Master Thesis:

# ‘Nanotechnology in Greece: From Research to Commercialization’

Kyparisis Papadopoulos

A thesis submitted for the degree of Master in Technology and Innovation Management

Committee:
Dr. George Vekinis (Co-Supervisor)
Professor Fotios Kitsios
Assoc. Professor Stelios Tsafarakis

School of Production Engineering and Management with the collaboration of the School of Electrical and Computer Engineering
Technical University of Crete

Greece, 2024

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I declare that this work is wholly mine and no conflict of interests exists with respect to any reported data or information.

# Acknowledgements

First of all, I would like to thank my supervisor Dr. Vekinis for his trust and the opportunity he offered me to conduct this study as well as his continuous support and guidance throughout its preparation. Moreover, I would like to thank the other members of the Committee, Associate Professor Stelios Tsafarakis and Professor Fotios Kitsios for their help and important suggestions during my research.

Additionally, I would like to express my gratitude, to all the professors and personnel of the Master of Technology and Innovation Management of the Technical University of Crete as well as my classmates, for the productive conversations and the general constructive environment during classes.

Finally, I would like to thank my family and my life partner, Ria, for their patience, their selfless love and support.

## Abstract

Innovations in nanotechnology are making a revolution in manufacturing and production, creating new materials and products through novel processes for commercial applications. New products based on nanotechnology, with novel characteristics are continued to grow and benefit the society. Nanotechnology holds great promise and is hyped by many as the next industrial evolution. Medicine, food, cosmetics, agriculture, environmental health, and technology industries already profit from nanotechnology innovations and their influence is expected to increase drastically in the near future.

Technology transfer from universities and investment decisions are major forces in how nanotechnology develops, and this is dependent on the support from Government, academia, private investors, and companies. Several commercialization strategies seem suitable: patenting, licensing, equity investment, spin off companies, strategic alliances, and private consortium or cluster alliance.

In Greece, many agencies, mainly groups of universities and research centers, are active in nanotechnology. In addition, the advantages of exploiting research results are beginning to be recognized. For example, academic entrepreneurship is strengthened through a multitude of government funding initiatives, supporting mechanisms (such as technology parks, incubators, etc.) with the aim of promoting innovation, enhancing economic development.

However, there are also many challenges that need to be overcome to bring a nanotechnological product or business to the market. Even the most impressive scientific achievements can become a commercial failure due to a lack of understanding of, and the absence of a strategy relating to, the legal and regulatory issues surrounding the commercialization of a technology.

This thesis will try to explore the factors influencing the transfer and utilization of research results by universities and research centers, aiming to identify optimal conditions for this process. Moreover, the innovation model in a country like Greece is investigated, which has limited experience in academic entrepreneurship, and it is examined if a framework for successful nanotechnology management is established. Additionally, the level of academic research in nanotechnology is assessed and the effectiveness of transferring research results to industry is studied. Overall, this research aims to contribute to improving innovation management and increase the success rate of nanotechnology inventions.

# Table of Contents

# List of Abbreviations/Acronyms

| Abbreviation/Acronym | Meaning |
|---|---|
| CSF | Critical Success Factor |
| EPO | European Patent Office |
| GDP | Gross Domestic Product |
| GPT | General Purpose Technology |
| GSRT | General Secretariat for Research and Technology |
| HFRI | Hellenic Foundation for Research & Innovation |
| IASP | International Association of Science Parks |
| IP | Intellectual Property |
| IPR | Intellectual Property Right |
| NBIA | National Business Incubation Association |
| NNI | National Nanotechnology Initiative |
| OECD | Organization for Economic Cooperation and Development |
| RC | Research Center |
| R&D | Research & Development |
| SCENIHR | Scientific Committee on Emerging and Newly Identified Health Risks |
| SME | Small & Medium Enterprises |
| TRL | Technology Readiness Level |
| TT | Technology Transfer |
| TTO | Technology Transfer Office |
| URC | Universities and Research Centers |
| USPTO | United States Patent and Trademark Office |

# 1. Introduction

## 1.1 Problem background

Technology transfer (TT) constitutes an integral component within the value chain that serves to bridge the gap between research endeavors and commercial application. The TT ecosystem is expansive, encompassing various stakeholders such as researchers, entrepreneurs, industries, TT specialists, and investors. Academic researchers typically perceive TT as the process of translating their research findings into patents, establishing companies, or forging collaborations with industry counterparts. In the context of Research Centers (RCs), TT advances further along the value chain, involving aspects such as patents, licensing and return-on-investment to sustain ongoing RC activities. Small and Medium Enterprises (SMEs) predominantly focus on leveraging their intellectual property (IP) to propel their enterprises toward profitability. Conversely, larger corporations, including multinational corporations, engage in TT through collaborative projects, with acquisitions and utilization of patented or licensed knowledge being common practices [1].

Nanotechnology, operating at a minute scale of less than one thousandth of the width of a typical human hair, is characterized as a horizontal, transverse, cross- cutting, disruptive and emerging technology. Undoubtedly, it stands as a pervasive key enabling technology with applications spanning various manufacturing processes and products. However, the transfer of nanotechnology, hereafter referred to as "nanotechnology transfer", presents unique complexities and demands compared to other technological domains. Nanotechnology is inherently multidisciplinary, involving physics, chemistry, biology, engineering, electronics, photonics, material science, medicine and other disciplines. Each discipline possesses its distinct language, scientific methodologies and gestation periods for technology deployment in the market [2].

Given that nanotechnology primarily evolves within the research laboratories of Universities and RCs (URCs), there is a critical need to enhance activities aimed at extracting added value from nanotechnology applications. In the knowledge-based society, universities have undergone a transformation from their traditional role, centered on education and research, to a more intricate role that includes fostering economic development through TT activities linking academia, industry, applications and society at large [3].

In the pursuit of transitioning to a knowledge-based economy, smaller countries such as Greece have implemented measures to support innovation, industry collaboration and the exploitation of research outcomes. These efforts, coupled with the advent of new technologies such as nanotechnology, present novel opportunities to rejuvenate economies and establish new industries [4]. This assumes particular significance as traditional industries contract and global competition intensifies. Consequently, to bolster national competitiveness, smaller nations aspire to fortify their capacity to commercialize government research outcomes, with a specific emphasis on strategic technologies like nanotechnology.

In light of the foregoing, the scope of this thesis encompasses an examination of the nanotechnology innovation model in Greece. It involves assessing the extent of nanotechnology research and entrepreneurship, scrutinizing transfer mechanisms and evaluating the utilization of nanotechnology research results emanating from Greek URCs. The investigation also delves into the critical factors influencing the successful commercialization of nanotechnology research outcomes.

The present work aspires to fill a research gap in academic entrepreneurship regarding the characteristics of nanotechnology. Furthermore, it will fill a knowledge gap regarding the study of URCs and countries with limited experience in commercialization of research results.

## 1.2 Problem statement & Research questions

While Greece has witnessed substantial advancements in nanotechnology research within laboratory settings, the translation of these innovations into successful commercialization remains a formidable challenge. Despite the immense potential of nanotechnology to revolutionize industries, the journey from lab-based discoveries to market-ready applications faces numerous hurdles. The gap between academic research and commercialization in the field of nanotechnology in Greece is a critical issue that demands focused attention.

The challenges encompass various dimensions, including regulatory complexities, market uncertainties, limited funding avenues and the need for enhanced collaboration between academic institutions, industry players and policymakers. The inability to bridge this gap hinders the realization of economic, societal and technological benefits associated with the commercial application of nanotechnology.

This study seeks to investigate the specific challenges and opportunities inherent in the process of transitioning nanotechnology innovations from laboratory research to successful commercialization in the Greek context. By addressing these challenges and proposing strategic solution, this research aims to contribute to the creation of an environment conducive to the effective integration of nanotechnology into the commercial landscape of Greece. Ultimately, understanding and addressing the hurdles impending the commercialization of nanotechnology is vital for unlocking the full potential of this transformative field and fostering innovation-driven economic growth in Greece.

In order to achieve this, important research questions should be answered by performing extended literature review and conducting survey with a questionnaire to nanotechnology experts. These research questions are:

- Which are the characteristics of nanotechnology innovation model in Greece? Which are the relations between Government, URCs, Industry and Civil Society?
- What is the level of nanotechnology research and entrepreneurship in Greece?
- Which are the critical factors for successful commercialization of nanotechnology research results?
- What are the existing challenges and barriers hindering the commercialization of nanotechnology in Greece?

## 1.3 Disposition

**Chapter 2: Literature Review –** In this chapter we will explain the theories and concepts that will be used to build the literature review. In this theoretical framework we will explain in detail research concerning academic entrepreneurship and commercialization of nanotechnology research results.

**Chapter 3: Research Methodology** – This chapter outlines the quantitative approach followed for this research to enable the researcher to answer the research questions. Details are discussed about the methods used for the preparation of the questionnaire survey, data processing and analyzing.

**Chapter 4: Results and Discussion** – This chapter summarizes and discusses the research results. The results reported cover the expert survey and their connections with the theoretical concepts described in literature review.

**Chapter 5: Conclusions and Recommendations** – This chapter presents the conclusions and recommendations of the research. It summarizes the research's contributions to knowledge and recommends some directions for future research.

# 2. Literature Review

## 2.1 Innovation

### *2.1.1 Conceptual approach of Innovation*

Innovation, a crucial factor for achieving business success, plays a pivotal role in driving growth, ensuring sustainability and enhancing competitiveness. This multifaceted concept encompasses a wide range of stakeholders, including government officials, scientists, business executives, marketing specialists and consumers. The diverse perspectives held by these various parties contribute to distinct interpretations of innovation. Consequently, there exists a varied understanding of this fundamental concept.

From a broad perspective, innovation can be described as a journey spanning from idea conception to market implementation. This involves taking initial concept or invention and transforming it into a tangible product, process or service. The process encompasses various stages, including idea generation, research and development, product creation, marketing and sales. While inventions serve as the essential seeds for innovation, it is important to note that not all inventions automatically result in true innovation [5].

Innovation is predominantly understood as the practical and commercial application of ideas or inventions. According to [6], innovation can be classified into four distinct types: product or service innovations, process innovations, marketing innovations and organizational innovations. These categories collectively contribute to the intricate landscape of innovation. Furthermore, innovation exhibits three degrees of novelty, as outlined by the OECD in 2005 [7]:

1. New to the firm: Innovations that are novel within the organization.
2. New to the market: Innovations that introduce something new to the industry or consumer base.

3. Entirely new to the world: Innovations that break new ground globally.

These dimensions- types of innovation, degree of novelty and innovation nature- interact to shape the expansive and dynamic innovation space. The combination of these factors provides a comprehensive framework for understanding and categorizing the various dimensions and manifestations of innovation within the business and technological landscape.

### *2.1.2 Innovation models*

Academia, industry and government play important roles in shaping the ecosystem for technological innovation. Academia, comprising universities and national research institutions, serves as the idea generator. Through both basic and applied research, it lays the groundwork for novel concepts and breakthroughs. Industry takes the baton from academia and transforms research innovations into practical solutions. By commercializing these innovations, industry make them accessible to the public, driving real-world impact. Government's role is multifaceted. It establishes the policy framework within which all parties operate. This framework ensures alignment, fosters collaboration and facilitates the translation of ideas into tangible outcomes.

Etzkowitz and Leydesdorff [8] introduced the concept of the Triple Helix to describe an innovative environment fostered by the interplay of government, universities and industry. This model envisions a collaborative ecosystem where traditional stakeholders- responsible for industrial innovation and academic knowledge creation- interact with political dimensions to drive economic growth through top- down approaches. There are three different ways that the Triple Helix can be implemented, as illustrated in **Figure 1**. The first model shows the statist paradigm where the government directs and coordinates the interactions between academia and industry. The second model presents the Laissez-faire model with very limited interaction among the three partners. In the third model, which is the trilateral hybrid, there is an active interaction and overlapping of responsibilities among the institutional partners, and thus it is the most desirable model [9] .

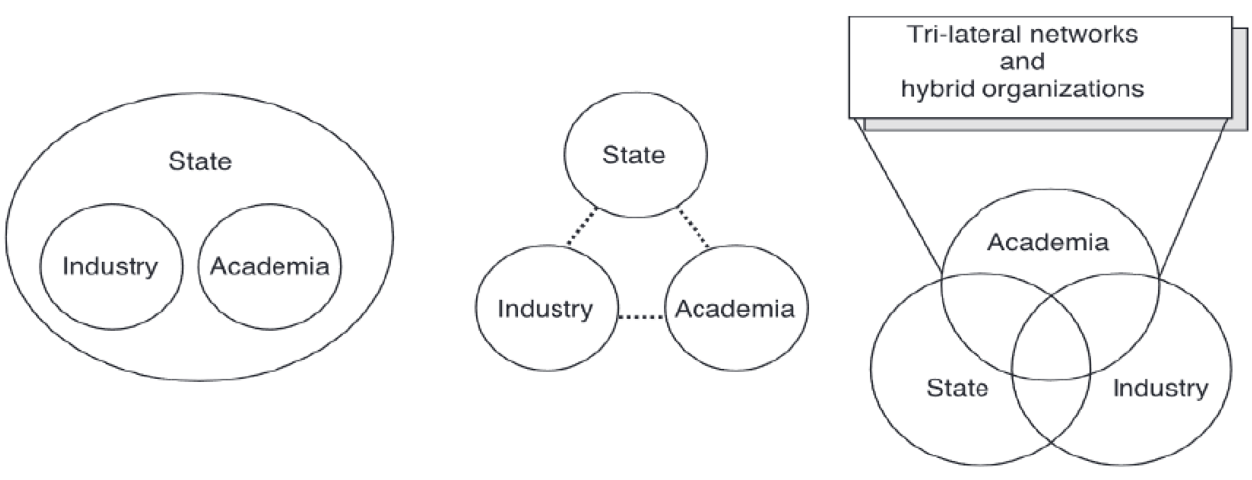



**Figure 1:** The three models of Triple Helix [9]

The triple Helix underscores the significance of distinct pillars, often referred to as “helices”, in driving innovation across key sectors: academia, industry and government. It places particular emphasis on the “tri-lateral” interconnections, situated within a broader context of evolving forms. In this framework, additional stakeholders are actively included to enhance collaboration and foster innovation.

As a result, Carayannis and Cambell (2009) suggested a Quadruple Helix Innovation System Framework [10]. In this context, civil society is introduced as a ‘fourth helix’ to the above stated helices. This fourth helix encompasses domains such as ‘media’, ‘creative industries’, ‘culture’, ‘values’, ‘lifestyles’, ‘art’. The inclusion of civil society underscores the need for a more comprehensive approach to knowledge production and innovation, emphasizing greater integration of the public within innovation systems [11].

In the context of 21st century societal development, discussions increasingly revolve around environmental safety and sustainable growth. To address these challenges, a novel model of innovation- the Penta or Quintuple Helix-has emerged [12]. This innovative framework expands upon the Triple Helix by incorporating additional dimensions. It aims to maximize the integration of ‘green’ innovations for the benefit of both business and the state. Notably, universities transition from mere generators of innovation to active creators of sustainable development values. These values manifest in practices such as zero-waste production, adoption of alternative energy sources and the use of biodegradable packaging.

The spiral (helix) nature of innovation activity arises from continuous formation of new relationships among business, science, education and the state **(Figure 2)**. These interactions give rise to emerging stakeholders with a keen interest in innovation. At each coil of this helix, fresh innovation needs emerge from society and the state. These needs find expression in the scientific and industrial collaboration between businesses and the state. Over the past two centuries, the transformation of classical universities into entrepreneurial institutions has forged novel connections between business and government. Beyond mere technological advancements and know-how, these connections foster values associated with social and environmental innovation. Concepts like crowdfunding, crowd investing, and the fruits of digitalization & technological convergence play a key role in shaping this dynamic landscape [13].

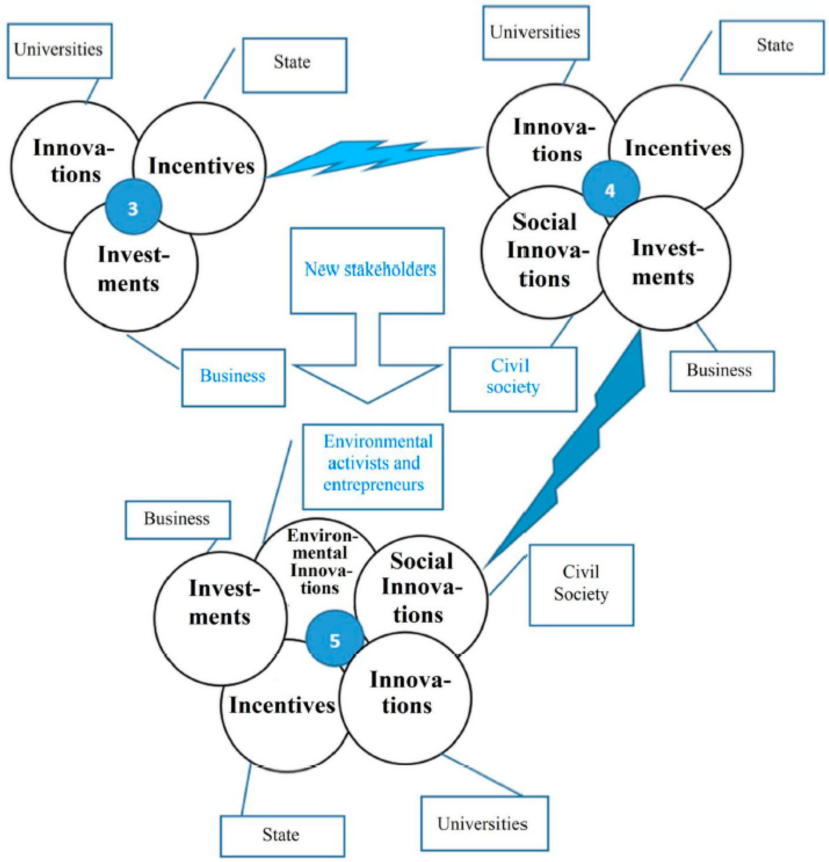



**Figure 2:** Transformation of models of innovative economic development- from a Triple to a Penta Helix [12].

## 2.2 Technology Transfer

### *2.2.1 Technology Transfer definition*

Technology, as defined by various researchers, plays a significant role in shaping research design, outcomes and government policies. From different perspectives, technology emerges as a multifaceted forced driving progress. First, it represents specialized knowledge applied practically to achieve specific objectives. Scientific understanding is harnessed to create products or services that meet existing or emerging needs. Second, technology embodies a fusion of intellectual creativity and physical innovation. It augments human capabilities, enhancing skills across diverse domains. Lastly, technology encompasses scientific and technical expertise related to processes, procedures, work programs and tangible elements (such as equipment and documentation). This knowledge empowers individuals to design, manufacture, operate, maintain and market products or complete specific tasks. In summary, technology bridges knowledge and practical implementation, shaping our world through continuous advancement [14].

In general, technology consists of two primary components:

1) A physical component which comprises of items such as products, equipment, blueprints, techniques and processes.

2) The informational component which consists of know-how in management, marketing, production, quality control, reliability, skilled labor and functional areas.

The concept of ‘technology transfer’ implies that the focus of the transfer lies in the technology itself. Although this express is quite broad, it’s essential to recognize that the term ‘technology’ originates from the Greek words ‘tecnhologia’ (combining ‘techno’ for art, skill and logia for study). This wide-ranging term warrants further explanation.

Technology Transfer is an integral aspect of the innovation process. It defies linearity and predictability, operating across multiple actors and stages. TT encompasses various activities, including the identification and development of novel technologies, safeguarding them through suitable intellectual property strategies (such as patents or copyrights) and devising plans of development and commercialization (such as licensing or creating new companies)[15].

Formal channels of TT encompass training, education, funded collaborative research and technical services. Informal mechanisms, on the other hand, involve diverse exchanges between researchers and those involved in technology applications. Additionally, structured knowledge sharing occurs through papers and events. The most common avenues for technology transfer include published literature, patents and presentations at conferences, workshops and webinars.

TT takes on different meanings for various participants in the process. Each entity plays a role in the value chain, spanning from knowledge creation to commercialization. Higher education and research institutions view technology transfer as a goal once research and development have progressed. Their aim is to secure buy-in from companies (including funding) or to patent a technology. Companies, on the other hand, initiate technology transfer after completing research, development and prototyping. Once the technology is ready (often through licensing), it can enter production (typically starting with pilot-scale production before full- scale implementation)[16].

### *2.2.2 Technology Transfer mechanisms*

The process of TT usually involves the transmission of technological innovation from a donor organization (e.g. URCs) to a host organization (e.g. company). So, this process includes all the stages related to the activities from R&D to commercial exploitation and beyond.

The transfer of technology has multiple objectives such as: the closer connection of the URCs with the industry, the enhanced prestige of the URCs, the social benefit, the strengthening of entrepreneurship, the increase of employment/work, the economic benefit and finally the strengthening of the national and regional economy. Additional benefits provided by the transfer of technology to URCs are its function as a means of promotion and attraction of students, staff and additional funding from industry. For this reason, it has been recognized as a potential source of revenue especially in the current economic situation, where URCs receive reduced financial support.

