Bilgi (34), 2017 Yaz / Summer : 70-94

Scientific Collaboration of Turkey with the EU Member States: The Case of Nanotechnology[1]

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Abstract: As an emerging technology field, there is an on-going motivation for analysing the trend of research networks of nanotechnology. This paper attempts to present the evolution of Turkey in nanotechnology research by taking into account the academic publications to indicate the overall trend and the leading actors and subject categories in the systems of nanotechnology innovation. The purpose of this paper is twofold: (i) to present the trend of nanotechnology research and (ii) to highlight Turkey's collaboration patterns in the relevant research sub-fields with the EU member states. In this framework, the study aims to show whether Turkey has the capability to collaborate with the advanced group of countries such as the EU in nanotechnology and to identify the sub-fields of common interests. Finally, the results of collaboration among two parties will be correlated with the Web of Science subject categories. The findings are expected to be useful for developing the future areas of research in nanotechnology domain in collaboration with the EU.

Keywords: Nanotechnology, Turkey-EU Scientific Collaboration, Bibliometric analysis

Jel Codes: C89, O30, O38

1. Introduction

As an emerging technology, nanotechnology introduces new dimensions to science and technology. Nanotechnology is an interdisciplinary field that en-

1. Supported by Yıldız Technical University Scientific Research Projects Coordination Department (BAPK) (No. 2014-02-01-GEP01).

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compasses a wide range of technological domains such as physics, chemistry, biology, pharmacy and various fields of engineering. Nanotechnology is widely considered as being such a general-purpose technology, affecting a variety of industries in the economy (Breshanan and Trajtenberg, 1995). This emerging domain involves a range of technologies performed on a nanometer scale with widespread applications as an enabling technology in various industries. Thus, nanotechnology is widely seen as having huge potential to bring benefits to many areas of research and application. Indeed, there have been significant developments in nanotechnology during the last decades and even more prominent developments are expected in the future.

Innovation is an interactive process among a wide variety of actors (Edquist, 1997). In the sectoral systems of innovation actors do not innovate in isolation and innovation is a collective process. Within this process actors such as universities, research institutions, government agencies and public and private companies interact with each other and actions are strongly influenced by their learning process, competences and institutions. Universities are crucial actors generate new knowledge that is a major innovation input, train the human capital that forms the backbone of the R&D laboratories of firms, sometimes patent in certain technologies, and often are a source of new firms in specific sectors such as in emerging technologies (Malerba, 2006). Accordingly, Malerba (2006) indicates that the notion of sectoral systems of innovation is a useful tool for examining innovation in a sector. He adds that going into sectoral analyses in much greater depth and relating the structure of knowledge in a sector to the type of actors and their relationships is crucial. Thus, the concept of systems of innovation rests on the premise that understanding the linkages among the actors involved in innovation is also key to improve technology performance.

As a consequence of this process, countries recognised the importance of systems of innovation that seeks to enhance a country's innovative and technological capacity. The aim of this paper is to examine the status of systems of innovation and research networks that produce nanotechnology and to identify the subfields of nanotechnology produced by those networks in Turkey by using bibliometric analysis. This paper is as follows: The first section of the study presents the evolution of nano-related research in Turkey from a vision strategy and institutional perspective. Following section

presents the development of nanotechnology publications of Turkey by using the basic statistics retrieved from Web of Science database. Next the collaboration patterns of Turkey with the EU member states by mapping the EU countries and Web of Science categories will be examined using Vantage Point software. Final section discusses policy implications and the future areas of research and collaborative patterns. The findings are expected to be particularly useful for furthering nanotechnology collaborations among Turkey and the EU member states.

2. Nanotechnology Research in Turkey

2.1. The Vision for a Nanotechnology Strategy in Turkey

In Turkey, the first attempts for policy formulations on science and technology started during the 1960s. The Scientific and Technical Research Council of Turkey (TUBITAK) was established in 1963 in order to prepare and coordinate the implementation of science and technology policies in Turkey. The basic policy during this period has been characterised by the promotion of basic and applied research in natural sciences. Later in 1983, a new institutional set up was established: The Supreme Council for Science and Technology (SCST) which is considered as the highest policy making body in the field of science and technology.

