were taken from the draft of the programmes published at www.strukturnifondovi.hr (accessed on 6/7/2022).

Estimates of the absorption of the available EU and national funds under the Energy and Sustainable Environment TPA were made on the basis of a number of assumptions. **The underlying assumption for both of the scenarios is that the Energy and Sustainable**

[5] In July 2022, the European Commission announced that the total grants allocated to the Republic of Croatia for the implementation of the National Recovery and Resilience Plan would be decreased from EUR 6.3 billion to EUR 5.5 billion because of the strong recovery of the Croatian economy in 2021. It remains to be seen what the impact of these changes will be on investment in RDI activities.

Environment TPA accounts for 25% of the total publicly available RDI funding. This percentage was determined by analysing the absorption results for the period between 2014 and 2020 for the various EU programmes intended for RDI activities in the context of the implementation of the Croatian Smart Specialisation Strategy 2016 –2020.[6] Another important assumption for both of the scenarios is that of the total allocation from the Integrated Territorial Programme 2021 and 2027. (ITOP), only 30% will be allocated to public research institutions. This is because the main beneficiaries of the funds are companies from the private sector.

Estimates related to the absorption of funds from EU programmes such as Horizon Europe, COST and others were made on the basis of disbursement data for 2020 as the last year available. The source of the data is the European Commission (EC).[7] For each of the scenarios, special assumptions were then developed to assess the absorption of publicly available funds for financing research activities.

Assumptions regarding the use of EU funds in the baseline scenario:
- 85% of the NRRP allocation for RDI activities will be used by 2026;
- 40% of the PCC allocation and 25% of the ITOP allocation for RDI activities will be contracted by 2026;
- by 2030, 85% of the ESIF allocation for the period between 2021 and 2027 will be used, and in the period between 2030 and 2035, 65% of the total allocation for the period between 2028 and 2034.
- the absorption capacity for Horizon Europe, COST, EIT and other centralised EU programmes for the period until 2026 and until 2035 will be 10% higher than the absorption for 2020; and
- by 2035, 50% of the total contracted allocation shall be for projects for cooperation with the economic sector.

Assumptions regarding the use of EU funds in the accelerated development scenario:
- 100% of the available NRRP allocation will be contracted by 2026;
- 50% of the PCC allocation and 30% of the ITOP allocation for RDI activities will be contracted by 2026;
- by 2030, the entire allocation for the period between 2021 and 2027 will be used, and in the period between 2030 and 2035, 65% of the total allocation for the period between 2028 and 2034.
- the absorption capacity for Horizon Europe, COST, EIT and other centralised EU programmes will be 100% higher after the completion of the NRRP (2026) in comparison to the disbursements in 2020; and
- after 2026, 70% of the total contracted funds shall be for projects for cooperation with the economic sector.

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[6] The main source of data on absorption is the HAMAG-BICRO report on the implementation of the Croatian Smart Specialisation Strategy 2016–2020 for the period between 2016 *to 2019.)* (HAMAG-BICRO, 2021).
[7] Specifically, the source was a web portal that provides information on all payments from the EU budget to each Member State. The web portal is available at https://ec.europa.eu/info/strategy/eu-budget/long-term-eu-budget/2014-2020/spending-and-revenue_en.

As regards the funds available through the CSF, the assessment was carried out on the basis of data on CSF funds disbursed in 2020. According to the data from the CSF Annual Activity Report, approximately HRK 158 million, i.e., EUR 21.1 million, was disbursed from the state budget for research activities in 2020.[8]

Assumptions regarding **the use of national funds through the CSF** in the baseline scenario:

- by 2026, the total disbursements funded through the state budget will remain at around EUR 21.1 million per year;
- in the period between 2026 and 2035, annual disbursements will amount to around EUR 22 million (about 5% more than in the previous period); and
- the Energy and Sustainable Environment TPA accounts for 25% of total disbursements.

Assumptions regarding the **use of national funds through the CSF** in the accelerated development scenario:

- by 2026, the total disbursements funded through the state budget will remain at around EUR 23.2 million per year (an increase of 10% in comparison to the baseline scenario);
- in the period between 2026 and 2035, annual disbursements will amount to around EUR 30 million (35% more than in the baseline scenario); and
- the Energy and Sustainable Environment TPA accounts for 25% of total disbursements.

The last category of funding sources includes all other programmes supporting research activities, such as funding from the European Economic Area Financial Mechanism, Norway Funds and others. The absorption assessment for such sources was made on the basis of the results of the conducted mapping, according to which around EUR 17.5 million was contracted in the period between 2011 and 2021. The estimated level of absorption for the period until 2026 and until 2035 is significantly higher, given the significantly higher amounts of funding that can be expected from such sources. In the baseline scenario, therefore, the annual amount of TPA disbursements until 2026 is estimated to be EUR 3 million per year and EUR 3.3 million per year for the period between 2027 and 2035. In the accelerated development scenario, these amounts are increased by 10% for the period until 2026 and by 100% for the period between 2027 to 2035. The reason for such a strong increase in absorption in the accelerated development scenario is the relatively small amount of funds, i.e. the low initial base amount, and the assessment that there are many additional options in the accelerated development scenario that are currently not utilised (e.g. international foundations, new bilateral programmes, etc.).

Based on the assumptions described above, the following table provides an estimate of the absorption of funds for the Energy and Sustainable Environment TPA for the period until 2026 and until 2035, respectively.

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[8] According to the data from the Annual Activity Report, the state budget funds accounted for 85% of the total funds disbursed by the CSF in 2020 (a total of HRK 186 million).

Table 12 — Estimate of RDI activities funding under the Energy and Sustainable Environment TPA, cumulative in millions of euros

Sources of funding	Estimate of disbursed funds until 2026		Estimate of disbursed funds until 2035	
	Baseline scenario	Accelerated development scenario	Baseline scenario	Accelerated development scenario
NRRP	61.2	72.0	61.2	72.0
ESIF programmes (PCC and ITOP between 2021 and 2027 and the programme absorption assessment for the period between 2028 and 2034)	35.6	45.3	327.1	396.4
EU programmes (Horizon Europe, COST, etc.)	19.8	21.6	64.4	102.6
CSF programmes	24.8	27.3	83.4	115.1
Other	**12.0**	13.2	41.7	72.6
Total	**153.4**	**179.4**	**577.7**	**758.7**
Of which for projects for cooperation with the economic sector	**76.7**	**89.7**	**288.9**	**495.2**

Source: Authors

The parameters of the development of the TPA in terms of future funding derived from the results of the TOWS, PESTLE and DELFI analyses are shown in the following table.

Table 13 — Parameters of the development of the TPA regarding funding

	Baseline scenario		Accelerated development scenario	
Factors of development	Direction of development by 2026	Direction of development by 2035	Direction of development by 2026	Direction of development by 2035
Total amount of funding available	moderate improvement (++)	significant improvement (+++)	moderate improvement (++)	significant improvement (+++)
Funding criteria[a]	unchanged status (0)	slight improvement (+)	moderate improvement (++)	significant improvement (+++)
Continuity of funding[b]	unchanged status (0)	slight improvement (+)	moderate improvement (++)	significant improvement (+++)
Total	**slight improvement (+)**	**slight improvement / moderate improvement (+ / ++)**	**moderate improvement (++)**	**significant improvement (+++)**

Source: Authors

[a] Refers generally to improving the quality of the selection process for research projects and to strengthening/improving the funding model based on previously achieved results.

[b] Refers to creating a long-term financial framework that will provide more stability for long-term research.

In the **baseline scenario**, development factors are expected to improve slightly on average in comparison to the current situation by 2026. A moderate improvement is expected in terms of the amount of available funding, which is mainly linked to the implementation of the NRRP, while the funding criteria and the ensuring of the continuity of funding are expected to remain unchanged. For the period until 2035, the availability of funding is expected to improve significantly, given the resources available through the ESIF programmes for the periods from 2021 to 2027 and from 2028 to 2034. The growing political support at the EU level to accelerating the development of new technologies that reduce the dependence of the EU on fossil fuels plays an important role in terms of the amount of the funding available.

A similar evolution of the situation in terms of the availability of funding is expected in the **accelerated development scenario**, only with a slightly greater increase in the funding available through the CSF as a result of higher total public investments in R&D funded through domestic sources. In contrast to the baseline scenario, the funding criteria and continuity are expected to improve moderately and significantly by 2026 and 2035, respectively, which is mainly linked to higher-quality project selection processes, improving long-term funding planning (calls for tenders) and aligning the continuation of funding of research teams with previously achieved results.

4.1.2. Development of Human Resources

The forecasting parameters for the development of human resources are based on an estimate of population trends, scientific policies at the level of the Republic of Croatia and specificities related to the TPA as well as on organisation within institutions and research groups. The parameters concerning population trends projections, which are considered a common factor that affects both of the TPA development scenarios equally, are elaborated on below. This is followed by an elaboration on the impact of other factors of the development of human resources, where a separate impact assessment is made for each of the scenarios.

Population projections are an important factor in the development of human resources since they provide a general estimate of labour availability in all sectors, including the research sector. According to available projections, the population was expected to decrease to its current number by 2030 (United Nations projections) or by 2040 (Croatian Bureau of Statistics projections). Because of significant discrepancies with the census results, the projections were adjusted. The depopulation dynamics were taken from the available projections while shifting the baseline year. According to UN projections, the population is expected to decrease from 3.9 to 3.5 million inhabitants, i.e., by 11.2%, by 2040. CBS projections suggest a somewhat faster decrease, from 3.9 to 3.4 million inhabitants over the same period (by 13.5%).

Table 14 — Projections of population trends in the Republic of Croatia until 2040 (in thousands of inhabitants)

	2020	2026	2030	2035	2040
UN	3,896.0	3,743.8	3,678.5	3,569.8	3,461.0
CBS	3,904.1	3,727.0	3,651.1	3,519.5	3,387.8

Source: Authors, based on CBS (2011) and UN (2017) data

The results confirm that Croatia's workforce will continue to decline, resulting in a declining supply of domestic labour for the purposes of the research sector. In such circumstances, a negative impact on the future development of the TPA can be expected, unless appropriate action is taken.

An additional source of pressure in terms of labour availability is the amount of funding for research activities. The increasing amount of funding also necessarily entails an increase in the number of researchers required for a high-quality absorption of the funds available. While the relation between the amount of funding and the number of researchers may be influenced by the funding structure (e.g. whether the funds are largely invested in expensive equipment serving a small number of researchers or whether significant resources are invested in the renovation of existing buildings, which does not necessarily create the need for additional recruitment), it is realistic to assume that, on average, an increased amount of funding results in increased recruitment needs.

Given that the previous chapter confirmed significant opportunities for funding research activities in the coming period, it is important to look at the extent to which the existing workforce is able to successfully absorb all the available resources. In this respect, a projection of labour needs was made for the scenario of using the funds from the NRRP and ESIF programmes for the period between 2021 and 2027 under the TPA. The projection period is until the end of 2030, that is, the last year of the use of ESIF programmes. The projection was made with a number of assumptions regarding the structure of expenditure for research projects:

- 60% of all costs are research costs;
- 30% of all costs are the costs of research infrastructure (buildings and equipment);
- 10% of the costs are miscellaneous costs;
- half of the research costs are salary costs and the other half are costs such as minor costs relating to research, training, study travel, cooperation, etc.; and
- the average total salary costs for the period until 2030 are HRK 30,000 per month (gross amount II), i.e. around EUR 4,000 per month.

This is a simplified attempt to estimate the average required workforce, which cannot cover the numerous specific aspects affecting the final calculation of labour costs in any given project. The following table shows the estimated labour needs based on the estimated RDI expenditure of the three most important EU-funded programmes.

Table 15 — Assessment of labour needs until 2030

Programme	Total for RDI activities under the TPA (in EUR)	Estimated cost of research until 2030 (in EUR)	Estimated salary costs until 2030 (in EUR)	Number of full-time positions required until 2030	Number of part-time positions required until 2030 (4 hours)
NRRP	72,000,000	43,200,000	21,600,000	113	226
PCC	158,961,600	95,376,960	47,688,480	124	248

ITOP	74,250,000	44,550,000	22,275,000	58	116
Total	**305,211,600**	**183,126,960**	**91,563,480**	**295**	**590**

Source: Authors

The results confirm that the implementation of the NRRP, the PCC and the ITOP will result in very significant need for labour. Projects funded through the PCC will have the greatest need as a result of the higher amount of funding. It is estimated that the implementation of all three programmes will require 295 researchers to work full-time or 590 researchers to work part-time, 4 hours a day. Given the estimate that there are around 800 researchers in total working within the TPA, it is clear that the implementation of these three programmes alone will require an extremely high level of labour from the existing workforce, i.e., additional workforce will very likely be necessary. The latter will depend primarily on the level of involvement of the existing workforce in the implementation of the projects funded by the said programmes. A lower level of involvement of the existing workforce will necessarily create the need to recruit additional labour that is currently outside the system.

One favourable circumstance is that the implementation period of the programmes coincides only partially, i.e. the implementation of the NRRP will be completed by 2026, when the implementation of the PCC and the ITOP is expected to commence. On the other hand, it should be noted that this is merely an estimate for the three programmes mentioned, i.e., it does not include estimates of workforce involvement under Horizon Europe, the CSF and other sources of funding. The issue of labour availability is further emphasised in view of the previously highlighted unfavourable demographic trends for the period until 2040, which will make it even more difficult to address the problem utilising the domestic workforce.

In addition to the factor of the number of available workers, there are a number of additional factors that influence the overall development of human resources. The following table contains a number of factors that have been identified on the basis of previously obtained mapping results, as well as the TOWS, PESTLE and DELFI analyses, and have been developed separately for the baseline and accelerated development scenarios. Additional development factors related to human resources development are: the quality of research groups, criteria for advancement in the scientific field, cooperation with other research groups in the Republic of Croatia and abroad, development of leadership/management competence, level of formal education completed by the researchers and the number of researchers. These are shown in the table below.