TT from URCs is implemented through various mechanisms, such as publications, education, collaborative research, consulting activities in industry, licensing, the creation of spin off companies and joint ventures. The models and mechanisms for the exploitation and transfer of

R&D results include various phases where strategic decisions and criteria have been set and are mainly implemented through the mechanisms of licensing and the creation of spin-off companies. [17]

Intellectual property (IP) is an important part of the commercialization of technology as it legally protects the property in order to pursue sales, licensing, spin-off companies, joint ventures and other types of agreements. Patenting the technology is the most often mean of IP protection as it gives ownership recognition and a legal basis for preventing potential usurpers. It should be mentioned that in several URCs, a large percentage of R&D activities are carried out in close cooperation with industrial bodies [18].

In that case, the copyright or patents belongs to the companies that fund the collaboration. Consequently, the results of such collaborations are implemented and utilized mainly by the companies involved. Whereas in the case of state- funded research, URCs have the freedom to commercially exploit the results of this research.

Publications can be a technology transfer mechanism, as articles published in scientific journals are the most common means of technology dissemination. Publications are intended for academic researchers and not for potential users. So, publications can be a suitable vehicle for the dissemination of R&D results, but they are not an effective mechanism for commercial action or exploitation.

Spin off companies are new companies created by individuals who are former employees of an organization or arise from the transfer of technology from an organization. So, spin off companies are the transfer of a technological innovation to a new business activity- company founded on the basis of this innovation. This approach of company formation is also known as the inventor-entrepreneur approach whereas when URCs encourage surrogate (external) entrepreneurs to assume the leadership role are called spin out companies [19], [20].

The research on spin off companies does not focus only on the company but mainly on the environment, the infrastructures, the supporting mechanisms and the national policy that support their creation and development. Druilhe and Garnsey [21] propose the categorization of corporate spin offs according to the type of activities and the resources required. The effect of resources on the creation process of the spin off companies has been recognized. The resources required by academics engaged in entrepreneurial actions vary considerably, depending on the activities of the spin off companies and their skills. Thus, they distinguish 5 categories of spin off companies as can be seen in **Figure 3**, where the differentiation of the activities of the spin off companies is represented according to the resources required and the skills of the academics who were active in the creation of the company. It seems that, the business models of corporate spin offs are modified as academic entrepreneurs improve their knowledge of the resources and opportunities available to them.

According to this study, the most affordable business model is spin off companies active in consulting activities and services. In contrast, spin off companies related to the production of products must create production infrastructures. Infrastructure, however, requires capital funding and this may be beyond the skills and experience of academics. According to this study, another affordable business model is spin off companies that are active in creating a portfolio of patents that can be licensed or sold to customers. Therefore, in this way the spin off company exploits IP rights (IPRs) commercially or creates new ones through R&D activities.

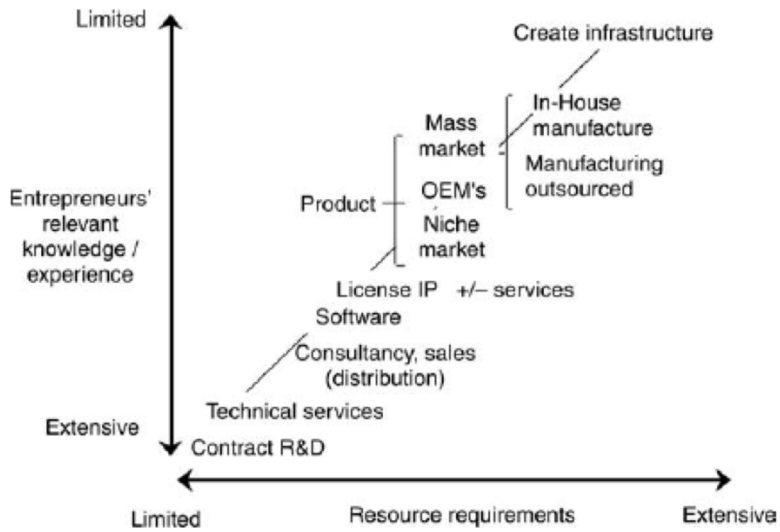



**Figure 3:** Categories of spin off companies depending on the required resources and skills [21].

Licensing is the assignment/transfer of rights to create/use/ trade a product/ design or process or other actions from one entity that has the right, to another entity. Licensing royalties are usually given in exchange for licensing an innovation. The amount paid from the assignment of rights (licensing royalties) can be a significant source of revenue for further research by URCs. URCs can choose the method of licensing payment either with a fixed amount or as a percentage of the units/products sold (unit royalty). Licensing contracts usually include both ways [22].

In order to avoid the dilemma of choice regarding the payment of licensing, URCs can participate in the share capital in the case of the creation of a spin off company in exchange for the right to use their IPs. There are three advantages to obtaining an equity interest over licensing royalties. First, the percentage of the spin off company's share capital provides financing opportunities to URCs from the company's future revenues. Secondly, the agreements with percentages on the equity capital of the spin off company, create the alignment of the stakeholders of URCs and the spin off company with a common goal of commercializing the technology. Thirdly, the percentages from the share capital can be an indication and act as a way of certifying the entrepreneurship nature of URCs. The existence of URCs, as a shareholder of a spin off company, is an indication to its investors that it has a valuable technology, and that URC is convinced of the value of the technology that the company has exploited.

### *2.2.3 Technology transfer agencies*

There are many countries that have developed various intermediary structures in order to support TT activities. Thus, many URCs have created Technology Transfer Offices (TTOs) and take part in the research commercialization system consisting of spin off companies, incubators, science and technology parks and industrial bodies. All mechanisms of this system can be key members of a cluster in a region. In addition, this ecosystem may include entrepreneurship training activities and initiatives such as funding for the creation of spin off companies [23]. Regional entrepreneurial university ecosystems are key structures for economic growth. Carayannis et. al. [24] explored and profiled the nature and dynamics of the Quadruple/ Quintuple Helix Innovation System model in such regional agglomerations of organizational and institutional entities.

The TTOs are considered by many to be the main determinants of the success of the URCs in terms of the process of commercial exploitation of the research results [25]. In the USA, TTOs were established in 1980, when the Bayh-Dole act was instituted, while in Europe they were established much later.

The involvement of TTOs in the process of technology transfer and commercial exploitation by URCs, is shown in **Figure 4** [26]. The process begins with an invention by a URC scientist/researcher. After completing the registration of the invention with the TTO (invention disclosure), then the scientist/researcher together with the TTO officials decide whether to patent the innovation developed. The TTO assesses the prospect of commercial exploitation and monitors the interest expressed by industry. URCs usually have limited amounts of funding to file patents which are usually high cost. When the patent has been assigned then the commercial exploitation method should be chosen. The choice concerns the creation of a spin off company or licensing. In the case of licensing, TTO can promote the technology to the market with the collaboration of scientists/researchers. The next stage involves working with the companies and entrepreneurs in order to negotiate the licensing agreement. In the case of the decision to create a spin off, the scientist/ researcher in collaboration with the TTO will prepare the business plan and seek funding. When the spin off company is created then the scientist/ researcher can act as a scientific partner or become a member of the board of directors and in addition receive part of the share capital. In the final stage, the technology is commercialized by turning it into a product either by existing companies or by creating a spin off company.

The National Business Incubation Association (NBIA) of USA [27] uses the following definition for business incubators: They are a dynamic business development process. This aims to hatch new businesses, to receive support so that they can survive during the period when they are created and are most vulnerable.

Incubator support activities include access to financing, business, technical and administrative services, rental space, offices, facilities, equipment. In addition, support includes access to networks of business or technology advisors capable of providing guidance and support on a variety of financial, business planning, marketing and legal support issues.

Obviously, not all incubators are efficient. Some of the reason incubators fail is the fact that while entrepreneurs are looking for high level experience and capital, the majority of incubators focus on infrastructure or simply fail to deliver the services they initially committed to and furthermore, with the same personnel services they provide in companies, the choice of entrepreneurs about the required resources is limited [27].

A business incubator must fulfill five actions in order to ensure its success: a) establish clear indicators of its success, b) provide business leadership skills, c) develop and deliver value-added services to host companies, d) develop a sound process for selecting new businesses and e) ensure that host companies access to the required human and financial resources. The entrepreneurial ecosystem plays a moderating role in the relationship between incubator strategy and performance and co-opetition significantly improves incubator performance [28].

The International Association of Science Parks (IASP) [29] uses the following definition: A S&T park is an organization managed by specialized professionals whose main objective is to increase

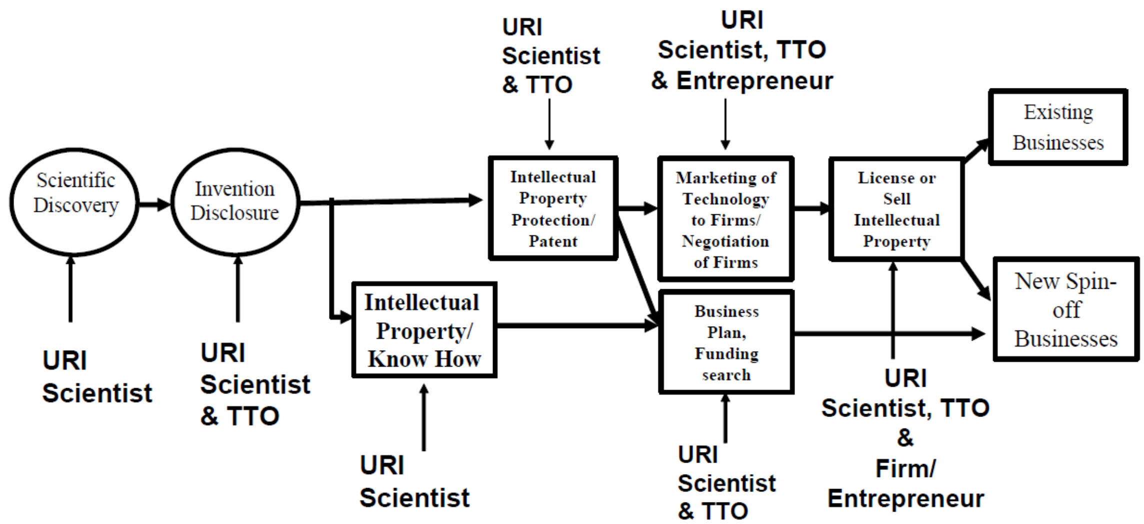



**Figure 4:** The involvement of the TTO in the activities of commercial exploitation of research results from the URCs (URI) [26].

the wealth of its community by promoting the culture of innovation and competitiveness of business based on knowledge. In order to achieve these goals, an S&T park includes the following activities: maintains links with URCs, manages knowledge and technology between URCs and companies, facilitates the creation and development of spin off companies, provides value added services and infrastructure in order for businesses to consolidate their actions.

Many URCs have established incubators and S&T parks in order to provide spaces that facilitate the creation and growth of spin off companies[30] [31]. S&T park initiatives are based on the idea that the environment in which a spin off company is established, influences its growth. Park location provides distinct advantages over establishing an off-park company. According to this claim, research has shown some advantages for park-based spin-off companies, such as being located at a "prestigious address", showing "social sensitivity", or that have an "image effect". According to studies, companies located in parks report that they benefited in terms of company image and had a higher survival rate than companies outside parks. Their high survival rate indicates that their needs are being met. The benefits that the companies reap from the location are mainly due to their collaboration with the universities in a way that the needs for their initial development are covered and at the same time the way for their further development is prepared [32].

#### *2.2.4 The transformation process from the idea to the realization of the innovation*

In Table 1 the structured breakdown of the transformation process from idea to innovation is presented, considering the Technology Readiness Levels (TRLs) [33]. The inception of any innovation begins with a spark- an idea that holds the promise of solving a problem or capitalizing on an opportunity. Researchers, inventors or entrepreneurs embark on this journey by identifying a need or envisioning a novel solution. At TRL 1, the concept remains abstract. Brainstorming sessions, market research and user need assessments lay the groundwork.

As the idea matures, it advances to TRL 2. Here the concept takes on a more tangible form. Researchers conduct feasibility studies, perform basic simulations and explore the technical landscape.

The heart of innovation beats within the realm of design and development. At TRL 3, the idea blossoms into a detailed design. Prototypes emerge and researchers validate functionality, assess risks and refine their vision.

By TRL 4, the innovation acquires a functional prototype. Controlled experiments reveal its strengths and limitations. Researchers scrutinize performance metrics, reliability and safety. Iterative improvements shape the design, inching it closer to real world applicability.

At TRL 5, the innovation steps out of the laboratory, into relevant environments. Field tests simulate real world conditions. Scalability and manufacturability demand attention. Researchers grapple with the delicate balance between ambition and practicality.

TRL 6 marks the arrival of a fully functional prototype. Rigorous testing ensues and data pours in, informing decisions.

TRL 7 heralds the pilot scale production phase. Innovators optimize processes, address supply chain complexities and fine tune manufacturing workflows. The innovation inches towards mass production. Regulatory compliance and safety certifications come into play.

At TRL 8, large scale production lines hum with activity. Innovators collaborate with manufacturers, distributors and end users. Market entry strategies take shape, and the world awaits.

Finally, at TRL 9, the innovation transcends novelty. It permeates everyday life, and the market embraces it. Continuous improvement cycles kick in, fueled by user feedback and changing landscape.

**Table 1:** The ten stages of the transformation process from the idea to the realization of the innovation [33].

| # | Stage | Focus of activities | TRL and Critical Milestone | Comments |
|---|---|---|---|---|
| 1 | Birth of idea | Originality, non-ambiguity, formulation, potential utility, precursors | TRL 1 | Start of the process, sometimes not clear or obvious |
| 2 | Proof of concept | $H_{2020}$/ERC/Ideas proposal, clarity of formulation, precision, reformulation, previous work | TRL 2-3<br>CM1 | Preliminary proof of concept for generic application |
| 3 | Research & Development | $H_{2020}$/RD proposal, rigorous research, potential applications, confidentiality | | Systematic and rigorous RD, reformulation and realignment if necessary |
| 4 | IPR protection | Patent or keep secret, first open announcement | TRL 4 | Crucial decision on protection before first open announcements |
| 5 | Technical feasibility validation | Potential applications followed by focused tests on technical feasibility, preliminary decision on start-up or joint venture | TRL 5<br>CM2 | Decision on which specific application to focus on, seeking support for industrial tests |

| | | | | |
|---|---|---|---|---|
| 6 | Scale up | $H_{2020}$/SME Instrument proposal, pilot tests, pilot plant processing, industrial advice, final decision on start up or joint venture | | First exposure to real world, decision on appropriate scaling up |
| 7 | Industrial prototyping | Design and building industrial prototype, probably in collaboration with industry | TRL 6 | Based on pilot tests build and test an industrial prototype for application |
| 8 | Industrial viability testing | Economic viability of the industrial prototype | TRL 7<br>CM3 | Cost-benefit analysis to prove economic viability |
| 9 | Industrialization | Innovation is ready. Actual installation in industry or actual production of a product | TRL 8 | Lessons learnt finally applied in industry |
| 10 | Commercialization | Valorization of the innovation and industrial production or marketing and sales | TRL 9 | Final Innovation in industrial production and sales |

## 2.3 Nanotechnology Research & Entrepreneurship

### *2.3.1 Introduction*

Nanotechnology operates at the nanoscale, where the manipulation of matter yields remarkable properties and functionalities, at the nexus of physics, chemistry, biology and engineering. This interdisciplinary convergence has unlocked a wave of transformative potential that is propelling advancement in a variety of fields, including materials science, energy, electronics and healthcare. Moving beyond the confines of the laboratory, we enter the world of entrepreneurship, where the results of research on nanotechnology can flourish in terms of commercialization and societal impact.

### *2.3.2 R&D in Nanotechnology*

Nanotechnology can be considered as a General-Purpose Technology (GPT) that can be applied in every economic sector. A GPT is defined as a fundamental invention that is "shared within and across industries and enables valuable inventions and innovations", fostering valuable innovations in diverse technological domains [34]. Hence, nanotechnology emerges as a crucial driver of advanced innovations and the evolution towards a knowledge-centric economy. Due to its GPT nature, nanotechnology has also brought about a "disruptive" and "revolutionary" impact on industrialization and wealth creation [35].

Kuhn, in his theory of scientific revolutions, describes scientific development through a process of evolution and replacement of scientific theories. According to this theory, there are periods of stability (referred to in normal science), punctuated by periods of crisis that lead to a revolution and a new normal science [36].

The process for scientific development according to Kuhn's theory is shown in the **Figure 5**. Normal science solves problems of a particular period, while unsolvable problems are an anomaly. In the case of failure to solve problems, these anomalies act as a brake on scientific development.

On the other hand, the barriers created encourage testing of any innovation that will revolutionize and contribute to scientific development.

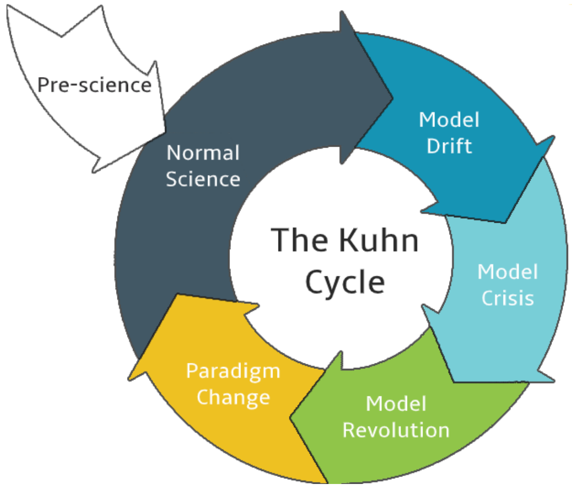



**Figure 5:** The process for scientific development.

The long-wave theory of Schumpeter explains the "technological revolution" underlying Kondratieff cycles or long wave of economic growth. According to Schumpeter, the phenomena of Kondratieff's five long cycles are a cause of technological change [37].

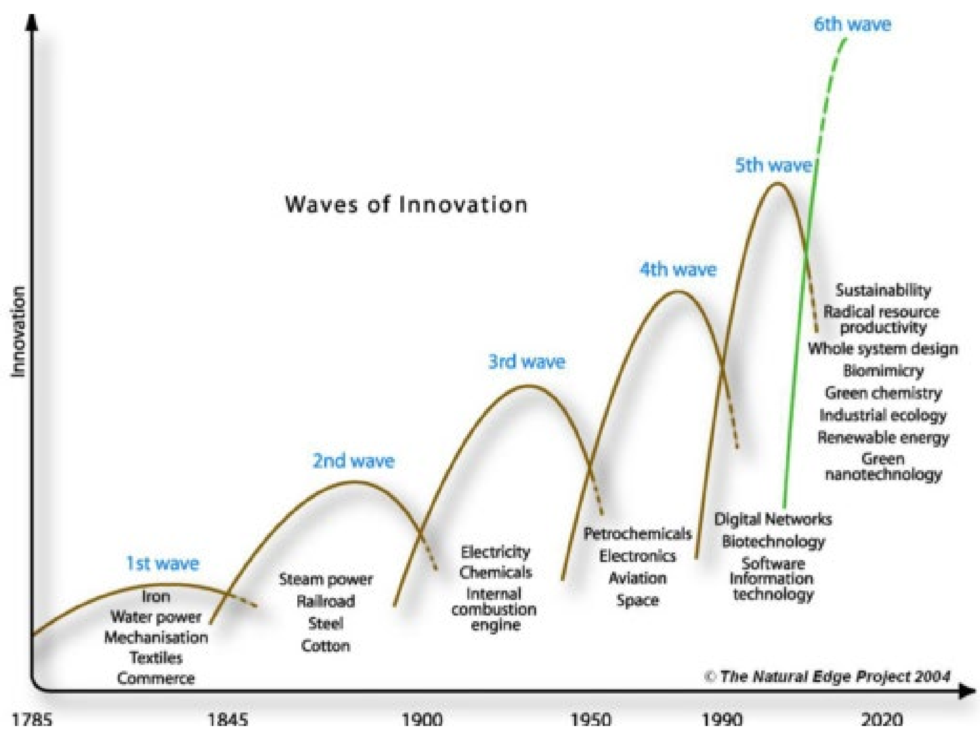



**Figure 6:** Schumpeter's Wave of Economic Growth.

From these 5 Kondratieff cycles, it is clear that nanotechnology can be a springboard for important scientific discoveries (**Figure 6**). According to [38], [39] nanotechnology can be seen as the sixth circle of Kondratieff that will bring about drastic changes in research and production. Based on Kuhn's and Schumpeter's theory of scientific and technological revolutions, nanotechnology is an evolution of normal science on solving problems of industrial production. This development can be realized through R&D activities in nanotechnology, so as to ensure future scientific and technological development.

The EU Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) has defined nanotechnology as follows:

*"Nanotechnology is the term given to those areas of science and engineering where phenomena that take place at dimensions in the nanometer scale are utilized in the design, characterization, production and application of materials, structures, devices and systems. Although in the natural world there are many examples of structures that exist with nanometer dimensions (hereafter referred to as the nanoscale), including essential molecules within the human body and components of foods, and although many technologies have incidentally involved nanoscale structures for many years, it has only been in the last quarter of a century that it has been possible to actively and intentionally modify molecules and structures within this size range. It is this control at the nanometer scale that distinguishes nanotechnology from other areas of technology."*

Definitions are typically a compromise because they must be understandable to users in order to have clear manufacturing and safety guidelines, to be marketed or to be supplied to another company, among other users. The Responsible Nano Code [40] was created because minimizing risks- both known and unknown- must come first. The code was intended to be implemented by businesses of all sizes, across all nations and in all legal frameworks. Additionally, it is based on seven tenets that are essential to the ethical advancement of nanotechnologies: 1) Stakeholder involvement, 2) board accountability, 3) worker health & safety, 4) public health, safety, environmental risks, 5) broader social environment, health and ethical implications and impacts, 6) business partner engagement, 7) transparency and disclosure.