A new national science and technology policy document "Vision 2023: Strategies for Science and Technology" was prepared for the period 2003-2023 to implement a long term technology policy considering scientific, technological, socioeconomic and political trends in the EU and the world. Accordingly, eight cross-cutting strategic technology areas were determined as; ICT technologies, biotechnology and gene technologies, energy and environmental technologies, material technologies, mechatronics, nanotechnology, design technologies, and production process technologies. Thus, the concept of nanotechnology was first mentioned in the Vision 2023 document. In this plan, a roadmap regarding the steps to be taken in nanotechnology domain has been introduced. Within this strategy, one of the main defined goals is to develop nanotechnologies in six sub-fields including (i) nanophotonics, nanoelectronics, nanomagnetism; (ii) nanomaterials; (iii) nanocharacterization; (iv) nanofabrication; (v) nanosized quantum information processing; and (vi) nanobiotechnology. Strategic technology roadmaps for

each field have been determined in the "Nanoscience and Nanotechnology Strategies: Vision 2023" document prepared by TUBITAK in 2004. As indicated in "Nanoscience and Nanotechnology Strategies: Vision 2023" document, in the field of nanophotonics, nanoelectronics and nanomagnetism, the strategic target is becoming an international production center for integrated circuit systems with nanostructures. Nanomaterials aim the production of advanced nanocomposite materials, bioinspired materials and catalysts, and nanoelectronic and nanomechanical devices by the method of self-assembly. The target of nanocharacterization subfield is to improve scanning probe microscopes and atomic force microscopes. In the area of nanofabrication it is aimed to produce nanostructures and integrated circuit systems with competency while nanosized quantum information processing targets to be competent on designing, simulating and producing of nanoscale units. Finally, in the field of nanobiotecnology it is planned to improve DNA diagnosis (TUBITAK, 2004b). Thus, strategic technology roadmaps were elaborated covering the each nanotechnology domain for the next 20 years.

Nanotechnology has been also included in several governmental documents. In the "Ninth Development Plan of 2007-2013" and "Turkish Industrial Strategy Document of 2011-2014 (Towards EU Membership)", it is also indicated that nanotechnology will be considered as a priority research field. The aim of the "Ministry of Science, Industry and Technology's Strategic Plan 2013-2017" is to prepare nanotechnology strategy documents on nanotechnology and introduce capacity building programs for public and private nanotechnology industries. The "National Science, Technology and Innovation Strategy 2011-2016" was adopted in December 2010 by the SCST. The strategy focuses on human resources development for science, technology and innovation, transformation of research outputs into products and services, enhancing interdisciplinary research and international cooperation. It is interesting to note that although nanotechnology has been indicated as one of the strategic technology areas in the previous documents, it has not been included in this most recent policy document.

2.2. Institutional Capacity of Turkey in Nanotechnology Research

It is a well-known fact that nanotechnology has in recent years become a leading area in the world and Turkey needs to keep up with this global trend.

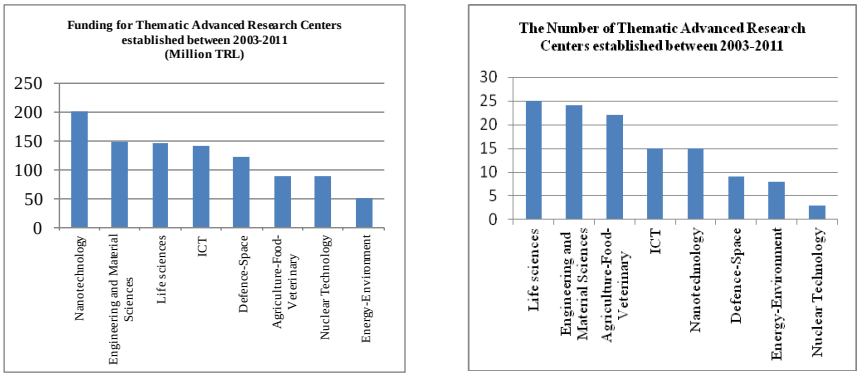
In this respect, Turkey recognizes the necessity of a well-defined and world-class national nanotechnology research and development policy. Additionally, many efforts are taken to overcome the shortcomings of the systems of nanotechnology innovation. The system of nanotechnology innovation in Turkey is currently at developing and mostly centred on research and the creation of knowledge. There are a number of studies that examine the state of nano related research in Turkey. For instance, according to Dumanli and Yurum (2010), the most of the Turkish nanotechnology research have been theoretical and stayed in individual basis. According to a survey employed by Duda and Sener (2010) nanotechnology research in Turkish universities are mostly theoretical in nature and with not much emphasis on a laboratory or an interdisciplinary approach. Although Turkey ranks modestly in terms of research in nanotechnology domain, there are a number of notable research centres in this field. Over the recent years, a number of universities established their own nanotechnology research and development centres, conducting their nanotechnology researches mainly focused on various nanotechnology subfields. Turkey started to have taken steps in the relevant domain with the establishment of National Nanotechnology Research Center (UNAM) at Bilkent University funded by the State Planning Organization and became operational in 2006. UNAM is dedicated to research on theoretical and experimental nanoscience and nanotechnology with strong emphasis on education and training. Following this development a number of research centers have been established. In the Middle East Technical University, the METU-Center project has been launched. METU-Center is a three-year project within the EU's 7th Framework Programme designed to improve and strengthen the human, information, and device infrastructure in the Central Laboratory of the METU in the fields including nanotechnology and nanosciences. Sabanci University Nanotechnology Research and Application Center, is developed by the State Planning Organization and Sabanci Foundation in 2011. The Center focus on multi-disciplinary research including advanced materials, nanobiotechnology, nanomedicine, nanoelectronics, micronano fluidics, nanomechanics, nanooptics, micromachining, micro and nano systems and alternative energy sources. In addition, centers such as the Gebze Institute of High Technology, and the TUBITAK Marmara Research Center are prominent public research centers where nanotechnology research is carried out.

