Smart strategies for the transition in coal intensive regions

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Research & Innovation strategy in the field of energy for the Region of Western Macedonia

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Authors: Charalampos Malamatenios, Centre for Renewable Energy Sources and Saving, Greece
Georgia Vezyrgianni, Centre for Renewable Energy Sources and Saving, Greece
Lefteris Giakoumelos, Centre for Renewable Energy Sources and Saving, Greece

Editors: Rita Mergner, WIP Renewable Energy, Germany
Rainer Janssen, WIP Renewable Energy, Germany

Contact: Centre for Renewable Energy Sources and Saving
Georgia Vezyrgianni
Email: gvezir@cres.gr
Tel: +30 210 6603 267
19th km Marathonos Avenue
19009 Pikermi-Attiki, Greece
www.cres.gr

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Executive summary

The elaboration of the R&I strategy in the field of energy for the Region of Western Macedonia has been initially based on the previous work implemented in the frame of Work Package 6 of TRACER project. The first step has been the elaboration of a report gathering a set of projections for the transition to 2030 / 2050 in all the target regions of the project (the Western Macedonia Region included). These projections mainly focused on the required energy mix for the meeting of the needs of the region until 2030 (and 2050 in the longer term).

As a second step, the principal two inputs that lead to the elaboration of the Research & Innovation (R&I) Strategy for the Greek target territory were the national policy directions as well as the main remarks and conclusions / outputs as derived by the consultation with the involved regional stakeholders, whose contribution played a crucial role in the development of an effective strategy. Furthermore, the Strategy is aligned to the corresponding national priorities on Research, Innovation and Competitiveness in the field of Energy, as derived during the preparation of the National Energy and Climate Plan (NECP).

The present R&I Strategy aims at ensuring on the one hand the complementarity and the synergy between the policies and programs related to R&I at the regional, national and EU levels, and on the other hand the alignment with the expected developments of the energy sector and the long-term goal for sustainability, climate change mitigation and environmental protection. The produced strategy in R&I shall contribute to the transition in a just and effective way, strengthening the competitiveness, development and commercial activation, in parallel safeguarding the environmental protection and enhancing the regional support for R&I activities in the region.

In the first Chapter the scope of the Strategy document together with the methodology used to conclude in this document is provided. In addition, with the aim of providing clarity on the interpretation and understanding of this Strategy document and its objectives, definitions of some key terms are further provided there. A brief profile of the Region of Western Macedonia, emphasizing on the regional economic and innovation performance indicators together with the projected status in 2030 and 2050 of the energy generation technologies in the target region are presented in Chapter 2. These are supplemented by the available information about the region's landscape in the field of R&I with emphasis on energy technologies, including the key actors (research institutes, universities, other relevant structures) active in the field, as well as with a SWOT analysis of the regional innovation potential and specialisation.

The objectives and envisaged outcomes of the Strategy (informed by and closely aligned to the outlook of the region's energy and environmental sectors) and the key guiding principles on which the development of this Strategy was based are developed in detail in Chapter 3. Then, in Chapter 4, the R&I policy design and implementation framework and the involved structures are described. In addition, the financial resources to support additional domestic R&I activities in line with the objectives of this Strategy are summarized. Then, the set of priority areas for R&I in the field of energy, indicating the main themes which will be considered as priority for the Region during the implementation of this Strategy, are listed. Last, the data collection process for the purpose of progress monitoring, upon which subsequent adaptations can be proposed bringing policy intelligence into the evaluation process, is described.

1 Introduction

The key role of R&I in contributing to and accelerating the attainment of regional ambitions is acknowledged at all levels (EU, national and regional). Bolstering the support for and guiding the direction of R&I so that it is tailored to local specificities and national priorities is thus considered an integral component for development and progress within the energy, and in a second step, the environmental sectors. In addition, driving targeted R&I for both excellence and impact will feed into boosting industrial competitiveness and economic development through instruments of knowledge.

This Strategy, i.e. the "*Research & Innovation strategy in the field of energy for the Region of Western Macedonia*", aims to ensure complementarity and synergy between the regional, national and EU-level R&I related policies and programmes, as well as alignment with the expected developments in the energy sector and the long-term drive for sustainability, climate change resilience and environmental protection. Working in line with national targets and policy documents, this Regional Strategy aims to encourage investment across multiple sectors throughout value chains and a wide array of scientific disciplines, as well as different actors and stakeholders.

Thus, this R&I Strategy explicitly serves three policy priorities:

1. contributing to Western Macedonia's transition to sustainability and decarbonisation in an effective, just and timely manner;
2. strengthening competitiveness, growth and commercial attractiveness whilst ensuring a high level of environmental protection and climate change resilience; and
3. increasing the level of domestic support for R&I in the Region of Western Macedonia.

The Region of Western Macedonia's Strategy for Research and Innovation (R&I) in the field of Energy is a sector-specific strategy developed to boost and support domestic R&I specifically in the area of energy within the wider R&I landscape and the energy projections for the region for 2030 and 2050. The document describes aspects of the current situation of R&I in Western Macedonia and the context for R&I in the upcoming decade, within which the Strategy will basically operate. The objectives and outcomes of the Strategy are outlined, along with the identified priority areas for R&I in energy – in the national and regional levels - during this period and the associated framework of support, including governance structures and research priorities.

1.1 Development of the Strategy: Overview of the process

Building on the results of the previous phases of the TRACFER project and, especially, on the entrepreneurial discovery process (EDP) foreseen, the sector-specific Strategy of the Region of Western Macedonia for R&I in the fields of energy (and of environmental management in the broadest sense) is proposed herein. This Strategy aims at exploiting innovation potential within the field of energy and, in broader perspective, of environmental management, yielding cross-cutting benefits through targeted R&I investment.

This would contribute towards the realisation of sustainable progress in the regional energy and environmental sectors, and may extend to wider economic and societal goals of job creation, increased competitiveness and higher quality of life. Also, it must focus at the issue of Smart Specialization, since the Smart Specialization strategies consist of a fundamental tool and a necessary precondition to benefit from the European Structural and Investment Funds.

As the Strategy needs to contribute to a better management and organisation of the changes that will arise in the structure of the new low-carbon economy status of the Region, it is necessary to know what will be the energy mix in the region the coming years. Thus, as a first

step, projections for the transition to 2030/2050[1] were made, which mainly focused on the energy mix required to cover the needs of the Region – and not only, as the Region intends to retain the title of "Greece's Energy Centre" - until 2030 at first, and for 2050 in the longer term.

Two fundamental inputs to the development of the Strategy were the national policy direction and stakeholder consultations. Indeed, national policy priorities for the energy and environment sectors constituted a central component in determining the direction of this Strategy. Thus, this Strategy is aligned to and seeks to reflect the R&I priorities implicit in the outlook and objectives established in the Hellenic Republic's National Energy and Climate Plan (2021-2030)[2].

It must be further mentioned that, this is also linked to the implementation of the Regulation of the Governance of the Energy Union (Regulation (EU) 2018/1999), which identifies R&I as one of the five dimensions of the Energy Union. This Regulation requires that the National Energy and Climate Plan (NECP) includes *national objectives and funding targets for public and, where available, private research and innovation relating to the Energy Union, including, where appropriate, a timeframe for when the objectives should be met*. This was the case when developing the corresponding section of the Greek NECP, where a complete set of specific R&I activities focused on the energy issues of interest that should be undertaken in Greece was developed and reported by the corresponding Working Group.

The Research & Innovation Strategy for the Region of Western Macedonia is harmonised with the respective guidelines of the Strategic Energy Technology (SET) Plan[3], which is the R&I pillar of the EU's energy and climate policy, as it was revised in 2015 to effectively line up with the Energy Union's R&I priorities, and more specifically the implementation plans of the fourteen (14) technology areas that have been selected as those that have the highest innovation potential for delivering quickly cost reductions and improvement of performance, and which can this way contribute to the decarbonisation of the European energy system. The emphasis is given on the development of public R&I capacities, always in consistency with the priorities of SET Plan.

Consultation and engagement of stakeholders and the regional authorities was considered to be crucial for the development of an effective Strategy that truly captures the interests of researchers and businesses and the concerns of citizens, identifies and builds upon domestic strengths, and addresses existing gaps. This is also the general concept of TRACER, where it is clearly mentioned that the strategy should build on the visions and priorities identified as part of the entrepreneurial discovery process (EDP) also foreseen in TRACER's procedures. For this purpose, the "governance structure" set up in the region was activated, in order also to ensure the 'ownership' of the strategy (and the corresponding roadmap) by stakeholders within the region.