Encompassing nanoscience, engineering and technology, nanotechnology involves the imaging, measurement, modeling and control of matter at this size scale. At the nanoscale the physical, chemical and biological properties of materials differ greatly from the properties of individual atoms, molecules and matter. In order to exploit these properties, R&D activities in nanotechnology are oriented toward understanding and creating improved materials, devices and systems [41].

The activities, procedures, raw materials, suppliers, essential resources and equipment needed to prepare the product are collectively referred to as the value chain. Utilizing the value chain framework in nanotechnology (**Figure 7**) enables decision-makers to classify research areas based on their contributions. Nanomaterials primarily align with fundamental research, while nano-intermediates are associated with applied research. The intermediate stage is where most of the innovation in nanotechnology is taking place and the stage with the greatest profit potential. Most of the companies in the nano-intermediates are new start-ups. Larger commercial entitles typically focus on nano-enabled products and services. Nanotools, which are used to manipulate and assemble nanomaterials are an important aspect of the nanotechnology value chain. Analyzing nanotechnology patents through this framework can significantly aid policy decisions and future planning efforts. Consequently, there is a need to establish supportive mechanisms to foster the development and patenting of more advanced nano-intermediate and nano-enabled products [42].

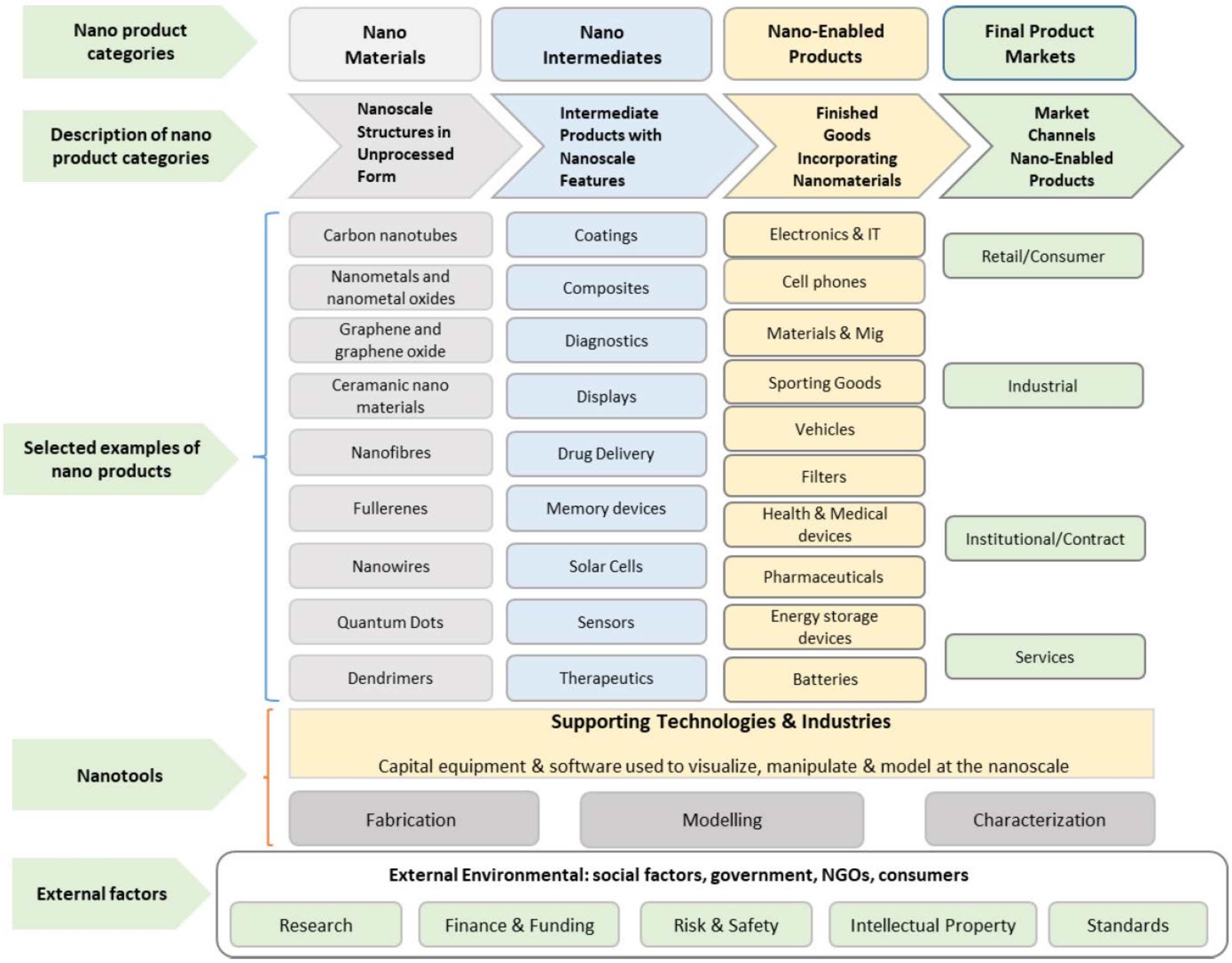



**Figure 7**: The nanotechnology value chain [42]

### *2.3.3 Critical Success Factors of Nanotechnology commercialization*

According to [43], nanotechnology R&D rely on six interconnected factors crucial for success: (1) understanding consumer demands and preferences, (2) integrating nanotechnology with existing industries and market requirements, (3) fostering multi- and interdisciplinary collaboration, (4) promoting technological convergence, (5) ensuring access to proficient R&D expertise (both scientific and entrepreneurial) and (6) cultivating an environment conducive to innovation. These six CSFs are interrelated, constructing the Nanotechnology Innovation Diamond depicted in **Figure 8.**

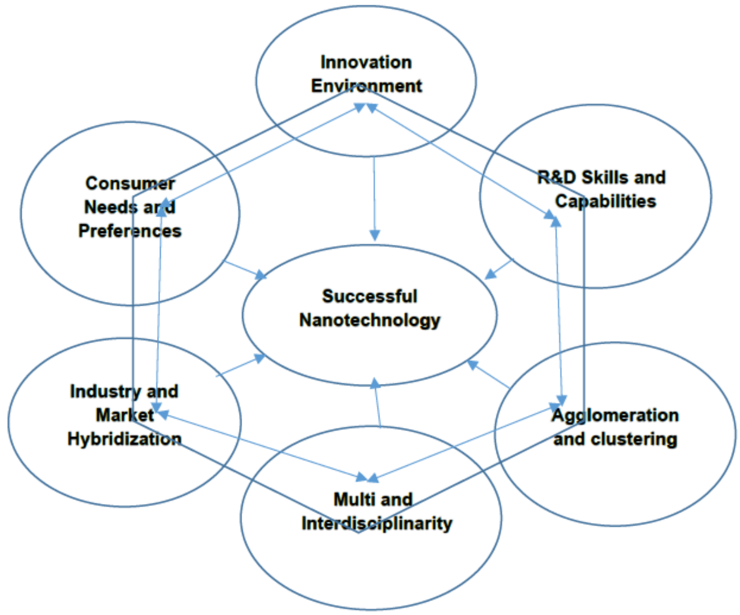



**Figure 8:** Nanotechnology Innovation Diamond [43]

The core of success in nanotechnology R&D lies in understanding consumer demands, preferences and acceptance, especially in fields such as medical, environmental, agricultural and food applications. The market for products utilizing nanotechnology is continually influenced by consumer needs and preferences. Consequently, for nano innovations to thrive, the must gain acceptance from end consumers, the public and industry stakeholders.

Meeting the demands of the market and industry entails integrating nanotechnologies into existing industries and addressing socio-economic needs (referred to as nanotechnology-hybridization). Examples of this integration include nanomedicine, nanoelectronics etc. Moreover, a single nanoscience breakthrough may have diverse applications across various technical fields. Consequently, nanotechnology researchers must continuously explore ways to align their innovations with current industry requirements and socioeconomic demands.

Nanotechnology transcends individual disciplines. It operates within both multidisciplinary and interdisciplinary frameworks. The convergence of numerous disciplines is exemplified by NBIA, which is regarded as the research frontier with the greatest potential for groundbreaking advancements. Effective nanotechnology breakthroughs typically involve collaboration among researchers from diverse fields. Furthermore, given its multidisciplinary scope and applicability across all technological domains, successful implementation of nanotechnology necessitates interdisciplinary research teams and engagement within high tech industry clusters.

The effective execution of nanotechnology R&D initiatives hinges on the presence of "scientist-entrepreneurs, individuals skilled in both theoretical and practical research, academic publication, intellectual property management and the commercialization of R&D breakthroughs. Consequently, it is imperative to establish appropriate educational systems to nurture these "scientist-entrepreneur". The Triple- Helix model is essential for developing a robust education and training framework. Collaboration between universities, businesses and government facilitates a deeper understanding of and response to the education and skill requirements of the private sector and government. This collaboration also prompts industry and government to support education by offering student internships, work-based learning opportunities, scholarships and funding joint research endeavors. As a result, strong partnerships between industry and academia are formed, fostering the development of human capital in science, engineering and technology.

Nanotechnology innovations hold the potential to benefit all sectors of industry. Therefore, nanotechnology researchers must continuously explore opportunities across various industries to uncover potential applications for their advancements. By establishing themselves in science parks or in close proximity to other industries, nanotechnology enterprises can enhance their capacity for innovation and increase their chances of commercialization. High tech clusters offer numerous advantages, including knowledge sharing, industry associations, the exchange of tacit knowledge, access to specialized infrastructure like nanofabrication facilities and readily available skilled labor. These factors create opportunities for integrating nanotechnology innovations with other industrial sectors. The emergence of nanoclusters in the field of nanotechnology, along with their superior comparative performance, underscores the significance of technological agglomeration for the success of nanotechnology research and innovation.

Another essential element driving successful nanotechnology R&D is the creation of a favorable innovation environment, facilitated by collaborative efforts among universities, research institutions, government entities and industry, utilizing systems like the Triplet Helix model and Public- Private Partnerships.

### *2.3.4 Mapping of nano-activities*

Due to the perspective of nanotechnology, most countries and international organizations have included it as one of the priorities of their science and technology policies. Individual researchers, representatives of national governments implement R&D mapping activities in nanotechnology at international levels.

Nanotechnology publications are the most appropriate measure of scientific excellence. **Figure 9a** indicates a linear increase of research papers in the subject of nanotechnology over the last few years, with 16.397 publications in 2000 rising to 246.732 in 2022. Furthermore, as the **Figure 9b** illustrates, China holds the top spot in 2023 with 110.622, having a long distance from the second India and third USA with 25.882 and 22.260 respectively. Among the countries of the European Union, Germany and the United Kingdom stand out [44].

The different rate of research production for each country is due to the fact that in many countries different conditions prevail, such as the rate and level of development, the level of education, of human resources, the characteristics of the industry.

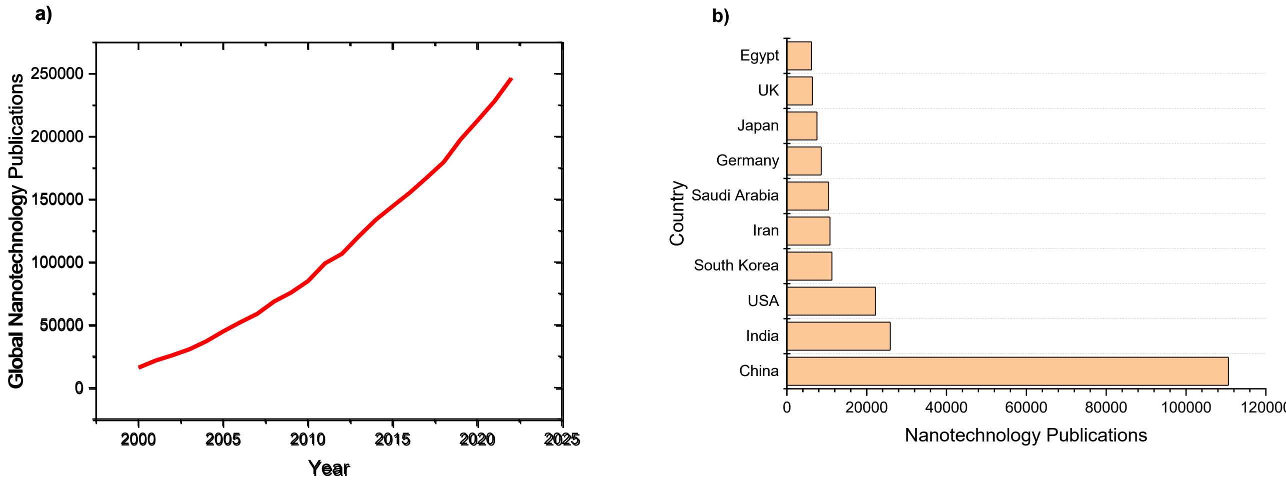
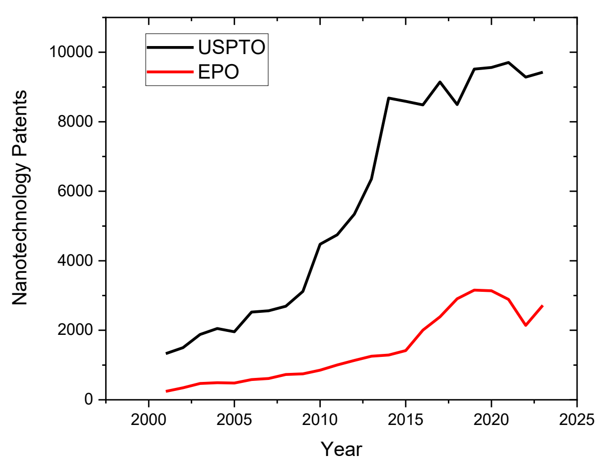



**Figure 9:** a) Evolution of global nanotechnology publications from 2000 to 2023, b) Top 10 countries in nanotechnology publications for 2023 [44]

Patents reflect the ability to transfer scientific results to technological applications and are often a prerequisite for the exploitation of research results. For this reason, their use in the analysis of the economic perspective of a technology is of central importance. Equally important is the identification of the most efficient and distinguished geographical regions worldwide in patents.

**Figure 10a** illustrates the evolution of nanotechnology patents filed in the two largest patent offices, the United States Patent & Trademark Office (USPTO) and the European Patent Office (EPO), from 2001 to 2023. In general, it is observed that the number of patents filed in the USPTO is more the EPO patents each year. For both type of patents, there is a continuous increase for the period 2001-2015. Since then, for the USPTO patents the growth rate has decreased while for EPO patents there has been a period of faster growth rate followed by a period of decline. However, in recent years there seems to be a trend towards an increase in the number of EPO patents. In 2023, the USA has filed by far the most nanotech patents in both offices, while Germany has the largest number of both USPTO and EPO patents, among European countries (**Figure 10b,c**) [45].



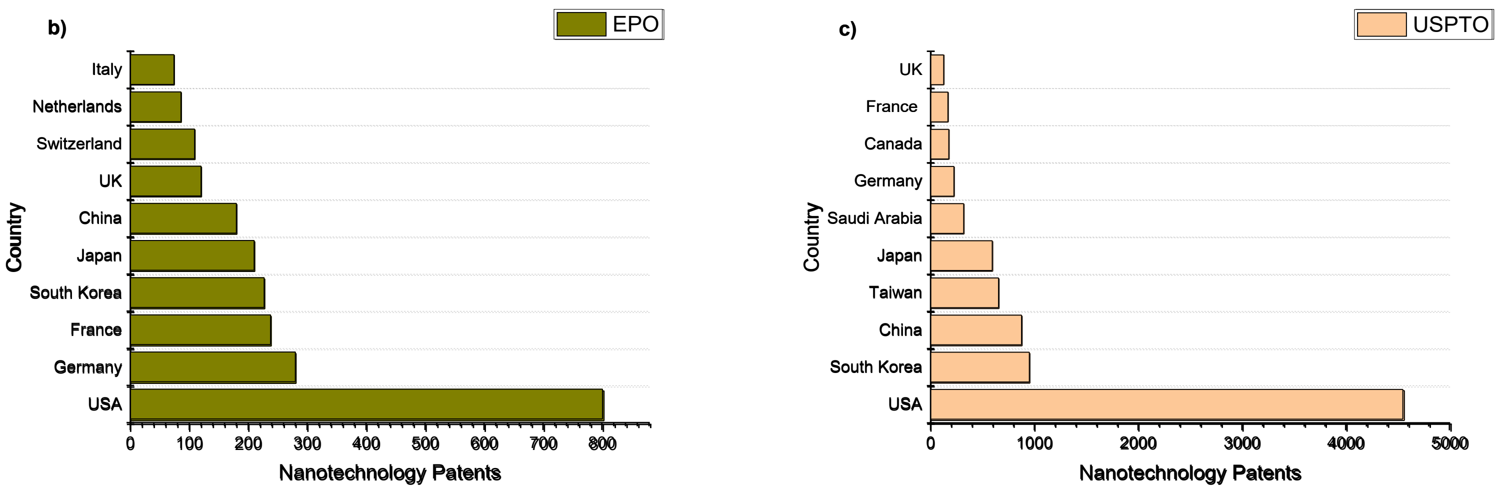



**Figure 10:** a) The evolution of EPO & USPTO nanotechnology patents from 2000 to 2023. Top 10 countries with the highest number of b) EPO and c) USPTO nanotechnology patents [45].

As far as entrepreneurship in the field of nanotechnology is concerned, according to StatNano, the USA is dominant with 1632 companies. This fact can be directly related to the large number of nanotechnology patents held by the same country, as we described above. The second country is China with 453 companies, followed by Germany, as the representative of the EU, with 409 (**Figure 11a**).

According to **Figure 11b**, the most nanotechnology companies (13.37 %) operate in the construction sector, where nanomaterials play an important role. Medicine (12.42%) and textiles (11.98%) are the next most important areas of business for nano companies. On the other hand, there are only few (1.21%) nanotechnology companies active in sports & fitness industry.

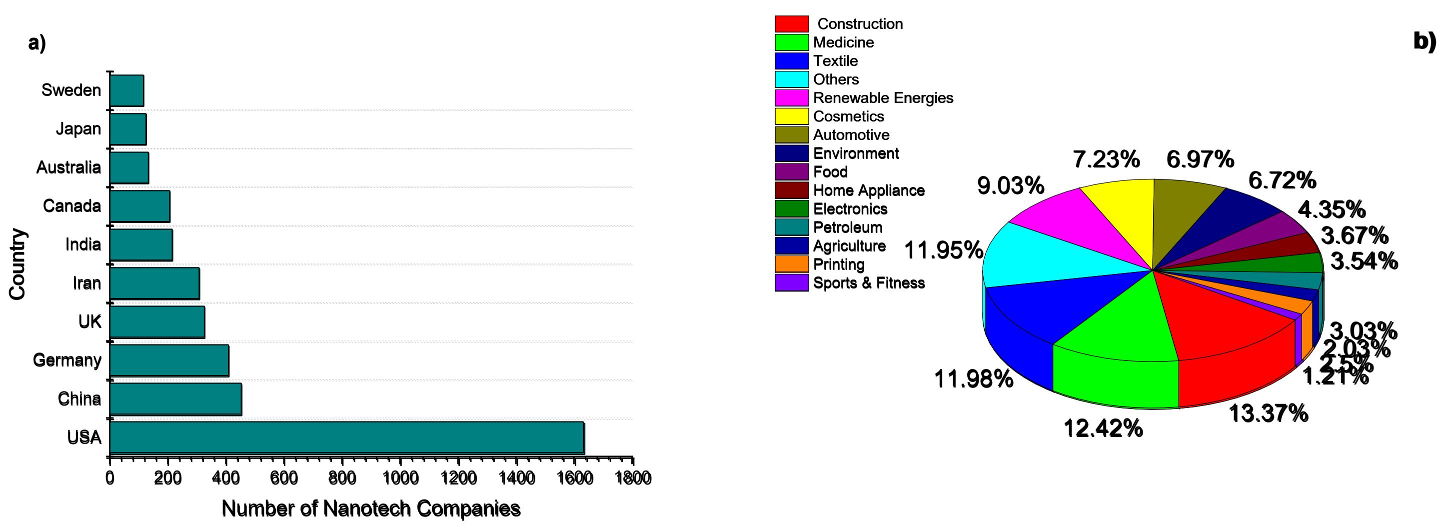



**Figure 11:** a) Top 10 countries with the highest number of nanotechnology companies. b) Percentage of global nanotechnology companies per industry [45].

As far as developments in most areas of nanotechnology are concerned, these are often associated with technical installations that require high-cost infrastructure investments. Therefore, research in nanotechnology and the development of products based on it, require a high degree of integration between URCs, spin-off companies, regional bodies and research facilities. USA, China and Germany, as representative of EU, due to their impressive indicators described above, worth further analysis concerning nanotechnology transfer and entrepreneurship strategies.