Table 1. Prominent Nanotechnology Related Research Centers in Public / Private Universities

	Year of establishment	**Research Areas**
Public Universities		
Marmara University: Nanotechnology and Biomaterials Research Center	2008	Nanotechnology, biomaterials
Hacettepe University: Nanotechnology and Nanomedicine Science Center	2009	Nanotechnology, nanomedicine, nanobiotechnology, nanomaterials, optics, nanoelectronics
Middle East Technical University: METU-CENTER	2007	Nanotechnology and nanoscience, multi functional materials, biology, biotechnology
Gebze High Technology Institute: Nanotechnology Research Center	2003	Nanotechnology
Private Universities		
Sabanci University: Nanotechnology Research and Application Center	2011	Advanced materials, nanobiotechnology, nanomedicine, nanoelectronics, micro-nano fluidics, nanomechanics, nanooptics, micromachining, micro and nano systems and alternative energy sources
Koc University: Surface Technologies Research Center	2011	Nanomaterials, spectroscopy, optics and photonics,
Fatih University: Bio-Nano Technology Research Center	2011	Bionanotechnology, bioorganics, biophysics, biotechnology, spectroscopy
Zirve University: Nanotechnology Research Center	2010	Nanoscience, nanotechnology

Recently, there are around twenty nanotechnology research centers established in different universities in Turkey. Table list the most prominent research centers and institutes located in various academic institutions in Turkey. It appears that many of the nanotechnology research centers or institutes are established after in the late 2000s.

Figure 1: Distribution of Research Funding and Research Centers Established According to Thematic Research Areas, 2003-2011



Source: Madenoglu, (2010)
http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/btyk/22/22btyk_dpt

In order to foster research in several technology fields, for instance, funding programmes, such as “Thematic Research Centers” and “Central Research Laboratories” were launched by the Ministry of Development. Figure demonstrates that the nanotechnology related thematic advanced research centers received the highest amount of investments during the period 2003-2011. Additionally, 15 nanotechnology related research centers have been established during the relevant period including the Institute of Materials Science and Nanotechnology of Bilkent University and Nanotechnology Research Center of Sabanci University. However, according to European Commission (2012), the impacts of these investments have not yet been assessed. Another problem is the sustainability of these research infra-

structures since the Ministry of Development does not allocate funds for the sustainability of these research centers and laboratories.

3. Methodology and Data

Innovation, which is considered as technological change, result in practical implementation and commercialization. The outcome of successful innovation is reflected in new products, processes and services. In the case of academia, innovators (scientists and engineers) contribute to public knowledge by publications and patents. Outputs such as publications and patents provide information about emerging technologies and recently have a growing trend.

Porter et al., (2008) indicate that the development in science, technology and innovation is recently monitored by new tools and many on-going efforts to assess the evolving nature of nanotechnology research and innovation systems are taken place. Among these efforts, tech-mining is a useful tool in exploiting information about emerging technologies such as nanotechnology to inform about the technological innovation processes (Brown et al., 1997: 321; Porter and Cunningham, 2005: 19). Tech-mining works by gauging the direct outputs of R&D such as publications and patents and explores the networking between innovators that produce innovation (Porter and Cunningham, 2005: 7).