It must also be noticed that the development of this Strategy was concurrent with that of the post-2020 Smart Specialisation Strategy, initiated by the General Secretariat for Research and Innovation (GSRI), the official government body responsible for R&I in Greece. It is important to be mentioned here that, the Smart Specialisation Strategy is drawn up and implemented both at the national and regional levels, through interaction between the two levels.

At national level, the methodology adopted consists in:

- Identifying vigorous thematic areas or sectors expected to contribute in the country's growth perspective. The sectors identified so far include (among others) the "Environment and

[1] TRACER Project, D6.1 "Projections for the transition to 2030 / 2050 in the target regions" (May 2021), available at: https://tracer-h2020.eu/tracer-d61_energy-projections/
[2] https://energy.ec.europa.eu/system/files/2020-03/el_final_necp_main_en_0.pdf
[3] https://energy.ec.europa.eu/topics/research-technology-and-innovation/strategic-energy-technology-plan_en

Sustainable Development", and "Energy", which are the closest ones to the TRACER's scopes and objectives.

- Specifying the above areas/sectors and identifying (in cooperation with the business sector and the research community) activities which, capitalizing on Research, Technology and Innovation, could bring about structural change (e.g. modernisation, differentiation, transition etc.) for the enterprises in each sector, and improve their competitiveness.
- Highlighting the critical research areas/technologies (and the appropriate policy tools) that should be included in the national strategy for RTDI, taking into account the RIS3 strategies defined by different Regions.

At regional level, Greek regions and local communities are expected to identify, structure and make full use of their competitive advantages, to support innovation and to focus on investments, in order to achieve the intended transformation of local economies by involving relevant stakeholders in all stages.

This is the so-called "entrepreneurial discovery process", a bottom-up approach, focusing on enterprises identifying new, innovative activities and the relevant technology needs. Results of the consultation exercises in each region and the respective regional RIS3 strategies drawn up so far are «combined» into the **national RIS3 strategy**. What has actually happened in Greece up to now regarding the RIS3 strategy, is the Open Consultation on the Research, Technological Development and Innovation Strategy for the Programming Period 2021-2027, which took place (in a national level) during July 2021.

Especially as concerns the Region of Western Macedonia, it must be mentioned that RIS3 is monitored and the relevant suggestions are made by the RIS Structure for Western Macedonia[4] through a relevant project of the Regional Development Fund of Western Macedonia from the ROP of Western Macedonia. The Western Macedonia's RIS Support Structure prepared in September 2021 the 1st plan for the "Regional Dimension of the National RIS3", which includes the "Sustainable Energy" and "Environment, Sustainable Development and Circular Economy" sectors. The plan emerged from EDP procedures and meetings with both Research Institutions and the University, and its consultation process is ongoing.

Although the timeframes diverge slightly, ensuring consistency and synergy between these "strategies", whilst avoiding duplication of efforts, is considered crucial for the cohesiveness of the domestic/regional R&I support landscape, given that the implementation periods overlap significantly. Therefore, throughout the development of these "Strategies", CRES, the RIS Structure for Western Macedonia and GSRI were in close cooperation to ensure coordination and, to the extent possible, complementarity between the Strategies which will be effective practically over the same time period (although the TRACER R&I strategy aims to be valid at least until 2030).

1.2 Definitions

With the aim of providing clarity on the interpretation and understanding of this Strategy and its objectives, the definitions of key terms are provided herein. So, starting with the term R&I, this, when used in the context of this document, is defined as:

- **Research (R)**: research and experimental development as defined by the Frascati Manual (2015), that is, the creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.

[4] See: https://pta.pdm.gr/domi-ris-dyt-makedonias/

- **Innovation (I)**: as defined by the Oslo Manual (2018), that is, a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).

As regards the rest of key terms related to R&I, these are based upon international guidance documents for R&I, particularly the Oslo Manual, jointly published by the OECD and Eurostat in 2018, and are as follows:

- **Applied research** is the work of original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective.
- **Experimental development** is the systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes.
- **Entrepreneurial discovery process (EDP)** is a participatory, active process of identifying and prioritising key activities that link research and innovation to economic growth and social well-being, taking into account the particularities and potential of the country and each one of its regions. It is achieved through structured consultation with all actors involved in the innovation ecosystem at national and regional level, with enterprises and the productive classes playing a leading role in highlighting technological priorities.
- **Marketing innovation** means the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing.
- **Organisational innovation** means the implementation of a new organisational method in the firm's business practices, workplace organisation or external relations.
- **Oriented basic research** stands for the work carried out with the expectation that it will produce a broad base of knowledge likely to form the basis of the solution to recognised or expected current or future problems or possibilities.
- **Process innovation** is the implementation of a new or significantly improved production or delivery method; this includes significant changes in techniques, equipment and/or software.
- **Product innovation** stands for the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses; yhis includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.
- **Research and experimental development** is the creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.
- **Smart specialisation** is about identifying the unique characteristics and assets of each country and region, highlighting each region's competitive advantages, and rallying regional stakeholders and resources around an excellence-driven and outward-looking vision of their future.

2 Setting the context

2.1 Regional profile and specialisation

West Macedonia is a mountainous, landlocked, region, situated in north-west Greece. The region has the lowest population density with 2.5% of the population in 2018 (269,222

inhabitants)[5] on 7.2% of the Greek land area. Although generating only 2.2% of the national GDP, with a GDP/capita of 15,319 € in 2018 representing 58% of the EU average, the region ranks 5th among the Greek regions in terms of wealth creation per inhabitant[6]. Even if education levels have improved since 2000, from 12.3% of the population aged 25-64 with tertiary education attainment to 24.5% in 2019, they remain well below the national (31.0%) and EU (31.4%) averages. Moreover, only 3.8% of adults aged 25-64 participated in lifelong learning in 2020 (Greece 4.1%, 9.2% EU27).

Infrastructure investments have greatly improved the road network (Egnatia road, etc.) and improved accessibility, although it remains below the national average and among the last placed regions. In terms of road density, Western Macedonia holds the 10th position in the country; however, the freight transport, due to the node position of the region (specifically of Kozani region), is extremely significant reaching the highest value in the country. The rail network of the region is considered as insufficient. In terms of air transport, Western Macedonia holds the 5th position in the number of commercial airports (has one airport with comprehensive network in Europe) but the penultimate position in the number of passengers per inhabitant. Moreover, even if the telecommunication network has been improved over the last decade, the region still lags behind in the digital economy.

The region has been hard hit by the economic crisis with unemployment rising from 12.1% in 2007 to 21.6% in 2020. The crisis accentuated existing problems since the region already had the highest unemployment rate amongst Greek regions due to de-industrialisation and the migration of labour-intensive industries to neighbouring low labour cost countries. It is estimated that over 20% of regional firms have ceased operations since 2008, whilst due to pay cuts and increased taxation the turnover of regional firms, particularly in the trade sector, has dropped by 40%[7].

Western Macedonia is endowed with rich natural resources such as energy and metallic minerals that have shaped its productive identity as one of the most important electric energy production centres in Greece (70% of country's total power was used to be produced in the Region). The tertiary sector accounted for 48.6% of the regional added value in 2019 and this is the largest sector in the region but with the smallest share and productivity level in relation to the other Greek regions.

The secondary sector accounted for 42.4% of the regional added value in 2019. The sector plays a major role in the regional economy, holding the second position in the relative productivity among the Greek regions. The industrial activity of Western Macedonia is based on its coal power plants, which for decades have been supplying electricity to the entire country. However, the secondary sector of the region is facing the challenge of the post-lignite era and has to be transformed and developing new activities that will enrich its production base. In the services sector, retail and wholesale trade, tourism and public administration services are the most important in terms of value added, while the health and financial sectors are gradually growing in importance

The productive structure of the region includes an important primary sector displaying a high GDP share in its economy (about 2.2 times as much as the national average and 5.8 times as much as the European average). More precisely, the share of the primary sector in Western Macedonia has raised to 9.0% of the regional added value in 2019 (compared to 7.4% in 2000). The relative productivity of the primary sector in Western Macedonia is equally significant holding the second position among the regions and with a much better performance than the EU (1.7 times than the EU average). As mentioned already, the region is at large mountainous, but its agricultural production is based on a number of significant agricultural products, such

[5] Source: ELSTAT (2019) - OECD (2020). Regions and Cities database. Accessed on 5 April 2020.
[6] All data provided is sourced from Eurostat and ELSTAT unless stated differently.
[7] Regional Innovation Monitor (2012), http://www.rim-europa.eu/index.cfm?q=p.baseline&r=GR13

as the Kozani saffron, aromatic and energy plants, peaches, wines, apples, peppers, vegetables and legumes and some livestock products like milk and cheese.