Table 16 — Scenario parameters related to human resources development

	Baseline scenario		Accelerated development scenario	
Factors of development	**by 2026**	**by 2035**	**by 2026**	**by 2035**
Quality of research groups	unchanged status (0)	slight improvement (+)	slight improvement (+)	moderate improvement (++)

Criteria for advancement in the scientific field	unchanged status (0)	slight improvement (+)	slight improvement (+)	significant improvement (+++)
Cooperation with other research groups in Croatia and abroad	unchanged status (0)	slight improvement (+)	slight improvement (+)	significant improvement (+++)
Development of leadership/management competence	unchanged status (0)	unchanged status (0)	slight improvement (+)	moderate improvement (++)
Level of formal education completed	unchanged status (0)	slight improvement (+)	slight improvement (+)	moderate improvement (++)
Number of researchers	unchanged status (0)	slight deterioration (–)	unchanged status (0)	slight improvement (+)
Total	**unchanged status (0)**	**unchanged status / slight improvement (0 / +)**	**slight improvement (+)**	**moderate / significant improvement (++ / +++)**

Source: Authors

In the baseline scenario, most of the factors are expected to remain unchanged by 2026 and to slightly improve by 2035. The only exception is the number of researchers that is expected to decrease slightly in the period until 2035 because of negative demographic trends and the growing competition from the private sector that offers increasingly better working conditions for young researchers. In the accelerated development scenario, slight improvements in the period until the end of 2026 are expected for all of the factors except the number of researchers. For the period until 2035, mostly moderate or significant improvements are expected, except for the number of researchers, where a slight improvement is expected. Key drivers of positive change in the accelerated development scenario are scientific and technological policy reforms and improvements in the internal regulations and processes of research institutions that support positive change. The slight increase in the number of researchers in the period until 2035 is mainly due to more attractive working conditions for young researchers. In terms of the development of leadership/management competence, it is assumed that no positive change will occur in the baseline scenario, while slight and then moderate improvement is expected in the accelerated development scenario, as a result of the introduction of specific training programmes to do with the quality of management as well as of better measurement of the performance of a given research institution and the associated system of funding.

4.1.3. Quality of Research Infrastructure

The results of the TOWS, PESTLE and DELFI analyses were used to identify key factors influencing the quality of research infrastructure as an important determinant of overall scientific excellence. This includes not only physical infrastructure such as equipment, but also human resources directly supporting the work of researchers or research groups (e.g.

accounting or finance support services) as well as intellectual property policies as an important factor affecting the innovation capacity of researchers or institutions. The scenario parameters related to the quality of infrastructure for the medium term and the long term are presented below.

Table 17 — Scenario parameters related to the quality of the research infrastructure

	Baseline scenario		Accelerated development scenario	
Factors of development	**by 2026**	**by 2035**	**by 2026**	**by 2035**
Availability of physical infrastructure (space, equipment, etc.)	slight improvement (+)	moderate improvement (++)	slight improvement (+)	significant improvement (+++)
Organising the use of the equipment	unchanged status (0)	slight improvement (+)	moderate improvement (++)	significant improvement (+++)
Logistical support for project preparation and implementation	unchanged status (0)	slight improvement (+)	moderate improvement (++)	significant improvement (+++)
Financing the maintenance of physical infrastructure	unchanged status (0)	slight improvement (+)	slight improvement (+)	significant improvement (+++)
An effective framework for fostering the protection of the intellectual property of the researchers/institutions	unchanged status (0)	unchanged status (0)	moderate improvement (++)	significant improvement (+++)
Total	**unchanged status (0)**	**slight improvement (+)**	**slight improvement / moderate improvement (+ / ++)**	**significant improvement (+++)**

Source: Authors

In the baseline scenario, the situation is expected to remain largely unchanged by 2026, meaning that researchers will continue to experience difficulties with organising the use of equipment, poor logistical support for research teams and funding for equipment maintenance, while the availability of equipment will only be slightly improved thanks to funding through the NRRP and other programmes. Infrastructure availability will improve moderately in the period until 2035 thanks to increased investment from EU-funded programmes. However, for the remaining factors, only a slight improvement is expected as a result of the partial efforts of the research institutions themselves and of the Ministry of Science and Education. The accelerated development scenario implies a slight improvement of the situation in terms of physical infrastructure availability and infrastructure maintenance funding by 2026, while organising the use of equipment and logistical support for project preparation and implementation are expected to improve moderately. Significant improvements across all factors are expected for the period until 2035. The differences in the scenarios are based on a significant improvement of the normative/financial framework at the central level concerning the organisation of the use of equipment, logistical support for project preparation and implementation and the funding of equipment maintenance, as well as on the numerous individual efforts of individual research institutions under the accelerated development scenario. Also, a significant difference is due to the creation of an encouraging framework for the protection of intellectual property at research institutions, which will stimulate researchers to develop new innovations. This encouraging framework can take the form of e.g. the adoption of national guidelines for intellectual property policies at universities and public institutions, which would form the basis for adopting individual policies at the level of individual institutions. In the accelerated development scenario, a significant improvement of the current situation is expected as early as by 2026, and this improvement would continue in the period until 2035. On the other hand, in the baseline scenario, the situation regarding the protection of intellectual property remains unchanged.

4.1.4. Cooperation with the Economic Sector

The underlying parameters related to the collaboration between the research and economic sectors derived from the TOWS, PESTLE and DELFI analyses for the baseline and accelerated development scenarios for the medium term and the long term are presented below.

Table 18 — Scenario parameters related to cooperation with the economic sector

	Baseline scenario		Accelerated development scenario	
Factors of development	**by 2026**	**by 2035**	**by 2026**	**by 2035**
Tax incentives for investment in R&D	unchanged status (0)	unchanged status (0)	slight improvement (+)	moderate improvement (++)
Substantive provisions of public calls for tenders that encourage cooperation with the economic sector	unchanged status (0)	slight improvement (+)	moderate improvement (++)	significant improvement (+++)
Financial impact of public calls for cooperation with the economic sector	moderate improvement (++)	moderate improvement (++)	moderate improvement (++)	significant improvement (+++)
Internal policies of scientific institutions regarding fostering cooperation with the economic sector	unchanged status (0)	slight improvement (+)	slight improvement (+)	significant improvement (+++)

Source: Authors

The legislation regulating aid for research projects provides for significant tax relief in terms of corporate tax liability to aid beneficiaries.[9] However, existing legislation does not in any way

[9] Detailed information can be found in the Act on State Aid for Research and Development Projects (NN No. 64/2018) and in the State Aid for Research and Development Projects Regulations (NN No. 9/2019).

encourage cooperation between entrepreneurs and research institutions. In the baseline scenario, this situation is expected to remain unchanged by 2035. On the other hand, in the accelerated development scenario, the legislation is expected to be amended so as to ensure a slight improvement by 2026 in terms of its direct impact on strengthening cooperation, with moderate improvement expected by 2035. If the criteria used to foster cooperation with the economic sector are improved, a moderate and significant improvement is expected in the medium term and the long term, respectively. In terms of the financial impact of the public calls for tenders, a moderate improvement is expected by 2026, mainly influenced by NRRP funding, and by 2035, this impact is expected to increase significantly, mainly driven by funding through ESIF programmes and, to a lesser extent, by funding through Horizon Europe and CSF programmes.

4.2. Baseline Scenario — 'Driven by EU Funding but without Key Changes'

In the baseline scenario, significant funding opportunities for research activities from different EU sources are the main driving force for the development of the TPA, while key system weaknesses remain. While the implementation of the NRRP necessarily also entails the implementation of reform activities within the R&D system as a condition for granting funding, the lack of political will as well as of the overall institutional capacities to plan and implement reform activities results in a very small impact of the activities carried out on effectuating improvements. The key weaknesses of the system thus continue to be reflected, above all, through the low involvement of domestic institutions in international competitive projects (under the Horizon Europe programme and others) and the weak connections between the funding of the public scientific sector and increased innovation based on research results.

In this scenario, problems with ensuring a sufficient number of researchers gradually increase. Negative demographic trends combined with the failure of the system to develop a sufficiently motivating framework for attracting and retaining young researchers gradually lead to a drop in the number of researchers and a decrease in the overall research potential. Competition from the domestic private sector and international markets, notably regarding the financial circumstances of employees, and a weak environment in terms of greater involvement of foreign researchers are some of the more important constraints on human resources development. The problems with attracting young researchers are particularly present outside of Zagreb, partly reflecting stronger negative demographic trends and partly a lower overall appeal of the living environments available to young researchers.

Furthermore, teaching responsibilities that are restricting researchers to a high (or excessive) extent and thus reducing their availability for research activities, remain an issue. Additionally, insufficient support from professional staff remains an important problem, be it joint support services (e.g. accounting and finance), professional collaborators in laboratories and other forms of research infrastructure or project management assistants.

The significant administrative workload associated with the implementation of projects funded through ESIF programmes, the NRRP and the CSF gradually leads to a decline in researchers' interest in applying for new projects. In such circumstances, the competent institutions try to ensure the effective absorption of EU funds by supporting large-scale infrastructure projects, which results, among other things, in a weaker focus by research institutions on the research projects themselves.

In terms of participation in prestigious EU programmes such as Horizon Europe, on the one hand, previous positive experience has a positive effect on the motivation of researchers to apply for new projects. However, on the other hand, the better availability of funding through national programmes, the continued fragmentation of research groups, low internationalisation and the lack of top researchers, as well as the insufficient administrative support mentioned above, make it difficult to achieve stronger participation under Horizon Europe and other programmes. The shortage of top researchers is partly linked to the still insufficiently regulated criteria for advancement that, if improved, would be a stronger incentive for the best performing researchers in terms of scientific excellence and cooperation with the economic sector. The outcome of the described circumstances is a persistently very low level of funding for research in the Republic of Croatia through Horizon Europe and other centralised EU programmes.

When it comes to cooperation with the economic sector, the significant funding available has a positive impact on the application and implementation of new projects, and their number is increasing. However, on the other hand, persistent weaknesses in the project selection system reduce the potential positive effects of their implementation on RDI, and the number of innovative products and services remains low. The lack of evaluation of researchers' performance in terms of collaboration with the economic sector as one of the criteria for their advancement continues to have a negative effect on the motivation and focus of researchers on this type of activities. Research institutions still largely fail to provide good logistical infrastructure for the efficient implementation of research projects to suit the needs of the economic sector (support services, clear organisation of the use of equipment, efficient handling of intellectual property protection matters, etc.). Contracted research for economic entities remains infrequent, thus reducing the potential of research institutions for increasing their revenue. In the absence of an effective framework for developing cooperation, there is also a lack of greater involvement of major public economic entities such as HEP, JANAF, Jadrolinija, Croatian Railways, Croatian Motorways and others in long-term partnerships with research institutions. There is no systematic approach to fostering academic entrepreneurship, which is particularly reflected in the absence of specific support programmes and institutions.

Domestic funding from the budget continues to play a very small role in the overall funding of RDI projects and does not complement funding through EU programmes in the manner needed (e.g. by funding topics not covered or insufficiently covered by EU programmes). Research institutions' lack of own revenue makes it difficult to finance the maintenance of research equipment, putting additional pressure on the MZO for funding from the budget.

The following table summarises the key outcomes of the baseline scenario.

Table 19 — Key outcomes in the baseline scenario

Scenario 1 Baseline scenario

For the medium term (for the period until 2026):

- There is a further increase in investment in the research sector as a result of nationally allocated EU funds.
- There are additional opportunities for funding investments under the TPA following a stronger political focus on the decarbonisation of the economic sector / society as a whole.
- The new funding makes it possible to retain most of the staff previously recruited through projects and to recruit fewer new staff. However, insufficient financial conditions and difficulties in ensuring continuous funding for research are increasingly reducing the appeal of the research sector while recruiting young researchers (as opposed to the private sector / foreign institutions).
- There is no fundamental improvement in the researchers' career advancement system that would improve scientific excellence and effective cooperation with the economic sector.
- Due to the excessive administrative workload and insufficient logistical support, some projects from the NRRP and other programmes are experiencing implementation delays and fail to complete on time.
- Insufficient logistical support and alternative funding opportunities through 'national calls for tenders' discourage some researchers from applying their projects to Horizon Europe and other calls for tenders at the EU and international levels.
- Research groups continue to be (too) fragmented and there is poor internationalisation of RIs.
- There are organisational and financial difficulties in using and maintaining the equipment purchased.
- Projects for cooperation with the economic sector do not have any significant effects on strengthening the research and innovation capacities of the business and public sectors.
- Research institutions (universities, their constituent units and public institutes) still do not have systematically regulated intellectual property protection policies that would encourage researchers.
- The impact of funded research on the innovativeness of the economic sector is low.
- The level of academic entrepreneurship is low and there is no systematic approach to strengthening it.

For the long term (for the period until 2035):

- The modernisation of research infrastructure continues, mainly using EU funding.
- There is still no systematic/strategic approach to funding. The connection between the funding of research institutions and the results achieved is insufficient. Once the implementation of the NRRP is completed, the dependence of funding on the ESI Funds is once again very high, with occasional calls for tenders hindering the continuity of funding.
- The problem of recruiting and retaining young researchers is increasingly pronounced and the total number of researchers under the TPA begins to decrease.
- There is a decline in the motivation of researchers to carry out research projects due to insufficient logistical support and a poor connection between research results and advancement in the scientific field.

- The poor cooperation within larger scientific teams and the marked fragmentation of research topics reduce the impact of funding, in particular in terms of capacity building for international competitive projects.
- There is a stagnation in the number of excellent researchers among the total number of scientists.
- Research institutions (universities, their constituent units and public institutes) still do not have systematically regulated intellectual property protection policies.
- There is still no systematic approach to strengthening academic entrepreneurship and key support is lacking.
- There are still human resources and financial difficulties in maintaining research equipment.
- The gap between centres of scientific excellence and regional centres widens.
- The impact of funded research on the innovativeness of the economic sector remains low and there is a stagnation in the quality of cooperation with the economic sector (it is dominated by routine projects without significant added value in terms of innovative solutions).

Projections of trends regarding the number of researchers

The estimated trends regarding the number of researchers and the density of researchers overall as well as regionally are presented in the following table, and are based on the following assumptions:

- a stagnation in the number of researchers by 2026;
- a decreased number of researchers in the period until 2030 and until 2035; and
- the trend of the concentration of researchers being slightly more dense in Zagreb.

Table 20 — Projections of trends regarding researchers in the baseline scenario

	2021	2026	2030	2035
Zagreb	538	569	557	512
Adriatic Croatia — South	77	73	71	73
Adriatic Croatia — North	91	86	84	86
Continental Croatia	95	73	72	82
TOTAL	**800**	**800**	**784**	**752**
Number of researchers per 1,000 inhabitants	**0.215**	**0.215**	**0.215**	**0.214**

Source: Authors

Note: for 2021, the data on the number of researchers under the TPA obtained in the mapping phases was used.

Projections of scientific productivity trends

In the baseline scenario, the current level of scientific productivity under the TPA is maintained. Scientific productivity is monitored by observing the number of scientific papers published in the relevant databases (WoS and Scopus), with a projected average of 2 papers per scientist per year for the period until 2035.