It is well-known fact that realizing the economic benefits and potential of nanotechnology depends on ongoing scientific developments. In this context, it is crucial to analyse the linkages between the actors in terms of knowledge flows and scientific collaborations. Thus the objective of this study is to analyse the subject categories of nanotechnology innovation in Turkey using publications in the relevant academic literature presenting (i) the overall trend of scientific articles related to nanotechnology and (ii) the structure of international collaboration in the relevant domain by paying particular attention to subject categories listed by Web of Science. Kay and Shapira (2009) identify three potential strategies of nanotechnology research collaboration: within country collaborations which include sub-national regional clusters; research collaborations among countries in a specific geographical region such as the European Union (EU); and collaborations with leader countries in nanotechnology research. This article focuses on the international collaborations of Turkey in nanotechnology with the EU countries.

Many scholars have developed and used nanotechnology research strategies to monitor the trends in this field (Kostoff et al. 2007; Mogoutov and Kahne, 2007; Porter et al., 2008; Huang et al., 2010; Maghrebi et al., 2011). In this paper, the data is developed using the definition of nanotechnology proposed by the most recent bibliometric search strategy of Arora et al. (2013) which captures the new developments and topics in nano-related research. They use a two-stage modularized Boolean approach. The first stage involves the application of eight research strings, while the second stage involves the exclusion of publications that fell outside the nanotechnology domain. [3] The correct choice of a search strategy is vital in bibliometric research and may impact the results significantly (Ovalle-Perandones et al., 2013) The usage of such a comprehensive set of keywords rather than the prefix "nano"* leads to a better understanding of the developments on nano-related research.

Using this search approach, the relevant data is derived from Thomson Reuters Web of Science – SCI for the time period of 1990-2012. The bibliometric data include the full records of the articles having at least one author affiliated to organizations in Turkey. Vantage Point[4] tech-mining software is used for data-cleaning, analysis and mapping. Statistics such as the trend in nano-related publications, leading institutions and international collaborations in nanotechnology domain are obtained.

4. A Profile of Turkish Nanotechnology Publications

Despite the importance of nanotechnology at the global level, there is weak knowledge about its applications in Turkey. The objective of this section is to critically evaluate and analyse the past developments and current research of nanotechnology in Turkey. As mentioned previously, there are

3. For more details on the refined keyword list, method and process used to develop nanotechnology keywords and the two-stage search approach, see Arora et al. (2013: 358-360).

4. Vantage Point development initiated by Georgia Tech's Technology Policy and Assessment Center (TPAC) and later developed by Georgia Tech and Search Technology Inc. Vantage Point is a powerful text-mining tool for discovering knowledge in search results from patent and literature databases. For more details see; https://www.thevantagepoint.com/

many activities and outcomes of research that can be counted. The most basic and common is the number of scientific journal publications, which may be used as a measure of output. According to a recent research of Statnano (2013), in 2012 Turkey ranked 22nd in terms of the number of publications and 25th in terms of collaborations at the global level. By using Maghrebi et al. (2011) search string used for retrieving nano-related publications from Web of Science, they found that Turkey has published 1037 scientific publications and the rate of collaboration accounted for 34.3 %.

Table 1 provides the number of nanotechnology publications from Turkey which are retrieved from Web of Science database on June 13th, 2013 by using the set of keywords proposed by Arora et al. (2013). According to the basic statistics on nanotechnology related publications in Turkey, after data cleaning it is found that, the nano-related scientific publication database contains 7727 papers published in 1098 journals, presenting the contributions of 10784 authors, 1259 organizations, and 75 countries.