The Location Quotient (LQ) index (ISIC Rev4, branches grouped in 10 sectors), which measures the specialization in production, shows that Western Macedonia has developed a (strong) specialization (with LQ>1.25) only in the sector of mining, energy, electricity and water supply. Moreover, Western Macedonia shows a less diversified production base, as it has developed some level of specialization in 8 (out of 38) NACE2 branches. Strong or high specialization is exhibited in mining and quarrying, energy supply and textile, wearing apparel and leather products, while weak to modest specialization in agriculture, repair and installation of machines and equipment, construction, education, and public administration and defence. The region displays overall specialization in 4 tradable branches[8].

Moreover, Western Macedonia is one of the least innovative of Greek regions, investing only €16,34m on R&D[9] (0.4% of the national total), or 0.3% of regional GDP (Greek average is 1.27%, EU28 2.15%) in 2019 (*28% of the Greek average and/or 8.8% of the EU28 average of R&D investments in € per inhabitant*). Most strikingly, regional businesses invested only €3.5m in R&D, i.e. 21.4% of the total Gross domestic expenditure on R&D (GERD), versus 46% nationally and 67% in the EU28.

Due to the crisis, private investment in R&D will most probably have fallen further. As a result, the majority of the regional R&D expenditure occurs in the higher education sector (€8.06m, i.e. 49.3% of GERD compared to an average of 30.6% in Greece and 21.6% in EU28) and in the government sector, which accounts for 28.3% (€4.6m) of the regional GERD (22.7% in Greece, 10.8% in EU28). It has to be noted that in the Regional R&D expenditures, activities related to lignite industry may not be fully illustrated due to the companies (e.g. PPC) logistic structure.

On the contrary, in terms of patent applications per million inhabitants, Western Macedonia holds the second position in the country above the national average in 2015 (153 against the 100-index corresponding to national average)[10]. Human Resources for Science and Technology (HRST) have increased steadily since 2000, in line with the reinforcement of the regional research capacities. In 2020, HRST accounted for 33.0% of the regional workforce (active population)[11] which represented 1.9% of the HRST in Greece.

To sum up, the regional economy faces significant challenges related to the need for restructuring of the economy towards higher value-added activities, the absence of foreign direct investment, the declining manufacturing sector and the pollution and degradation of the natural environment resulting from decades of mining and energy production activities. Other problems that need to be mentioned are: (a) the adverse weather conditions, (b) the distance from large urban centers which burdens the cost of selling consumer goods produced in Western Macedonia, and (c) the fact that for many decades the productive potential of the region had turned to the exploitation of lignite (complacency) and had withdrawn its interest from any other activity (monoculture).

The recent economic crisis along with discontinuities in regional research and innovation policies have magnified the structural deficiencies of the local economy, characterised by small companies, traditional industries, high unemployment, and low competitiveness. Scientific specialisation is limited and focused essentially on energy technologies. From the economic side, the region has a very strong sectoral specialisation in energy and has implemented a

[8] "Regional Policy for Greece Post-2020", REGIONAL PROFILES, OECD Territorial Reviews, 2020
[9] Source EUROSTAT (with own calculations): https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do
[10] Sources: National Documentation Centre (2019), Ministry of Development and Investments (March 2020)
[11] This indicator gives the percentage of the total labour force in the age group 15-74, that is classified as HRST, i.e. having either successfully completed an education at the third level or is employed in an occupation where such an education is normally required.

number of targeted projects. Despite this focus, the region has not managed to create a competitive advantage and is trapped in a vicious circle where efforts towards differentiation and development in the energy sector have reinforced the dominance of the public sector.

2.2 Western Macedonia's energy outlook

As it was described in detail in the corresponding deliverable of the TRACER project (D6.1 "*Projections for the transition to 2030 / 2050 in the target regions*" – May 2021), according to the decisions of the Greek government published in November 2019 with the new National Energy and Climate Plan (NECP - ESEK), at the end of 2023 all (except one) of PPC lignite plants will be withdrawn and lignite mines will be closed in the regions of Western Macedonia and Peloponnese. The units that will be closed (of a total of 3400 MW net capacity / 3775 MW installed capacity in Western Macedonia) include the relatively recent units Meliti 1 (330 MW), which was put into operation in 2002, and Agios Dimitrios 5 (375 MW), which was put into operation in 1997, the interruption of which is considered by techno-economic criteria early. The only exception is the new Ptolemaida 5 unit, with a capacity of 660 MW, which is expected to be put into commercial operation in 2022. This unit is expected to operate until 2028 with lignite and / or a mixture of fuels (according to future decisions, it may continuous its operation under new configuration and fuel).

The withdrawal of the lignite power plants will bring changes in the district heating of the neighbouring municipalities, as it is provided at a relatively low cost by the operation of the TPP units of PPC SA. In Western Macedonia, the district heating provided today by PPC in Amyntaio, Ptolemaida and Kozani will be able to continue to be provided under a common district heating scheme by the new unit Ptolemaida 5, as well as by a number of electric and natural gas boilers and a CHP unit that will be (or have already been) installed in the "closed" power plant of Kardia. At the same time, the Municipality of Amyntaio has constructed a new district heating unit with lignite and biomass fuel.

More generally, it is noted that the energy utilization of biomass (as well as the residue from the treatment of solid waste) will offer a reliable solution to meet the heating needs of the areas of Western Macedonia that were dependent on power plants. Equally important will be the introduction of the use of natural gas in district heating units. The construction of TAP pipeline has been completed in the area while a new gas pipeline is expected to be build introducing natural gas to Western Macedonia, which had no access to this fuel option until today.

Apart from biomass, other Renewable Energy Sources (RES) that are expected to expand a lot in the area in the coming years are wind energy, with wind energy projects being in various stages of the licensing procedure in Western Macedonia (including those with Operation License) rising up to 2132 MW of capacity, and photovoltaics, for which it is expected:

1. the rapid maturation and installation of photovoltaic parks of approximately1.9 GW installed capacity from the partnership between PPC and RWE;
2. the immediate construction of a 204 MW photovoltaic park in Kozani from the partnership between ELPE and the German company Juwi.

It must be further mentioned that the Greek government (i.e. the Ministry of Environment and Energy) is considering a solar-based hydrogen production initiative through major-scale photovoltaic facilities planned at the state-controlled power utility's (PPC) lignite fields in Western Macedonia (Ptolemaida), on the way out as a result of Greece's decarbonization plan. The construction of PV Parks provides the possibility of the research and development of hydrogen units that will be connected to renewable energy sources and for which investment interest has already been expressed (see the "White Dragon" project).

In addition, and in connection with the increase of the generated power, it is important to notice that the latest list of projects of common interest (PCI) of ENTSO-E includes the installation of

lithium-ion batteries in the region of Western Macedonia, in Ptolemaida (a project of Eunice, with a capacity of 250 MW). PPC Renewables is also advancing in this field, having received 8 Electricity Production Licenses using storage batteries in the regions of Western Macedonia (6 projects) and Arcadia (2 projects), with a total capacity of 950 MW (able to store 3 GWh of energy).

2.3 Western Macedonia's current energy related R&I landscape

As mentioned previously, the Human Resources for Science and Technology in Western Macedonia have increased steadily since 2000, in line with the reinforcement of the regional research capacities. In 2005, there were 154 full-time equivalent (FTE) R&D personnel, or 0.13% of the regional active population (0.69% Greece, 0.95% EU27). Not surprisingly, most worked in higher education (109 FTE) and in the government sector (27 FTE) and only two were in a business. The number of researchers was even lower (0.08% of the active population, 0.4% Greece, 0.59% EU27) and 81 of the 98 regional researchers worked in higher education and only one in a company.