USA was the first to introduce an interagency program for coordinating, planning, and managing R&D in nanoscale science, engineering and technology called The National Nanotechnology Initiative (NNI) [46]. It was established in 2001 by President Clinton after a succession of breakthrough nanoscale discoveries in 1999. The divergence nature of NNI created knowledge is reflected to the over thirty participating agencies. The Initiative has successfully achieved the development of an active global community of professionals and organizations involved in different aspects of the multidisciplinary nanotechnology industry, influencing the culture of scientific research by fostering interdisciplinary academic research partnerships and establishing cutting edge nanotechnology infrastructure across all 50 states in both government and academic institutions. An R&D investment of $40 billion by 2023 is estimated [47]. In addition, Silicon Valley, where some of the world's foremost clusters of varied industries are located, offer significant opportunities for nanotechnology startup companies [48].

The infrastructure and guidance required for this shift from manufacturing dubbed to an innovation driven, knowledge-based economy have been greatly aided by China's central government. Since 2020, Chinese national R&D investment as share of GDP has surpassed the EU average while closing in United States **(Figure 12)** [49]. China's growing share of global R&D investments and innovation performance is also reflected in the steady increase in patents currently in force in China. This rapidly transformation of China as leader in science and innovation has been attributed to an increasing investment in the establishment of science parks, as characteristic example of the triple helix innovation model, supported by large national investments and a strong positioning of science and technology in national policymaking, planning and strategic programs since the beginning of the 1980s. The "Nanopolis" in Suzhou is the focal point of China's nanoscience infrastructure. This nanotech industrial zone is the biggest in the world. It is home to numerous international corporations as well as Chinese nanotechnology startups. Recently, it was announced the establishment of the Zhangjiang Science City in Shanghai and the Huairou Science City in Beijing as new type of science parks. The construction plan for Huairou Science Park was included in the 13th Five-Year Plan for Beijing in January 2016, and formally approved by Beijing Municipality in November 2016. The plan's stated ambition is to turn the capital of China into an international high-tech and scientific center. The Huairou Science City is envisaged to be fully operational by 2035. It is planned to span more than 100 square kilometers, and host 16 large-scale, cross-disciplinary research institutions (e.g., a High Energy Photon Source), almost 50.000 researchers, and the main campus of the University of Chinese Academy of Sciences (UCAS). The Beijing municipal government alone has committed to spend USD 2.27 billion on this major science infrastructure project The Huairou Science City covers the five major scientific areas of space science, material science, earth system science, life sciences, and intelligent science and will contain a large number of research institutes including the Institute of Nanoenergy and Nanosystems [50].

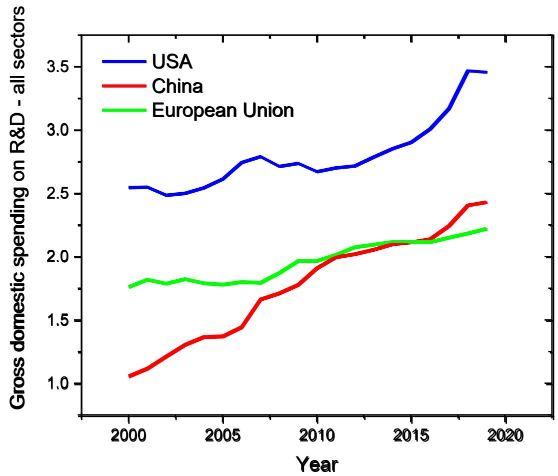



**Figure 12:** Spending on R&D [49]

Research and Innovation in nanotechnology are well-established in Germany. Numerous top-tier research institutes (Max Planck Institutes, Fraunhofer Society), academic institutions (Technical University of Munich, RWTH Aachen University) and clusters specializing in nanoscience and nanomaterials are located there. German businesses actively work with academic institutions to create and market applications utilizing nanotechnology. The close cooperation of industry and academia makes technology transfer easier. The country has a history of making consistent investments in R&D in a number of fields, including nanotechnology. Innovative research is financed by both public and private sources and nanotechnology transfer is promoted. Furthermore, Germany has a strong IP law system that supports entrepreneurs and inventors. Ensuring that innovations are recognized and monetized is one way that robust intellectual property protection. In addition, Germany has set up networks and industry clusters dedicated to nanotechnology. These platforms facilitate collaboration and knowledge exchange by bringing together researchers, startups and established companies. The country's most advanced science and technology park, Berlin Adlershof, act as a center for many different fields, including nanotechnology. Moreover, the Heidelberg Technology Park is a communication platform where researchers, developers, startups, research institutions and large-scale companies collaborate.

### *2.3.5 Nanotechnology transfer in Greece*

In Greece there are universities and research centers located all over the country. The universities are active in educational and research activities and about half of them are multi-disciplinary type while others focus on technological, agricultural, artistic, economic and business studies. All Greek universities are state self-governing organizations supervised by the Ministry of Education Religious Affairs and Sports.

While universities remain under the supervision and funding of the Ministry, their research activities are funded mainly from other sources. These funding sources include the General Secretary for Research and Technology (GSRT) of the Ministry of Development, the European

Commission and industry. The whole system works "bottom up", so the orientation of the research activities depends on the personal strategies of the faculty members and on the potentiality of the various funded programs.

As for the research center in Greece, they have strong ties with universities, although they are independent organizations. State research centers are self-governing organizations and are supervised by the GSRT. The sizes of the research centers differ since they have been created in different periods of Greek economic history and display a different culture and dynamic.

The business sector is the weakest part of the Greek R&D system. Businesses in Greece that were to be modernized and grow usually depended on technology transfer and technological support from abroad. Such an approach does not contribute to the development of research activities within the companies themselves [51]. However, efforts are being made for Greek businesses to cooperate with the URCs, aiming knowledge and technology transfer.

Since 2000, there has been a significant development in Europe's innovation policies. Innovation policies, funding possibilities and performance differ significantly between European countries, while optimal policies tend to focus on various directions, according to national needs. Towards this direction, the Greek governments prioritized the transition to a knowledge-based economy, the promotion of entrepreneurship, regional development and the opening to Europe and the world [52].

Efforts to transition to the knowledge- based economy led to measures to support innovation, research, collaboration with industry and the utilization of the results of government- funded research [53]. The main national policies on R&D and innovation are implemented through the *«ΕΣΠΑ» programs* by the Ministry of National Economy and Finance, which largely reflect the new priorities of the European Commission and the new development priorities of Greece for the coming years [54]. Additional funding sources are *the Hellenic Foundation for Research & Innovation (HFRI)* as well as *the Horizon Europe program* by the European Commission [55], [56]. Within the framework of these national and European funding programs, URCs and companies have been jointly enlisted in order to facilitate research collaboration and technology transfer.

Greek URCs have made significant progress in nanotechnology R&D and are active specifically in the fields of nanomaterials, micro-nanoelectronics and nanobiotechnology. As a result, Greek research, innovative activities in nanotechnology today cover a wide field of scientific and technological topics and include applications such as nanomedicine, smart materials, organic electronics, catalysts, etc.

Most of these groups (either laboratories or individuals) are members of the two nanotechnology networks in Greece.

The thematic network NanoNet [57] is an initiative, started in 2003 by the Aristotle University of Thessaloniki (AUTH). Various organizations such as laboratories from universities, research centers and companies participate in NanoNet from Greece, Balkans, Europe and USA. The network coordinates the services of the AUTH laboratories, but also of other laboratories in Greece and abroad, which are active in the area's nanotechnologies and nanobiotechnologies.

The MicroNano Scientific Society [58] was founded in 2004. It is a civil non-profit non-governmental organization that brings together the entire academic community of the country, several technocrats and companies active in the scientific field of Digital Technologies, Micro(Nano)electronics and Micro(Nano)technology.

The technology transfer and the creation of spin off companies are supported by various government funding initiatives that have as their ultimate goal the promotion of innovation and the modernization of Greek industry. These initiatives have led to the creation of a critical mass of supporting mechanisms in Greece for the transfer of technology from URCs and the strengthening of academic entrepreneurship.

In the last decades, most Greek URCs have created technology transfer offices. The existence of TTOs facilitates and accelerates TT activities while their experience ensures the success of their activities [59],[60]. In particular, in nanotechnology, which is mainly developed in URCs, appropriate commercialization supported by these is necessary for use in applications.

The first state initiatives for the development of technology parks and incubators were undertaken in 1989. Their goal was to create supporting mechanisms for spin-off companies, which will be "close" to the research infrastructures of the URCs. State policies encouraged URCs to commercialize R&D results and also aimed to attract other businesses to benefit from access to knowledge produced by URCs. In this way 6 Science and Technology Parks were created in different regions of Greece:

LEFKIPPOS Attica Technology Park [61] was established at National Centre for Scientific Research Demokritos and is located within the Center's facilities. Its purpose is to enhance the development of new companies and strengthen their efforts to commercialize innovative ideas and cutting-edge technologies.

Patras Science Park [62] was an initiative of the Foundation for Research and Technology and the Institute of Chemical Engineering Sciences (FORTH/ICE-HT) back in 1989, that became in 2001 an independent Public Limited Company owned by the Greek Ministry of Finance. Its primary objective is the promotion of innovative technological units and businesses.

Lavrion Technological Cultural Park [63] replaced the old French «Compagnie francaise des mines du Laurium» in 1992 at the initiative of National Technical University of Athens and with the cooperation and support of the Lavrion social agencies, Hellenic Republic and the European Union. The LTCP aims to connect the scientific and technological research carried out at NTUA with the needs and interests of the business world.

Science & Technology Park of Crete (STEP-C) [64] is an action by the Foundation of Research & Technology- Hellas that dates to 1988. The main goal of the park was to present the important research activities of the Institutes to society and at the same time to contribute substantially to the development of the region. Thus, the main role of STEP-C is to disseminate the know-how produces in the URCs of the region and to provide services to businesses established in its premises.

Scientific and Technological Park of Epirus (STEPE) [65] was founded in 1999 by the University of Ioannina and the Region of Epirus. The construction and equipment were financed by the Epirus PEP 2000-2006 of the 3$^{rd}$ Community Support Framework and Thessaly-Sterea Hellas- Epirus OP 2007-2013 of the NSRF. Since 2003, the management company "Scientific and Technological Park of Epirus SA" has taken over the operation of the park. The mission of STEPE is to be the main support body for the introduction of new and innovative technologies in both the private and public sector.

In 2019, the creation of the Thessaloniki Innovation and Technology Center (Thess INTEC) [66] was announced. The park is set to host educational, research, financial and industry bodies allowing direct communication between stakeholders. Private investors, large business interests and individual patrons have already expressed interest in the park.

According to [49], there is an increase in funding for R&D in Greece. From 0.55% in 2003, R&D investments as share to GDP raised to 1.46 % in 2021 (**Figure 13**). The expenditure in R& D is acknowledged that leads to product and process innovations, if the country comply with the European funding strategy, promote the creation of regional technological hubs and combine the national economic priorities with the international scientific and technological trends, such as nanotechnology [67].

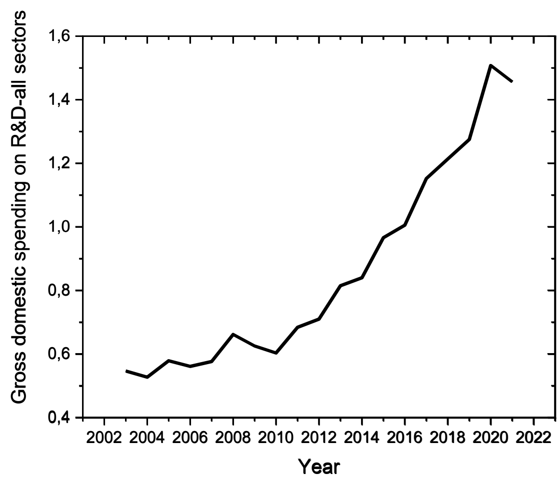



**Figure 13:** Greece spending on R&D.

**Table 2** summarizes the trends of nanotechnology publishing in Greece from 2007 to 2021, derived from the Web of Science Core Collection database [44]. There were 473 publications in 2007 which increased to 979 in 2021, showing a 207% growth rate. On the other hand, total publications for all disciplines raised from 10447 in 2007 to 20034 in 2021, which is an increase of 192%. Hence, the growth of nanotechnology related research publications outpaced that of all other areas.

**Figure 14** indicates that the overall contribution of nanotechnology articles raised from 4.53% in 2007 to 4.9% in 2021, whereas in 2016 and 2019 reach a value over 5.4%. These results suggest a low annual growth from 2007 to 2021.

**Table 2:** Nanotechnology publication trend for Greece

| Year | Total Scientific Publications | Nanotechnology Publications | % Nanotech Share |
|---|---|---|---|
| 2007 | 10447 | 473 | 4.53 |
| 2008 | 11244 | 496 | 4.41 |
| 2009 | 11901 | 511 | 4.29 |
| 2010 | 12382 | 519 | 4.19 |
| 2011 | 12683 | 555 | 4.38 |
| 2012 | 13061 | 592 | 4.53 |
| 2013 | 12880 | 623 | 4.84 |
| 2014 | 12929 | 663 | 5.13 |
| 2015 | 12964 | 676 | 5.21 |
| 2016 | 13700 | 748 | 5.46 |
| 2017 | 14200 | 739 | 5.20 |
| 2018 | 14596 | 790 | 5.41 |
| 2019 | 16150 | 823 | 5.1 |
| 2020 | 17752 | 896 | 5.05 |
| 2021 | 20034 | 979 | 4.89 |

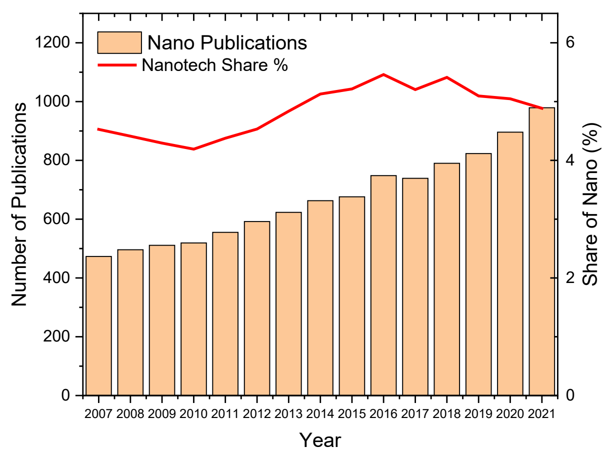



**Figure 14:** Greece nanotechnology publications.

The onset year of nanotechnology patents in Greece is 2008. Since then, there is an increasing trend for both EPO and USPTO patents (**Figure 15**). Greece is the 37th country in total number of EPO nanotechnology patents and the 40th country in total number of USPTO patents, respectively [45].

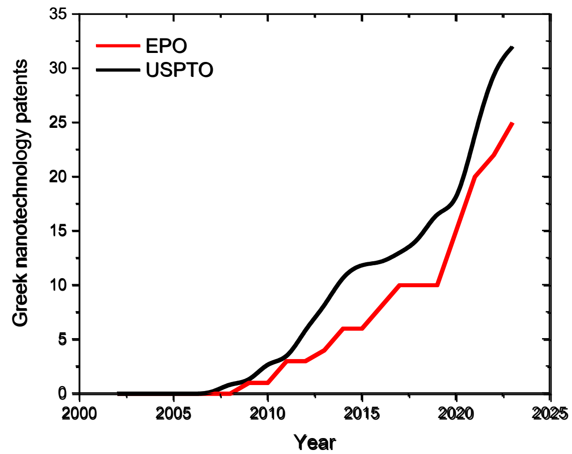



**Figure 15:** Evolution of Greek EPO & USPTO nanotechnology patents.

From StatNano data [45], there are 16 nanotech Greek companies, mainly spin off and SMEs. The majority of them (25%), belong to construction sector whereas there are companies in textiles (18.75%), medicine (12.5%), renewable energies (12.5%), automotive (12.5%), home appliance (6.25%), agriculture (6.25%) and other businesses (6.25%) (**Figure 16**).

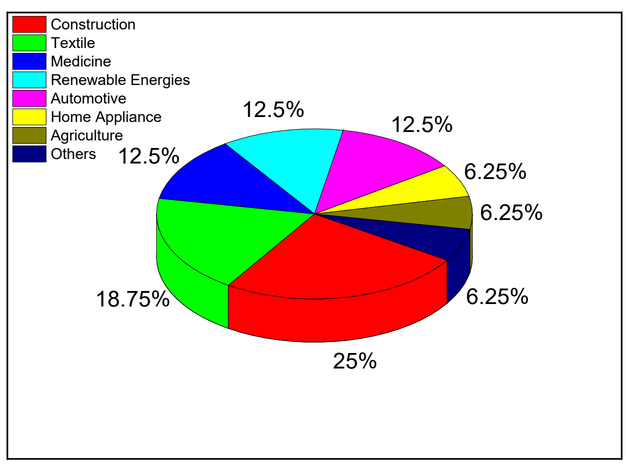



**Figure 16:** Distribution of Greek nanotechnology companies in different industries.

The low production of nanotechnology patents and the small number of nanotech companies, despite of the increased R&D investment and the growing number of nanotechnology research publications, can be attributed to the problematic mediating institutions in the technology transfer process. A recent survey on the TTOs of 12 major Greek universities and research centers [68] revealed an underdeveloped innovation ecosystem with lack of collaboration patterns between universities, research centers and industry, unrefined regulations and budget constraints. Furthermore, Greece's economic instability is difficult to create a conducive environment for efficient TT procedures.

# 3. Research Methodology

## 3.1 Introduction

As already indicated, this research aimed at bringing to light the nanotechnology innovation model in Greece, technology transfer and the critical success factors for the commercialization of nanotechnology research results produced by Greek URCs. A questionnaire survey was conducted, including both academic and industrial participants, to investigate the Greek nanotechnology innovation ecosystem spherically.

## 3.2 Population

Experts in nanotechnology related fields from Greece make up the survey population. The study population was built by combining databases of nanotechnology URC laboratories and spin off companies from the two Greek nanotechnology networks mentioned above, NanoNet and MicroNano and information on diverse nanotechnology research and entrepreneurship initiatives around the country that is freely available on the internet. The university laboratories, the research center institutes and spin off/spin out companies that participated in our study are gathered in Appendix A. In order to increase the validity of our research, we chose only faculty members and senior researchers of URCs and managers of nanotechnology companies to attend. Consequently, a sample of 425 was selected and a total of 72 replies were received, representing a response rate of 17%. Because at least one response was received from each of the targeted academic & research organizations and companies, 17% of respondents, despite the low response rate, accurately represent the study's target population (Appendix B).

## 3.3 Data collection

Questionnaire in the form of link (online Google form) was sent to nanotechnology experts via email. The link for questionnaire was (https://forms.gle/4FtKpna1qdYP6EcN8). The response was received on the Google sheet which was analyzed. Electronic survey data collection is becoming more popular, replacing posted surveys or human administered surveys. Its benefits include quick response times, low costs and simple distribution.

In our case, with 425 participants, the sample size is sizable and widely dispersed across Greece. Therefore, contacting 425 people via an electronic survey is more cost effective and practical than doing so through postal survey or interviews. In addition, experts in the field of nanotechnology research, development and entrepreneurs have mail addresses. For this reason, electronic surveys are most suitable for this group.

## 3.4 Questionnaire Structure

The questionnaire shown in Appendix C was developed for this study, inspired by Ref. [12], [17], [33], [43]. The instrument has four sections described below:

**Section A: Demographic information** – In this section, the demographic information of the respondents was gathered. First, this data is used as a quality control measure to make sure the appropriate experts in nanotechnology innovation respond. Its second purpose is to determine a respondent's position within the nanotechnology innovation value chain. Close-ended questions are used in this section to gather nominal data.

**Section B: Nanotechnology critical success factors** – This section is designed to evaluate the "successful nanotechnology" construct. It evaluates what experts consider to be successful nanotechnology R&D and investigates the critical factors for successful nanotechnology innovations, using sets of five- point Likert scale questions.

**Section C: Technology Transfer** – In this section the efficiency and parameters of nanotechnology transfer are explored with close ended questions.

**Section D: Nanotechnology Innovation Model in Greece** – This section ranks the research areas in nanotechnology according to their impact on science and socioeconomic development, as determined by the expert survey. Moreover, the nanotechnology innovation model in Greece is investigated by sets of five- point Likert scale questions.

## 3.5 Questionnaire Processing and Analysis

The survey data was analyzed using OriginPro 2018 (SR1 b9.5.1.195, OriginLab Corporation). Microsoft Excel was used to complement data analysis. Both descriptive and inferential statistics were used to present results and interpret data.

# 4. Results and Discussion

## 4.1 Demographic information of the respondents

The demographic statistics of the respondents were evaluated according to their job descriptions and the stage of the nanotechnology value chain at which they are involved. These results are reported in **Figures 17, 18**.

**Figure 17a** shows the job descriptions of the survey participants. The majority of the respondents (80.55%) work as researchers and academics whereas R&D managers and engineers constitute 19.45% of responses. **Figure 17b** shows that most of the participants work at research centers (52.78%) and universities (38.89%) and only 8.33% indicate that they are occupied in industry.