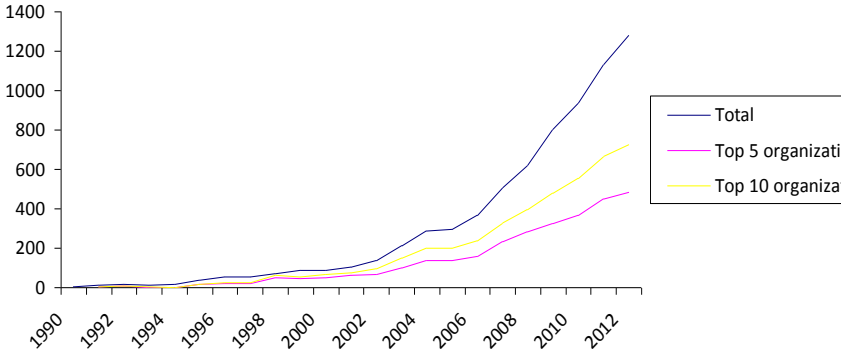
Table 2. Basic Statistics on Nanotechnology Related Data Sources in Turkey

	Publications
Source	Web of Science
Unit of Analyses	Publication record
Period	1990-2012
# Records	8333
# Records (keywords excluded)	7727
# Author affiliations	1735
# Author affiliations (cleaned)	1259
# Authors	13536
# Authors (cleaned)	10784
# Journals	1102
# Journals (cleaned)	1098
# Countries	79
# Countries (cleaned)	75

Source: Based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

For quantitative analysis, overall trends of the total number of publications, as well as the number of publications published by top five and top ten universities are presented. Turkish nanotechnology publications have grown exponentially over the period 1990-2012. The number of records was only 3 in 1990 and it reached to 1282 records in 2012. As a result of the fast pace of developments in nanotechnology at the global level and the increased activity and funding in nano-related research, it is seen that the number of publications has started to increase by mid-2000s. Additionally, the number of publications doubled between 2008 and 2012. By end-2012, using Arora et al. (2013) nano search approach, a total of 7727 Web of Science articles are identified published since 1990.

Figure 2. Nano-related Scientific Publications from Turkey, 1990–2012



Source: Based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

The trend analysis also presents that the concentration of nanotechnology publications has gradually decreased especially after 2000s. On the one hand, while in the beginning of 2000s the top ten universities published 75 % of total number of records; it decreased to 57 % in 2012. On the other

hand, the share of the top five universities decreased from 59 % to 38 % in the relevant period. As a consequence of this gradual decrease in concentration, one can argue that nanotechnology research has become dispersed.

Table 3. Nanotechnology Research Profiles

	Number	% of all organizations
Nationality		
Domestic	230	18.2 %
Foreign	1028	81.6 %
Ownership		
Public	974	77.3 %
Private	280	22.2 %
Organization Type		
Academic	948	75.2 %
Government	93	7.3 %
Industry	133	10.5 %
Hospital	43	3.4 %
Other (Foundation, association)	33	2.6 %
Total	1259	

Source: own calculations based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

In the analysis, institutions are classified under three groups namely nationality, ownership and organization type (Table 3). After data-cleaning and classification of organization list, it is found that in Turkey approximately a total of 230 domestic organizations undertake nano-related publications. Public institutions are more active than private institutions in nano-related research. In their study, Kay and Shapira (2009) suggest six different types of organizations: Academic institutions, governmental institutions, industry, hospitals and other types of organizations such as foundations or associations. According to this classification, academic institutions are among the most active institutions producing 75.2 % of total nano-related publications. In general, in developing countries, the share of public

Table 4. Leading Author Affiliations undertaking Nanotechnology Research

Rank	Author Affiliations (Organization Only)	# Records	% of Total Publications
1	Middle East Technical University	909	6.19
2	Bilkent University	744	5.06
3	Istanbul Technical University	663	4.51
4	Hacettepe University	537	3.65
5	Ege University	373	2.54
6	Gazi University	368	2.50
7	Gebze Institute of Technology	323	2.20
8	Dokuz Eylul University	275	1.87
9	Ankara University	256	1.74
10	Istanbul University	233	1.58
11	Anadolu University	220	1.49
12	Ataturk University	210	1.43
13	Yildiz Technical University	202	1.37
14	Sabanci University	198	1.34
15	Marmara University	190	1.29
16	Koc University	182	1.23
17	Selcuk University	181	1.23
18	Cumhuriyet University	173	1.17
19	TUBITAK	167	1.12
20	Firat University	164	1.11
21	Others	8110	55.2

Source: own calculations based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

investment in total nanotechnology R&D basket is relatively greater in comparison to private sector (TERI, 2010). Although the growing importance of private industry cannot be underestimated, industry is always expected to be a much lower producer of research publications than the universities and public institutions (Kay and Shapira, 2009:271). This assump-

tion is also valid for Turkey since only about 10.5 % of scientific publications are from the industry. The low levels of industry involvement in nanotechnology research in Turkey may be considered as a weakness. One of the reasons for this weakness is that the nanotechnology research in Turkey is still at its early stages of development.