The University of Western Macedonia (UoWM), created in 2003, and the Technological Education Institute of Western Macedonia (TEIDM) were, until recently, the main regional research performers, as in 2019 the Technological Institute of Western Macedonia was merged with the UoWM. Looking at the scientific production, between 2014 and 2018 the UoWM produced 568 publications (0.9% of total Greek academic publications), with 39% of them involving national co-authorship and 61% international collaboration[12]. Publications of the UoWM were cited 5,468 times over the period, giving the UoWM an overall citation impact of 0.9%. Due to the absorption of the TEIDM by the UoWM, the publications of the University include those of the TEIDM. The main fields of scientific activity of the UoWM are natural sciences (320 publications from 2014-18, 3,798 citations, citation score 1.97) and engineering and technology (315 publications, 3,705 citations, citation score 1.95).

Another important player in the field of R&D in Northern Greece is the Centre for Research and Technology-Hellas (CERTH), founded in 2000, with main premises in Thessaloniki and a branch office in Western Macedonia (Ptolemaida), which initially was established as individual institute in 1987 dealing with the lignite industry and gradually expanded its expertise to sustainable energy technologies. As primal fields of activity CERTH has climate change, artificial intelligence, advanced robotics, Internet of Things, holistic approaches to healthcare and nutrition, autonomous vehicles, smart cities of the future and circular economy, and is organised around five (5) institutes, namely the Chemical Process & Energy Resources Institute - CPERI, Information Technologies Institute - ITI, Hellenic Institute of Transport - HIT, Institute of Applied Biosciences - INAB, and the Bio-economy and Agro-technology Institute.

Moreover, the Cluster of Bioeconomy and Environment of Western Macedonia (CLuBE) should be mentioned as a key regional stakeholder in the field of R&I. CLuBE is non-profit legal entity established among local actors and stakeholders of the Region of Western Macedonia as a platform for cooperation of the three pillars of the regional economy: the public sector, research & entrepreneurship. The Cluster seeks to develop synergies between local and regional players and businesses in bioenergy and the environment, aiming at introducing and developing innovation in the sector and increasing its added value. CluBE is developing R&D and business activities in the fields of bioenergy and environment, in order to reinforce smart, bio, green and circular economy in the region and the neighbouring area.

Last, but not least, the Regional Development Company of Western Macedonia SA (ANKO) should be mentioned. Although ANKO is not a 'pure' RTD organization, it has been created by the local authorities, the State, the agricultural cooperatives and Chambers of Commerce, in

[12] Greek scientific publications in international journals https://metrics.ekt.gr/en/scientific-publications

order to act as a pioneering scientific organisation for the regional development approach. The company's aim is the promotion, support and contribution to integrated regional development, in order to make West Macedonia a place for healthy and safe life and a model for sustainable growth, through study, promotion, administration, monitoring and evaluation of programs and projects on development, in collaboration and complement action with local authorities, the state and the private sector, and support of authorities and inhabitants, consistent informing, awareness, motivation, activation, contribution in the configuration of development strategies and the coordination of actions for the implementation of innovative development projects.

In terms of scientific specialisation, according to the RIM report (2012), the bulk of RTDI efforts of the research organisations in the region are concentrated mainly in energy related issues such as energy production, clean energy technologies, hydrogen and alternative energy sources, energy saving and related environmentally friendly technologies. This clearly is in line with a main player in the regional economy, the Public Power Company (PPC SA), and with the push to develop renewable energy but nevertheless suggest other key clusters may not be so well served. The following figure shows a SWOT analysis of the regional innovation potential and specialisation (according to the "RIS3 Regional Assessment: Dytiki Makedonia"[13]), as it was enriched by the opinions of the local experts participating in the consultation procedure.

Figure 1: SWOT of regional innovation potential and specialisation

Strengths	Weaknesses
• Natural endowments • Level of education of the population rapidly growing • Presence of regional academic research capacities • Key player in the energy production sector	• Quasi inexistent R&D investments by businesses • Very low level of overall R&D investment • Traditional structure of the economy • Low level of ICT diffusion and use • Low level of life-long learning practices • No data on patenting activities • Low level of science-business collaboration • Lack of innovation culture within firms • Inability to attract research staff due to geographical and other constraints
Opportunities	**Threats**
• Better incentives for business investments in R&D activities • Increased coordination of national and regional policies to support ICT diffusion • Smart specialisation in the energy area • Improved support to upgrading of SMEs technological capacity • Existence of primary sector activities that directly require marketing innovation and organizational innovation • Conditions for the development of agricultural - energy sector coexistence	• Economic specialisation in low-tech sectors (agriculture, tourism) • Pollution and environmental damages associated to mining activities and energy production • Brain drain • Weakening of the University (regional) in the context of the restructuring of the country's academic map

[13] "RIS3 Regional Assessment: Dytiki Makedonia" - A report to the European Commission, Directorate General for Regional Policy, Unit I3 - Greece & Cyprus, December 2012.

• Attraction of foreign direct investments	

3 R&I in Energy (and Environment): Vision for 2030 & 2050

In the 2021-2030 period, but also in the longer term (i.e. until 2050), the region needs to adopt a holistic strategy towards a new long-term sustainable development vision, given the certain environmental degradation. The development vision for the Western Macedonia Region is "*the contribution to the creation of a sustainable and competitive regional economy with viable jobs, quality environment and social cohesion*". All the initiatives undertaken up to now were of a circumstantial character and lacked a long-term perspective. The vision for the new strategy should be oriented towards the post-mining era and include certain mechanisms that will contribute to the impairment of the region's over-dependence on the operations of the Public Power Corporation S.A.

3.1 Objectives and outcomes

The vision of Western Macedonia Region for an enhanced development and competitiveness of business enterprises and a progress towards sustainability in both the environmental and energy sectors is closely linked to the primary objectives of this Strategy. These are to:

1. Strengthen and support R&I that addresses the national and regional policy priorities and challenges, and/or bolsters regional competitiveness and growth in a diversity of sectors.

2. Increase the coordination and cooperation among the wide array of stakeholders in the fields of energy and the environment, thereby ensuring that the outcomes of the R&I activities are translated into tangible positive impacts.

The objectives and envisaged outcomes of the Strategy are informed by and closely aligned to the outlook of the energy and environment sectors. It is thus expected that R&I that will be supported through the implementation of this Strategy will contribute in a tangible manner to the long-term vision of sustainability for the Region. This may be achieved with implementing research that informs policy tools, provides solutions to the regional challenges being faced in the energy and environmental sectors and contributes to economic competitiveness.

It must be mentioned that, this "R&I Strategy" maintains a clear distinction between the two corresponding objectives of: (a) solving societal challenges, and (b) enhancing industrial competitiveness. This is because of the fact that the procedure followed by the R&I addressing one of the above mentioned two aspects tends to be distinct from (and not necessarily complementary to) the R&I respectively carried out for the other. The industry operates on the rational of competitiveness and profit, while the societal challenges reflect the interests of the citizens and the civil society, thus implying a divergence in the research focus and the desired outputs. This diversification may also be translated into differences in the primary actors who would be involved in such R&I activities and thus in the type of support which would be required. Nevertheless, there is a clear and unbiased alignment of the two aspects of the first objective in their common direction towards the overall objective of long-term decarbonisation and resource efficiency, yet from different perspectives and setting different priorities.

The second objective stems from discussions with stakeholders while developing this Strategy, during which the need and the desire for more frequent interaction between all parties was highlighted and emphasised. At first, creating a more dynamic relationship between the local government and the academic community would enable research outcomes to better feed into the national and regional policies, and would also place researchers in a stronger position to tailor their work as well as to anticipate R&I needs that will arise from upcoming changes in the EU and national / regional policy direction.

Secondly, a more frequent and better structured interaction between the private sector and the academic community shall facilitate a deeper understanding of the industry needs and the R&I to be undertaken accordingly. This may also lead to the development of more "active" partnerships between the industry and the academic community, in the frame of which opportunities for mutual gain can be maximised and the outcomes from such activities get incorporated into products, processes and marketing applications for the wider benefit of the region (and the country, more general).

Furthermore, the establishment of formal communication links between a large pool of stakeholders from a variety of fields implies the potential for a particular issue to be tackled through the adoption of a novel perspective or approach. This contrasts with current practices whereby partnerships are established according to personal relationships, therefore the type of solution to the issue in question is already dictated by the associated researchers' area of specialisation. Thirdly, the enhanced cooperation between these stakeholders would serve two important horizontal purposes, namely the one of knowledge-sharing in all spheres, as well as the one of coordination to reduce fragmentation of the domestic R&I landscape.