Projections of trends regarding excellent researchers[10]
The number of excellent researchers within the total number of researchers within the TPA is stagnating in this scenario. This indicator also outlines the trends regarding the quality of research groups. In line with the parameters, in the baseline scenario, the quality of research groups is unchanged in the medium term and only slightly improved in the long term.

4.3. Accelerated Development Scenario — 'With Scientific Excellence towards New Drivers of Economic Growth'

The accelerated development scenario assumes that high financial investment in R&D under the TPA is accompanied at the same time by very significant changes in the overall research system leading to significant qualitative improvements in the environment for research work and the contribution of the TPA to overall economic development. This scenario entails two key outcomes: (1) a significant improvement of scientific productivity under the TPA and (2) the achievement of a high level of multiplicative effects of strengthened scientific capacities on the innovativeness of economic entities. This scenario also involves strong financial support for research topics with a very high positive impact on overall scientific capacities and the development of innovation potential in the economic sector.

As in the baseline scenario, researchers within the TPA are met with abundant opportunities for the funding of research projects in the period until 2026 and until 2035. This is mainly the result of significant investment through EU-funded domestic programmes (the NRRP, the OPCC and the ITOP). The key difference in funding in comparison with the baseline scenario is increased funding through centralised EU programmes (most notably Horizon Europe), significantly higher revenues from contractual research for the economic sector as well as significantly higher investment through the domestic budget. NRRP funds become an important instrument for strengthening overall research capacities in the public and private sectors and act as a catalyst for strengthening the capacity to use funds from the most demanding EU programmes (Horizon Europe and others).

The strengthened absorption capacities to use these funding sources are the result of numerous qualitative changes that take place in a planned and continuous manner throughout the entire period. One part of the changes relates to the functioning of the research system as a whole and the second part to changes within individual research institutions. Research institutions set very clear research priorities for the short and medium term, creating an initial research framework for the work of individual research teams.

Particularly important changes are those relating to attracting and retaining young talented researchers and to a better evaluation of researchers' advancement, primarily regarding their cooperation with the economic sector. In addition to scientific papers, highly professional projects are increasingly valued with regards to advancement in the scientific field, in particular projects implemented in cooperation with the economic sector and the protection

[10] Refers to the category of researchers established in the mapping phase that includes the most scientifically successful researchers.

of intellectual property based on research results. Furthermore, the practice of financial rewards for excellent scientific output is increasing under the programme agreements, encouraging researchers to improve the quality of scientific research. The salary financing system for work on research projects becomes much more flexible, which has a positive impact on attracting and retaining researchers, including those from abroad. Scholarship schemes are introduced for the best final-year students, and they financially encourage their participation in research activities within a domestic research institution. National RDI funding programmes particularly encourage a higher number of researchers to collaborate on fewer priority research topics, thus strengthening the concentration and specialisation of research capacities. Specialisation also has an important regional dimension, providing additional support for regional hubs with a high level of specialisation. The MZO strengthens its practice of evaluating the effects of funding and of the science and technology foresight as a basis for determining the direction of future funding in terms of research topics.

Furthermore, the synergy between the MZO and research institutions strengthens the capacities of support services to prepare and implement projects, with a particular focus on those funded through Horizon Europe. A common framework is also adopted for regulating intellectual property protection policies at all research institutions in the Republic of Croatia, which further strengthens the incentives for innovation and the commercialisation of innovation in the public scientific sector. Further important developments in terms of strengthening academic entrepreneurship are pursued through the increasing establishment of incubators/accelerators within RIs and through the establishment of special programmes for supporting student/academic start-ups.

Under programme agreements, the MZO adopts new criteria for funding research institutions and these criteria place more emphasis on performance-based funding, with cooperation with the economic sector being particularly highlighted in the results. In such circumstances, and further influenced by a series of public calls for tenders that fund projects for collaboration between the scientific and economic sectors and by the improving infrastructure at scientific institutions, there is a strong increase in contractual research for the economic sector. The competent state bodies ensure the continued funding of research vouchers for micro-, small- and medium-sized enterprises. The MZO, in cooperation with other state bodies, systematically encourages the entering of major public economic entities such as HEP, JANAF, Jadrolinija, Croatian Forests, Croatian Railways, Croatian Motorways and others into long-term partnerships with domestic research institutions. This further strengthens the strategic contribution of research institutions active within the Energy and Sustainable Environment TPA to the better functioning of key public activities.

The strengthened capacities for research activities result in an improving international reputation of domestic institutions, accompanied by, among other things, the increased involvement of domestic research institutions in various European and international initiatives, as well as more and more examples of scientific leadership at the international level. There is also a growing interest of large private companies from the Republic of Croatia and abroad in mutual cooperation in the field of R&D.

Table 21 — Key outcomes in the accelerated development scenario

Scenario 2 Accelerated development scenario
For the medium term (for the period until 2026): • Calls for tenders under the NRRP, the OPCC and the ITOP ensure new investment in R&D, including additional investment in equipment. • Additional funding for projects under the TPA is secured because of political importance. • New projects allow for the retention of staff previously recruited through projects and for the recruitment of new staff. • New criteria for advancement in the scientific field that put greater emphasis on improving research excellence and cooperation with the economic sector are established. • More encouraging conditions are provided for attracting and retaining researchers (student scholarship schemes, flexible remuneration for working on projects, etc.). • Stronger incentives are provided for connecting researchers into larger research groups and for their continuous research work. • The systematic establishment of entrepreneurship-strengthening policies is commenced in RIs (including intellectual property policies, the establishment of incubators/accelerators, student/academic start-up programmes, etc.). • New policies for the use of research infrastructure are established. • The systematic strengthening of support services and the improvement of project management expertise is commenced. • Systematic outreach to target groups and the general public about the results and capacities of RIs is initiated with a view to reducing information asymmetry. • A growing impact of funded projects on strengthening the research and innovation capacities of the business and public sectors, owing to a better environment, is observed. • Changes are initiated to increase the flexibility of the management model for RIs (the possibility of introducing certain management positions not requiring science-related prerequisites as well as developing and piloting an RIs management performance-monitoring system). **For the long term (for the period until 2035):** • RIs have a clear long-term research plan that becomes the framework for the work of individual researchers. • A system of advancement in the scientific field is in place that serves to achieve key strategic objectives, in particular regarding the cooperation with the economic sector. • An RI funding system is in place that serves to achieve key strategic objectives, including policies for the recruitment and retention of young scientists (more flexible conditions for the financing of labour costs under the projects). • Appropriate logistical conditions are ensured for the efficient work of research teams (support services and the organisation of the use of equipment). • There are stronger connections between research groups from different institutions and increasing specialisation in research topics. • The overall internationalisation of RIs (cooperation, foreign researchers, etc.) is greatly improved. • The growing reputation of domestic RIs leads to a strong increase in their involvement in different initiatives at the EU and international levels (joint projects or research missions).

The number of partnerships with different international foundations that fund research activities in the Republic of Croatia is also increasing.

- The number of excellent researchers among the total number of scientists is increased.
- There is significantly increased motivation of private companies to cooperate with RIs and a significant increase in the importance of contractual research in the overall funding of RIs.
- A number of new partnerships are established between public scientific organisations and domestic as well as foreign economic partners, in particular with large companies.
- An integrated infrastructure is in place to foster entrepreneurship within RIs.
- There is significant improvement in the impact of funded research on the innovativeness of the economic sector.
- The reputation of research institutions among entrepreneurs is improved (RIs are widely recognised as partners that offer a fundamental qualitative advantage in terms of competitiveness).
- Better conditions for the management of RIs are ensured through more flexible criteria for appointing managers, the introduction of mandatory management KPIs and the related financial rewards system.

Projections of trends regarding the number of researchers

The estimated trends regarding the number of researchers by regional centres are presented in the following table, and are based on the following assumptions:

- the increased amount of funding leads to the recruitment of new researchers, especially in the period between 2026 and 2035, when the positive effects of most of the changes described above have an impact on increasing the appeal for young researchers within recruitment;
- the projected growth rate for the number of researchers for the period between 2021 and 2026 is 1.02%, followed by 2.24% for the period between 2026 and 2030 and 2.64% for the period between 2031 and 2035; and
- the regional hubs record the same rates of increase in the number of researchers as Zagreb.

Table 22 — Projections of trends regarding researchers in the accelerated development scenario

	2021	2026	2030	2035
Zagreb	538	565	616	691
Adriatic Croatia — South	77	81	88	99
Adriatic Croatia — North	91	96	104	117
Continental Croatia	95	100	109	122
TOTAL	**801**	**842**	**917**	**1,029**
Number of researchers per 1,000 inhabitants	**0.206**	**0.226**	**0.251**	**0.292**

Source: Authors

Note: for 2021, the data on the number of researchers under the TPA obtained in the mapping phases was used.

Projections of scientific productivity trends

In the accelerated development scenario, an increase in the level of scientific productivity under the TPA is projected. Scientific productivity is monitored by observing the number of scientific papers published in the relevant databases (WoS and Scopus), with an expected increase of 40% for the period until 2035.

Projections of trends regarding excellent researchers[11]
The number of excellent researchers among the total number of researchers under the TPA is increased as a result of an overall better environment for their work and advancement. In line with the parameters, in the accelerated development scenario, the quality of research groups is slightly improved in the medium term and moderately improved in the long term.

4.4. Performance Indicators

In order to facilitate the monitoring of the future development of research capacities and the contribution of activities under the TPA to the broader development of society, TPA performance indicators have been developed and targets set for 2026 and 2035. The target values vary depending on the scenario.

Table 23 — Key performance indicators for the development of the Energy and Sustainable Environment TPA

	Baseline values	Baseline scenario		Accelerated development scenario	
	2021	2026	2035	2026	2035
Value of disbursements for research projects from national and EU sources (in millions of euros, cumulative)	-	149,7	565,2	175,3	741,4
Value of EU disbursements for projects under Horizon Europe, EIT and COST in millions of euros (cumulative)	4,5	19,8	64,4	21,6	102,6
Number of ERC grants	0	0	2	1	5
Number of citations in papers published in WoS/Scopus per scientist	462,2	470	485	475	577
Value of disbursements for collaborative projects with the economic sector in millions of euros (cumulative)[a]	-	74,8	282,6	87,6	484,0
Number of newly developed/improved technologies[c]	6	25	75	30	150
Number of enterprises established as a result of academic entrepreneurship[d]	3	5	15	10	60
Number of intellectual property protection applications submitted by RIs/researchers (cumulative)[e]	4	15	51	20	110
Number of strategic partnerships established for long-term research[b] (cumulative)	-	-	-	5	15

[11] Refers to the category of researchers established in the mapping phase that includes the most scientifically successful researchers.

[a] Refers to all the projects where one or more entrepreneurs participate as a partner.
[b] Refers to partnering with domestic and foreign entrepreneurs as well as public institutions.
[cde] This is an estimation based on survey data from the mapping phase.

In terms of the value of the projects contracted directly with the economic sector, a slight increase in cooperation can be expected in the first period as a result of the improving infrastructure of RIs and the experience gained from previously implemented projects. However, the positive changes will be limited in scope compared to the results achieved in the accelerated development scenario because of the absence of effective reform activities explained in the descriptions of the scenarios.

On the other hand, in the accelerated development scenario, increasing the scope of available research is accompanied by a number of changes in the way research systems function, which have a positive impact on improving scientific excellence and the motivation of researchers and research groups in submitting projects to EU and other international competitive calls for tenders. Additionally, changes in the system are a strong incentive for researchers to step up their activity in terms of cooperation with the economic sector (and vice versa), which is consequently reflected in the indicator values.

When it comes to the use of indicators, it should be noted that some of the proposed indicators have not been used until now even though the conditions for their inclusion are there, such as indicators of the number of principal researchers for projects financed through the ERC. Data on the number of principal researchers is regularly monitored by the EC, so it can very easily be used for performance monitoring purposes. Some indicators are nevertheless more demanding, as there is currently no foundation for systematic data collection. For example, the data on newly developed technologies was obtained in the mapping phase through a survey and as such is not part of the existing data collection system. For such data, it would be advisable for the MZO to establish a process of regular collection as part of a system of regular reporting by research institutions to the MZO on the results of their work.

The following table gives a visual overview of the dynamics of the three key indicators for the development of the TPA for each scenario and for three different periods until 2035.

Table 24 — The dynamics of the selected TPA development indicators for each scenario (compared to the previous period)

Significant negative change	Slightly negative change	No change	Slight improvement	Significant improvement

	Baseline scenario	Accelerated development scenario
Total funding for R&D projects		
2022–2026	Significant improvement	Significant improvement
2026–2030	Significant improvement	Significant improvement
2030–2035	Slight improvement	Significant improvement

Value of disbursed funds for international competitive projects (Horizon Europe and others)		
2022–2026	↗	↗
2026–2030	→	↗
2030–2035	→	↑
Value of projects contracted by RIs with the economic sector		
2022–2026	↗	↗
2026–2030	↗	↑
2030–2035	→	↑

Source: Authors

The table shows how both of the scenarios imply a significant increase in funding for the period until 2030, while a gap forms for the period between 2030 and 2035, mainly because of the higher success of RIs in attracting funding from the economic sector as well as higher success in terms of participation in international competitive programmes (Horizon Europe and others). An important reason for this gap is the absence of effective reform activities that would encourage research teams to participate more in programmes such as Horizon Europe and that would facilitate and further encourage cooperation between scientific institutions and entrepreneurs domestically and internationally (including the differences in creating a favourable environment for the development of academic entrepreneurship).

5. Proposed Priority Topics in the Energy and Sustainable Environment TPA

5.1. Global Trends in Technology Development

Globally, the policies for limiting climate change guide the development of technologies in the field of clean energy and a sustainable environment. The focus is on clean energy technologies and on the 'green and digital' transformation. There is no universal approach to categorising technologies and assessing their potential. For example, the International Energy Agency (IEA), in addition to energy transformation technologies (electrical energy, thermal energy, biofuels, hydrogen, ammonia and synthetic fuels), recognises that carbon dioxide (CO_2) infrastructure (capture from air, transport and storage), the construction and transport industries and industry-specific technologies (e.g. paper, aluminium, battery recycling, iron and steel) play a significant role in this field (IEA, 2021). The key trends relate to the development of systems that use clean energy and that are key to achieving zero net emissions by 2050 and limiting global warming to 1.5 °C. On the other hand, in addition to clean energy technologies (PV, batteries and energy storage, wind energy, hydrogen and renewable gases as well as carbon sequestration), the IPCC focuses on technologies in forestry, construction, industry, agriculture and waste management in order to ensure a sustainable environment (IPCC, 2018a).