Scientific publications show crucial facts about universities, research institutes and companies develop and diffuse nanotechnology innovation. In order to determine the nano-related leading Turkish institutions, data-cleaning was made of the Web of Science field "Author Affiliations" and top 20 institutions were ranked according to their scientific output. Table 4 shows the most active institutions undertaking nanotechnology research in Turkey where all top leading institutions are universities except TUBITAK. Nanotechnology research shows a more organizational concentrated pattern. Nanotechnology research is clustered primarily in four public universities contributing to 19% of total number of publications. It should be noted that all four universities host Turkey's most prominent research institutes. In addition, the top ten universities are located in Istanbul, Ankara and Izmir which are the most developed cities of Turkey.

Two facts seem interesting in this analysis. First most prolific organizations in Turkey generated nano-related articles are all domestic institutions. Moreover, nineteen out of top twenty organizations are universities except for the governmental organization – TUBITAK. A plausible explanation of this is the fact that in Turkey, R&D activities are mostly carried out by universities. Secondly, there are only three private universities –Bilkent, Sabanci and Koc University- which are among the most active institutions in Turkey. It is crucial to note that there are also a total of 8110 records of institutes each contributes to a small share of publications.

4.3. Turkey's Collaborative Networks in Nanotechnology

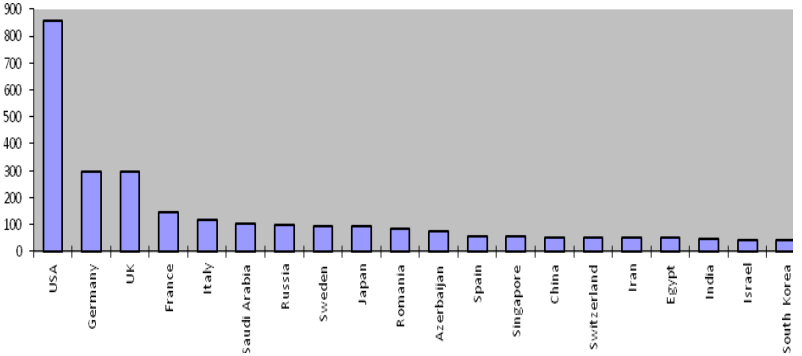
4.3.1. Turkey's Nanotechnology Research Networks at the Global Level

World economies are fast becoming knowledged-based and R&D, innovation and technology are determining factors in global competition and economic growth. Within this process, there has been an increasing interest in international scientific collaboration (Luukkonen et al. 1993). As a consequence, countries increasingly started to draw on each other's expertise and

share costs and resources by collaboration which enables the rapid sharing and exploitation of new knowledge (Adams et al., 2011).

It is a well-kown fact that it is vital for emerging countries to adjust their strategies and priorities in order to fully benefit the positive effects brought about collaboration in the areas of science, technology and innovation. In this frame, it is important to analyse the international collaboration networks with the technologically advanced countries. Thus, strong collaborative patterns would allow countries to catch-up with the innovation leaders. According to StatNano (2013) China ranks first and the US second in production of nanoscience, their international collaboration rate is among the lowest in the world. Saudi Arabia, Austria and Ireland have most collaboration among countries published more than 500 nano-articles in 2012.

Figure 3. Top Collaborating Countries with Turkey, 1990-2012



Source: Based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

Based on Web of Science data, Figure 3 shows the top 20 collaborator countries with Turkey. Between the period 1990 and 2012 Turkey has collaborated with a total of 75 countries. It is necessary to indicate that scientific publications may have more than two collaborative countries and thus the total country percentage shares may be more than 100 percent. In the analysis it

is found that, while the US is the most collaborative nation with its well-equipped, prestigious research centers and universities and around one-fifth of all Turkey's internationally-collaborated scientific publications undertaken with the US collaborators in 2010. Germany and the UK appear to have a vital place in Turkey's collaboration patterns of nanotechnology.