The implementation of this Strategy, through its forward-looking approach and the provision of additional financial resources for R&I activities, is expected to contribute to progress in various sectors and have a positive impact on both stakeholders and the wider society. An overview of the expected outcomes is provided in the following paragraphs.

Benefits for the academic community: For those primarily involved in research, whether in the HES or private research institutes, this Strategy seeks to provide clarity and certainty on the direction of R&I in the field of energy (and the environment, in a more general perspective) at the regional level over the coming decade (and in the longer term, until 2050). Through the support framework established by this Strategy and the resources that will be made available, the output of high-quality knowledge from this sector is expected to be amplified and the mass of research staff supported. The additional support to be received by researchers in Western Macedonia is also expected to provide them with improved standing within international research communities, increasing their chances of successful participation in international R&I projects, as experienced staff is increasingly retained and the number of publications/projects by such teams also increases.

Benefits for the business sector: Providing clarity to business enterprises about the future R&I landscape concerning the fields of energy and the environment, in addition to the provision of resources, will aid in increasing the activities of those already undertaking R&I initiatives and mobilising interested companies that are unfamiliar with the available support. This is expected to be further enhanced through an increase in public-private partnerships. In this manner, research will be targeted towards those areas where it is mostly required, and thus, where the impacts of R&I outcomes will be mostly felt. This is expected to contribute to the direction of improving the efficiency and the productivity in the business sector, and to strengthen the development of knowledge-intensive exports.

Benefits for policy development: In line with the main objectives of this Strategy, the R&I activity will be closely linked to the regional policy priorities in the energy and environmental sectors (as the latter is affected by the energy production/transport/use cycle) and undertaken in close collaboration with the main stakeholders in the public sector. This will amplify the knowledge base of such entities, thus providing improved capabilities and substantial input to guide the development of new (and potentially cross-sectoral) tools to address policy issues and societal concerns. In this way, R&I will effectively contribute to and accelerate progress in achieving national sectoral objectives as well as the wider goal of sustainable development and inclusive growth

3.2 Key guiding principles

The key guiding principles while developing the R&I Strategy of Western Macedonia in the field of energy were:

Ensuring complementarity with national and EU policies, avoiding duplication and enhancing synergies: This R&I Strategy is being developed within the wider framework of national and international support programmes for R&I. Thus, it is essential to avoid overlap or duplication of efforts as this will only serve to increase fragmentation. Actions and resources should be channelled to effectively target niches or gaps that are not sufficiently addressed. This also implies the potential to exploit arising synergies; this Strategy seeks to identify and amplify such opportunities for the maximisation of resources and the impact of R&I outcomes. Complementarity is also being established with national policies and the EU long-term vision for the energy and environmental sectors. Indeed, the development of this Strategy follows that of the Greek National Energy and Climate Plan for the period 2021-2030. The package of national policies, emanating from national policy direction and Greece's commitments as an EU Member State, shall act as a stimulus for research - from the supply-side (support through structures, financial instruments) and demand-side (regulations, objectives) - and as a receiver of the successful outcomes from the R&I.

Creating a balance between research and innovation: Meeting the objectives of this Strategy by addressing national policy priorities and societal concerns, as well as contributing to industrial competitiveness and growth, will require a combination of research-focused (oriented-basic research, applied research and experimental design) and innovation-focused activities (product, process and marketing innovation). Furthermore, it must be emphasised that innovation in the context of this Strategy is not merely viewed exclusively in terms of product development, but also as a process and marketing innovation. The focus lies not on purely technological topics but with a more holistic view of the complex system within which policy tools and regulatory issues, institutional and behavioural norms, technical constraints and opportunities, and economic priorities and evaluations co-exist. R&I that facilitates the realisation of national objectives and targets must necessarily span this wide spectrum of considerations; technological innovation alone is not sufficient.

Ensuring coordination and cooperation between public, private and research entities: The key to the success of any strategy is the capability of implementing entities to devise governance structures that enable cross-sectoral and cross-institutional coordination. This is important as it is a sectoral strategy that must fit harmoniously into an already existing complex R&I landscape. Thus, the coordination between public bodies providing support for R&I, the academic and research institutions and business enterprises involved in R&I is essential during the planning of the Strategy and its successive multiannual work programmes. Furthermore, creating consistent links and facilitating frequent coordination between the public and private sector and the research community, positions stakeholders in a better status so as to maximise opportunities to their mutual benefit. This may be achieved either through joint undertakings or through the exploitation and incorporation of outputs from R&I activities within various sectors. The highest impact of R&I is made when these three communities work together.

4 Support framework for R&I in Energy (and Environment)

4.1 Multi-level governance structure for R&I policies in Western Macedonia

Western Macedonia has a good experience in participatory research and innovation programmes having realised the RIS (1996-1999) and RIS+ (2000-2002) projects, the Regional Programme of Innovative Actions "Knowledge-Clusters" (2003-2006), and the Regional Innovation Pole of Western Macedonia (2006-2009), while it has developed its own

RIS3 Strategy for the Programming Period 2014-2020. As in the case of the other Greek regions, RTDI policy design and implementation over the years 2007-2013 (also, partially, in the 2014-2020 period) was centralised, and was undertaken by the General Secretariat for Research and Technology (GSRT) – or General Secretariat for Research and Innovation (GSRI), as it is now called. The Regional Authority was not systematically informed about the projects implemented in the region (through the national OP) and the projects did not take into account recommendations and priorities arising from previous initiatives.

Most of these priorities still remain relevant for the region and form a useful foundation for the R&I Strategy in the field of energy for the Region of Western Macedonia. As regards the "governance system" for R&I in Western Macedonia, this is actually related to the governance system of the Smart Specialization formed by all those involved in the formulation, implementation and monitoring of the Smart Specialization Strategy and in particular participants in 4-fold helix of the innovation system, the RIS3 Support Office at Regional Development Fund of Western Macedonia, the Regional Research and Innovation Council (PSEC), the Special Management Service of the Operational Program of the Region of Western Macedonia (EYD OP PDM), and, in an executive role, the Regional Council and the Regional Governor of Western Macedonia.

The Regional Research and Innovation Council (PSEK) was established in the framework of the implementation of the Smart Specialization Strategy in each region, as an instrument to support research, technological development and innovation development actions. As was the case until 2021 (PSEK's term ended last year and an invitation was issued to create a new PSEK), the PSEK of Western Macedonia consisted of 11 members, of which 6 were university professors and researchers of research centers supervised by the Minister of Education and Religious Affairs, and the rest 5 came from professional chambers and scientific associations, cultural institutions, the local government and productive bodies in the region.

In addition, as already mentioned in Section 2.3, Western Macedonia has a limited, but significant, number of stakeholders that have been successively engaged in the previous regional innovation initiatives, such as the ANKO, the UoWM, the local branch of CERTH (formerly the "Institute for Solid Fuels Technology and Applications - ISFTA", now the "Chemical Process & Energy Resources Institute – CPERI"), business clusters and business associations. For the period until 2030, in the short-term, and until 2050, in the longer term, the Regional Authority needs to collaborate with the local stakeholders in order to define clear strategic objectives for the Region as regards the R&I in the field of energy.

4.2 Funding opportunities

The financial resources to support additional domestic R&I activities in line with the objectives of this Strategy are (in brief) described in the following paragraphs (data taken from the "Regional Policy for Greece Post-2020" OECD Territorial Reviews[14]).

Public Investment Program

The Public Investment Program is one of the most powerful development policy tools available, which through its national and co-financed programs supports infrastructure, entrepreneurship and the development of human resources. At the same time, its regional allocation is considered an indication of the commitment of the State to regional cohesion and balanced growth. Western Macedonia receives 7% of the Public Investment national budget against a

[14] "Regional Policy for Greece Post-2020", REGIONAL PROFILES, OECD Territorial Reviews, 2020. Available at: https://www.oecd.org/cfe/regional-policy-for-greece-post-2020-cedf09a5-en.htm

population share of 2.5% and a GDP share of 2.2%. As a result, the per capita figure is the highest in Greece.

European Structural Funds

The allocation of the 2014-20 European Structural Funds was aligned to the economic characteristics of the region, as Western Macedonia received 5.57% of the amount of the "Partnership Agreement for the Development Framework" 2014-2020, also known as ESPA, allocated to Regional Operational Programs in Greece and 3.0% of the total amount of ESPA. Western Macedonia has also got 7.2% of the Rural Development Program (Common Agricultural Policy), a figure that is the eighth highest among the Greek regions and corresponds to the weight of the agricultural sector of the region.