5.2. EU Strategic Priorities

The latest EU Strategic Foresight Report (EC, 2022) outlines the relationship between the digital and green transitions to achieve climate neutrality objectives and halt environmental degradation by 2050. The key objectives, which require technological developments and societal changes to be achieved, are set out in the European Green Deal.

The European Green Deal defines the objective of climate neutrality by 2050. By 2030, the European Climate Law (Regulation 2021/1119) requires a reduction in greenhouse gas emissions of 55% compared to 1990. To achieve this, it is necessary, among other things, to increase the presence of RESs, increase energy efficiency and develop an alternative fuels infrastructure. The establishment of an encouraging framework for circular economy is also planned, e.g. via the Batteries Regulation (EC, 2020).

Legislation defining new objectives is being prepared as part of the 'Fit for 55' package, the goals of which were further broadened by the REPowerEU package (EC, 2022e). These include amendments to the Renewable Energy Directive (Directive EU 2018/2001, hereinafter: RED II), the Energy Efficiency Directive, the Directive on the deployment of alternative fuels infrastructure (Directive 2014/94/EU) (EC, 2021d), the Proposal for the Batteries Regulation fostering the development of a circular economy regarding batteries, from mining to recycling, the Solar Energy Strategy (EC, 2022f), the Biomethane Action Plan (EC, 2022g) and investment in research and production of green hydrogen (EC, 2022h; EC 2022i).

The proposed amendments to RED II increase the target for the percentage of RESs in primary energy consumption from 32% to 40% (EC, 2021b). With the REPowerEU package, the Commission proposed to increase the main target for RESs by 2030 from 40% to 45% (EC, 2022d) and the Revision of the Energy Efficiency Directive plans an improvement in the targets for reducing primary and final energy consumption to 39%, i.e. 36% by 2030, compared to the updated baseline projections from 2020 (EC, 2021c). Through the REPowerEU package, the Commission proposed to further improve long-term energy efficiency measures, including increasing the mandatory energy efficiency target from 9% to 13% and an increase in the use of heat pumps, solar systems, hydrogen and biomethane.

The goals set are very ambitious: the EU Solar Energy Strategy sets a target of 600 GW of total installed capacity in solar power plants, of which 320 GW by 2025, i.e. twice the amount when compared to 2020. The integration of such capacities into the system is challenging and creates opportunities for innovation and its application.

5.3. Proposed Priority Research Topics for the Period until 2035

Monitoring global trends, meeting European and national strategic priorities and objectives requires R&D and close cooperation with the economic sector. The proposed priority research topics for the period until 2026 and until 2035 is based, on the one hand, on the priorities identified in the key national and abovementioned EU strategic documents and, on the other hand, on the views expressed by experts in the mapping phase and in the TOWS, PESTLE and DELFI analyses described above.

With regard to national documents, the Integrated National Energy and Climate Plan (Ministry of Environment and Energy, 2019) and the Croatian Smart Specialisation Strategy 2016– 2020, as well as the draft of the new Smart Specialisation Strategy, are particularly important.

The Integrated National Energy and Climate Plan identifies the following benefits in the economic sector:

- industrial capacities related to EES electrical equipment (e.g. voltage and distribution transformers, rotary machines, wind turbines and PV modules) and the supporting industry for the creation of large structures made of metal and concrete (shipyards);
- tradition and experience in designing and building energy facilities, power lines, substations and control systems with very good global export potential;
- presence of natural resources suitable for generating energy from RESs (water resources, the construction and equipping of hydropower plants, bioplants capable of receiving residue material from the Croatian agricultural sector, wind to be used for further technological upgrades and investment in wind farms, etc.);
- numerous educational institutions and university courses in which students are educated in the fields of manufacturing, engineering and maintenance;
- a number of public and private research institutions with proven competence in this field that can support and improve the competitiveness of the industry through R&D; and
- an existing market requiring the upgrade and expansion of production capacities.

In addition, the need for research under the following topics has been identified:

- the development of models and methods for integrated carbon management, for improving emission/sink calculations, for emission/sink projections and for the application of total life-cycle calculations;
- research on technologies and technical and non-technical measures for reducing emissions and improving sinks in all sectors (energy, transport, agriculture, forestry, waste management and industrial processes);
- research on CO_2 use, storage, transport and geological storage opportunities;
- exploring links between climate change mitigation and adaptation, as well as interactions with other environmental aspects;
- developing integrated models for assessing the economic, environmental and social impacts of climate change mitigation policies and measures;
- research into the sociological aspects of climate change, development of models and methods of promotion and increasing public awareness of climate change;
- exploring the potential of biomass, biomass production, biomass use and related socio-economic aspects;

- exploring the potential of all RESs, the costs and benefits of their use and their impact on the environment, nature and the Natura 2000 network;
- studies of integrated solutions, energy efficiency and RESs in all sectors as well as optimisation models for smart cities, green cities and urban infrastructure;
- research on advanced grids and smart systems;
- developing smart city concepts and planning;
- research related to building a circular economy and introducing systems of resource, energy and carbon footprint management;
- research on sustainable urban mobility and cooperative, intelligent and automated transport solutions; and
- research on possibilities for increasing carbon storage on forest and agricultural land and possible innovative measures in livestock farming.

In addition, the Integrated National Energy and Climate Plan states that technological progress is particularly expected in the application of ICT technologies in all sectors, especially with a high impact in the fields of energy and transport. The results of the surveys and the DELFI, TOWS and PESTLE analyses complement these findings and show that, in addition to ICT technologies, other advanced technologies (described in more detail in Chapter 4.2.) have significant potential to improve scientific excellence as well as to strengthen cooperation with the economic sector under the Energy and Sustainable Environment TPA. These are technologies related to advanced materials, IT security and industrial biotechnology, GIS tools and their advanced use, meteorology, the advanced use of meteorological infrastructure, weather forecasts, data and tools, digital twin technologies, bioprinting, 5G and 6G networks, etc.

In terms of the Croatian Smart Specialisation Strategy 2016–2020, the following topics were highlighted as a priority under the Energy and Sustainable Environment TPA.

Energy technologies, systems and equipment:

- new technologies and improvements related to RES power plants, substations, components and systems;
- new research related to increasing the efficiency and production capacities of industrial, agricultural and forestry facilities and machinery;
- advanced energy storage systems;
- diagnostics and better energy equipment management;
- energy management systems for planning, investing, real-time management and monitoring of energy efficiency and CO_2 emissions reduction;
- energy management systems and support for the functioning of energy markets at the microgrid, smart grid and smart city levels;
- advanced conventional energy solutions;
- applying smart grids and complex energy systems;
- energy-efficient, interconnected and multi-purpose lighting systems;
- sustainable transformation of biomass into energy; and
- biogas technologies for the generation of electrical and thermal energy.

Environmentally friendly technologies, equipment and advanced materials:

- environmental sustainability of manufacturing;

- technologies and solutions related to reducing resource consumption and waste;
- optimising resource use by including new or advanced materials in 'more with less' manufacturing;
- laboratory treatment of waste water and streams as well as techniques for the protection of biological diversity;
- energy-saving technology combined with efficient use of RES capacities;
- industrial CO_2 emission reduction technology through the deployment of innovative new technologies and solutions;
- technologies and technological processes related to environmental sustainability;
- development of marine protection technology and equipment;
- energy-saving technology combined with efficient use of RES capacities;
- integrated water management to minimise water use and for the reuse or recycling in industrial facilities;
- research on first-generation and second-generation biopolymers and bioplastics, bioreactors and atmospheric biotechnology;
- new sources of biomass and bio-based products;
- bio-based chemical products with added value and environmentally friendly biomaterials;
- waste water monitoring and innovation in prediction and reduction of environmental pollution;
- surveys of seas and marine habitats using autonomous underwater vehicles; and
- the use of autonomous unmanned vehicles for environmental monitoring (marine, land and air).

The draft of the new Smart Specialisation Strategy until 2029 outlines the following priority areas for funding under the Smart and Clean Energy TPA:

- smart grid technology;
- transformation of waste into energy;
- energy storage;
- carbon capture;
- green thermal energy;
- geothermal energy;
- digital technologies;
- advanced materials; and
- hydrogen.

It is also worth noting once more that, during the mapping phase, researchers identified **priority research topics** in terms of the potential for publishing in scientific journals in the next 5 to 10 years, which are related to the Energy and Sustainable Environment TPA. Several interesting topics related to research on advanced technologies and materials (23 researchers), sustainable materials and sustainable management (16 researchers), research on circular economy (22 researchers), alternative fuels and energy sources (15 researchers), energy transition (13 researchers) and energy storage research (13 researchers) were highlighted. Topics related to digital transformation, digitalisation and optimisation (9 researchers), RESs (9 researchers) and energy efficiency (8 researchers) were also mentioned. Other topics included artificial intelligence and energy systems management.

Based on the analysis of global trends, EU priorities, national development documents and the TOWS, PESTLE and DELFI analyses, the following **thirteen priority areas of research for the period until 2035** are proposed**:**

1. development of energy storage technologies, 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 environmental protection and/or sustainability;
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 heating/cooling technologies, systems, equipment and devices;
7. development of technologies, systems, equipment and devices for the generation of electrical and thermal energy from RESs;
8. development of smart grid technologies and the digitalisation of the energy system;
9. development of hydrogen production and/or storage technologies, systems and devices;
10. development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings;
11. development of electrical energy transmission and distribution technologies, systems, equipment and devices;
12. development of carbon capture and storage systems; and
13. development of nuclear power generation technology, systems, equipment and devices.

In this context, particular attention should be paid to the use of different digital technologies that increase the efficiency of new technological and other solutions. The above list of topics should in no way be considered as definitive but should be updated at regular intervals. Updates to the list should be based on the continuous monitoring of strategic priorities at the international, European and national levels as well as of the research capacities and performance of domestic research institutions and the economic sector.

6. Conclusions

The science and technology 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 areas with the highest growth potential and to the key opportunities and obstacles to the further development of the RDI system in this area. The are 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 settings for the development of the scenarios were prepared on the basis of the implemented SWOT, TOWS, PESTLE and DELFI analyses.

In accordance with the methodology set out above, two basic scenarios for the development of the TPA by 2026 and by 2035 were developed: a baseline scenario and an accelerated development scenario. The baseline scenario represents a TPA development trajectory characterised primarily by the use of significant funding from EU sources, but without any substantial improvements in the working environment of the researchers, particularly regarding the cooperation with the economic sector. On the other hand, the accelerated development scenario implies a number of major and minor changes in the research system which lead to a deep strengthening of research capacities, a significant increase in international visibility of national research institutions, and a much more visible impact on the innovation of the Croatian economy.

Both scenarios elaborated on the key changes for the following four areas:

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

In the baseline scenario, the total size of available funding, the funding criteria and the continuity of funding are expected to improve slightly by 2026, mainly in connection with the implementation of the NRRP, while the funding criteria and the continuity of funding are expected to remain mostly unchanged. In the period up to 2035, generous funding is expected to continue, owing primarily 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, which creates new opportunities for research teams from Croatia.

A similar development in terms of availability of funding is expected under the accelerated development scenario, where an increase in available funding through the CSF is expected as a result of growing public investments in R&D from the national budget. The gradual strengthening of the national component in the funding is key to securing the continuity of investment funding once the NRRP resources are exhausted. The main difference compared to the baseline scenario is the improving of the funding criteria and ensuring the continuity of funding for research projects. In this respect, a moderate improvement is expected by 2026, and a significant improvement by 2035. Improvements are primarily linked to better national research project selection procedures. In addition, they are linked to improved planning of public calls for research, with careful coordination of EU and national sources, and to link between continued funding for research teams and their earlier results.

In the baseline scenario, in the area of human resources development, 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, all factors are expected to improve by the end of 2026, except for the number of researchers, which are expected to remain the same in this period. In the period up to 2035, moderate or significant improvements are expected in the accelerated development scenario, 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. One factor that stands out among the most important individual factors is the increasing financial valorisation of research excellence which leads to an increase in motivation among researchers to implement high-quality research. Programme agreements are becoming a key instrument for ensuring a new approach.

The following were recognised as key factors influencing the quality of research infrastructure: 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. These factors remain mostly unchanged in the baseline scenario by 2026, which means that researchers still have difficulties with organising the use of equipment, poor logistical support for research teams, and equipment maintenance funding. 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 new projects. To conclude, infrastructure availability is expected to improve moderately by 2035.

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. In the period up to 2035, all factors are expected to improve significantly, primarily in connection with the improvement 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 (for example, greater cooperation with the economic sector leads to more funding for equipment maintenance). 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, primarily in connection with the adoption of national guidelines which would encourage the adoption and a certain level of standardisation of policies on intellectual property protection at universities and public institutes. The approach would continue to be improved further by 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, the situation as it is today is expected to remain unchanged by 2035. On the other hand, in the accelerated development scenario, the legislative regulations are expected to be supplemented and thus enable a slight improvement by 2026 in terms of the direct impact on strengthening cooperation with the economic sector. This improvement is expected to become moderate by 2035. The possibility to give priority to cooperation with research institutions over the company’s own investment in R&D in the sense of tax advantages or exceptions would be the biggest incentive in the field of legislation. 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 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 some of the indicators and these are updated regularly, while for other indicators, data collection processes still need to be set up. Establishing a linked system of unique project, researcher and research institution identifiers would significantly facilitate the process of data collection. In addition, reporting within the programme agreement represents an important opportunity for collecting relevant data to monitor the successful development of the TPA. The chapter also showed the indicator targets for each scenario, and these serve as an excellent illustration of the key differences between the outcomes of the two scenarios. Even though both scenarios have the same level of EU funding available, these differences in outcomes are not negligible.

DELFI analysis was used to identify the attitudes of researchers regarding the innovation and research potential of individual themes under the Energy and Sustainable Environment TPA in the next 5 to 15 years. Out of the eleven initially proposed research themes, a total of thirteen research themes with the highest potential to strengthen research excellence and innovation were developed in the end. Particular attention is drawn to the need to continuously monitor the successful realisation of potentials of these themes as a basis for modifications in theme coverage. Indeed, the data collected during the mapping phase on the number of newly developed technologies from 2011 to 2021 shows that only two themes are highly prevalent when it comes to the number of newly developed technologies. This only confirms the need for the competent authorities responsible for implementing S3 to actively monitor the results at the level of individual research themes.