Table 5. Leading Foreign Affiliations undertaking Nanotechnology Research, 1990-2012

Rank	Author Affiliations (Organization Only)	Country	# Records
1	California University	USA	70
2	Azerbaijan Academy of Science	Azerbaijan	67
3	Royal Institute of Technology KTH	Sweden	64
4	Russian Academy of Science	Russia	60
5	Essex University	UK	58
6	King Saud University	Saud Arabia	50
7	Nanyang Technology University	Singapore	50
8	Max Planck Institute	Germany	47
9	CNRS France	France	41
10	National Institute of Material Physics Romania	Romania	40
11	Harvard University	USA	39
12	Washington University	USA	35
13	University of Sheffield	UK	33
14	Ain Shams University	Egypt	31
15	University of Illinois	USA	29
16	Sheffield Hallam University	UK	28
17	Florida State University	USA	26
18	University of Florida	USA	25
19	King Abdulaziz University	Saud Arabia	24
20	Texas A&M University	USA	24

Source: Based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

It is also found that the most frequent collaborators of Turkey in nano-related scientific publications are mostly with advanced countries which are considered as nanotechnology leaders. It is crucial to note that collaborative links with other countries provide equal or greater benefit to the developing countries compared to that gained by advanced countries (Statnano, 2013). The emerging nanotech countries Russia, China and India are also collaborative countries with Turkey, respectively. Within the top 20 collaborative countries Turkey also has two less advanced collaborative countries, namely Romania and Azerbaijan. An explanation would be that, neighbour countries have many motivations to collaborate in developing science and technology and thus geographical proximity evidently does play a key role.

Table 5 shows the leading foreign institutions undertaking nanotechnology research in Turkey. Turkey's international collaboration is largely characterized by the US universities. By contrast, only 5 universities located in the EU are ranked among the top 20 foreign organizations collaborating with Turkey. The following section focuses on Turkey's collaboration patterns with EU at the country level and Web of Science categories in the relevant field.

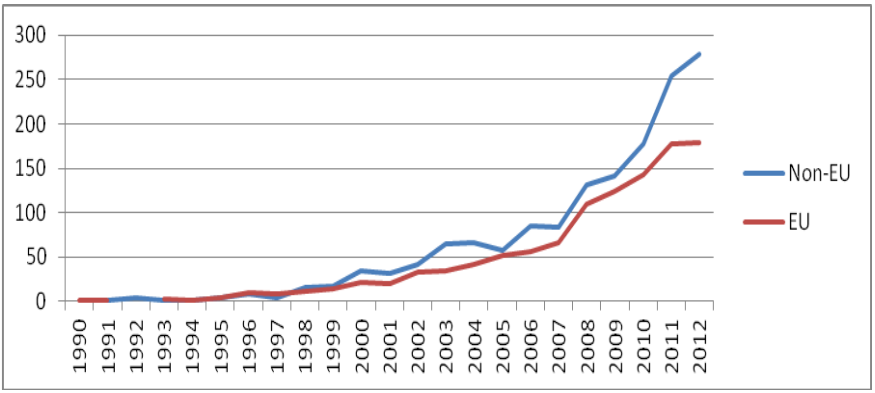
4.3.2. Turkey's Nanotechnology Collaboration with the EU Member States

The European Commission is the largest funding organisation of nanotechnology research in Europe and as an individual agency even worldwide (Hullman, 2006). The expanding network of research collaboration has become a predominant feature of the EU research base. For instance, international collaboration is the cornerstone of EU's Framework Programmes for research and technological development (FP). FP is the EU's primary funding mechanism for supporting collaborative, transnational research and development. Nanotechnology has appeared in the two latest FPs, namely FP6 and FP7, under the research activity area "Nanosciences, Nanotechnologies, Materials and New Production Technologies". The openness of the FP programs towards third countries[5] has played an important role in

5. The third countries associated to FP7 are as follows: Switzerland, Israel, Norway, Iceland, Liechtenstein, Turkey, Croatia, the Former Yugoslav Republic of

fostering the international collaboration. Thus, within Europe, FP facilitated researchers from participating countries to form a network for collaborative nanotechnology linkages. Since joining the FPs, Turkey has been a prolific third country participant in EU research area. This section deals with the collaboration efforts of Turkey with the EU countries and correlates the collaboration patterns of Turkey with the EU funding programmes.