ESPA Regional Operational Program

The Regional Operational Program (ROP) of the Region of Western Macedonia includes a Vision, 6 Strategic Objectives and 10 (out of 11) ESIF Thematic Objectives that altogether define the development strategy of the Region. The development strategy, after a period of open consultation with regional stakeholders, was decided by the Regional Council of Western Macedonia, included in the programming documents of the ROP and finally approved by the European Commission. This is also the case in the new programming period (2021-2027), and as concerns the so-called "Corporate Regional Development Pact 2021-2027" (ESPA 2021-2027).

The ROP of Western Macedonia was about 295 million euros, measured in terms of commitments, a figure that includes EU funding and national co-funding (public expenditure). More than half of these funds address environmental (40.1%) and transport (13.1%) projects or actions, while an equally high share of resources is/was devoted to human resources development and protection (31.7%). A relatively smaller amount is available for actions in support of entrepreneurship (6.5%) and for research & technology (6.6%). Compared to the share of total resources of the 13 ROPs in different policy priorities, the ROP of Western Macedonia assigned more resources to research & technology (138%) and environment (120%), and less to entrepreneurship (98%), human capital & social care (94%), and transport (73%).

The progress in the implementation of the ROP has been improving over the years, reaching about 60.3% of the budget of ROP (situation as of December 2020) contracted for projects and actions and just 34.0% actually spent. This progress, which was still below the national performance, signals that the worst performance in the implementation process in terms of spending is observed in the research & technology (3.6%) and the transport (12.7%) priorities, and the best in the human capital and social care (61.3%).

ESPA Sectoral Operational Programs

The resources of the ROP are matched by the funds (about 638.6 million euros, counted in terms of total public expenditure for funding approved projects to date) allocated to Western Macedonia by the ESPA Sectoral Operational Programs (SOPs). The SOPs are managed in the 2014-20 programming period by the Ministry of Development and Investment. The SOPs of ESPA directed to Western Macedonia devote a relatively higher share to environment, and relatively close shares to human capital and entrepreneurship, while lower shares directed to transport and research & technology. These programs also reserve some resources for the restructuring and modernization of public administration in Western Macedonia (1.6%).

European Research Area & European R&I Programs

The European Research Area (ERA) is based on excellence, competitive, open and talent-driven. The New ERA will improve Europe's research and innovation landscape, accelerate

the EU's transition towards climate neutrality and digital leadership, support its recovery from the societal and economic impact of the coronavirus crisis, and strengthen its resilience against future crises.

The New ERA has four main strategic objectives:

- Prioritise investments and reforms in research and innovation towards the green and digital transition, to support Europe's recovery and increase competitiveness;
- Improve access to excellent facilities and infrastructures for researchers across the EU;
- Transfer results to the economy to boost business investments and market uptake of research output, as well as foster EU competitiveness and leadership in the global technological setting;
- Strengthen mobility of researchers and free flow of knowledge and technology, through greater cooperation among Member States, to ensure that everyone benefits from research and its results

More precisely, the opportunities provide for R&I in the field of energy in the European level are as follow:

- ERA GROUPS (Science Policy and Strategical Discussion)
- HORIZON EUROPE (ERC, MSCA, Research Infrastructures, Widening): The EU Framework Programme for Research and Innovation is the main EU funding instrument for R&I. The current programme, Horizon Europe, will run from 2021 to 2027 and has a budget of €95 billion. The previous programme, Horizon 2020, ran from 2014 to 2020.
- EURATOM (Euratom Research and Training Programme 2021-2025)
- COST (European Cooperation in Science and Technology): It is a funding organisation for research and innovation networks. COST Actions help connect research initiatives across Europe and beyond and enable researchers and innovators to grow their ideas in any science and technology field by sharing them with their peers. COST Actions are bottom-up networks with a duration of four years that boost research, innovation and careers.
- ERA PARTNERSHIPS (have been used since FP6 to optimise the contribution of public and private players in achieving sustainable growth and competitiveness and addressing societal challenges, and to ensure that national policies and EU policy are mutually consistent; now under Horizon 2020 and Horizon Europe Consortia and Joint Transnational Calls)
- EUROPEAN RESEARCH INFRASTRUCTURES (Research Infrastructures are facilities that provide resources and services for research communities to conduct research and foster innovation. They can be used beyond research e.g. for education or public services and they may be single-sited, distributed, or virtual. They include: major scientific equipment or sets of instruments, collections, archives or scientific data, computing systems and communication networks, any other research and innovation infrastructure of a unique nature which is open to external user)

4.3 Priority areas for Research and Innovation

The proposed research and innovation activities in the field of energy are strongly related to the technologies promoted within the framework of the Energy Union, and in full accordance with the priorities of the SET Plan. It should be noted that the majority of the R&I actions that are described in the following paragraphs coincide with the set of Priority Areas identified in the National Energy and Climate Plan (NECP) of Greece (in the specific section related to "*Research, Innovation & Competitiveness*"), as these have been worked by the corresponding Working Group that has been established for this purpose, taking into account the local necessities, capacities and specializations.

Thus, according to the energy efficiency improvement objectives set in all areas of end use of energy in the NECP, there is an urgent need to step up research into new materials and innovative applications of heating and cooling systems, with an emphasis on improving their reliability and automated operation. At the same time, the maturation and integration of innovative energy-saving technologies that contribute significantly to improving energy efficiency, need to be facilitated.

In particular, the R&I priority activities related to improving the energy efficiency of buildings should include:

- ✓ New building materials: Innovative materials and building technologies that will support a recycling process, innovative thermal insulation building systems with improved thermal performance, innovative thermal insulation system without materials derived from mineral sources.
- ✓ Prefabricated active roof and facade elements: Standard panels for ventilated facades or roofs combining photovoltaic and thermal solar systems, thermal insulation, phase change materials, batteries.
- ✓ Cost-effective, intelligent, flexible heat pumps and high-temperature heat pumps: Intelligent heat pump adjustable to provide additional services to the grid, versatile heat pump to provide a wider operating range and operation control equipment, further development & deployment of absorption technologies and heat pump adsorption systems.
- ✓ Digital programming and operational optimisation: Automated fault detection and diagnosis, combining statistics and technical data to improve energy demand forecasts and updating-upgrading building assessment methods.

Accordingly, the following R&I activities need to be supported in the industrial sector:

- ✓ Energy-efficient heating and cooling technologies: High temperature compression refrigeration cycle heat pumps with low global warming potential refrigerants for use in industrial medium temperature applications and in district heating and cooling.
- ✓ Heat/refrigeration recovery: Use of low temperature waste heat to generate electricity at higher efficiency, high temperature waste heat recovery with sCO_2, hybrid waste heat recovery stations incorporating RES in industrial plants and processes.
- ✓ Integration of systems: Industrial integration of energy-intensive industries to exploit energy loss streams and better energy management globally, unconventional sources of energy in the manufacturing industry, further integration of digitisation into process and plant management.
- ✓ Specifically for the chemicals and pharmaceuticals sectors, provision is made for the (re)design and optimisation of the chemical reactor and process, the development of alternative energy efficient separation technologies and the introduction of electricity into the chemical processes.

Achieving the goal of reducing greenhouse gas emissions in all sectors of economic activity is expected to lead both to the full and market-based integration of mature decarbonization technologies in the energy market and to the gradual penetration of less competitive technologies. This particular transition to a new production and demand model presents significant technological challenges, requiring the development of know-how and the promotion of innovative technologies. In particular, in the NECP provision is made to support research and innovation on the RES technologies shown in Table 1 in the coming period.