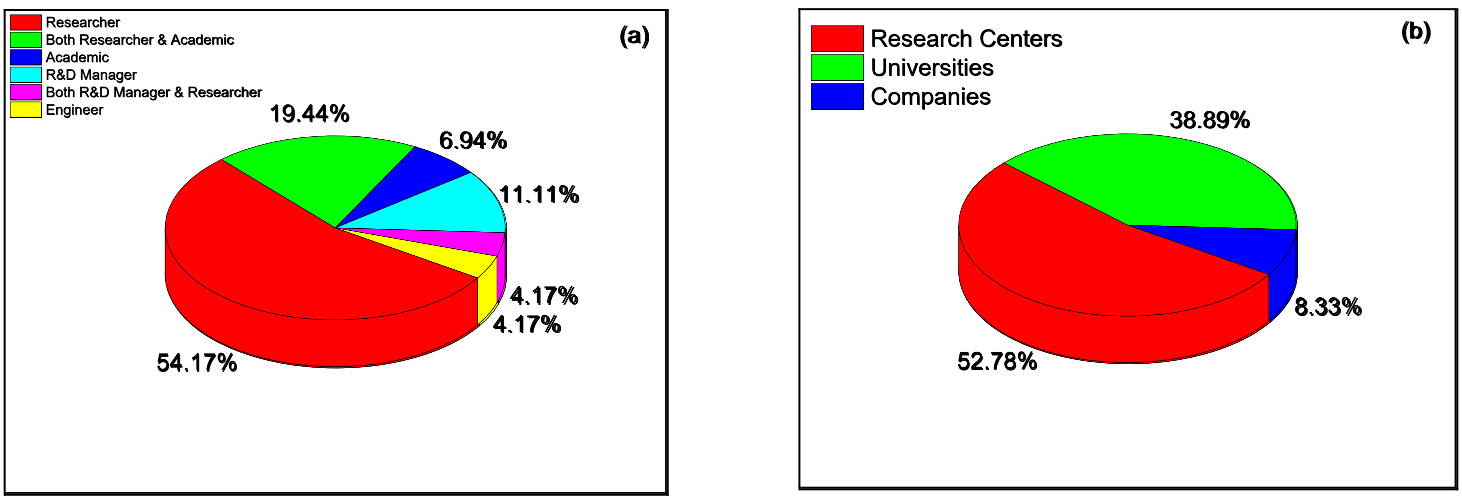



**Figure 17:** Respondents a) job description and b) workplace.

**Figure 18** presents the stage of the nanotechnology value chain at which the respondents work. The highest percentage of the nanotechnology experts, 73.6%, work in the initial stage of the value chain (nanomaterials). The second and third stages which are nano-intermediaries and nano-enabled products have 36.1% and 44.4% respectively. Hence, from a foresight and technology management perspective, there is a need for more nanotechnology experts to concentrate in the development of nano-intermediaries and nano-enabled products so that Greece can position itself to produce more nanotechnology products. The external environment makes up 9.7% and nanotools, which are essential to the nanotechnology value chain and are used at all three stages, hold 8.3%.

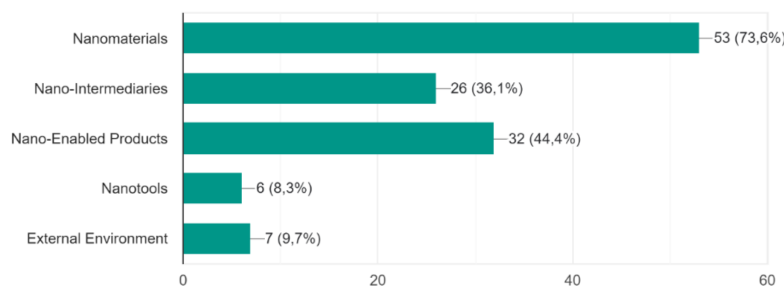



**Figure 18:** Stage of the nanotechnology value chain at which respondents work.

## 4.2 Critical Success Factors for Nanotechnology

This section presents the descriptive statistics for the constructs on successful nanotechnology and critical success factors for nanotechnology. The experts ranked the corresponding variables for each one, using a 5-point Likert scale which ranges from 1= Strongly disagree to 5= Strongly agree.

The descriptive statistics for the concept of successful nanotechnology and its associated variables are shown in **Table 3**. The most important factor found, was that successful nanotechnology improves already- existing goods and services. The fact that successful nanotechnology leads to the commercialization of research results was the variable with the lowest ranking. The mean score for each of the six variables ranged from 3.750 to 4.208, suggesting that respondents generally agreed that these factors are associated with successful nanotechnology innovation.

**Table 3:** Successful Nanotechnology

| **Variable** | **N** | **Mean** | **Std. Deviation** | **Rank** |
|---|---|---|---|---|
| 6(b) Successful nanotechnology R&D results in the improvement of existing products and services | 72 | 4.208 | 0.627 | 1 |
| 6(a) Successful nanotechnology R&D results in the development of new products and services | 72 | 4.097 | 0.715 | 2 |
| 6(d) Successful nanotechnology R&D leads to new technology licensing opportunities | 72 | 4.014 | 0.722 | 3 |
| 6(c) Successful nanotechnology R&D results in the production of patents and/or trade secrets | 72 | 4.014 | 0.741 | 4 |
| 6(f) Successful nanotechnology R&D leads to the formation of new companies and/or spin-off companies | 72 | 3.931 | 0.845 | 5 |
| 6(e) Successful nanotechnology R&D leads to commercialization of research results | 72 | 3.750 | 0.900 | 6 |

**Table 4** presents the descriptive statistics for a conducive innovation environment. The two most important variables are strategic partnerships (4.375) and government- supported infrastructure (4.139). The respondents ranked the alignment of nanotechnology to government strategy as the least important variable. All four variables had a mean score between 3.014 and 4.375, implying that respondents agreed that they are essential.

**Table 4:** Conducive innovation environment

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 7(c) Strategic partnerships between government, industry, academia, and research institutions are important for successful nanotechnology innovation. | 72 | 4.375 | 0.740 | 1 |
| 7(d) Government-supported research infrastructure, and skills development are critical for successful nanotechnology innovations. | 72 | 4.139 | 0.924 | 2 |
| 7(a) The primary factor driving successful nanotechnology innovations is a conducive innovation environment created by government policies. | 72 | 3.417 | 1.071 | 3 |
| 7(b) Most successful R&D innovations in nanotechnology are those aligned with government priorities. | 72 | 3.014 | 1.120 | 4 |

The descriptive statistics on the variables related to consumer perceptions and needs are observed in **Table 5.** The fulfillment of consumer's need or demand is the most crucial factor. The mean score for each of the four variables ranged from 3.708 to 4.139, indicating that respondents generally agreed that the variables are important.

**Table 5:** Consumer perceptions & needs

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 8(a) In order for Nanotech innovations to be successful in the market, they must fulfill a need or a demand. | 72 | 4.139 | 0.793 | 1 |
| 8(d) Most consumers of nanotechnology products are not aware that they are using nanotechnology-based products. | 72 | 4.069 | 0.719 | 2 |
| 8(b) Positive market perceptions of nanotechnology products by the public are a key success factor for nanotech innovations, especially those with applications in medicine, environment, cosmetics, and food. | 72 | 4.014 | 0.661 | 3 |
| 8(c) Successful nanotechnology research must incorporate consumer and market needs early in the research. | 72 | 3.708 | 1.013 | 4 |

The descriptive statistics for the variables involved in agglomeration and clustering are shown in **Table 6.** The mean score for the variables ranged from 3.514 to 3.958. The factor that ranks highest is the fact that clustering and centers of excellence provide a conducive environment for startup creation. The second top-ranked variable is that clustering efforts improve nanotechnology's success rate.

**Table 6:** Agglomeration & clustering

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 9(d) Nanotechnology clusters and nanotech centers of excellence provide a conducive environment for entrepreneurs and nanotech start-up companies. | 72 | 3.958 | 0.721 | 1 |
| 9(c) Working within a nanocluster enables sharing tacit knowledge, specialized infrastructure, and resources. Hence it increases the success rate of nanotechnology innovations. | 72 | 3.903 | 0.715 | 2 |
| 9(b) There is a higher success rate for nanotechnology research conducted within nanotech research centers, science parks, and clusters. | 72 | 3.889 | 0.928 | 3 |
| 9(a) The physical location of nanotechnology R&D facilities is a significant factor that contributes to innovation success; some locations present a competitive advantage in facilitating successful nanotech innovations. | 72 | 3.514 | 0.964 | 4 |

The results for R&D skills necessary for successful nanotechnology are presented in **Table 7**. With an average score of 3.750 technological entrepreneurship skills found to be the most crucial. The lowest ranked skill was intellectual management with an average of 3.611.

**Table 7:** R&D Skills

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 10(d) Successful nanotech innovations emanate from R&D teams that have technological entrepreneurship skills. | 72 | 3.750 | 0.783 | 1 |
| 10(b) Successful nanotech innovations emanate from R&D teams that possess innovation management and commercialization skills. | 72 | 3.736 | 0.888 | 2 |
| 10(a) Successful nanotechnology innovations emanate from R&D teams with high skills in scientific research, e.g., teams that have a high number of publications, a high number of citations, etc. | 72 | 3.625 | 0.985 | 3 |
| 10(c) Successful nanotech innovations emanate from teams with intellectual property management skills such as the ability to patent and license innovations. | 72 | 3.611 | 0.881 | 4 |

The conclusions for the nano-hybridization variables are displayed in **Table 8**. Collaborations between academia and industry rank first. Secondly, nanotechnology needs to be in line with economic and social needs, like those for nanomedicine and nanoenergy. The means of the four variables ranged from 3.736 to 4.250.

**Table 8:** Nano-hybridization

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 11(b) Industry and academia collaborations are essential for successful nanotechnology innovations. | 72 | 4.250 | 0.868 | 1 |
| 11(c) Successful nanotechnology innovations must be aligned to socio-economic needs, e.g., energy security, clean water, medical needs, among others | 72 | 4.125 | 0.838 | 2 |
| 11(d) Strategic R&D partnerships between industry and national research facilities are important for successful commercialization nanotechnology research | 72 | 4.097 | 0.772 | 3 |
| 11(a) Successful nanotechnology innovations must be aligned to existing industry sectors, for example, nano-energy, nanobiotechnology, nanoelectronics, nanoagriculture, and nanomedicine. | 72 | 3.736 | 0.979 | 4 |

The results for the last CSF, interdisciplinarity and multidisciplinarity in nanotechnology, are shown in **Table 9**. The two most important factors are that nanotechnology is a multidisciplinary field and a combination of several cross-cutting scientific skills. The score for the four variables ranged from 4.250 to 4.681.

**Table 9:** Multi-Interdisciplinarity

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 12(a) Nanotechnology is a multidisciplinary field | 72 | 4.681 | 0.601 | 1 |
| 12(c) Nanotechnology cannot be viewed as a stand-alone discipline but combines several cross-cutting scientific skills | 72 | 4.389 | 0.683 | 2 |
| 12(b) Successful Nanotechnology innovations are produced by interdisciplinary teams | 72 | 4.292 | 0.701 | 3 |
| 12(d) Due to its multidisciplinarity and interdisciplinarity nature, nanotechnology is emerging as the core for the convergence of several disciplines. | 72 | 4.250 | 0.666 | 4 |

Finally, **Figure 19** illustrates the summary of the six CSFs. The mean of all CSFs ranged from 3.681 to 4.403. R&D skills were ranked last, while multi- and interdisciplinarity and nano-hybridization were selected as the top two.

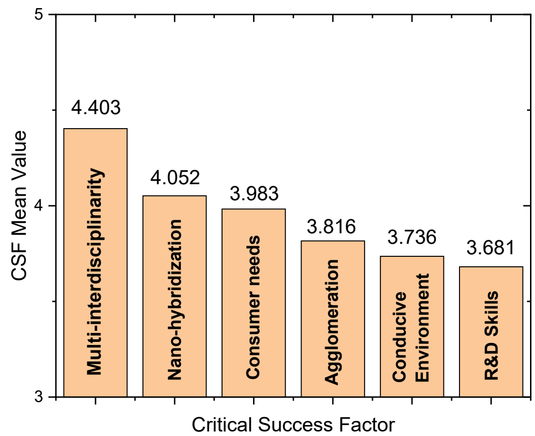



**Figure 19**: CSFs mean ranking.

The next step was to identify if there was a statistical difference between the means of the six CSFs. **Table 10** presents the paired samples t-Test at a 95% confidence level for the CSFs. The results were used in evaluating hypothesis stated below:

- Null Hypothesis: There is no statistical difference between the means of nanotechnology CSFs ($H_o$: $\mu_1=\mu_2$)
- Alternative Hypothesis: There is a statistical difference between the means of nanotechnology CSFs ($H_a$: $\mu_1\neq\mu_2$)

If $p< 0.05$ (significant), there is a statistically difference between the means. If $p> 0.05$ (non-significant), there is not statistically difference between the means.

The results prove that out of the 15 possible mean combinations, only 3 pairs have statistically insignificant differences in their mean $p> 0.05$. Most of the pairs, which is 12, have a statistically significant difference in their means. Therefore, the null hypothesis, which states that the paired population means are equal for all six CSFs is rejected and the alternative hypothesis is accepted.

**Table 10:** Paired samples t-Test for CSFs

| Pair | Paired Differences | | | t | df | Sig. (2-tailed) | Result |
|---|---|---|---|---|---|---|---|
| | Mean Difference | Std. Difference | Std. Error Mean | | | | |
| \|Multi-Interdisciplinarity-Nano-hybridization\| | 0.35069 | 0.98345 | 0.05795 | 6.052 | 287 | 0.000 | Significant |
| \|Multi-Interdisciplinarity-R&D Skills\| | 0.72222 | 0.98025 | 0.05776 | 12.503 | 287 | 0.000 | Significant |
| \|Multi-Interdisciplinarity-Agglomeration\| | 0.58681 | 1.02211 | 0.06023 | 9.743 | 287 | 0.000 | Significant |
| \|Multi-Interdisciplinarity-Consumer needs\| | 0.42014 | 0.98448 | 0.05801 | 7.242 | 287 | 0.000 | Significant |
| \|Multi-Interdisciplinarity-Conducive Environment\| | 0.66667 | 1.26326 | 0.07444 | 8.956 | 287 | 0.000 | Significant |
| \|Nano-hybridization-R&D Skills\| | 0.37153 | 1.10943 | 0.06537 | 5.683 | 287 | 0.000 | Significant |
| \|Nano-hybridization-Agglomeration\| | 0.23611 | 1.04921 | 0.06183 | 3.819 | 287 | 0.000 | Significant |
| **\|Nano-hybridization-Consumer needs\|** | **0.06944** | **1.05363** | **0.06209** | **1.119** | **287** | **0.264** | **Non-Significant** |
| \|Nano-hybridization-Conducive Environment\| | 0.31597 | 1.23571 | 0.07282 | 4.340 | 287 | 0.000 | Significant |
| \|R&D Skills-Agglomeration\| | 0.13542 | 1.10387 | 0.06505 | 2.082 | 287 | 0.000 | Significant |
| \|R&D Skills-Consumer needs\| | 0.30208 | 1.06695 | 0.06287 | 4.805 | 287 | 0.038 | Significant |
| **\|R&D Skills-Conducive Environment\|** | **0.05556** | **1.3449** | **0.07925** | **0.701** | **287** | **0.484** | **Non-Significant** |
| \|Agglomeration-Consumer needs\| | 0.16667 | 1.13543 | 0.06691 | 2.491 | 287 | 0.013 | Significant |
| **\|Agglomeration-Conducive Environment\|** | **0.07986** | **1.19983** | **0.0707** | **1.130** | **287** | **0.260** | **Non-Significant** |

| |Consumer needs- Conducive Environment| | 0.24653 | 1.31395 | 0.07743 | 3.184 | 287 | 0.002 | Significant |
|---|---|---|---|---|---|---|---|

**Note:** The bold highlighted mean pairs have no statistically significant difference

As final analysis, we investigated the correlations between the CSFs and between the CSFs and "Successful Nanotechnology". **Table 11** presents the Pearson linear correlations between all the possible CSFs pairs. The 11 pairs have a significant positive linear correlation with each other. Conducive innovation environment seems to have significant Pearson correlation only with nano-hybridization and agglomeration, whereas there is no correlation between agglomeration and consumer needs.

**Table 11**: Paired Pearson correlations between the CSFs

| Pair | Correlation Test Means | N | Correlation (r) | Sig. (p) | Result |
|---|---|---|---|---|---|
| 1 | Multi-Interdisciplinarity- Nano-hybridization | 72 | 0.23115 | 0.000 | Correlation |
| 2 | Multi-Interdisciplinarity- R&D Skills | 72 | 0.23729 | 0.000 | Correlation |
| 3 | Multi-Interdisciplinarity- Agglomeration | 72 | 0.12783 | 0.030 | Correlation |
| 4 | Multi-Interdisciplinarity- Consumer needs | 72 | 0.14976 | 0.011 | Correlation |
| **5** | **Multi-Interdisciplinarity- Conducive Environment** | **72** | **0.07167** | **0.225** | **No Correlation** |
| 6 | Nano-hybridization- R&D Skills | 72 | 0.21296 | 0.000 | Correlation |
| 7 | Nano-hybridization- Agglomeration | 72 | 0.27128 | 0.000 | Correlation |
| 8 | Nano-hybridization- Consumer needs | 72 | 0.23685 | 0.000 | Correlation |
| 9 | Nano-hybridization- Conducive Environment | 72 | 0.25117 | 0.000 | Correlation |
| 10 | R&D Skills- Agglomeration | 72 | 0.19405 | 0.000 | Correlation |
| 11 | R&D Skills- Consumer needs | 72 | 0.21812 | 0.000 | Correlation |
| **12** | **R&D Skills- Conducive Environment** | **72** | **0.10865** | **0.07** | **No Correlation** |
| **13** | **Agglomeration- Consumer needs** | **72** | **0.08003** | **0.176** | **No Correlation** |
| 14 | Agglomeration- Conducive Environment | 72 | 0.27853 | 0.000 | Correlation |
| **15** | **Consumer needs- Conducive Environment** | **72** | **0.10182** | **0.085** | **No Correlation** |

**Note:** The bold highlighted mean pairs have no statistically significant linear correlation

**Table 12** shows the correlation between the CSFs and Successful Nanotechnology. The results indicate that except of agglomeration and conducive innovation environment, the rest CSFs have a statistically positive linear correlation to successful nanotechnology.

**Table 12**: Paired Pearson correlations between the Successful Nanotechnology and CSFs

| Pair | Correlation Test Means | N | Correlation (r) | Sig. (p) | Result |
|---|---|---|---|---|---|
| 1 | Multi-Interdisciplinarity- Successful Nanotechnology | 72 | 0.29318 | 0.000 | Correlation |
| 2 | Nano-hybridization- Successful Nanotechnology | 72 | 0.18354 | 0.002 | Correlation |
| 3 | R&D Skills- Successful Nanotechnology | 72 | 0.23891 | 0.000 | Correlation |
| **4** | **Agglomeration- Successful Nanotechnology** | **72** | **0.09524** | **0.107** | **No Correlation** |
| 5 | Consumer needs- Successful Nanotechnology | 72 | 0.17169 | 0.003 | Correlation |
| **6** | **Conducive Environment- Successful Nanotechnology** | **72** | **0.02817** | **0.634** | **No Correlation** |

**Note:** The bold highlighted mean pairs have no statistically significant linear correlation

In conclusion, Greek nanotechnology experts validated the concept of Nanotechnology Innovation Diamond and its six edges as critical factors for successful commercialization. These CSFs are correlated in such a way that nanotechnologies and current socioeconomic needs can hybridize as a result of consumer needs, giving rise to industries like nano-textiles, nanoelectronics, nano-cosmetics, nanomedicine, nano-agriculture. Agglomeration/ clustering of nanotechnology R&D is essential due to the need for interdisciplinary teams and to form partnerships with other economic sectors. The URC's ability to conduct research and commercialize nanotechnology will be enhanced by this clustering. Businesses will benefit from clusters due to the availability of skilled labor, industry alliances, sharing of technical knowledge, localized special infrastructure and expert knowledge spillover effect across businesses. Ultimately, it is imperative to function within an ecosystem that fosters creativity, like the Triple Helix, a framework that facilitates public-private partnerships in R&D to optimize assets and skills. However, the non- linear positive correlation between some of the CSFs and between agglomeration- Successful Nanotechnology and Conducive Innovation Environment- Successful Nanotechnology dictates that Nanotechnology Innovation Diamond concept is not fully adopted by Greek nanotechnology experts and that further actions should be done toward this way.

## 4.3 Nanotechnology Transfer in Greece

This section discusses the survey results regarding the Greek nanotechnology transfer and innovation model. According to **Figure 20,** the most projects nanotechnology experts are involved in, are TRL 3 (47.89%). This is a logical finding as the primary active entities in the field of nanotechnology are URC's research groups. On this stage, inventors should start thinking of how to protect their IPs, for example by patent or licensing. Conversely, projects with high technology readiness level (TRL 7, 8, 9) are only 7,05% in total.