In conclusion, researchers active in the Energy and Sustainable Environment TPA can expect very favourable funding opportunities in the period up to 2035. This is primarily linked to the availability of very generous funding from EU sources. In addition, the current challenges of climate change, environmental conservation and energy sufficiency translate to a growing policy support for implementing research in this area. In order to make the most of these opportunities, a number of steps must be taken to ensure the strengthening of capacities in the science and research system in general and, consequently, in the Energy and Sustainable Environment TPA. Some of the possible steps were laid down in this study, while a more detailed elaboration was given in the accompanying document ('Guidelines for improving strategic documents'). In this respect, the research carried out can serve as a kind of guide for looking ahead and promoting the understanding of consequences of (non)action by key actors. At the same time, it needs to be recognised that most of the difficulties that hamper the faster development of research capacities under the TPA are of a general nature, which is to say that they affect the entire system of research and science in Croatia. Therefore, the necessary solutions are above all comprehensive and remove the key limitations to faster scientific and technological development. If public policy makers and the persons in charge of individual research institutions decide on a more ambitious approach to addressing limitations and making use of opportunities, the research teams in this TPA could make a much greater contribution to the development of Croatian economy, as well as to a better international position of Croatian research institutions. This would also provide for a very solid foundation for the further development of scientific and technological capacities after 2035.

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Appendix 1: Technological development priorities in the Energy and Sustainable Environment thematic area

This section describes the priority areas of strategically important technological development, concerning the strategic documents both at the EU and the Republic of Croatia level.

The International Energy Agency (IEA) estimates that by 2030 most of the CO_2 reductions will be achieved by the technologies that already exist on the market, and by 2050 almost half of the emission reductions will come from technologies currently in the demonstration or prototype phase (IEA, 2021).

In the Clean Energy Technology Guide, the IEA lists more than 400 technologies and their components, together with an indication of their market readiness level. The categories are divided into several levels: by demand sectors (transport, industry, buildings), subdivided into sub-sectors (e.g. road, rail, air, freight traffic), technology groups (e.g. vehicles and components, infrastructure, propulsion), technologies (e.g. battery electric vehicles, fuel cell electric vehicles, methanol-fuelled engines, ethanol-fuelled engines), sub-technologies and components (e.g. lithium batteries) (IEA, 2020).

A platform for the development of new technologies in Great Britain, Tech Nation, identifies the best emerging energy technologies and groups them into three categories: clean energy, energy efficiency and energy storage (Tech Nation, 2022).

Following are the key topics for energy R&D that the EC specifically monitors:

- Energy storage, which is currently the most prominent in pumped hydropower plants. As the prices of batteries go down, their role strengthens. Lithium-ion batteries are the most common form of electrochemical storage and research questions address the options for recycling and life-cycle efficiency. The UK and Germany currently have the largest capacities. Local storage (behind the meter) is on growth and its distribution depends on market models and regulatory incentives (Andrey et al, 2020).
- Batteries Europe, a technological and innovative platform and a one-stop shop for R&I;[12]
- Market flexibility, enabled by the integration of different technologies, with the key EU initiative in this area being BRIDGE, a cooperation group in the areas of Smart Grid, Energy Storage, Islands and Digitalisation.[13]
- Energy and smart cities, linking the objectives of the Energy Union, the Urban Agenda, the energy performance of buildings (in line with the EPBD) improvement, the Charter of the Global Covenant of Mayors for Climate and Energy, the Strategic Energy Technology Plan (SET Plan), the Smart Cities Information System, SCIS).
- Fusion and ITER, which is considering using fusion within the ITER project (Southern France).[14]
- The digitalisation of energy, enabling the transformation of the energy system, the integration of RES and decarbonisation. The digitalisation of the system flexibilisation

[12] Batteries Europe (europa.eu).

[13] https://www.h2020-bridge.eu/.

[14] ITER - the way to new energy.

is a separate theme, and virtual systems for identifying critical points of the system, options related to the use of vehicles as storage devices (price-based charging/discharging, real-time energy flow management based on price signals, managing the demand response and other ancillary services) are still in the research phase (EC, 2022a).

- The competitiveness of clean energy, assessed on the basis of a set of indicators, such as the state of the technology, installed capacity and market potential assessment (EC, 2021e).

The EC progress report on the competitiveness of clean energy technologies groups clean energy systems into three market segments:

i. renewable energy, including manufacturing and installation of equipment and energy generation from RES;
ii. energy efficiency and management systems that include technologies and activities such as smart meters, smart grids, storage and renovation of buildings; and
iii. electric mobility, which includes components such as batteries and fuel cells essential for electric vehicles and charging infrastructures (EC, 2021e).

The European Strategic Energy Technology Plan (SET Plan) is the most important strategic framework to boost the transition towards a climate-neutral energy system through technological development. Its objective is to accelerate technological developments and reduce research costs through coordinated research efforts by promoting cooperation among the Member States. The plan covers ten key areas of technological development in the field of energy: renewable technologies, reduced technology costs, new technologies and services for consumers, resilience and security of energy systems, new materials and technologies for buildings, energy efficiency for the industry, competitiveness in the global battery sector and e-mobility, renewable fuels and bioenergy, carbon capture and storage and nuclear safety.

The SET Plan consists of the SET Plan Steering Group, European Technology and Innovation Platforms (ETIPs), the European Energy Research Alliance (EERA) and the SET Plan Information System (SETIS).

EERA aims to accelerate energy technology development through cooperation on pan-European programmes. It brings together more than 250 research organisations from 30 countries, involved in 17 joint programmes. For the time being, the only Croatian institutions participating in the EERA are the Institute of Physics, participating in the Joint Programme on Nuclear Materials, and the Energy Institute Hrvoje Požar (Joint Programme Smart Cities).[15] The EERA Joint Research Programmes are presented in Box 1.

[15] Members - EERA (eera-set.eu), accessed on 18/05/ 2022.

Box 1. EERA Joint Programmes

- AMPEA (Advanced Materials in Processes for Energy Applications)
- Bioenergy
- Carbon Capture and Storage
- Concentrated Solar Power
- Digitalisation for Energy
- E3S (Joint Programme on Economic, Environmental and Social Impacts of the Energy Transition)
- Energy Efficiency in Industrial Processes
- Energy Storage
- Energy Systems Integration
- Fuel Cells and Hydrogen
- Geothermal Energy
- Hydropower
- Nuclear Materials
- Ocean Energy
- Photovoltaic Solar Power
- Smart Cities
- Smart Grids
- Wind Energy

Source: EERA Joint Programmes (eera-set.eu)

In 2020, the High Voltage Direct Current (HVDC) & Direct Current (DC) Technologies working group was set up. HVDC has been identified as a key technology for grid coupling, energy transmission and offshore plant integration. Medium Voltage Direct Current (MVDC) could facilitate the transmission and integration of local systems as well as improve the charging of electric vehicles. Additionally, the need for stronger cooperation between different groups is growing. According to the published data, Croatia participates in activities related to wind energy and nuclear safety.

Main EC findings on the progress of clean energy technologies competitiveness

The EU has a strong position in the wind energy sector. Photovoltaic solar power, renewable hydrogen, heat pumps and renewable fuels are areas with growth potential, depending on R&I results. In the period up to 2030, the most noticeable relative growth is projected for the EU in the development and deployment of wind and solar technologies. Electricity storage technologies, such as batteries and renewable hydrogen, are key to increasing the overall flexibility of the energy system while optimising the market integration of electricity from RES. Investment in such technologies and their development are necessary to achieve the objectives of the Green Deal. Heat pumps could have a significant role in decarbonising the building sector. Renewable fuels are needed to facilitate the decarbonisation of certain transport modes. Smart grids are considered a horizontal technology that will facilitate the combination of different technologies for energy production, distribution and consumption.

Following is a more detailed description of the state of investment in R&D in specific energy production, distribution and storage technologies in the EU.

Wind energy

In 2020, the total wind energy installed in the EU reached 178.7 GW[16], of which 10.5 GW capacity wind farms (both onshore and offshore) were built in 2020. In 2020, onshore wind farms accounted for 13.7% of total electricity generation. The 2030 Climate Target Plan scenarios project production of 847 TWh by onshore wind farms in 2030 (the share in total electricity generation: 27.3%) and 2,259 TWh in 2050 (share: 32.9%).

By 2030, the instalment of further 47 GW capacity offshore wind farms is planned in the North Sea, but significant production can also be expected in other sea basins, notably in the Baltic Sea (21.6 GW), the Atlantic Ocean (11.1 GW), the Mediterranean (2.7 GW) and the Black Sea (0.3 GW). The transition to new sea basins will require further developments of floating technology and the development of port infrastructure. The construction of the future offshore grid is linked to hybrid projects[17], which can reduce costs and use of space needed to increase the deployment of offshore wind farms.

Onshore, the growth of wind farms number has been slowing down since 2018, when complex permit-granting rules were introduced in Germany, leading to a slower instalment of wind farms. Part of the EU's onshore and offshore wind farms is at the end of its lifespan. Replacing wind turbines with new ones or extending their lifetime by upgrading certain components is an opportunity for modernisation. A significant part of the components of existing wind turbines is not reusable or recyclable, posing a challenge when it comes to decommissioning and resource efficiency.

Private investment in technology R&I over the last 10 years was between EUR 1.6 billion and EUR 1.9 billion per year (WindEurope, 2021) and was 10 times higher than public investment. The EU share of high-value patents in this area in 2015 –2017 was 57% (mostly in Denmark and Germany), the US had a share of 18%, Japan 11%, China 5% and Korea 1%.[18] Most high-value patents are filed by large OEMs in the EU, but their lead has been decreasing since 2012 and the manufacturers from the US (e.g. General Electric) and Japan (e.g. Mitsubishi Heavy Industries, Hitachi) are catching up. When it comes to the most quoted research institutions, nine out of twenty are located in the EU.

The circularity of components is insufficient, in particular the composite wind turbine blades, as they remain difficult to recycle. Circularity key elements, including reuse, recycling and substitution, are priority areas of innovation to reduce the risks associated with the supply of critical raw materials while improving the overall sustainability of the sector. These are the

[16] JRC, based on the Global Wind Energy Council (GWEC) report, 2021.
[17] Hybrid offshore infrastructure has a dual functionality: it combines the transmission of offshore wind energy to the shore (for consumption) and interconnectors.
[18] JRC, based on the European Patent Office's Patstat database.

priorities of Horizon Europe for the 2021 –2022 period. Research on the cumulative effects of offshore wind farms on ocean ecosystems is also needed.

European offshore production in ports (current production capacity: 6–8 GW per year) will have to increase significantly to reach 16 GW of annual capacity to meet demand in the 2030 –2050 period[19].

Photovoltaic solar power

The photovoltaic solar power sector is growing faster than expected and is innovative. More than 3.1 TW of solar PV capacity is projected to be installed at the global level by 2030 reaching 14 TW by 2050. It is projected that by 2030 solar PV power plants will generate 0.4 TW of energy and 1 TW by 2050[20,21.]. The sector itself predicts an even greater penetration in its scenario[22].

Residential systems, which prevailed five years ago in the EU, are now ranked second in terms of the share of installed capacity (25.4%), with the large solar PV power plants (30.5%) taking the first place. Installations built by energy communities have great potential. Their installed capacity in Europe is at least 6.3 GW and the share at the national level is 1–2% and 7% in Belgium, the largest contributor. Most of the capacity was generated by the solar PV energy sector, followed by the onshore wind energy sector. There is a need for research in the design and efficiency increase of PV cells.

The EU is a global leader in R&D of PV technology, polysilicon production, equipment and machinery for the production of PV cells[23].

The EU performs best in terms of the energy produced compared to the energy consumed in the production and operation of PV systems, followed by China and the US[24]. The EU also has the lowest carbon intensity of energy produced by PV systems, followed by the US and China. The EU also has the highest carbon energy return, while China performs the poorest in this regard and the US is in the middle[25].

Heat pumps for building applications

Heat pumps for building applications are mature and commercially available devices. They can be classified according to the source from which they extract energy (air, water or ground), the medium to which they transfer heat (air or water), their purpose (space heating/cooling,

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[19] JRC's Wind energy manufacturer database, 2021, and WindEurope, 2020.
[20] IEA, *WEO 2020 Sustainable Development Scenario*.
[21] IRENA, *World Energy Transitions Outlook*: *1.5°C Pathway* 2019.
[22] https://www.solarpowereurope.org/wp-content/uploads/2020/04/SolarPower-Europe-LUT_100-percent-Renewable-Europe_mr.pdf?cf_id=11789.
[23] BNEF, *Solar PV Trade and Manufacturing, A Deep Dive*, 2021.
[24] F. Liu and J.C.J.M. van den Berg, Energy policy (2020), 138:111234.
[25] F. Liu and J.C.J.M. van den Berg, Energy policy (2020), 138:111234.

domestic water heating) and target market segments (residential or commercial buildings, heating networks).

Thermal energy production from heat pumps in the EU has grown 11.5% per year in the last five years, reaching 250 TWh in 2020[26]. This trend will grow because the electrification of heating will be a key contributor to the building sector transition to climate neutrality.
Heat pumps are very efficient; their typical seasonal coefficient of performance is 3, which means that for each kWh of electricity consumed, 3 kWh of heat is generated[27]. Therefore, the use of heat pumps for building heating can be cost-effective compared to gas boilers only if the electricity-to-gas price ratio does not exceed 3. This ratio varies greatly between Member States[28], from 1.5 to 5.5.

The heat pump sector is characterised by a global and competitive market where innovation is crucial. The adaptations to evolving EU climate and environmental regulations and strategies are competing with the improvement of product performance and costs in small, medium or large enterprises of the EU, where R&D capacities are limited. Nevertheless, they bring about opportunities for the industry to propose innovative products.

In the period 2011 –2021, more than 37% of the quoted scientific publications on heat pump technology came from the EU, followed by China (23%) and the US (20%). The EU is also at the forefront of inventions in the area of 'heat pumps used mainly for heating, for building applications': in 2015 –2017, 42% of patents for high-value inventions were filed in the EU, followed by Japan (20%), the US (8%), South Korea (7%) and China (4%)[29].

Building on this knowledge and innovation base, the EU research institutions and industry can propose innovations. In 2014 –2020, Horizon 2020 research and innovation programme (now Horizon Europe) provided a total of EUR 146.8 million for projects on heat pumps for building applications. The largest share was used for the integration of heat pumps with RES (60.9 %), compared to the development of heat pumps for residential purposes (6.5 %) and district heating (32.6 %).

Based on the projections in the EU's long-term strategy[30], the sales of heat pumps in the EU are expected to increase rapidly by 2030 for electrification in the building heating sector, followed by slower penetration growth. Faster penetration into the EU's leading market is an opportunity for the EU industry to grow and develop competitive production by 2030, and then benefit from global sustainable growth, as predicted by the IEA[31]. Heat pumps play an important role in energy system integration and flexibility, so their promotion is envisaged in the Renovation Wave[32].