Table 1: R&I actions in RES technologies to reduce greenhouse gas emissions in all sectors of economic activity

RES technology	R&I priority actions
Solar thermal energy for electricity generation	• Implementation of linear concentrating solar power (CSP) collectors' technology with storage capacity at a commercial scale. • Reduction of the costs and increase of the efficiency of Fresnel CSP linear collectors. • Development of new heat storage materials and techniques suitable for CSP systems.
Solar thermal energy for heating and cooling applications	• Development, standardisation and implementation of hybrid systems in intelligent buildings. • Digitisation of solar thermal systems: development and experimental production of smart meters, development and demonstration of applications for users and professionals. • Work models and pilot applications for the integration of solar thermal systems into smart grids, integrated hybrid RES systems for heating and air-conditioning in buildings with a priority in solar thermal systems. • New materials, production methods, solar thermal system parts to ensure cost savings and to be used into integrated systems. • Development of standardised solar thermal systems for heat generation in industrial processes.
Bioenergy (bio-solids, bio-liquids, bio-gases and bio-energy intermediates)	• Development of high efficiency heat and electricity cogeneration using biomass as fuel on a large scale. • Development, demonstration and scaling up of solid, liquid and gaseous bio-energy intermediates through biochemical / thermo-chemical / chemical conversion from sustainable biomass.
Wind power (wind farms & small wind turbines)	• Operation & maintenance of wind farms: data collection-processing system for continuous operational control of wind turbines, software for processing large volumes of data from the operation & maintenance of wind farms and analysis of operating parameters, drones or robotics for control and maintenance of wind turbines, evaluation methodologies for the residual life of wind turbines. • Small wind turbines: pre-industrial standards with improved aerodynamic efficiency or low sound footprint, quality control and certification procedures & infrastructures. • Integrated environmental footprint capture and assessment methodologies, end-of-life management system, feasibility studies and pilot applications for utilising existing lignite infrastructure.

RES technology	R&I priority actions
Photovoltaic (PV) energy	• Integration of PV systems into buildings and other infrastructures: new high performance thin film cells, hybrid systems incorporating various PV technologies with other power generation technologies, innovative systems for integrating PV in buildings and infrastructure and interconnection with other applications, methods for measuring the efficiency and durability of PVs in real time and in the long term and in accelerated aging conditions. • Development of high energy efficient multi-contact technology photovoltaic cells: perovskite technology multi-contact cells deposited on Si/CGIS, new methods and tools for deposition and transport of III/V absorber, GaP deposition techniques on Si, manufacturing techniques for wide-bandgap semiconductors as upper absorbers, adaptation of Si/CGIS technology as lower absorbers, performance test in real conditions. • PV parks and installations monitoring and operating systems: advanced and automated analysis of various databases, standardisation and self-monitoring of sensors, communication of inverters of a PV module and between different PV installations.
Deep geothermal energy	• Materials, methods and equipment to improve operating availability: plastic materials for pipelines and heat exchangers for the 90-99ºC temperature range, anti-salinity agents specific to fluids from Greek geothermal fields. • Improving the permeability of conventional geothermal reservoirs, with interest from users already exploiting or intending to exploit low enthalpy geothermal fields. • Improvement of electricity conversion efficiency and direct use of heat: hybrid geothermal-biomass power plant, geothermal power plant with cooling water to supply the district heating network. • Development of new geothermal potential exploration techniques, including geothermal potential forecasting and exploratory drilling. • Integration of geothermal heat and electricity into the energy system (development of a variable load geothermal power plant that will complement wind and PV energy). • Developing a zero-emission geothermal power plant.

The key priority of R&I for the coming period in the field of energy networks are the challenges of digitising them and developing smart grids. The main R&I actions to be strengthened in the area of electricity distribution networks, based on hierarchical assessment of the corresponding SET Plan actions, are as follows:

- ✓ Creating an innovation environment for the development of smart services: Market planning for the marketing of heterogeneous flexibility products, cyber security of critical energy infrastructure, innovation regulatory zones, process chain for interoperability of ICT systems, systemic and socio-economic impacts of digitisation on the energy system.
- ✓ Developing an optimised electricity network:
    - Developing and implementing solutions to increase the observability and controllability of the energy system: Increased observability and controllability

of medium and low voltage networks with high penetration of distributed energy resources, smart-flexible design, programming and operation of the network based on improved transmission network observability.

- Developing and implementing solutions and tools for load profile management through demand response and control in order to optimise network usage and defer investment in networks: Customer involvement and new markets & business models, EV/PHEV charging infrastructure and integration into smart energy systems, demand response engineering.
- Developing and implementing solutions to increase the flexibility of all types of production: Interactions between flexible generation and the power generation system, ancillary services in scenarios with very high RES penetration and low mechanical inertia, increasing flexible production through the use of integrated storage in power plants.
- Reducing the cost of all energy storage solutions by minimising the total cost of the system: Multi-service storage applications to facilitate innovative synergies between system administrators and market players, advanced energy storage technologies for energy and power applications.

✓ Developing integrated local and regional energy systems:

- Integrating RES at regional and local level, including different energy providers: Optimising the design, management and monitoring of integrated regional energy systems, a transnational joint programming platform for smart, integrated, regional energy systems.
- Creating an innovation environment for smart services in collaboration with ICT platform solution providers.

In addition, innovative actions relating to electric vehicles and to strategies for their recharging are necessary and emphasis will be placed on the fact that the electricity consumed should come from RES and hydrogen produced by various forms of energy. Similar actions for the development of innovative technologies in the case of biofuels as renewable fuels for sustainable transport (fuels for road transport, air transport) are foreseen, which include:

✓ Developing and demonstrating advanced liquid and gaseous biofuels through biochemical/thermochemical/chemical conversion from sustainable biomass and/or autotrophic microorganisms and primary energy from RES.

✓ Developing and demonstrating other liquid and gaseous fuels (excluding hydrogen) through thermochemical/chemical/biochemical/electrochemical conversion of energy neutral carriers with renewable energy.

✓ Production of renewable hydrogen from electrolysis of water and electricity from RES (installed electrolytes at renewable hydrogen refuelling stations).

With regard to energy storage, actions need to be taken to strengthen the development of new or improved electricity or thermal energy storage technologies with higher efficiency, availability, durability, security and at the lowest cost. R&I actions are needed in the field of electrochemical energy storage technologies, which relate primarily to RES applications for utilisation in non-interconnected electricity networks or in remote points in the electricity network, in particular:

✓ Developing 4.5-5V high-voltage and fully solid state lithium-ion batteries for all vehicle power applications (developing additives or materials modifications to improve safety, determining performance characteristics at low temperatures).

✓ Studying the effect of quick/very quick charging of lithium-ion batteries on materials and battery degradation.

- ✓ Progress on batteries for static energy storage applications, e.g. for achieving fixed interfaces for extending the life cycle and lifespan of the systems.
- ✓ Other battery technologies (after Li-ion) for electromobility (developing appropriate detection, monitoring, thermal management and security systems).
- ✓ Li-ion and after Li-ion battery recycling (developing low-cost packaging for secure reverse logistics; developing an improved reverse logistics business model).
- ✓ Lithium recovery from geothermal brines and sustainable enrichment processes for indigenous lithium deposits in hard rock (mapping and locating interesting geothermal resources in terms of lithium content).
- ✓ Enhancing the development of cell and battery production equipment (change in sheet & coating thickness, cost-effectiveness of switching from high-power to high-energy materials, etc.).
- ✓ Developing hybrid battery systems for static energy storage applications (study of new materials for hybrid systems, design of components and systems specifically for hybrid systems, study of advanced battery management systems for hybrid systems).
- ✓ Second use and smart integration of batteries into the grid (feasibility study for quantification of 2nd life criteria, creation of test protocols according to the 2nd use end-application, implementing aging tests to the most promising batteries, developing models to better understand and predict the performance of current and next-generation Li-ion batteries, establishment of a roadmap of convergence from the current situation, updating and/or creating a common set of standards, developing proposals for a set of demonstration projects to gain more knowledge and experience of using batteries for EV applications in the Fixed Storage Market, a standardised platform with the key characteristics of the batteries and their components).

Taking into consideration the ambition of Western Macedonia to become a hub of hydrogen production and to create primary and secondary employment corresponding to the presence of PPC in the region, it was considered by the experts participating in the consultation that it is necessary to include a number of R&I priority actions necessary to build a robust, efficient and sustainable hydrogen industry to support the Region's aims. As such priorities (which are more or less the same of the global priorities in support of clean hydrogen industry development[15]) the following can be listed:

- Reductions in clean hydrogen production costs through upscaling to larger size, more efficient and cost-effective hydrogen electrolysers (equipment improvements through increasing module size, stack density as well as low-cost catalyst systems, materials improvements through the use of fewer critical materials in electrolyser stacks and creation of catalysts from less scarce materials, scaling-up and improvement in manufacturing processes, lower cost Balance of Plant designs and components).
- Further investigation of production solutions at lower level technology readiness (emerging electrolysis technologies having higher efficiencies and broader acceptance of feedstocks or electrolysers that remove the need for precious metals, hydrogen production through biomass conversion, direct solar/thermal water splitting, permeable membranes that can improve hydrogen purity).
- Improving the volume or mass density of hydrogen through the use of hydrogen derivative carriers (such as ammonia and methanol) and improved compression and liquefaction technologies to reduce the costs for hydrogen storage, distribution and dispensing.