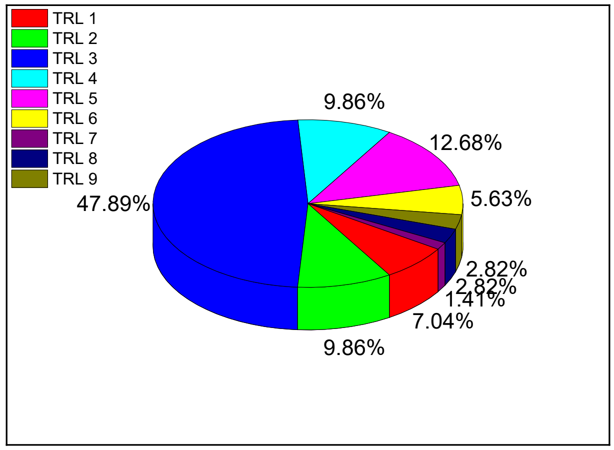



**Figure 20:** TRL of nanotechnology projects that respondents participate.

Concerning the main funding source (**Figure 21**), national funding initiatives seem to be the most common in nanotechnology R&D projects, followed by international investments, mainly in the form of Horizon Europe grants. On the other hand, a hybrid National/Private funding type is the most unusual to occur. An interesting fact is that most of the respondents agreed that nanotechnology entities are unable to support R&D without follow up funding (**Figure 22**).

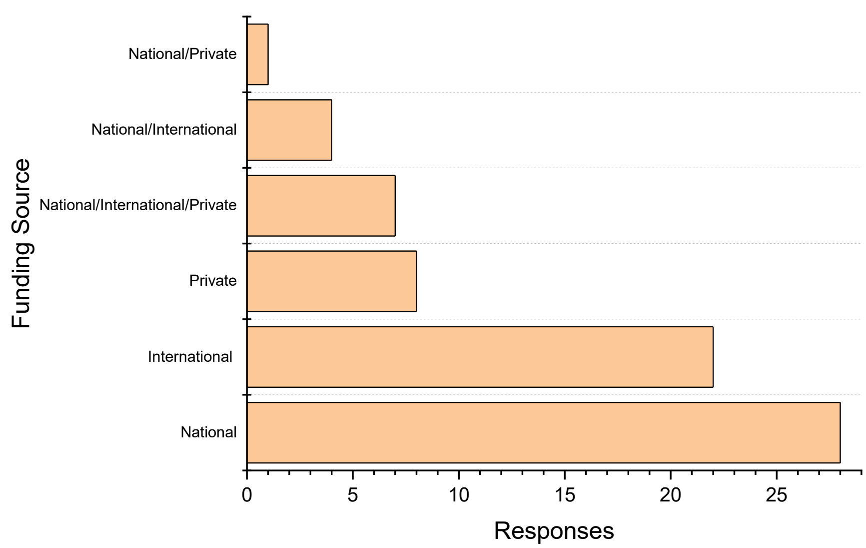



**Figure 21**: The main funding source of nanotechnology projects.

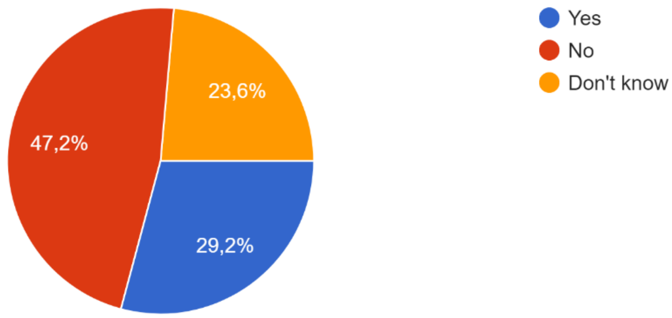



**Figure 22**: Answers of the survey participants to the question if nanotechnology entities are able for further R&D, without follow up funding.

According to **Figure 23a,** most of the nanotechnology experts (54.2%) have commercialization and TT skills whereas the 52.8% of the participants are interested to participate in commercialization actions (**Figure 23b**), even if this would take time off their research work (**Figure 23c**).

The majority of survey respondents (73.6%) converge on the necessity of a commercialization partner (**Figure 24a**). However, 62.5% of the population have never co-operated with the TTO of their institution (**Figure 24b**). This may be due to the imbalance between a substantial research capacity in Greece and a less advanced technological valorization process [68].

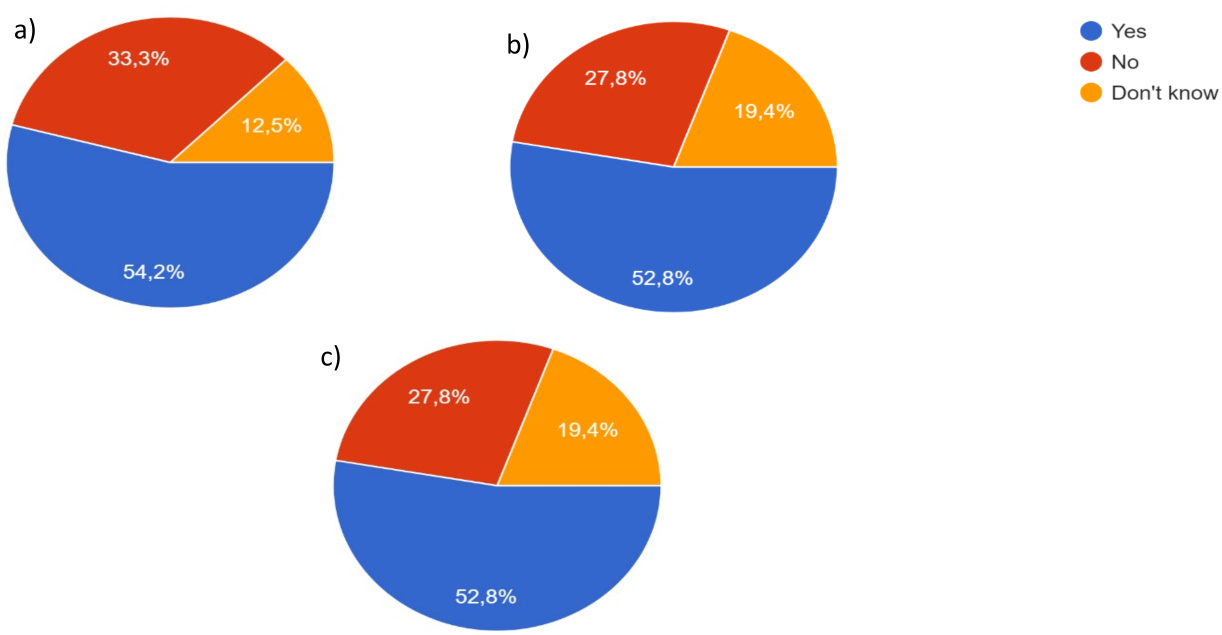



**Figure 23:** Answers of the survey participants a) if they have TT or commercialization experience, b) if they are interested in taking active role TT or commercialization and c) if they would time off their research work to commercialize technology.

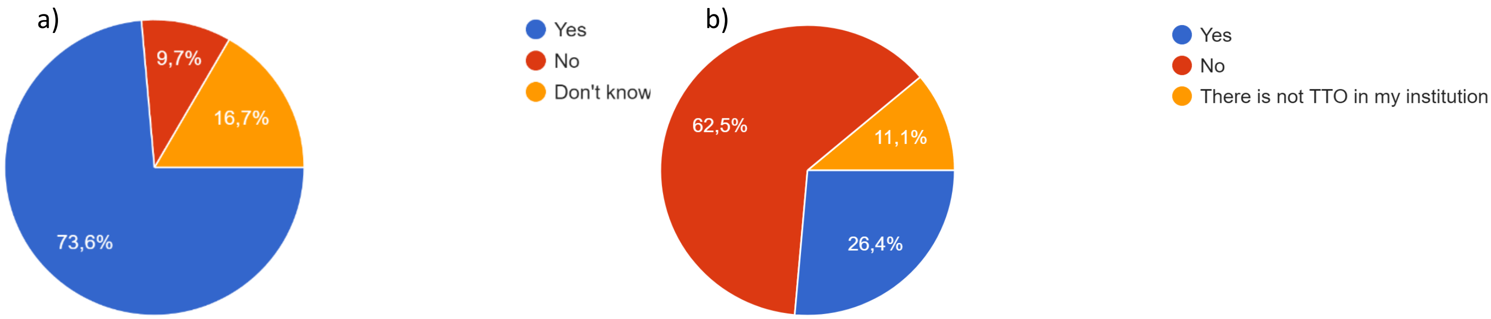



**Figure 24:** Answer of the respondents a) if there is a need for commercialization partner and b) if they ever co-operated with their institution TTO.

The establishment of appropriate standards, which define interfaces, govern safety and health issues, regulates terminology, measurement and testing procedures, is crucial to the commercial success of applications utilizing nanotechnology [69]. According to **Figure 25a**, the most nanotechnology projects need to conform to specific regulations. However, the respondents are relatively divided on whether this fact is considered an obstacle to commercialization as 41% are in favor and 45.9% are against.

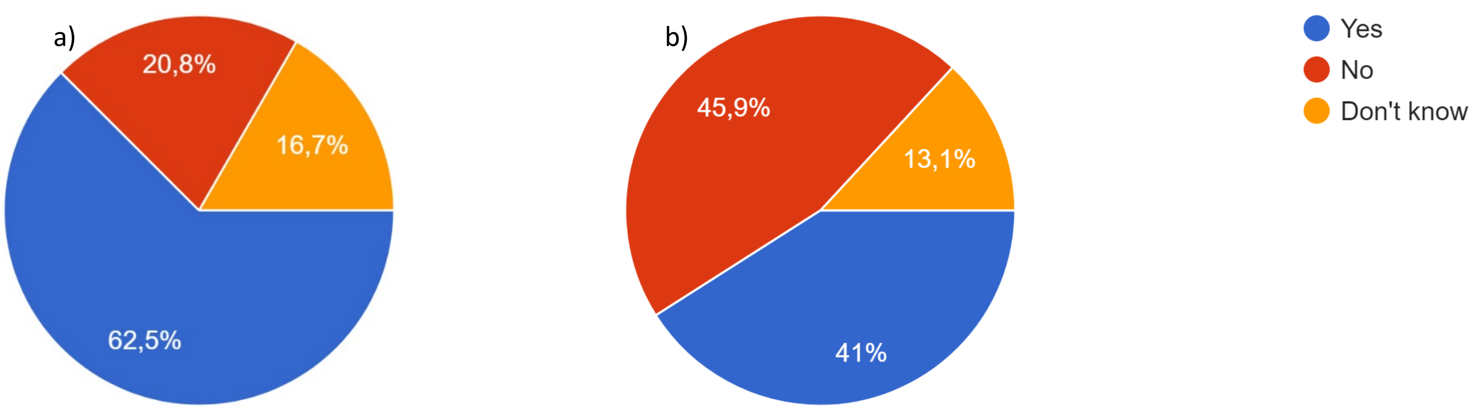



**Figure 25**: Answers of the survey experts a) if their nanotechnology needs to conform to any regulations and b) if they believe this is an obstacle for commercialization.

Furthermore, the experts were asked to rank identified research areas in respect of scientific feasibility and socio-economic importance. The respondents were asked to take into account the technology's R&D stage, whether it is still theoretical or has advanced to an applied stage, as well as the resources and skill set that are available in Greece when evaluating technological feasibility. Experts were asked to rank socio-economic importance of each research area in relation to the need of Greece's socio-economic development.

The survey experts ranked the identified technologies using a 5-point Likert scale where both criteria had ranks from 1= Very unlikely to 5= Very likely. The results are presented in **Figure 26**. Research areas scoring 75% and above on both importance and feasibility were considered as critical. The top two satisfying both criteria the most, are nanomedicine and next generation PV-solar cells. On the other hand, nanofluids and magnetic materials are selected as the less socio-economically and technologically important.

We sought to determine whether the creation of regional nanotechnology fabrication facilities is crucial to the success of nanotechnology innovation in Greece, in keeping with the finding that shared facilities, agglomeration and clusters are essential for successful nanotechnology commercialization. Results of the expert's questionnaire shown in **Figure 27** indicate that 79.2% of respondents considered that regional nanotechnology fabrication facilities are required for success.

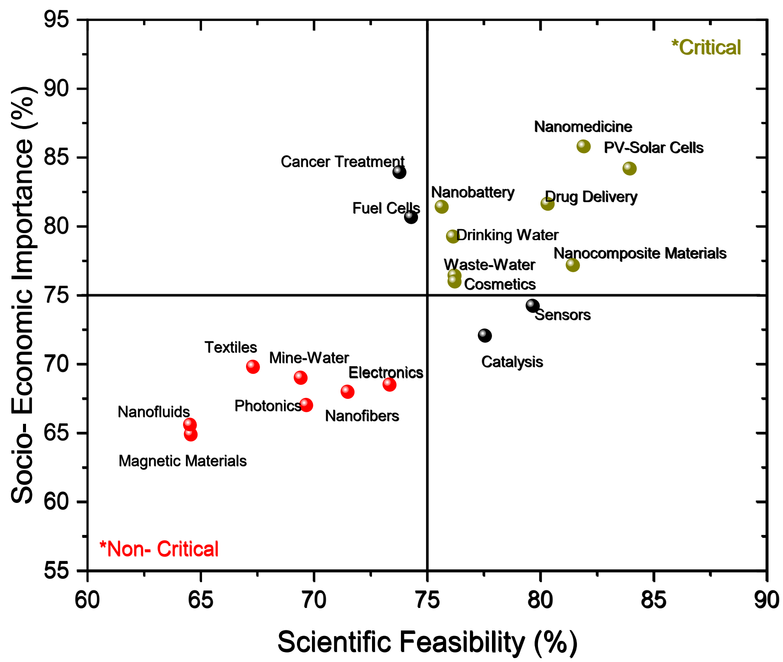



**Figure 26**: Key nanotech research areas ranking scatter plot.

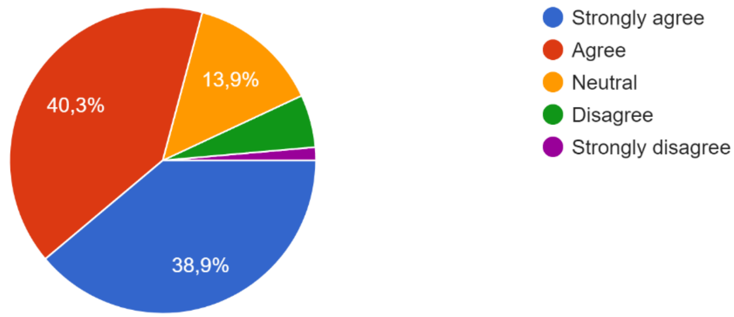



**Figure 27**: Responses on the need to set up regional nanotechnology fabrication facilities in Greece.

Understanding which fabrication techniques are deemed necessary for Greece was another goal of the research. The creation of local facilities for the manufacture of nanotechnology products can be assisted by this data. The distribution of necessary fabrication techniques is depicted in **Figure 28**. The three most promising fabrication techniques are roll-to-roll processing, chemical vapour deposition and laser deposition.

Toward this way, the two recently announced projects, COPE-Nano [70] of Aristotle University of Thessaloniki and Flex2Energy [71] of OET spin out company, will boost the regional entrepreneurship of Macedonia by clustering all the relevant academic and industrial entities on the research area of roll-to-roll processing and the organic electronic technologies such as PV-solar cells.

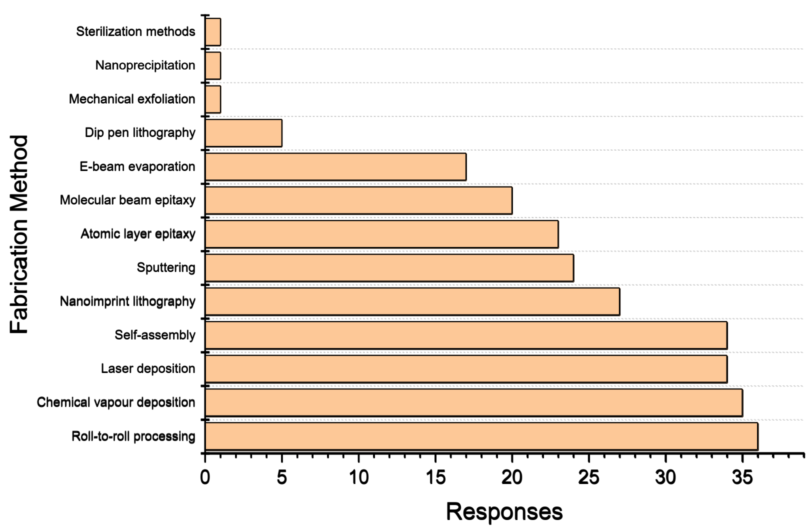



**Figure 28**: Nanotechnology fabrication techniques required in Greece.

COPE- Nano will be an autonomous, self-sustained Centre of Excellence for Nanotechnologies which will develop innovations on nano-electronics, nanomedicine and nanomaterials, will enhance scientific and technological capacity of Greece, will create initiatives and business activities with high tech industries, will strengthen and highly impact regional, national economic growth to lead in the Green Energy and Digital transformation priorities.

The Flex2Energy project by OET company, sets an ambitious and critical goat at the European level: The mass production of 3rd generation photovoltaics, while bringing Thessaloniki to the center of international developments as an automated roll to roll production line for the production of photovoltaics is created.

So, such initiatives in critical research areas as we discussed above, clustered regionally in a conducive innovation environment, bridging academia with industry and society can be the key for nanotechnology innovation thrive.

## 4.4 N-helix Nanotechnology Innovation model in Greece

The evolution from an industrial economy to a knowledge-based economy and subsequently towards a sustainable development economy, is non-linear. This progression entails the engagement of novel stakeholders within the innovation process.

Since the 1990s, the widely accepted Triple Helix model of innovation development has underscored the links between the three principal actors: the state, academic institutions and businesses. Their shared interests have fostered a robust framework for enhancing national competitiveness.

In modern form, the links between business, universities and the state that form the Triple Helix of innovative development include the variables presented in **Table 12**. The survey participants were asked to rank these variables to the probability to occur in a nanotechnology project. The aim was to investigate the existence of the specific model to the Greek nanotechnology innovation ecosystem and how it is expressed. From **Table 12**, it is derived that the most common links between the three stakeholders of the Triple helix in nanotechnology include research relations within the framework of grants or contracts with firms. The most unusual relationship seems to be in company training in new technologies with the participation of university professors under licensing.

**Table 13:** Rank of the variables of nanotechnology triple helix

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 25(a) Research relations within the framework of grants or contracts with firms | 72 | 4.083 | 0.900 | 1 |
| 25(f) Convergent research – joint research of several universities within the framework of convergent technologies commissioned by large companies in the fields of information-cognitive, nano-biochemical, bio-information technologies. | 72 | 3.458 | 1.162 | 2 |
| 25(b) Consultations on the introduction of new technologies, post-project support of contracts with firms. | 72 | 3.444 | 0.902 | 3 |
| 25(c) Licensing relations– the transfer of rights to objects of intellectual property created by universities to business firms, and the sharing of these rights with the state. | 72 | 3.375 | 0.999 | 4 |
| 25(d) Financial relations– providing investments for the creation of laboratories, stands, pre-competitive research. | 72 | 3.306 | 1.158 | 5 |

| | | | | |
|---|---|---|---|---|
| 25(e) In-company training in new technologies with the participation of university professors under licenses transferred to business firms. | 72 | 3.250 | 1.135 | 6 |

Concurrently, notable trends in economic development over the past two decades, including digitalization, networking, the shift towards sustainable development and the adoption of environmentally- conscious practices in production and consumption, engender new coils in the helix.

The Quadruple helix is a continuation of the theory of knowledge and innovation economy, embodied in the Triple Helix, where the knowledge that is created at universities and transferred by business or state is used by society. According to **Table 13**, the most possible way to be expressed in the Greek nanotechnology innovation ecosystem is by strategies organized by government entities that ensure digitalization related to the principles of sustainable development and the integration of different social groups. On the other hand, as it is concluded by the very low mean score of 2.736, nanotechnology innovative development in the form of Quadruple helix cannot be promoted by local authorities interested in promoting digital initiatives among the general population to improve the quality of life.

**Figure 29** compares the total mean scores of both innovation models. As it is obvious, from the low value of the mean of Triple helix and the even lower mean of Quadruple helix, additional actions are needed to establish the first innovation model, thus, subsequently to transit to the latter.

**Table 14:** Rank of the variables of nanotechnology quadruple helix

| Variable | N | Mean | Std. Deviation | Rank |
|---|---|---|---|---|
| 26(a) Government organizations at the international and national levels that create strategies, ensure innovative development and digitalization related to the principles of sustainable development and the integration of different social groups. | 72 | 3.319 | 1.136 | 1 |
| 26(d) Organizations in the field of education and culture, except for universities (schools, educational centers, museums, libraries, engaged in actively raising the educational and cultural level of the population) | 72 | 3.167 | 1.021 | 2 |
| 26(c) Public organizations that develop digital employment, healthcare, and education services | 72 | 3.153 | 1.057 | 3 |
| 26(f) Public organizations that specify their needs for innovation through surveys, open discussions and the participation of their representatives in the implementation and evaluation of digital initiatives | 72 | 3.042 | 1.013 | 4 |
| 26(e) Employers interested in improving the innovative and digital competencies of their employees | 72 | 3.042 | 1.192 | 5 |
| 26(b) Local authorities interested in promoting digital initiatives among the general population to improve the quality of life | 72 | 2.736 | 1.035 | 6 |

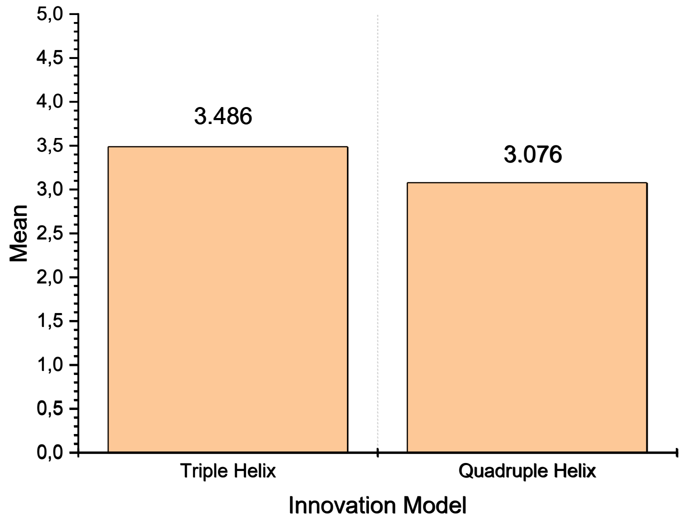



**Figure 29:** Triple & Quadruple Innovation model mean ranking.

However, the majority of the nanotechnology experts in Greece (66.7%) agree that eventually nanotechnology research will lead to social and environmental innovation, supported by crowd funding and crowd investing, with the fruits of digitalization and technological convergence (**Figure 30**). Building the Penta Helix of innovative development, depends on the emergence of new actors- the subjects of the green economy and civil society, and the full expression of their economic interests.