[26] European Heat Pump Association database.
[27] The coefficient can be lower or higher depending on the climate zone, nature of the heat source and temperature.
[28] Energy prices and costs in Europe, COM(2020) 951 final.
[29] JRC, based on the European Patent Office's Patstat database. Y02B 10/40, 30/12, 30/13, 30/52.
[30] In-depth analysis with the long-term strategy COM(2018) 773 final.
[31] IEA, *Net zero by 2050* May 2021.
[32] A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives, COM(2020) 662 final.

Batteries

Lithium-ion battery technology is important for electro-mobility, which is experiencing a strong demand for batteries, connected to the clean energy transition[33]. In the wider energy system, stationary batteries will be essential for energy storage, which will allow a major contribution to the energy from the volatile RES in the electricity mix. In addition, the interaction of electric vehicles with the electricity network has a great potential that should be harnessed.

In 2020, electric vehicles (EVs) became cost-competitive in more than 50% of the whole European automotive market, based on the total cost of ownership. Average prices of lithium-ion battery packs for electric vehicles fell by 89%, to USD 137 per kWh (EUR 115 per kWh) in 2020 in comparison to 2010. The average price of battery packs is projected to be USD 101 per kWh by 2023, while the purchase price of electric vehicles is expected to be lower than that of conventional cars by 2027[34].

The average energy density of electric vehicle batteries is increasing at a rate of 7 % per year[35] and the average battery pack capacity in light-duty EVs (electric and hybrid vehicles only) increased from 37 kWh in 2018 to 44 kWh in 2020, while the battery capacity for electric cars only ranges from 50 to 70 kWh in most countries[36]. Trends in increasing car sizes are jeopardising the increase of energy efficiency and the availability of critical raw materials.

In 2020, sales of electric vehicles accounted for 10.5% of the automotive market (an increase from 3% in 2019)[37] in the EU, but the percentages vary significantly among the Member States (from 0.5% in Cyprus to 32% in Sweden). The number of electric vehicles on EU roads doubled in 2020, reaching more than 2 million, corresponding to more than 60 GWh of energy storage capacity. More than 50 million electric vehicles are expected on EU roads by 2030[38].

In 2020, the EU's new stationary battery market increased to 1.3 GWh, with a cumulative installed capacity of approximately 4.3 GWh (mainly lithium-ion batteries)[39]. By promoting self-consumption, Germany has taken two thirds of the European market for home energy storage in batteries (2.3 GWh)[40]. By 2030, stationary batteries could be able to store almost as much energy as pumped hydropower plants can today, measured by the power generation that lithium-ion batteries can efficiently store for up to five hours, while new technologies, including flow batteries, can better meet the need for longer energy storage.

The 'European Battery Innovation'[41] project worth EUR 2.9 billion involves 12 Member States and dozens of companies and research institutions. The project proves that batteries are gaining importance when it comes to funding R&I. Additionally, the EU has earmarked EUR

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[33] Avicenne energy, *EU battery demand and supply (2019–2030) in a global context*, 2021.
[34] BloombergNEF, *Electric Vehicle Outlook 2021*, 2021.
[35] BloombergNEF, *Electric Vehicle Outlook 2021*, 2021.
[36] IEA, *Global EV outlook 2020*, 2021.
[37] Transport and Environment, *CO_2 targets propel Europe to 1st place in e-mobility race*, 2021.
[38] The central MIX scenario of proposals in the Fit for 55 package.
[39] The European Association for Storage of Energy (EASE), *EMMES 5.0 market data and forecasts electrical energy storage*, 2021.
[40] Solar Power Europe, *European market outlook for residential battery storage 2020–2024*, 2020.
[41] IP/21/226: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226.

925 million for the Batteries European Partnership Association within Horizon Europe for the 2021 -2027 period.

Most of the batteries in the EU are produced in subsidiaries of foreign, mostly Korean companies, which produce 44 GWh lithium-ion batteries[42]. There is a plan to establish 10 manufacturing facilities in the EU in the coming years. Lithium-ion battery production capacity in the EU is growing and has accounted for 6% of the global capacity[43] since 2021, which is an increase from 3% in 2018.

The automotive industry in the EU has accepted the transition to e-mobility. Recycling capacities have so far been limited and end-of-life batteries are currently mostly shipped to Asia[44].
The EU is far behind China in the production and deployment of electric buses. China has already electrified 60% of its bus fleet. In 2020, only 1,714 electric buses were sold in the EU[45], compared to 61,000 in China[46].

Renewable hydrogen

Hydrogen produced through water electrolysis using RES (belonging to renewable fuels of non-biological origin) has the potential to decarbonise sectors that are hard to electrify and hard to abate, such as the industry and heavy-duty vehicle transport, and to contribute to energy services, like seasonal storage. The main technological challenge involves energy efficiency losses linked to the conversion of energy from RES to hydrogen, as every unit of hydrogen produced using RES requires 1.5 units of electricity from RES. This requires huge amounts of RES energy, mainly wind and solar energy, as well as reducing the cost of RES electricity to make renewable hydrogen competitive with fossil-based hydrogen.

The industrial demand for hydrogen in the EU, amounting to around 7.7 million tonnes per year[47], is mainly met by fossil fuel-based production. Hydrogen produced through water electrolysis is estimated to account for less than 1 % of the total production[48]. The current EU target is to install 40 GW of electrolysers by 2030 to produce up to 10 million tonnes of hydrogen per year through water electrolysis using RES[49]. Electrolyser capacity in the European market by 2050 is predicted to range from 511 GW[50] to 1000 GW[51].

Some key performance indicators for electrolysers are summarised below for different technologies: alkaline electrolysers (AE), proton exchange membrane electrolysers (PEME), anion exchange membrane electrolysers (AEME) and solid oxide electrolysers (SOE). AEM

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[42] EBA250.
[43] EBA250; U.S. Department of Energy, National Blueprint for Lithium Batteries 2021–2030, 2021.
[44] EBA250.
[45] ACEA, *Medium and heavy buses (over 3.5t) new registrations by fuel type in the EU*, 2020.
[46] https://insideevs.com/news/481987/ev-buses-sales-2020-china-byd-yutong/.
[47] Fuel Cell Observatory: https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand.
[48] In addition, 2–4% is estimated to come from chloralkali electrolysis.
[49] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.
[50] A clean planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773 final.
[51] Kanellopoulos, K., Blanco Reano, H., *The potential role of H_2 production in a sustainable future power system – An analysis with METIS of a decarbonised system powered by renewables in 2050*, EUR 29695 EN, Luxembourg: Publications Office of the European Union, 2019, ISBN 978-92-76-00820-0, doi:10.2760/540707, JRC115958.

does not have the same level of maturity as other technologies (still developing but available for limited commercial use). SOE is starting to be used for demonstrations. AE and PEME are fully commercial technologies.

Table 1. Key performance indicators for four main electrolyser technologies in 2020 and projections for 2030

	2020				**2030**			
	AE	PEME	AEME	SOE	AE	PEME	AEME	SOE
Characteristic temperature [°C]	70–90*	50–80*	40–60*	700–850*	-	-	-	-
Cell pressure [bar]	<30*	<70*	<35*	<10*	-	-	-	-
Efficiency (system) [kWh/kgH2]	50	55	57*	40	48	50	<50*	37
Degradation [%/1000h]	0.12	0.19	-	1.9	0.1	0.12	-	0.5
Capital cost range [EUR/kW – based on 100 MW production]	600	900	-	2700	400	500	-	972

Source: Addendum to the Multiannual Work Plan 2014 –2020, Fuel Cells and Hydrogen Joint Undertaking, 2018, and for the parameters marked with *, elaboration by the Directorate-General for Energy (EC) based on 'Green Hydrogen Cost Reduction' by IRENA, 2020.

Note: Waste gas degradation is presented as a percentage of efficiency loss at nominal capacity.

The Fuel Cells and Hydrogen Joint Undertaking has invested around EUR 150.5 million since 2008 in the development of electrolyser technologies (EUR 74.7 million for research activities and EUR 75.9 million for innovation activities). The main beneficiary countries were Germany with around EUR 31 million, France with around EUR 25 million and the UK with around EUR 18 million. Around EUR 90 million was made available under the Horizon Europe-funded European Green Deal Call for three project consortia to develop and operate 100 MW electrolysers in real-life settings.

Japan has been filing patents in this technical area for many years, and the number of patents in other regions (especially in China) is growing. Europe (including the UK) files a comparatively higher number of international patent categories in the field of electrolysers (patent applications filed and published in several international patent offices) than other leading economies[52].

The European Clean Hydrogen Alliance has more than 1500 members, pointing to a very dynamic and rapidly evolving sector. By 2030, projects are planned for electrolysers with a total power of around 60 GW, most of which will use electricity from RES.
The electrolyser market shows great potential for development. Large-scale deployment of electrolysers will depend on the availability of RES and electricity from low-carbon energy sources needed to produce hydrogen through water electrolysis using RES and low-carbon hydrogen.

[52] JRC, based on data from the European Patent Office, EPO Patstat data, 2020. and https://iea.blob.core.windows.net/assets/b327e6b8-9e5e-451d-b6f4-cbba6b1d90d8/Patents_and_the_energy_transition.pdf.

Smart grids

It is estimated that technologies such as advanced measurement, automation or electrification of transport will each contribute around 8% of the estimated investments in electricity distribution networks in the EU and the UK by 2030[53]. Overall, markets for connected digital services, including distribution automation, home energy management systems (HEMS), smart meters and smart charging, are also expected to continue growing and thus deliver on the objectives of the European Green Deal.

Distribution automation and smart measurement can rely on familiar and market-ready devices and software. By the end of 2020, almost 150 million smart meters had been installed in the EU, Norway, Switzerland and the UK (average penetration rate of 49%). By 2025, they are expected to be close to 215 million (69% penetration rate)[54], while second-wave technologies will be more focused on decentralisation and consumer services.
Home energy management systems and smart charging are at an early stage of development. Research projects to advance technology impact growth. Standardisation, interoperability and cyber security are common challenges for all technologies and there is a risk of slowing down their deployment in an often fragmented market.
Recently, aggregators and tech companies have appeared in this market, focusing their business models solely on HEMS and sometimes offering products or services to major companies, avoiding covering the whole HEMS production chain.

Three key findings regarding the supply chain of EV charging infrastructure are as follows[55]:

- the producer supply chain is mainly local and/or regional, especially for EU-based sellers,
- essential electronic components are purchased in Asia,
- the market and the value chain are not yet fully developed, while sellers develop, design and manufacture products mainly in-house, with some contract manufacturing.

However, given that the deployment of distributed energy sources and electric vehicles will progress rapidly over the course of this decade, the smart charging sector will also become a growing part of the EV charging market worth billions of Euro, in particular in the area of slow charging which, according to the latest edition of the IEA Global EV Outlook, will be larger than that for fast charging[56].

Given the growing importance of software in smart grid technologies, the business model partially aligns with the business model of the clean software industry and develops more towards the market for services[57].

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[53] *Connecting the dots: Distribution grid investment to power the energy transition* – Eurelectric – Powering People .
[54] The portal of the Eurosystem Single Market Infrastructure Gateway (ESMIG), based on figures from the report by Berg Insight, June 2020.
[55] Guidehouse Insights, *Asset Study on Digital Technologies and Use Cases in the Energy Sector*, 2020.
[56] IEA, *Global EV Outlook 2021, Accelerating ambitions despite the pandemic*, 2021.
[57] Alexander Krug, Thomas Knoblinger, Florian Saeftel, *Electric vehicle charging in Europe*, Arthur D. Little Global, Internet publication, January 2021, www.adlittle.com/en/insights/viewpoints/electric-vehicle-charging-europe.

Building on ambitious policy objectives (like the European Green Deal, Energy Systems Integration), a favourable regulatory environment (e.g. the Electricity Directive) and public funding (e.g. Horizon Europe, the Cohesion Policy, the EU Innovation Fund, the Recovery and Resilience Facility), the EU aims to take the lead in the deployment of smart grids. That way it will, together with the long-established EU companies that provide network technologies, support European market leaders and solid technology manufacturers in all four technology domains. At the same time, as the global market analysis reveals strong development trends in the US and the Asia-Pacific region (China, Japan, South Korea), European companies will have to face strong competition before 2030.

Renewable Fuels for Aviation and Shipping

Renewable fuels, including advanced biofuels[58] and renewable synthetic fuels[59], are short-term commercialised solutions to decarbonise the aviation and maritime sectors[60]. Renewable fuels are projected to supply 5% (or 2.3 Mtoe) of total jet and shipping fuel consumption in the EU by 2030 and 63% (or 28 Mtoe) by 2050[61]. The announced total annual capacity of renewable aviation fuels in the EU by 2025 is around 1.7 million tonnes, which is 0.05% of total aviation fuel in the EU. By comparison, the installed capacity in the US is twice as high (3.6 million tonnes) and accounts for around 60% of the global capacity[62]. The share of renewable marine fuels is still negligible, but it is projected to reach 8.6% of the total fuel mix by 2030 and 88% by 2050[63].

The commercialisation and scale-up of renewable fuel production are hampered by high capital expenditure (CAPEX), reaching as much as EUR 500 million for a single plant and 80% of total production costs. In particular, according to current estimates, the production costs of renewable fuels are three to six times higher than the current market price of conventional fuels[64]. Co-processing (or co-hydrotreating in the case of aviation fuels) in existing refineries and other industries is developing and contributing to lowering capital costs.

Public funds that the Member States invest in R&I for biofuels[65], including advanced biofuels, remain constant at around EUR 400 million per year since 2008. In addition, the EU has increased its funding for renewable fuels from EUR 430 million in 2012 –2016 to EUR 531

[58] Fuels produced from organic material listed in Annex IX. to the Directive (EU) 2018/2001. The current installed capacity for advanced biofuels in the EU is 0.36 Mt/year, mainly for cellulose ethanol, hydrocarbon fuels from sugar and pyrolysis oil. An additional 0.15 Mt/year is being developed and a further 1.7 Mt/year is planned, with about half produced by biomass gasification. Power-to-gas and power-to-liquid fuel capacity in the EU is currently very limited, amounting to only 0.315 Kt/y.
[59] Fuels derived from renewable sources in accordance with Article 2(36) of the Directive (EU) 2018/2001.
[60] IRENA (2021), *Reaching Zero with Renewables: Biojet fuels*, International Renewable Energy Agency.
[61] Impact assessment report – SWD(2021) 633, p. 38
[62] Based on data compiled from the internal database of Flightpath 2020.
[63] Impact assessment report – SWD(2021) 635, p. 53
[64] Depending on the cost of jet fuel derived from oil and the feedstock used to make renewable fuels.
[65] Data reported after 2014 depends on how funding is allocated between biofuels and other bioenergy technologies and lacks the granularity to distinguish conventional from advanced biofuels.

million in 2017 –2020. The amounts specifically earmarked for aviation and marine fuels have been increased from EUR 84 million to EUR 229 million for the periods above[66].