[15] "Hydrogen Research Development and Innovation; Global priorities in support of clean hydrogen industry development", CSIRO (Australia's national science agency), 21 October 2021. Available at: https://research.csiro.au/hyresource/wp-content/uploads/sites/378/2021/10/21-00418_EN_WORD_Report_HyrdrogenResearchDevelopmentInnovation_FINAL_CLEAN.pdf

- Continued development of fuel cell mobility solutions and upscaling of refuelling infrastructure for road transport applications, especially in the heavy and/or long-distance market segments.
- Better understanding and managing of impacts on pipeline and network materials, domestic and commercial appliances, and metering systems in case of blending of hydrogen into existing natural gas networks or repurposing existing pipeline systems into dedicated hydrogen transmission infrastructure.
- Development of hydrogen solutions in difficult to decarbonise heavy industry and mobility applications such as steel production, metals processing, seaborne transportation and aviation.
- Further development of gas turbines, stationary fuel cells, and of ammonia engines and turbines, which support hydrogen's potential as a low-carbon option for co-generation, and for providing flexibility in power systems reaching high shares of variable renewable power.
- Research in 'cross cutting' areas to support standards and safety, appropriate regulatory reforms and domestic and international hydrogen production emissions certification schemes, environmental impacts of projects, and studies of global supply chain business models and social and labour market impacts.

Some more areas which are of specific interest in this metallignant region, although not being directly related to energy uses, and in which the development (or strengthening of existing) research activities is needed are indicatively highlighted here:

(1) Carbon Capture Utilization and Storage (CCUS) Technologies (despite the existing and possibly revised ban). Especially in terms of storage, the transfer of excess CO_2 from activities in metallignant areas to underground geological reservoirs (e.g. Prinos area) should be considered, as well as the transfer to these reservoirs of CO_2 from other parts of the country from activities that produce it there.

(2) Research on the techniques and processes of production of products from non-electrical uses of lignite such as e.g. the production of methanol, synthetic fuels, rare earths, activated carbon, carbon fiber, nanotubes, graphene, etc.

Finally, innovative applications that contribute to mitigating the environmental impact of businesses and the impact of climate change on the urban environment, as well as promoting the circular economy, with an emphasis on the recovery of materials and the recovery and reuse of energy, concentrating on the recovery of materials and the recovery and reuse of wasted energy as well as innovative CO_2 capture and reuse techniques has been considered as necessary to be supported.

4.4 Evaluation and Monitoring

Promoting research and innovation in the energy sector requires the active involvement of all market players (i.e. not only the R&TD institutes / centres). The strategic choices made by the enterprises in the sector (power generation but also those dealing with power transmission and distribution), the policies pursued by public bodies and authorities, as well as the tools for financing the actions implemented by the enterprises should be driven by synergies to the greatest possible extent.

Horizontal support policies include:

- ✓ Establishment of a monitoring and control mechanism to maximise synergies between energy, research and competitiveness policies and support it with the necessary resources

- ✓ Regulatory measures for the easier and more efficient implementation of research or pilot projects by all market players, with the ultimate goal of creating benefits for final consumers.
- ✓ Measures to promote partnerships between all stakeholders by supporting advisory and networking actions among stakeholders to facilitate the transfer of know-how and the maximisation of synergies.

In the specification and implementation of these policies and measures, there will be close cooperation with national and regional smart specialization planning and implementation bodies. Energy is already one of the priority areas of the National Smart Specialization Strategy and certain regional ones. The involvement of stakeholders from the energy sector in the business discovery process is the key to maximizing the intended results.

The capabilities for monitoring, evaluation and analysis of innovation programmes and performance should be further solidified and embedded in both the new regional government structures and the wider partnership. A specific budget line could be set aside for a partnership based regional innovation observatory that could fund studies and doctoral/post-graduate research into innovation practice in regional firms, etc.

Guidance on evaluation methodologies for innovation measures is already available for the 2014-20 period[16] and the IMA, regional authorities, etc, should make themselves aware of and use such materials to develop an evaluation plan. At a minimum, one official should be specifically tasked with setting up an evaluation and monitoring system for innovation measures in the IMA.

5 Concluding note

The further and focused promotion of research and innovation in the field of energy (and not only) is a vital and necessary condition for the development and operation of most of the aforementioned projects and actions, as well as of the 'emblematic project/actions' foreseen in the Territorial Just Development Plan (TJDP) for Western Macedonia[17]. The development and support of research and innovation is an independent post-lignite activity that should be promoted in the affected areas. In the Western Macedonia Region there is already a large research community within the operation of the University of Western Macedonia and CERTH. There is a need for a systematic and focused strengthening, reconstruction and empowerment of research bodies in this "metallignant" area and their focus on exploring the technologies and production techniques of the priority developments that have been (or, will be, in the future) selected for the area.

The role of the University of Western Macedonia is considered particularly important, which with the appropriate support and encouragement and in the context of international collaborations, could develop relevant research activities for innovative products aimed at exports. Initiatives can be developed by the University of Western Macedonia for the development of educational and research activities for innovative ideas in energy and in general in efficient applications that meet environmental objectives. At the same time and in cooperation with the Regional Administrations, the necessary planning should be made in order to offer rapid training in new and efficient technologies, by importing new knowledge and skills that the market will need.

[16] See: http://bit.ly/Igzx5T

[17] Territorial Just Development Plan (TJDP) for Western Macedonia, February 2021, Available (in Greek) at: https://www.sdam.gr/sites/default/files/2021-02/ΕΔΑΦΙΚΟ20%ΣΧΕΔΙΟ%20%ΔΥΤΙΚΗΣ%20%ΜΑΚΕΔΟΝΙΑΣ%20ΔΙΑΒΟΥΛΕΥΣΗ_08%2002.pdf

As it was highlighted previously, an important factor that makes the region lagging behind in terms of business and growth indicators is the lag of companies in terms of innovation. Particularly important for the purpose of enhancing the competitiveness of the productive system is the role of research and innovation and the connection of universities and research centers with business. Therefore, it is an urgent need to support research, development and innovation activities, with the aim of developing high value-added businesses, products and services and, consequently, creating jobs above the average wage level. In this direction, it was proposed the creation of a *specialized Innovation Zone in Western Macedonia for Clean Energy and Environmental Technologies*, in the current energy axis of Kozani-Ptolemaida-Amyntaio-Florina, according to the standards of the international Innovation Zones.

To this end, an announced Regional goal for Western Macedonia is the establishment and development of an innovation hub for hydrogen (H_2) and green energy technologies and environmental technologies, with emphasis on green hydrogen, RES and energy savings, in order to signal a new environment for the development of the new economy in Western Macedonia. In this direction, and in addition to the proposal of the "White Dragon" Project which attracts the interest of major energy groups in the country and Europe, the Region of Western Macedonia will soon acquire a complete hydrogen ecosystem. This will include a Center for Hydrogen Studies based at the University of Western Macedonia, a cluster of CERTH-based hydrogen companies in Ptolemaida and an electronic platform for hydrogen technology applications.

At the same time, a hydrogen technology park will complement the infrastructure of this modern technology, in order to quickly promote the use of green hydrogen and to favour the investment environment for corresponding large-scale productive investments in Western Macedonia. This decision has already been taken at the last meeting of the executive committee of the Region and, together with a number of other innovative proposals and important projects and studies, will be submitted for inclusion in the forthcoming invitation of the Green Fund. In this context, the know-how of the universities, research institutes and the innovation ecosystem of the region will be utilized, whose capabilities and role will be drastically upgraded with the appropriate infrastructure and actions, while promoting the conclusion of collaborations with respective bodies in Greece and abroad.

Another important issue that was raised during the consultations - although not directly related to the commonly understood R&I actions - is that efforts should be placed on capitalizing on the infrastructure left by the universal withdrawal of the lignite industry in the region, such as:

- In the change of use of lignite power plants (Re-use);
- In the integration of the depleted lignite mines in the urban fabric of the area in terms of circularity and sustainability;
- In Practices of Industrial Coexistence between the new lignite plant (Ptolemaida 5), DIADYMA SA (the waste management company / agency of Western Macedonia) and the local industry as a single ecosystem.

In other words, it is important to explore which of the existing infrastructures (as a value chain), but also which know-how are judged as assets for the course of the transition.