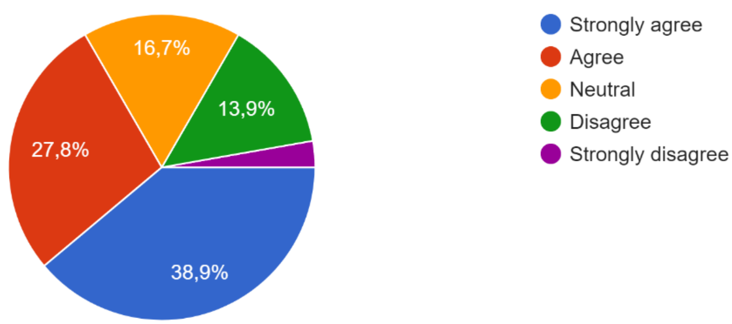



**Figure 30:** Responses of the participants on whether Nanotechnology research can lead to social and environmental innovation, supported by crowd funding and crowd investing, with the fruits of digitalization and technological convergence.

# 5. Conclusions and Recommendations

Since 2000, the scientific field of nanotechnology has experienced exponential growth. From the standpoint of business management, it is crucial to understand that the market for nanotechnology-enabled commercial products is expanding exponentially, primarily due to the wide range of practical applications of nanoscience discoveries. From an economics standpoint, nanotechnology is anticipated to drive the next Schumpeterian wave of economic growth. The majority of nations have therefore started nanotechnology research initiatives in order to take advantage of this fantastic opportunity.

In Greece, nanotechnology has enormous potential for innovation and economic growth. Nanotechnology has the potential to drastically improve a number of industries, including energy, healthcare and material science. The country's strong academic research base, particularly in fields like chemistry, physics and engineering provides a solid foundation for nanotechnology development. Greece's advantageous location at the intersection of three continents – Africa, the Middle East and Europe- also presents chances for cooperation and access to a variety of markets. Through utilizing its scientific proficiency and cultivating an innovative atmosphere, Greece can establish itself as a nanotechnology innovation hub, propelling economic prosperity.

However, a significant gap between the scientific research and the commercialization of R&D results is observed, due to an immature system for capitalizing on technology. Therefore, this thesis aimed to close some of these knowledge gaps on nanotechnology innovation management by exploring the nanotechnology transfer and innovation model in Greece as well as, investigating if Nanotechnology Innovation Diamond's critical success factors are expressed and in which way.

A hybrid qualitative-quantitative research approach was used to address the study questions and objectives. The research was implemented in two steps which were comprehensive literature review of the topic and an expert's survey.

Firstly, the optimal actions and environment for promoting the nanotechnology innovation by investigating the nanotechnology research and entrepreneurship system of the most active, in this specific technological field, countries were determined. Additionally, the weaknesses of the Greek nanotechnology innovation ecosystem were spotted, by recording the nanotechnology research productivity and nanotechnology transfer results since 2000. Although the increased R&D investments and funding opportunities, there is a low patent production and spin off creation, mainly due to the dysfunctional TT processes and agencies. Searching for the deeper reasons, a survey of Greek nanotechnology experts was conducted.

The majority of Greek nanotechnology experts work as lecturers or scientists, with a primary concentration on the nanomaterials stage of the value chain, as evidenced by demographic statistics data. From a strategic management perspective, it is critical for Greece to adopt policies and programs that encourage the development of nano-intermediate and nano-enabled products research.

To examine if a successful nanotechnology management framework is adapted, the participants were asked to validate the six critical success factors of the Nanotechnology Innovation Diamond. They concluded that consumer needs and preferences, nanotechnology hybridization with existing industries and market needs, multi-interdisciplinarity, technological agglomeration, availability of the right R&D skills and a conducive innovation environment can indeed be considered as CSFs for nanotechnology commercialization. However, the non-linear correlation between some of the six CSFs as well as between successful nanotechnology – agglomeration and successful nanotechnology- conducive innovative environment implicates that the Nanotechnology Innovation Diamond is not fully accepted and that more actions should be done to be cultivated across nanotechnology expert population.

Greek ongoing nanotechnology projects have mainly low TRL and the most of them are granted by national initiatives which usually have lower budget compared to the international funds that facilitates networking and collaboration on a wider scale, connecting Greek researchers with international peers, institutions and industries. International grants may lead to broader knowledge exchange and access to diverse expertise and resources. Greek nanotechnology entities cannot support further R&D, without follow-up funding.

A very optimistic finding is that the majority of nanotechnology experts have already technology transfer skills or are willing to be correspondingly educated, a fact that is fundamental principle of nanotechnology innovation diamond model. A frustrating issue is that even if the necessity of a commercialization partner is admitted, cooperation with TTOs is not selected. Improving the effectiveness of TTOs in Greece requires a multi-faceted approach, addressing both structural and operational aspects such as, enhanced funding and resources, simplified IP protection process, promotion of entrepreneurship and innovation culture, flexible licensing and commercialization strategies, performance metrics and evaluation.

Nanotechnology enterprises tend to hub regionally in certain places rather than being widely spread across the country. The most promising nano-fabrication methods that such clusters should focus on are roll-to- roll processing, chemical vapour deposition and laser deposition. Furthermore, several strategic nanotechnology research areas aligned to socio-economic needs for Greece have been identified. Nanomedicine, PV-solar cells, nanocomposite materials, drinking & wastewater and cosmetics are considered to be the most critical.

Such clustering of organizations is critical to operate in an environment that promotes innovation, such as the Triple Helix, a model that supports public-private collaborations in R&D to harness resources and talents. This model in the Greek nanotechnology innovation ecosystem is generally expressed by research relations within the framework of grants or contracts with firms, highlighting the synergistic interactions between academia and industry in driving innovation and knowledge exchange. However, the statistical analysis of the results dictates that there is still room for further improvements in order to create the proper conducive environment to transit to the more advanced Quadruple helix. General belief among the nanotechnology expert population is that eventually nanotechnology research will lead to social and environmental innovation, supported by crowd funding and crowd investing, with the fruits of digitalization and technological convergence (Penta helix).

An important fact that needs to be mentioned is that the low number of the responses of the Greek nanotechnology experts, mainly coming from URCs can be considered as a limitation of this research. Therefore, there is a need to validate the study's outcomes with a larger pool of experts working in diverse aspects of nanotechnology.

In conclusion, for nanotechnology innovations to succeed, research leaders need to establish interdisciplinary teams, work in a cluster and view nanotechnology as a research field whereby one discovery or invention has numerous potential technological applications. In other words, they need to examine how a nanotechnology invention can integrate with existing industries and social needs. The results of this study, from a practical innovation management perspective, can be used to manage nanotechnology R&D leading successful innovations and technology transfer effectively, strategic planning and research portfolio management. Increasing the success rate of nanotechnology innovations and technology transfer, ultimately will lead to improving the knowledge economy and economic competitiveness, solving developmental challenges such as sustainability and improving Greek society's quality of life.

## References


[1] I. M. Gachanja, "Influence of technology transfer from universities on manufacturing firms' innovative performance," International Journal of Innovation Studies, vol. 7, no. 2, pp. 115–126, Jun. 2023, doi: 10.1016/j.ijis.2022.12.003.

[2] K. Miyazaki, N. I.- Technovation, and undefined 2007, "Nanotechnology systems of innovation—An analysis of industry and academia research activities," Elsevier, Accessed: Mar. 11, 2024. [Online].

[3] J. A. Dinglasan, D. J. Anderson, and K. Thomas, "Scientific entrepreneurship in the materials and life science industries," Methods Mol Biol, vol. 726, pp. 379–391, 2011, doi: 10.1007/978-1-61779-052-2_24.

[4] C. Demetzos, "The innovations in science and technology as a demand for bio-better medicines in Europe," Adv Exp Med Biol, vol. 822, pp. 203–208, Jan. 2015, doi: 10.1007/978-3-319-08927-0_25.

[5] "Trott, P. (2008). Innovation Management and New Product Development. 4th edition. Harlow, England: Pearson Education Limited. - Google Search." Accessed: Feb. 12, 2024. [Online].

[6] M. Terziovski, "Building Innovation Capability in Organizations: An International Cross-Case Perspective," p. 254, Sep. 2015, Accessed: Feb. 12, 2024. [Online]. Available: https://espace.curtin.edu.au/handle/20.500.11937/47746

[7] "OECD. 2005. Oslo Manual: The Measurement of Scientific and Technological Activities – Guidelines for Collecting and Interpreting Technological Innovation Data. 3rd Edition. Paris: OECD. - Google Search." Accessed: Feb. 12, 2024. [Online].

[8] H. Etzkowitz, L. L.-E. review, and undefined 1995, "The Triple Helix--University-industry-government relations: A laboratory for knowledge based economic development," papers.ssrn.comH Etzkowitz, L LeydesdorffEASST review, 1995•papers.ssrn.com, Accessed: Feb. 12, 2024. [Online].

[9] H. Etzkowitz and L. Leydesdorff, "The dynamics of innovation: from National Systems and 'Mode 2' to a Triple Helix of university–industry–government relations," Res Policy, vol. 29, no. 2, pp. 109–123, Feb. 2000, doi: 10.1016/S0048-7333(99)00055-4.

[10] E. G. Carayannis and D. F. J. Campbell, "'Mode 3' and 'Quadruple Helix': Toward a 21st century fractal innovation ecosystem," International Journal of Technology Management, vol. 46, no. 3–4, pp. 201–234, 2009, doi: 10.1504/IJTM.2009.023374.

[11] R. J. Steenkamp, “The quadruple helix model of innovation for Industry 4.0,” Acta Commercii, vol. 19, no. 1, 2019, doi: 10.4102/AC.V19I1.820.

[12] S. A. Zhironkin, Y. Y. Suslova, S. K. Demchenko, A. V. Voloshin, and O. S. Demchenko, “From a Triple to a Penta Helix: The Evolution of Innovative Economy Development Methodology,” Journal of Siberian Federal University - Humanities and Social Sciences, vol. 15, no. 12, pp. 1854–1864, 2022, doi: 10.17516/1997-1370-0957.

[13] R. Taratori, P. Rodriguez-Fiscal, M. A. Pacho, S. Koutra, M. Pareja-Eastaway, and D. Thomas, “Unveiling the Evolution of Innovation Ecosystems: An Analysis of Triple, Quadruple, and Quintuple Helix Model Innovation Systems in European Case Studies,” Sustainability 2021, Vol. 13, Page 7582, vol. 13, no. 14, p. 7582, Jul. 2021, doi: 10.3390/SU13147582.

[14] R. J. Van Wyk, “Technology analysis and R&D management,” R&D Management, vol. 20, no. 3, pp. 257–261, 1990, doi: 10.1111/J.1467-9310.1990.TB00715.X.

[15] J. C. Guan, C. K. Mok, R. C. M. Yam, K. S. Chin, and K. F. Pun, “Technology transfer and innovation performance: Evidence from Chinese firms,” Technol Forecast Soc Change, vol. 73, no. 6, pp. 666–678, Jul. 2006, doi: 10.1016/j.techfore.2005.05.009.

[16] I. M. Gachanja, “Influence of technology transfer from universities on manufacturing firms’ innovative performance,” International Journal of Innovation Studies, vol. 7, no. 2, pp. 115–126, Jun. 2023, doi: 10.1016/J.IJIS.2022.12.003.

[17] G. Vekinis, “The Researcher Entrepreneur,” 2023, doi: 10.1007/978-3-031-44358-9.

[18] P. Ganguli and S. Jabade, Nanotechnology intellectual property rights: research, design, and commercialization. 2017. Accessed: Mar. 11, 2024. [Online].

[19] S. J. Franklin, M. Wright, and A. Lockett, “Academic and surrogate entrepreneurs in university spin-out companies,” Journal of Technology Transfer, vol. 26, no. 1–2, pp. 127–141, 2001, doi: 10.1023/A:1007896514609.

[20] F. Pacheco-Torgal, “Introduction to start-up creation for the smart eco-efficient built environment,” Start-Up Creation: The Smart Eco-Efficient Built Environment, pp. 1–17, Jan. 2016, doi: 10.1016/B978-0-08-100546-0.00001-7.

[21] C. Druilhe and E. Garnsey, “Do academic spin-outs differ and does it matter?,” Journal of Technology Transfer, vol. 29, no. 3–4, pp. 269–285, 2004, doi: 10.1023/B:JOTT.0000034123.26133.97.

[22] J. P. Dopazo and F. Zivic, “Supporting university ventures in nanotechnology, biomaterials and magnetic sensing applications: Policies, practices, and future,” Supporting University Ventures in Nanotechnology, Biomaterials and Magnetic Sensing Applications: Policies, Practices, and Future, pp. 1–181, Jul. 2017, doi: 10.1007/978-3-319-61237-9.

[23] A. R. Ilker Murat, S. Temel, M. Dabic, J. Howells, A. Mert, and R. Baris Yesilay, “The Role of Supporting Factors on Patenting Activities in Emerging Entrepreneurial Universities,” IEEE Trans Eng Manag, vol. 70, no. 6, pp. 2293–2304, Jun. 2023, doi: 10.1109/TEM.2021.3069147.

[24] E. G. Carayannis, E. Grigoroudis, D. F. J. Campbell, D. Meissner, and D. Stamati, “The ecosystem as helix: an exploratory theory-building study of regional co-opetitive entrepreneurial ecosystems as Quadruple/Quintuple Helix Innovation Models,” R and D Management, vol. 48, no. 1, pp. 148–162, Jan. 2018, doi: 10.1111/RADM.12300.

[25] D. H. Hsu and J. M. Kuhn, "Academic stars and licensing experience in university technology commercialization," Strategic Management Journal, vol. 44, no. 3, pp. 887–905, Mar. 2023, doi: 10.1002/smj.3458.
[26] M. Chachamidou and S. Logothetidis, "Spin-off creation behaviour of universities and research institutions: an initial approach for nanotechnology," International Journal of Technology Transfer and Commercialisation, vol. 7, no. 4, p. 384, 2008, doi: 10.1504/IJTTC.2008.021036.
[27] "InBIA: Global Network of Entrepreneurial Ecosystem Builders InBIA." Accessed: Mar. 11, 2024. [Online]. Available: https://inbia.org/
[28] C. Theodoraki, K. Messeghem, and D. B. Audretsch, "The Effectiveness of Incubators' Co-Opetition Strategy in the Entrepreneurial Ecosystem: Empirical Evidence From France," IEEE Trans Eng Manag, vol. 69, no. 4, pp. 1781–1794, Aug. 2022, doi: 10.1109/TEM.2020.3034476.
[29] "IASP: Global Network of Science & Technology Parks & Innovation Districts – IASP." Accessed: Mar. 11, 2024. [Online]. Available: https://www.iasp.ws/
[30] K. K. Rådberg and H. Löfsten, "The entrepreneurial university and development of large-scale research infrastructure: exploring the emerging university function of collaboration and leadership," Journal of Technology Transfer, Feb. 2023, doi: 10.1007/S10961-023-10033-X.
[31] J. Wang and P. Shapira, "Partnering with universities: A good choice for nanotechnology start-up firms?," Small Business Economics, vol. 38, no. 2, pp. 197–215, Feb. 2012, doi: 10.1007/S11187-009-9248-9.
[32] M. Smales and D. Komuczki, "Identifying the role played by university research laboratories in increasing technology transfer to industry: linking technology transfer, innovation with biotechnology venture performance," J Commer Biotechnol, vol. 28, no. 2, pp. 40–52, 2023, doi: 10.5912/JCB2077.
[33] G. Vekinis, "Mastering Technology Transfer: From Invention to Innovation," 2023, doi: 10.1007/978-3-031-44369-5.
[34] T. F. Bresnahan and M. Trajtenberg, "General purpose technologies 'Engines of growth'?," J Econom, vol. 65, no. 1, pp. 83–108, 1995, doi: 10.1016/0304-4076(94)01598-T.
[35] C. M. Shea, R. Grinde, and B. Elmslie, "Nanotechnology as general-purpose technology: Empirical evidence and implications," Technol Anal Strateg Manag, vol. 23, no. 2, pp. 175–192, Feb. 2011, doi: 10.1080/09537325.2011.543336.
[36] T. S. Kuhn et al., "The nature of scientific revolutions," degruyter.com, vol. 2, no. 2, 1970, Accessed: Mar. 11, 2024. [Online].
[37] J. Köhler, "A comparison of the neo-Schumpeterian theory of Kondratiev waves and the multi-level perspective on transitions," Environ Innov Soc Transit, vol. 3, pp. 1–15, 2012, doi: 10.1016/j.eist.2012.04.001.
[38] J. W.- Technovation and undefined 2005, "The nano-revolution of Schumpeter's Kondratieff cycle," Elsevier, Accessed: Mar. 11, 2024. [Online]. tj0Mtf3M4_2Lt_PXQ
[39] A. Prof. Dr. C. O. Tuncel, "Neo-Schumpeterian Long Wave Theory and Nanotechnology: Assessing the Future of Manufacturing Industry," Journal of Economics and Development, vol. 3, no. 1, 2015, doi: 10.15640/JEDS.V3N1A5.