Consistent investments of the EU are maybe the reason it is among global innovation leaders. However, evidence shows that it is lagging behind the US, whose companies file twice as many patents for aviation fuels than EU-based companies, and have more leading innovators[67]. The EC also points out that Japanese and EU-based companies account for one third of all patents in the maritime sector, but the evidence is not reliable, as it includes some non-renewable fuels technologies and there is no detailed data.

Overall, renewable fuels in the aviation and maritime sector are not only a strategic element for the transition to a climate-neutral economy but can also provide an opportunity for growth and employment.
Advanced biofuels are mainly based on non-recyclable waste and residues, which is a more sustainable option, with less impact on land use and biodiversity than biofuels from food and feed. The choice of material for biomass may impact sustainability, production costs and potential supply bottlenecks. That is why we need mature alternative production processes based on different materials other than waste, especially in the case of increased production of advanced biofuels in order to avoid bottlenecks.

The renewable fuels market in aviation and shipping is currently very limited. The new policies in the European Green Deal implementation package[68] are expected to significantly increase demand and expand these markets in this decade and decades to come. The strong global market position of the EU in road transport biofuels[69] as well as the concentration of leading advanced biofuel producers mean a good starting position to expand to these new markets. However, with dedicated initiatives[70] and installed capacity that is double the EU installed capacity[71], US producers of sustainable aviation fuel can also compete for EU markets.

As the process of converting power into liquid fuels depends on cheap RES electricity, the production of synthetic fuels could depend more on the Middle East and North Africa (MENA) region. On the other hand, synergies with existing EU fuel production facilities (integration with refineries, reuse of production and ancillary infrastructure, availability of skilled workforce, availability of CO_2 for capture and reuse, as well as other factors) unlock potential for economically competitive production of synthetic fuels in the EU.

Breakthrough technologies

The importance of breakthrough technology is best illustrated by solar fuels. The need for alternatives to liquid fossil fuels drives R&I to develop cost-efficient renewable fuels of high

[66] Data compiled from the European Commission database of EU-funded R&I projects https://cordis.europa.eu/projects/enhttps://cordis.europa.eu/projects/en.
[67] JRC SETIS research and innovation data: https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.
[68] In particular: COM(2021) 562 final, COM(2021) 561 final and COM(2021) 557 final.
[69]The EU is currently the global leader in the production of conventional biofuels with a net trade balance of roughly EUR 4 million.
[70] Namely, the Federal Alternative Jet Fuels Research and Development Strategy adopted in 2016 and the ongoing work on the Commercial Aviation Alternative Fuels Initiative (CAAFI).
[71] Including the planned capacity by 2025. Based on data compiled from the internal database of Flightpath 2020.

energy density and with ample raw materials. While advanced biofuels and synthetic fuels are being developed and some become commercial, solar fuels remain on a low technology readiness level (TRL) and in a conceptual or experimental phase. However, by 2050, tailored investments in these breakthrough technologies could increase the availability of cost-effective fuels with high energy density while reducing pressure on the demand for raw materials and resources.

In addition to the rapid deployment of available technologies, to reach net-zero emissions by 2050, new technologies that are now in the TRL category will need to be brought to market[72]. Similarly, in the past, targeted R&I activities made it possible to bring to market technologies that 30 years ago were still on low technology readiness levels or even only in the conceptual phase, such as offshore wind energy, renewable fuels and lithium-ion batteries for electric vehicles.

Solar fuel production includes a range of anthropogenic and bio-assisted processes for the direct conversion of solar energy into fuels, chemical products and materials from sunlight, air (e.g. CO_2 and nitrogen) and water. It includes using solar energy directly from sunlight, often called *artificial photosynthesis*, and heat from sunlight to initiate high-temperature heat processes[73].

In particular, photoelectrochemical (PEC) water splitting is a promising process of hydrogen production using solar energy with the potential for highly efficient conversion at low operating temperatures by using cost-effective thin layers and/or particles of semiconductor material. Tailored investments could make the PEC cost-competitive with fossil fuels by 2040 and available on the market[74].

The EU is at the forefront of clean energy research and the annual number of patents filed in the EU and globally is growing. At the global level, the EU has a greater share of 'green' inventions in climate change mitigation technologies compared to other major economies. The EU has a significant position in the wind energy sector, and in the PV industry, European manufacturers show a renewed interest in investing in the EU, based on the latest technologies. In the battery sector, the major investments in the EU are for battery production, increased demand for electric vehicles and the reorientation of the EU automotive industry, and focused on recycling to address the raw materials issue. The market potential of heat pumps, renewable fuels, smart grids and renewable hydrogen sectors is growing due to the expansion of relevant markets, driven by policy measures. Their competitive position will depend on their speed of penetration/development, the inclusion of planned investments/market readiness and a favourable legal framework, as well as the development of other sectors (e.g. aviation and maritime transport) (EC, 2021).

While boosting R&I in clean energy solutions and their market uptake, reliable, sustainable and unhindered access to raw materials is needed, making the circular economy increasingly important. Further R&I is needed in this area.

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[72] IEA, Net-zero by 2050 – a roadmap for the global energy sector 2021.
[73] Mission Innovation, *Innovation Challenge 5: Converting Sunlight into Solar Fuels and Chemicals Roadmap 2020–2050*, 2021.
[74] *Artificial Photosynthesis: Potential and Reality* EUR 27987 EN.

Technologies for a sustainable environment

Identifying the technologies analysed in the study is based on the RDI topics for the thematic priority sub-area 2 within the Smart Specialisation Strategy. These are:

- environmentally sustainable manufacturing,
- technologies and solutions for reducing resource consumption and waste,
- optimising resource use by including new or advanced materials in terms of 'more with less' manufacturing,
- laboratory treatment of waste water streams, techniques and protection of biodiversity,
- energy saving technologies combined with the efficient use of RES,
- technologies to reduce harmful emissions of industrial CO_2 through the deployment of innovative new technologies and solutions,
- technologies and technological processes related to environmental sustainability,
- the development of marine protection technology and equipment,
- energy saving technologies combined with efficient use of RES,
- integrated water resources management to minimise water use, reuse or recycling in industrial facilities,
- research in first- and second-generation biopolymers and bioplastics, bioreactors, atmospheric biotechnology,
- new sources of biomass and bio-based products,
- bio-based chemical products with added value and environmentally friendly bio-based materials,
- waste water monitoring, innovations in the prediction and reduction of environmental pollution,
- monitoring seas and marine habitats using autonomous underwater vehicles,
- technologies and the use of unmanned autonomous vehicles for environmental monitoring (maritime, land and air). (Government of the Republic of Croatia, 2016).

This list of topics is complemented by sustainable environment technologies related to the transition to a circular economy, the protection and restoration of biodiversity and ecosystems, pollution prevention and control, sustainable use and protection of water and marine resources, as well as water supply, sewerage, waste management and remediation activities. This classification is based on the activities identified in Commission Delegated Regulation 2021/2139 (EC 2021b) as economic activities that can significantly contribute to climate change adaptation. They are technologies and systems for:

- water collection, treatment and supply,
- waste water collection and treatment,
- anaerobic digestion of sewage sludge,
- anaerobic digestion of biowaste,
- composting of biowaste,
- material recovery from non-hazardous waste,

- landfill gas capture and utilisation,
- transport of CO_2,
- underground permanent geological storage of CO_2.

Under Horizon Europe, the listed themes are ranked under Cluster 6: Food, Bioeconomy, Natural Resources, Agriculture.

Appendix 2: TOWS and PESTLE matrix forms

TOWS MATRIX

	Strengths (S)	Weaknesses (W)
	- - -	- - -
Opportunities (O) - - -	**How to improve our strengths by using opportunities?**	**What external opportunities can we use to reduce our weaknesses?**
Threats (T) - - -	**How to reduce threats using strengths?**	**How to overcome weaknesses and avoid/reduce threats?**

S-O connection – How to improve our strengths by using opportunities?

S-T connection – How to mitigate threats using strengths?

W-O connection – What external opportunities are there that we can use to mitigate our weaknesses?

W-T connection — How to overcome weaknesses and avoid/mitigate threats?

PESTLE MATRIX

Aspect of the environment	External factors influencing the scientific and technological development of the TPA	Relative factor importance (E, VI, IM, NVI, IN)	Positive/ negative trend
Political (P)	–		
	–		
	–		
Economic (E)	–		
	–		
	–		
Technological (T)	–		
	–		
	–		

Social (S)	–		
	–		
	–		
Legislative (L)	–		
	–		
	–		
Environmental (E)	–		
	–		
	–		

E = essential
VI = very important
IM = important
NVI = not very important
IN = insignificant

Appendix 3: DELFI Analysis Questionnaire

Science and technology foresight in the thematic priority area 'Energy and Sustainable Environment'

Introductory notes regarding the survey

Thank you for your participation in the survey under the 'Science and Technology Foresight' Project of the Ministry of Science.
The objective of the survey is to identify the key factors defining the development of the scientific and technological potential of the Republic of Croatia under the **thematic priority area 'Energy and Sustainable Environment' of the Croatian Smart Specialisation Strategy**, as well as to identify the research topics with the highest growth potential over the next five to fifteen years.
The survey is to be conducted in two rounds. Once we collect all the answers from the first survey round, we will analyse and summarize them, and subsequently prepare the second round of questions to be sent to you. You will also be asked to examine and explain any views that significantly deviate from the general view of the respondents. The results thus obtained will serve as a basis for elaborating research potential development scenarios under the thematic priority area Energy and Sustainable Environment. Individual data will only be available to researchers.

1 Please read the GDPR notice and tick the box if you consent to this survey.

By filling out this Questionnaire, the respondent gives their consent to the Institute for Development and International Relations in Zagreb for collecting and processing of the personal data contained in the Questionnaire, namely for the sole purpose of implementing the 'Science and Technology Foresight' Project. The personal data contained in the questionnaire will be processed in accordance with the applicable personal data protection rules and will not be publicly disclosed. The respondent may withdraw their consent and request that the processing of their personal data be terminated, namely at any time and without having to provide an explanation. The consent can be withdrawn via email.

I have read the notice and agree to participate in this survey: YES NO

2 Please provide your name and surname: ________________________________

3 Please provide the name of the organisation you work for: _______________________

Strengthening the participation of research institutions in European Union programmes

In the 2011–2020 period, organisations from the Republic of Croatia implemented a significant number of research projects under the thematic priority area Energy and Sustainable Environment. The said projects were funded through various European Union programmes aimed at supporting research, such as Horizon 2020, COST, and others. However, the need for an increased participation of applicants from the Republic of Croatia in such programmes remains noticeable.
In your opinion, how likely is it that the following outcomes will be achieved in the next 5 or 15 years, thus leading to a higher level of participation of Croatian organisations (from the energy and sustainable environment field) in European Union research programmes?
An indicative likelihood percentage was added to each descriptive probability score.

4–9 Please indicate the likelihood of the outcomes being achieved in the next 5 or 15 years.

	Almost impossible (less than 10%)		Unlikely (10–30%)		Moderate likelihood (30–60%)		Unlikely (60–90%)		Almost certain (probability >90%)		I do not see a connection between the outcomes being achieved and a higher level of participation in EU projects	
	In the next 5 years	In the next 15 years	In the next 5 years	In the next 15 years	In the next 5 years	In the next 15 years	In the next 5 years	In the next 15 years	In the next 5 years	In the next 15 years	In the next 5 years	In the next 15 years
Reforms of the system of science and higher education can lead to a significantly more successful participation in EU programmes through increased financial and other types of support for research teams that												

have proven successful.												
Reforms of the system of science and higher education can lead to a significantly more successful participation in EU programmes by reducing the fragmentation of research capacities and fostering stronger inter-institutional cooperation, as well as through more internationalisation.												

Almost all research institutions adopt their own policies aimed at strengthening the support for research teams preparing projects for tenders under Horizon Europe and other EU programmes.												
Research institutions have significantly improved their infrastructure, which led to greater opportunities in terms of submitting tenders under Horizon Europe and other EU programmes.												
Most research institutions have developed project management competences and provide strong logistical support for researchers when it comes to submitting tenders under Horizon Europe and other EU programmes.												

Most research institutions have effective intellectual property policies that encourage researchers to apply for research projects (especially those with strong commercial potential).												

10 If you believe that the achievement of another outcome may lead to increased participation in European Union research programmes, please specify what outcome you are referring to (as well as the likelihood of the outcome being achieved):
____

11 Your comments/clarifications regarding the assumptions and the likelihood of them being achieved: ___

Strengthening cooperation between research institutions and the business community

In the 2011–2020 period, a large number of research projects were carried out under the TPA, and most of the said projects were cooperation projects with the economic sector. However, the need for stronger cooperation between research institutions and the economic sector remains noticeable.

In your opinion, how likely are the following assumptions to be achieved by 2026 and 2035, thus leading to a higher level of cooperation between the research institutions and the business community under the thematic priority area Energy and Sustainable Environment?

An indicative likelihood percentage was added to each descriptive probability score.

12–18 Please select one answer for the period until 2026 and one for the period until 2035.

	Almost impossible (less than 5%)	Unlikely (5–20%)	Possible (21%–80%)	Probable (81%–95%)	Almost certain (probability >95%)	I do not see a connection between the outcomes being achieved and a higher

											level of participation in EU projects	
	In the next 5 years	In the next 15 years	In the next 5 years	In the next 15 years	In the next 5 years	In the next 5 years	In the next 15 years	In the next 15 years	In the next 5 years	In the next 15 years	In the next 5 years	In the next 15 years
A strong increase in technologically advanced industrial production in the TPA leads to a significant increase in demand for IP activities by the economic sector.												
An increased political interest in decarbonisation and an increased energy independence lead to a significant increase in the funding of research activities, with a particular focus on their commercialisation.												
Reforms of the system of science and higher education can lead to a significant strengthening of incentives for cooperation												

between the scientific and the economic sector through new funding criteria for research institutions and promotion in science.												
An increasing number of examples of successful commercialisation of research projects leads to a significant increase in the business sector's interest in collaborating with research institutions.												
Research institutions have significantly improved their infrastructure, which led to increased cooperation with the business community.												
Most research institutions have developed project management												

competences and provide strong logistical support for researchers when it comes to cooperating with the business community.													
Most research institutions have effective IP policies in place to encourage researchers to commercialise innovative solutions.													

19 If you believe that the achievement of another outcome may lead to better cooperation between research institutions and the business community, please specify what outcome you are referring to (as well as the likelihood of the outcome being achieved):

____

20 Your comments/clarifications regarding the assumptions and the likelihood of them being achieved:

____

Importance of research topics in the field of energy and sustainable environment

Please assess the potential of the topics below for the **future research excellence** of research institutions from the Republic of Croatia under the thematic priority area 'Energy and Sustainable Environment'.

Future research excellence pertains to the performance of domestic researchers in terms of an increase in the number of published papers, their citation and impact, as well as participation in European Research Council projects and Marie Sklodowska-Curie activities in the next 5–15 years. For instance, if you expect researchers to significantly increase research excellence pertaining to a particular topic in the upcoming years, such a topic can be assessed as a high or very high potential topic.

21 Topic 1: Development of technologies, systems, equipment, and devices for generating electricity or electricity and thermal energy from renewable energy sources

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

22 Topic 2: *Development of technologies, systems, equipment, and devices for the generation of nuclear power*

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase						

research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

23 Topic 3 Development of technologies, systems, equipment, and devices for electricity transmission and distribution

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

24 Topic 4: Development of energy storage technologies, equipment and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						

The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

25 Topic 5: Development of technologies, systems, and devices for the production of hydrogen

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

26 Topic 6: Development of hydrogen storage technologies, systems and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase						

research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

27 Topic 7: Development of heating/cooling technologies, systems, equipment and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

28 Topic 8: Development of waste management systems and equipment and environmental technologies (for anaerobic biowaste digestion, composting, recovery of materials from waste, extraction and storage of landfill gas, etc.)

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence						

over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

29 Topic 9: Development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

30 Topic 10: Development of electric vehicle charging infrastructure systems and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

31 Topic 11: Development of carbon capture and storage systems

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic to increase research excellence over the next 5 years						
The potential of the topic to increase research excellence over the next 15 years						

Your comment on the assessment of the topic's relevance in terms of a possible increase in research excellence in Croatia (if any):

____

32 Some other topic (specify what topic you are referring to and assess its relevance):

____

Importance of research topics in the field of energy and sustainable environment

Please assess the relevance of the topics below for the **future innovation development** in the Republic of Croatia under the thematic priority area Energy and Sustainable Environment. Innovation development pertains to the development of new products/services, processes, or designs.

33 Topic 1: Development of technologies, systems, equipment, and devices for generating electricity or electricity and thermal energy from renewable energy sources

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.

The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

34 Topic 2: *Development of technologies, systems, equipment, and devices for the generation of nuclear power*

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

35 Topic 3 Development of technologies, systems, equipment, and devices for electricity transmission and distribution

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.

The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

36 Topic 4: Development of energy storage technologies, equipment and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

37 Topic 5: Development of technologies, systems, and devices for the production of hydrogen

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.

The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

38 Topic 6: Development of hydrogen storage technologies, systems and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

39 Topic 7: Development of heating/cooling technologies, systems, equipment and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.

The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

40 Topic 8: Development of waste management systems and equipment and environmental technologies (for anaerobic biowaste digestion, composting, recovery of materials from waste, extraction and storage of landfill gas, etc.)

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

41 Topic 9: Development of instruments and devices for measuring, regulating and controlling the energy efficiency of buildings

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

42 Topic 10: Development of electric vehicle charging infrastructure systems and devices

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):

____

43 Topic 11: Development of carbon capture and storage systems

	No potential	Low potential	Moderate potential	High potential	Very high potential	I am unable to estimate.
The potential of the topic for the future development of innovation in Croatia in the next 5 years						
The potential of the topic for the future development of innovation in Croatia in the next 15 years						

Your comment on the relevance of the topic for the future innovation development (if any):
____

44. Some other topic (specify what topic you are referring to and assess its relevance):
____

Relevance of advanced technologies for the development of the energy and sustainable environment field

Please assess the relevance of the advanced technologies below for **increasing research excellence** and **increasing cooperation between the scientific and the business sector in Croatia** under the thematic priority area Energy and Sustainable Environment.
Note: The list of selected advanced technologies is largely based on the 2021 report 'Advanced Technologies for Industry – Methodological report' of the European Commission (available at: https://ati.ec.europa.eu/reports/eu-reports/advanced-technologies-industry-methodological-report).

45 Please assess the relevance of the advanced technologies below for increasing research excellence under the Energy and Sustainable Environment TPA (e.g. through integration with research topics specific for the Energy and Sustainable Environment TPA).

*By research excellence, we mean an increase in the number of research papers published in prestigious scientific publications, as well as their citation and impact.

	Not important	Not very important	Important	Very important	Essential	I am unable to estimate.
Virtual/augmented reality technologies						
Internet of Things						
Artificial intelligence						
Blockchain technology						
Cloud computing (cloud and data services)						
Security/cybersecurity IT						
Big data						
Advanced materials (new materials that facilitate recycling and reduce the carbon footprint as well as the need for raw materials that are rare in Europe)						
Photonics						
Robotics						
Advanced technologies for the processing industry, including process technologies based on robotics and automation						
Micro and nanoelectronics						
Industrial biotechnology (use of biotechnology for the industrial processing and production of chemicals, materials, and fuels)						

Some other technology (specify what technology you are referring to and assess its relevance):

____

46 Please assess the relevance of the advanced technologies below for potentially **increasing cooperation between research institutions and the business sector** under the Energy and Sustainable Environment TPA

	Not important	Not very important	Important	Very important	Essential	I am unable to estimate.
Virtual/augmented reality technologies						
Internet of Things						
Artificial intelligence						
Blockchain technology						
Cloud computing (cloud and data services)						
Security/cybersecurity IT						

Big data						
Advanced materials						
Photonics						
Robotics						
Advanced technologies for the processing industry, including process technologies based on robotics and automation						
Micro and nanoelectronics						
Industrial biotechnology (use of biotechnology for the industrial processing and production of chemicals, materials, and fuels)						

Some other technology (specify what technology you are referring to and assess its relevance):

____

Relevance of specific programmes/tenders

Please assess the relevance of the programmes/tenders below for increasing research excellence and cooperation with the business sector.

47 How relevant would you say the programmes/tenders below are for **increasing research excellence?**
*By research excellence, we mean an increase in the number of research papers published in prestigious scientific publications, as well as their citation and impact.

	Not important	Not very important	Important	Very important	Essential	I am unable to estimate.
HORIZON Europe						
COST (European Cooperation in Science and Technology) programme						
European Institute of Innovation and Technology (EIT) tenders						
R&D tenders of competent ministries funded through ESI Funds (e.g. RDI tenders)						
Tenders of the Croatian Science Foundation						
Territorial cooperation programmes (INTERREG, etc.)						

Bilateral cooperation programmes (e.g. the Swiss-Croatian Cooperation Programme)						

Some other programme (specify which one): ____

48 How relevant would you say the programmes/tenders below are for **strengthening cooperation between research institutions and the business sector**?

	Not important	Not very important	Important	Very important	Essential	I am unable to estimate.
HORIZON Europe						
COST (European Cooperation in Science and Technology) programme						
European Institute of Innovation and Technology (EIT) tenders						
R&D tenders of competent ministries funded through ESI Funds (e.g. RDI tenders)						
Tenders of the Croatian Science Foundation						
Territorial cooperation programmes (INTERREG, etc.)						
Bilateral cooperation programmes (e.g. the Swiss-Croatian Cooperation Programme)						

Some other programme (specify which one and assess its relevance): ____

Factors for increasing research excellence and assessment of further excellence strengthening

Please assess the relevance of the elements below for increasing research excellence in the thematic priority area ‘Energy and Sustainable Environment’ and the likelihood of research excellence being increased in the upcoming period.

49 Please assess the relevance of the factors below for further **research excellence strengthening** under the thematic priority area ‘Energy and Sustainable Environment’?

*By research excellence, we mean an increase in the number of research papers published in prestigious scientific publications, as well as their citation and impact.

	Not important	Not very important	Important	Very important	Essential	I am unable to estimate.
Personal characteristics of researchers (strong work ethics, talent, etc.)						
High-quality formal education of researchers (quality of graduate/doctoral studies)						
High quality of the research group (quality leadership, good communication, good structure of collaborators, etc.)						
Improved promotion criteria in science						
Increase in the number of researchers						
Increase in the number of researchers from abroad						
Enhancing the quality of the institution where the research activities are carried out (organisation of the institution, quality of support for the researchers' work, etc.)						
Improved links with other research groups in the country and/or abroad						
Better quality of the research infrastructure						
Improved cooperation of research institutions with the economic sector						
Increased research funding						
Ensuring the continuity of funding of research activities						

Some other element (specify which one and assess its relevance):
____

50 What do you expect in terms of **research excellence** under the thematic priority area 'Energy and Sustainable Environment' **in the next 5–15 years**?
*By research excellence, we mean an increase in the number of research papers published in prestigious scientific publications, as well as their citation and impact.

	I expect research excellence to deteriorate.	I expect that the current research excellence level will be maintained.	I expect a slight increase in the level of research excellence.	I expect a significant increase in research excellence.	I expect a drastic increase in research excellence.	I am unable to estimate.
In the next 5 years						

In the next 15 years						

Your comments/explanations regarding your answer (if any):

____

Factors for strengthening cooperation with the business sector and assessment of future cooperation

Please assess the relevance of the elements below for increasing cooperation between research institutions and the business sector in the thematic priority area 'Energy and Sustainable Environment' and the likelihood of the said cooperation increasing in the upcoming period.

51 Please assess the relevance of the factors below for **increasing cooperation between research institutions and the business sector** under the thematic priority area 'Energy and Sustainable Environment'.

	Insignificant	Not very important	Important	Very important	Essential	I am unable to estimate.
Personal characteristics of researchers (strong work ethics, talent, etc.)						
High quality of the research group (quality leadership, good communication, good structure of collaborators, etc.)						
Improved promotion criteria in science						
Increase in the number of researchers						
Increase in the number of researchers from abroad						
Enhancing the quality of the institution where the research activities are carried out (organisation of the institution, quality of support for the researchers' work, etc.)						
Better quality of the research infrastructure						
Strengthened capacities of expert services supporting the carrying out of research activities (finance/accounting department, project assistants, etc.)						
Personal characteristics of managers/directors in the business sector (e.g. openness to cooperation with the scientific sector)						
Availability of programmes/tenders (such as RDI) to encourage cooperation between the scientific and the business sector financially						
Tax policy that promotes cooperation between the scientific and the business sector						

Some other factor (specify which one and assess its relevance):

____

52 What do you expect in terms of **future cooperation between the scientific and the business sector** under the thematic priority area 'Energy and Sustainable Environment' (**in the next 5–15 years**)?

	I expect research excellence to deteriorate.	I expect that the current research excellence level will be maintained.	I expect a slight increase in the level of research excellence.	I expect a significant increase in research excellence.	I expect a drastic increase in research excellence.	I am unable to estimate.
In the next 5 years						
In the next 15 years						

Your comments/explanations regarding your answer (if any):

____

53 Your final comment on the research topic (if any): ____

Appendix 4: List of associates involved in the research

I. Members of the Mapping and Foresight Working Group (a panel established by the Ministry of Science and Education for the implementation of the 'Science and Technology Foresight' Project):
   1. Ankica Kovač, PhD, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
   2. Marinko Stojkov, PhD, University of Slavonski Brod, Faculty of Mechanical Engineering
   3. Branimir Pavković, PhD, University of Rijeka, Faculty of Engineering
   4. Tomislav Capuder, PhD, University of Zagreb, Faculty of Electrical Engineering and Computing
   5. Goran Krajačić, PhD, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
   6. Tea Žakula, PhD, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
   7. Ivan Tolj, PhD, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
   8. Robert Spajić, PhD, Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences
   9. Vjekoslav Jukić, PhD, Ministry of Economy and Sustainable Development
   10. Marija Šćulac Domac, MSc, Croatian Chamber of Economy
   11. Hrvoje Lovrić, MSc, HELB d.o.o.
   12. Goran Pavlov, IRI Centar
   13. Diana Krčmar, Ministry of Economy and Sustainable Development
   14. Anton Tomičić, Ministry of Science and Education

II. List of associates involved in the DELFI analysis
   1. Ankica Kovač, PhD, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
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   4. Tomislav Capuder, PhD, University of Zagreb, Faculty of Electrical Engineering and Computing
   5. Goran Krajačić, PhD, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
   6. Tea Žakula, PhD, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
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   8. Robert Spajić, PhD, Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences
   9. Hrvoje Lovrić, MSc, HELB d.o.o.
   10. Goran Pavlov, IRI Centar, Split
   11. Nikola Biliškov, PhD, Ruđer Bošković Institute
   12. Tonći Tadić, PhD, Ruđer Bošković Institute
   13. Stjepko Krehula, PhD, Ruđer Bošković Institute
   14. Krunoslav Juraić, PhD, Ruđer Bošković Institute
   15. Daniela Marić Pfannkuchen, PhD, Ruđer Bošković Institute

16. Ana Sunčana Smith, PhD, Ruđer Bošković Institute
17. Milko Jakšić, PhD, Ruđer Bošković Institute
18. Tarzan Legović, PhD, Libertas International University, Zagreb
19. Sibila Borojević-Šoštarić, PhD, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering
20. Marko Vinceković, PhD, University of Zagreb, Faculty of Agriculture
21. Daria Karisalihović Sedlar, PhD, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering
22. Ivan Marasović, PhD, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
23. Daniel Rolph Schneider, PhD, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
24. Kristian Lenić, PhD, University of Rijeka, Faculty of Engineering
25. Biljana Kulišć, PhD, Energy Institute Hrvoje Požar
26. Nina Štirmer, PhD, University of Zagreb, Faculty of Civil Engineering
27. Božo Terzić, PhD, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
28. Damir Jakus, PhD, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
29. Anet Režek Jambrak, PhD, University of Zagreb, Faculty of Food Technology and Biotechnology
30. Ernest Vlačić, PhD, Novamina d.o.o.
31. Mladen Perkov, Končar-Digital d.o.o.
32. Robert Pašičko, PhD, UNDP
33. Jakov Baleta, PhD, University of Zagreb, Faculty of Metallurgy