[40] "Wayback Machine." Accessed: Mar. 11, 2024. [Online]. Available: https://web.archive.org/web/20200606193125/http://ec.europa.eu/research/science-society/document_library/pdf_06/nanocode-apr09_en.pdf
[41] R. Pisano and A. Durlo, "Feynman's Frameworks on Nanotechnology in Historiographical Debate," pp. 441–478, 2023, doi: 10.1007/978-3-031-27510-4_26.
[42] S. Dikweni, B. Makgabutane, and S. D. Mhlanga, "Lab-to-market guide for commercialisation of nanomaterials: A South African university perspective," S Afr J Sci, vol. 119, no. 1–2, pp. 1–3, Jan. 2023, doi: 10.17159/SAJS.2023/14912.
[43] B. Masara, J. A. van der Poll, and M. Maaza, "The 'Nanotechnology Innovation Diamond', a model for successful nanoscience research and development," Journal of Nanoparticle Research, vol. 23, no. 3, pp. 1–15, Mar. 2021, doi: 10.1007/S11051-021-05150-3/TABLES/4.
[44] "Clarivate." Accessed: Mar. 11, 2024. [Online]. Available: https://access.clarivate.com/login?app=wos&alternative=true&shibShireURL=https:%2F%2Fwww.webofknowledge.com%2F%3Fauth%3DShibboleth&shibReturnURL=https:%2F%2Fwww.webofknowledge.com%2F%3FDestApp%3DUA%26action%3Dtransfer%26mode%3DNextgen%26path%3D%252Fwos&referrer=mode%3DNextgen%26path%3D%252Fwos%26DestApp%3DUA%26action%3Dtransfer&roaming=true
[45] "Nanotechnology Statistic: Science, Technology and Innovation Indicators by Countries - Nano-related indicators | STATNANO." Accessed: Mar. 11, 2024. [Online]. Available: https://statnano.com/indicators/nano
[46] "Triennial review of the national nanotechnology initiative," Triennial Review of the National Nanotechnology Initiative, pp. 1–173, Jan. 2014, doi: 10.17226/18271.
[47] M. C. Roco, "National Nanotechnology Initiative at 20 years: enabling new horizons," Journal of Nanoparticle Research, vol. 25, no. 10, Oct. 2023, doi: 10.1007/S11051-023-05829-9.
[48] B. V. Dean, B. I. Nagel, and A. Osland, "Entrepreneurial system: Application to silicon valley nanotechnology companies," Portland International Conference on Management of Engineering and Technology, vol. 2005, pp. 433–443, 2005, doi: 10.1109/PICMET.2005.1509722.
[49] "World Bank Open Data | Data." Accessed: Mar. 11, 2024. [Online]. Available: https://data.worldbank.org/
[50] M. Grasten and S. Haakonsson, "A New Model for Global Science and Innovation Infrastructure? The Construction of Huairou Science City".
[51] V. Souitaris, "Strategic Influences of Technological Innovation in Greece," British Journal of Management, vol. 12, no. 2, pp. 131–147, 2001, doi: 10.1111/1467-8551.00190.
[52] Y. Caloghirou and N. Constantelou, "Learning from Technology Transfer in the Greek Context: The Case of Digital Telecommunication Switches," Journal of Technology Transfer, Jan. 2000, Accessed: Mar. 11, 2024. [Online].
[53] E. I. Gkanas, V. MagkouKriticou, S. S. Makridis, A. K. Stubos, and I. Bakouros, "Nanotechnology and Innovation, Recent status and the strategic implication for the formation of high tech clusters in Greece, in between a global economic crisis," Mar. 2013, Accessed: Mar. 10, 2024. [Online]. Available: https://arxiv.org/abs/1303.5290v2

[54] “ΕΣΠΑ 2021 - 2027.” Accessed: Mar. 11, 2024. [Online]. Available: https://www.espa.gr/el/Pages/default.aspx
[55] “HFRI - Hellenic Foundation for Research & Innovation.” Accessed: Mar. 11, 2024. [Online]. Available: https://www.elidek.gr/en/homepage/
[56] “Horizon Europe - European Commission.” Accessed: Mar. 11, 2024. [Online]. Available: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en
[57] http://www.nano-net.gr/
[58] “Home en - micro-nano.” Accessed: Mar. 10, 2024. [Online]. Available: https://www.micro-nano.gr/en/
[59] “Γραφεία μεταφοράς τεχνολογίας στην Ελλάδα. Μια πρώτη αποτύπωση | Metrics.” Accessed: Mar. 10, 2024. [Online]. Available: https://metrics.ekt.gr/publications/440
[60] E. Sachini et al., “Mapping the Technology Transfer Offices in Greece: Initial Outcomes Concerning Medical and Health Technologies and Next Steps,” Journal of the Knowledge Economy, 2024, doi: 10.1007/S13132-023-01715-W.
[61]: :“Τεχνολογικό Πάρκο ‘ΛΕΥΚΙΠΠΟΣ’::” Accessed: Mar. 10, 2024. [Online]. Available: https://lefkippos.demokritos.gr/
[62] “Patras Science Park - A unique place for Startups.” Accessed: Mar. 10, 2024. [Online]. Available: https://psp.org.gr/
[63] “Lavrion Technological and Cultural Park.” Accessed: Mar. 10, 2024. [Online]. Available: https://en.ltcp.ntua.gr/
[64] “Αρχική - STEP-C.” Accessed: Mar. 10, 2024. [Online]. Available: https://www.stepc.gr/
[65] “Αρχική - STEPE - Science and Technology Park of Epirus.” Accessed: Mar. 10, 2024. [Online]. Available: https://step-epirus.gr/?lang=en
[66] “Thess INTEC - Tour.” Accessed: Mar. 10, 2024. [Online]. Available: https://www.thessintec.eu/
[67] I. Voutsinas, C. Tsamadias, E. Carayannis, and C. Staikouras, “Does research and development expenditure impact innovation? theory, policy and practice insights from the Greek experience,” Journal of Technology Transfer, vol. 43, no. 1, pp. 159–171, Feb. 2018, doi: 10.1007/S10961-015-9454-3.
[68] E. Sachini et al., “Mapping the Technology Transfer Offices in Greece: Initial Outcomes Concerning Medical and Health Technologies and Next Steps,” Journal of the Knowledge Economy, pp. 1–36, Jan. 2024, doi: 10.1007/S13132-023-01715-W/FIGURES/11.
[69] K. Blind and S. Gauch, “Research and standardisation in nanotechnology: Evidence from Germany,” Journal of Technology Transfer, vol. 34, no. 3, pp. 320–342, 2009, doi: 10.1007/S10961-008-9089-8.
[70] “Home.” Accessed: Mar. 25, 2024. [Online]. Available: https://cope-nano.eu/
[71] “Flex2Energy.” Accessed: Mar. 25, 2024. [Online]. Available: https://flex2energy.eu

# Appendix A

## <u>Greek Nanotechnology entities chosen for the research population</u>

<u>Greek Universities</u>

| **University** | Aristotle University of Thessaloniki | | | |
|---|---|---|---|---|
| **Department** | Physics | Chemical Engineering | Electrical & Computer Engineering | Chemistry |
| **Laboratory** | 1)Lab for Thin Films-Nanobiomaterials-Nanosystems & Nanometrology<br>2)Electron Microscopy and Structural Characterization of Materials<br>3)Laboratory of Advanced Materials and Devices | 1) Laboratory of Materials Technology | 1) Laboratory of Materials for Electrotechnics | 1) Laboratory of Biochemistry<br>2)Laboratory of Polymer and Colors Chemistry and Technology |

| **University** | National & Kapodistrian University of Athens |
|---|---|
| **Department** | Pharmacy |
| **Laboratory** | 1) Laboratory of Pharmaceutical Nanotechnology |

| **University** | Democritus University of Thrace |
|---|---|
| **Department** | Molecular Biology & Genetics |
| **Laboratory** | ALL |

| **University** | University of West Attica |
|---|---|
| **Department** | Electrical and Electronics Engineering |
| **Laboratory** | 1) Laboratory of Microsystems, Sensors, Embedded Devices and Automation |

| **University** | National Technical University of Athens | |
|---|---|---|
| **Department** | Chemical Engineering | Physics |
| **Laboratory** | 1) Lab of Advanced, composite, Nano Materials & Nanotechnology | 1) Laboratory of advanced materials and micro/nano devices |

| **University** | University of Patras | | |
|---|---|---|---|
| **Department** | Physics | Chemical Engineering | Chemistry |

| | | | |
|---|---|---|---|
| **Laboratory** | 1) Laser Laboratory | 1) Nanotechnology & Advanced Materials<br>2) Surface Science Laboratory | 1) Advance Polymers & Hybrid Nanomaterials Research Laboratory |

| **University** | University of Ioannina | |
|---|---|---|
| **Department** | Materials Engineering | Medicine |
| **Laboratory** | 1) Composite and Smart Materials Laboratory | 1) Nano Research Group UOI |

| **University** | Hellenic Mediterranean University |
|---|---|
| **Department** | Electrical & Computer Engineering |
| **Laboratory** | 1) Center of Materials Technology and Photonics (CEMATEP) |

| **University** | University of Crete | |
|---|---|---|
| **Department** | Chemistry | Physics |
| **Laboratory** | 1) Laboratory of Biophysical Chemistry | 1) Crete Center for Quantum Complexity and Nanotechnology |

| **University** | Technical University of Crete |
|---|---|
| **Department** | Chemical and Environmental Engineering |
| **Laboratory** | ALL |

## Greek Research Centers

| **Research Center** | **Institute** | **Link** |
|---|---|---|
| NCSR Demokritos | Institute Nanoscience Nanotechnology | https://inn.demokritos.gr/ |
| | Institute of Biosciences & Applications | http://bio.demokritos.gr/ |
| National Hellenic Research Foundation | Theoretical & Physical Chemistry Institute | http://www.eie.gr/nhrf/institutes/tpci/index-en.html |
| | Institute of Chemical Biology | http://www.eie.gr/nhrf/institutes/icb/index_en.html |

| | | |
|---|---|---|
| Foundation for Research and Technology | Institute of Electronic Structure and Laser | https://www.iesl.forth.gr/en |
| | Institute of Molecular Biology & Biotechnology | https://www.imbb.forth.gr/en/ |
| | Institute of Chemical Engineering Sciences | https://www.iceht.forth.gr/en/ |
| | Biomedical Research Institute | https://www.bri.forth.gr/en/ |
| Center for Research & Technology Hellas | Chemical Process & Energy Resources Institute | https://www.cperi.certh.gr/ |
| | Institute of Applied Biosciences | https://www.inab.certh.gr/ |

Greek Nanotech spin off/out companies

| **Company Name** | **Link** |
|---|---|
| Helbio Hydrogen & Energy Systems S.A. | https://helbio.com |
| PCNanomaterials | https://pcnmaterials.com/ |
| Nanoplasmas | https://www.nanoplasmas.com/ |
| Organic Electronic Technologies | https://oe-technologies.com/ |
| Nanometrisis | https://www.nanometrisis.com/ |
| Θmetrisis | https://www.thetametrisis.com/ |
| Amen New Technologies | https://www.amen-tech.com/ |
| Biopix DNA Technology | https://biopix-t.com/ |
| Brite | https://www.britesolar.com/ |
| BL-Nanobiomed | https://www.plin-nanotechnology.com/ |
| Plin | https://www.biomimetic.gr/ |
| Biomimetic | https://www.adamant-composites.com/ |
| Adamant Composites | https://bfp-tech.com/site/ |
| BFP Advanced Technologies | https://www.pleione-energy.com/ |
| Pleione Energy S.A. | https://www.plin-nanotechnology.com/ |

# Appendix B

**Distribution of Participants**

| UNIVERSITIES | |
|---|---|
| **Entity** | **Participants** |
| Aristotle University of Thessaloniki | 11 |
| University of Ioannina | 3 |
| University of Patra | 2 |
| National Technical University of Athens | 5 |
| National and Kapodistrian University of Athens | 2 |
| University of West Attica | 2 |
| Technical University of Crete | 2 |
| Hellenic Mediterranean University | 2 |
| Democritus University of Thrace | 1 |
| **RESEARCH CENTER** | |
| **Entity** | **Participants** |
| National Center for Scientific Research Demokritos | 12 |
| Center for Research & Technology Hellas | 8 |
| Foundation for Research and Technology- Hellas | 9 |
| National Hellenic Research Foundation | 7 |
| **SPIN OFF/OUT COMPANY** | |
| **Entity** | **Participants** |
| BL-Nanobiomed | 1 |
| Nanometrisis P.C. | 1 |
| Amen New Technologies | 1 |
| Helbio Hydrogen & Energy Systems S.A. | 1 |
| Organic Electronic Technologies P.C. | 1 |
| Nanoplasmas P.C. | 1 |

# Appendix C

## Questionnaire

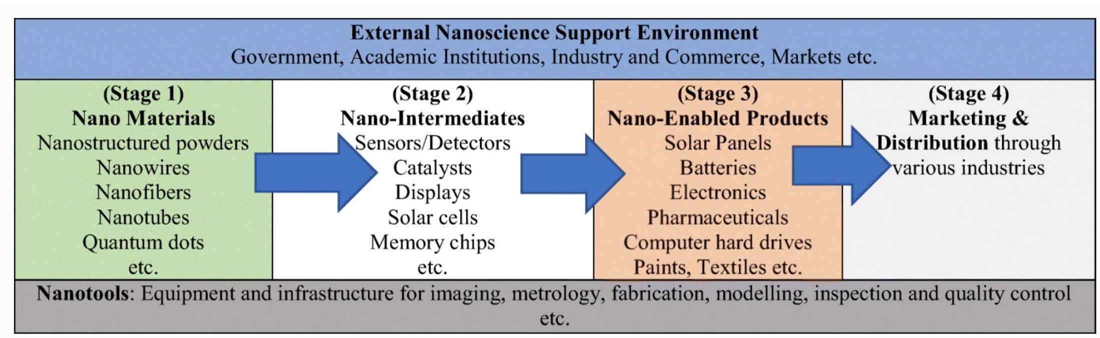
**SECTION A: Demographic Information**

1. Name of your Academic Institution/Research Center/Company:

2. Please select a category that closely describes your current job description place a tick against the closest job description.

| | |
|---|---|
| Researcher | |
| Engineer | |
| Academic | |
| Both Researcher and Academic | |
| Research, Development & Innovation (RDI) Manager | |
| Policy Maker | |
| Both Researcher and RDI Manager | |
| Other (Specify) | |

3. The nanotechnology value chain has 5 main segments which are: nanomaterials industry, nano-intermediaries, nano enabled products, nanotools and the supporting external environment, as shown in figure 1 below.




Please indicate the stages within the value chain that closely describe the nature of nanotechnology related industry you are involved in. Please tick appropriate box (s) below

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Nanomaterials | | Nano-Intermediaries | | Nano-Enabled Products | | Nanotools | | External Environment | |

4. Current Technology Readiness Level (TRL) of the nanotechnology project you are involved in:

5. Are you located in:

| | |
|---|---|
| Incubator | |
| Technological Park | |
| Research Institution | |
| Other | |

**SECTION B: Nanotechnology critical success factors**

6. (a) According to your experience, successful nanotechnology R&D results in the development of new products and services

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) Neutral | iv) disagree | v) strongly disagree |

(b) According to your experience, successful nanotechnology R&D results in the improvement of existing products and services

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(c) According to your experience, successful nanotechnology R&D results in the production of patents and/or trade secrets

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(d) According to your experience, successful nanotechnology R&D leads to new technology licensing opportunities

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(e) According to your experience, successful nanotechnology R&D leads to commercialization of research results

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(f) According to your experience, successful nanotechnology R&D leads to the formation of new companies and/or spin-off

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

7. (a) The primary factor driving successful nanotechnology innovations is a conducive innovation environment created by government policies.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(b) Most successful R&D innovations in nanotechnology are those aligned with government priorities.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(c) Strategic partnerships between government, industry, academia, and research institutions are important for successful nanotechnology innovation.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(d) Government-supported research infrastructure, and skills development are critical for successful nanotechnology innovations.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

8. (a) In order for Nanotech innovations to be successful in the market, they must fulfill a need or a demand

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(b) Positive market perceptions of nanotechnology products by the public is a key success factor for nanotech innovations, especially those with applications in medicine, environment, cosmetics, and food.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(c) Successful nanotechnology research must incorporate consumer and market needs early in the research.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(d) Most consumers of nanotechnology products are not aware that they are using nanotechnology-based products.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

9. (a) The physical location of nanotechnology R&D facilities is a significant factor that contributes to innovation success; some locations present a competitive advantage in facilitating successful nanotech innovations

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(b) There is a higher success rate for nanotechnology research conducted within nanotech research centers, science parks, and clusters.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(c) Working within a nanocluster enables sharing tacit knowledge, specialized infrastructure, and resources. Hence it increases the success rate of nanotechnology innovations.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(d) Nanotechnology clusters and nanotech centers of excellence provide a conducive environment for entrepreneurs and nanotech start-up companies.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

10. (a) Successful nanotechnology innovations emanate from R&D teams with high skills in scientific research, e.g., teams that have a high number of publications, a high number of citations, etc.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(b) Successful nanotech innovations emanate from R&D teams that possess innovation management and commercialization skills.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |

(c) Successful nanotech innovations emanate from teams with intellectual property management skills such as the ability to patent and license innovations

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

(d) Successful nanotech innovations emanate from R&D teams that have technological entrepreneurship skills.

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

11. (a) Successful nanotechnology innovations must be aligned to existing industry sectors, for example, nano-energy, nanobiotechnology, nanoelectronics, nanoagriculture, and nanomedicine.

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

(b) Industry and academia collaborations are essential for successful nanotechnology innovations.

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

(c) Successful nanotechnology innovations must be aligned to socio-economic needs, e.g., energy security, clean water, medical needs, among others

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

(d) Strategic R&D partnerships between industry and national research facilities are important for successful commercialization nanotechnology research

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

12. (a) Nanotechnology is a multidisciplinary field

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

(b) Successful Nanotechnology innovations are produced by interdisciplinary teams.

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

(c) Nanotechnology cannot be viewed as a stand-alone discipline but combines several cross-cutting scientific skills.

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

(d) Due to its multidisciplinarity and interdisciplinarity nature, nanotechnology is emerging as the core for the convergence of several disciplines.

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

**SECTION C: Technology Transfer**

13. Please name the type of your main funding source (National/International/Private)
14. Does your institution have adequate resources for further R&D, if necessary, if it cannot obtain follow up funding?
15. Does your nanotechnology need to conform to any regulations or standards? If yes, do you believe this is an obstacle for its commercialization?
16. What is the current Commercialization Readiness Level?
17. Is there a need for a commercialization partner?
18. Do you or any other team member have experience with Technology Transfer or commercialization of any technology?
19. Are you or any other team member interested in taking an active role in technology transfer or commercialization?
20. Would you take months or even years off your research work to commercialize your technology?

21. Did you ever co-operate with your institution's technology transfer office for possible commercialization of your research results?

**SECTION D: Nanotechnology Innovation model in Greece (triple, quadruple or quintuple helix)**

22. The establishment of regional nanotechnology fabrication facilities is key to the success of nanotechnology innovation in Greece.

| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |
|---|---|---|---|---|

23. Which of the following nanofabrication techniques do you consider as critical for Greece's nanotechnology innovation? You can choose more than one option.

| | |
|---|---|
| Chemical vapour deposition | Roll-to-roll processing |
| Molecular beam epitaxy | Self-assembly |
| Atomic layer epitaxy | Sputtering |
| Dip pen lithography | E-beam evaporation |
| Nanoimprint lithography | Laser deposition |
| Other | |

24. Please evaluate the following nanotechnology research areas with respect to their probable Scientific and Technological Feasibility in Greece. Please answer all you have experience with.

| **RESEARCH AREA** | **Scientific & Technological Feasibility** | | | | |
|---|---|---|---|---|---|
| | 1. Very Unlikely | 2. Not Likely | 3. Neutral | 4. Likely | 5. Very Likely |
| 1) Nano Medicine | | | | | |
| 2) Nano-based Fuel Cell Technology | | | | | |
| 3) Nano-based High-Capacity Battery Technologies | | | | | |
| 4) Nano-based Photovoltaic Solar Cells | | | | | |
| 5) Nano-based Targeted Drug Delivery | | | | | |
| 6) Nano-based Cancer Treatment | | | | | |
| 7) Nano-based Acid Mine Water Treatment | | | | | |
| 8) Nano-based Wastewater Treatment | | | | | |
| 9) Nano-based Drinking Water Purification | | | | | |
| 10) Nano-based Photonic Materials | | | | | |
| 11) Nano-based Electronic Devices & Components | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 12) Nano-based Magnetic Storage and Memory | | | | | |
| 13) Nano-based Photonic Devices and Components | | | | | |
| 14) Nano-based Catalysis | | | | | |
| 15) Nano-based Sensors and Detectors applications | | | | | |
| 16) Nanofibers | | | | | |
| 17) Nano-composite Materials | | | | | |
| 18) Nanofluids | | | | | |
| 19) Nano-based Cosmetics | | | | | |
| 20) Nano-based Textiles | | | | | |
| 21) Nano-based Engineering Materials | | | | | |

25. Please evaluate the following research areas with respect to their socio-economic importance to Greece's socio-economic development needs. Please answer all you have knowledge of.

| **RESEARCH AREA** | **Socio-Economic Importance** | | | | |
|---|---|---|---|---|---|
| | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| 1) Nanomedicine | | | | | |
| 2) Nano-based Fuel Cell Technology | | | | | |
| 3) Nano-based High-Capacity Battery Technologies | | | | | |
| 4) Nano-based Photovoltaic Solar Cells | | | | | |
| 5) Nano-based Targeted Drug Delivery | | | | | |
| 6) Nano-based Cancer Treatment | | | | | |
| 7) Nano-based Acid Mine Water Treatment | | | | | |
| 8) Nano-based Wastewater Treatment | | | | | |
| 9) Nano-based Drinking Water Purification | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 10) Nano-based Photonic Materials | | | | | |
| 11) Nano-based Electronic Devices & Components | | | | | |
| 12) Nano-based Magnetic Storage and Memory | | | | | |
| 13) Nano-based Photonic Devices and Components | | | | | |
| 14) Nano-based Catalysis | | | | | |
| 15) Nano-based Sensors and Detectors applications | | | | | |
| 16) Nanofibers | | | | | |
| 17) Nano-composite Materials | | | | | |
| 18) Nanofluids | | | | | |
| 19) Nano-based Cosmetics | | | | | |
| 20) Nano-based Textiles | | | | | |
| 21) Nano-based Engineering Materials | | | | | |

26. Please evaluate the following links or relations between business, universities and the state in respect to their probability to occur in a nanotechnology project

| | | | | | |
|---|---|---|---|---|---|
| Research relations within the framework of grants or contracts with firms. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Consultations on the introduction of new technologies, post-project support of contracts with firms. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Licensing relations– the transfer of rights to objects of intellectual property created by universities to business firms, and the sharing of these rights with the state. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Financial relations– providing investments for the creation of laboratories, stands, pre-competitive research. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| In-company training in new technologies with the participation of university professors under licenses transferred to business firms. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |

| | | | | | |
|---|---|---|---|---|---|
| Convergent research – joint research of several universities within the framework of convergent technologies commissioned by large companies in the fields of information-cognitive, nano-biochemical, bio-information technologies. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |

27. Please evaluate the following groups in respect to their participation in nanotechnology projects

| | | | | | |
|---|---|---|---|---|---|
| Government organizations at the international and national levels that create strategies, ensure innovative development and digitalization related to the principles of sustainable development and the integration of different social groups. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Local authorities interested in promoting digital initiatives among the general population to improve the quality of life. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Public organizations that develop digital employment, healthcare, and education services | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Organizations in the field of education and culture, except for universities (schools, educational centers, museums, libraries, engaged in actively raising the educational and cultural level of the population) | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Employers interested in improving the innovative and digital competencies of their employees. | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |
| Public organizations that specify their needs for innovation through surveys, open discussions and the participation of their representatives in the implementation and evaluation of digital initiatives | Very Unlikely | Not Likely | Neutral | Likely | Very Likely |

28. Nanotechnology research can lead to social and environmental innovation, supported by crowd funding and crowd investing, with the fruits of digitalization and technological convergence.

| | | | | |
|---|---|---|---|---|
| i) strongly agree | ii) agree | iii) neutral | iv) disagree | v) strongly disagree |