Figure 4. Time Trend of Turkey's Nanotechnology Collaboration with EU vs. Non-EU Countries



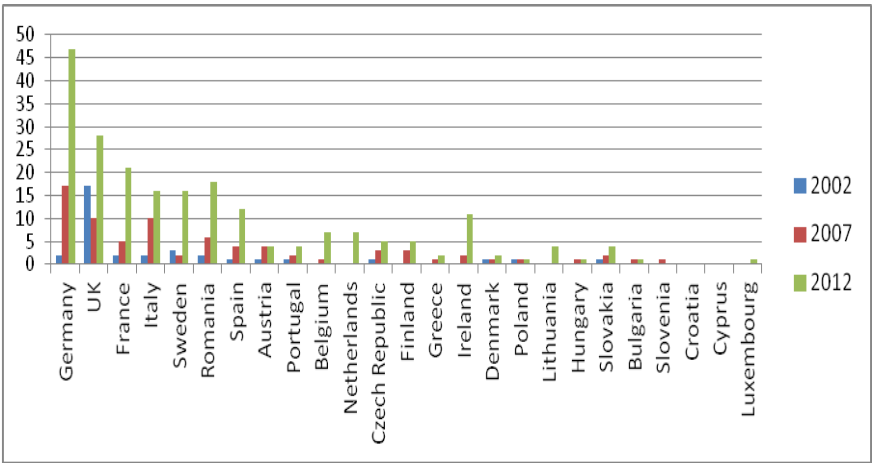
Source: Based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

During the relevant period Turkey has collaborated with a total of 25 EU member states except for Malta, Estonia and Latvia. The newest member state of the EU – Croatia – is also included in the analysis. Figure 4 provides a further analysis of nanotechnology publications with the EU member states versus the non-members. Although the collaboration with the non-EU countries are higher than the EU counterparts, it is seen that the collaboration patterns with the EU states has increased after 2007. From

Macedonia, Serbia, Albania, Montenegro, Bosnia & Herzegovina, Faroe Islands and Republic of Moldova.

1990 towards 2012, Turkish researcher's collaboration with the non-EU members produced 1508 articles, while 1113 articles produced with the colleagues from the EU countries.

Figure 5. Annual Nanotechnology Publications in Collaboration with the EU Member States



Source: Based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search approach

To have a more detailed picture of the collaboration patterns, the snapshots of all EU countries has been presented in Figure 5. The analysis is based on three different years; the year 2002 as the launch of the FP6, the year 2007 as the launch of the FP7 and 2012 as the most recent year for the data available. Among the EU member states, Germany plays the most significant role, but on a rather moderate level when compared to the US as discussed previously (see Figure 3). The year 2012 witnessed the rise in the number of collaborative papers between parties. The steepest rises were observed for Germany, UK, France Sweden, Romania, Spain and Ireland. However, the level of scientific collaboration with the rest of the EU has not changed so dramatically and still remains low.

Table 6. Turkish Nanotechnology Papers and Turkey-EU Collaboration based on Top Web of Science Subject Categories, 1990-2012

All Turkish Nano-related Publications			
Rank	Web of Science Subject Category (The total number of WoS subject categories 152)	**1**	**2**
1	Materials Science, Multidisciplinary	1 963	12.9
2	Physics, Condensed Matter	1470	9.7
3	Physics, Applied	1385	9.1
4	Chemistry, Physical	1051	6.9
5	Nanoscience & Nanotechnology	857	5.6
6	Polymer Science	821	5.4
7	Chemistry, Multidisciplinary	572	3.7
8	Optics	457	3.0
9	Engineering, Chemical	441	2.9
10	Engineering, Electrical & Electronic	389	2.5
11	Electrochemistry	345	2.2
12	Chemistry, Analytical	341	2.2
13	Materials Science, Coatings & Films	329	2.1
14	Metallurgy & Metallurgical Engineering	259	1.7
15	Physics, Multidisciplinary	221	1.4
16	Materials Science, Ceramics	219	1.4
17	Materials Science, Biomaterials	218	1.2
18	Chemistry, Applied	195	1.2
19	Energy & Fuels	190	1.2
20	Biotechnology & Applied Microbiology	184	1.2
Turkish Nano-related Publications with EU Collaboration			
Rank	Web of Science Subject Category (The total number of WoS subject categories 99)	**1**	**2**
1	Materials Science, Multidisciplinary	356	14.6
2	Physics, Applied	247	10.1
3	Physics, Condensed Matter	246	10.1
4	Chemistry, Physical	187	7.6
5	Nanoscience & Nanotechnology	147	6.0
6	Chemistry, Multidisciplinary	117	4.8
7	Polymer Science	102	4.1
8	Chemistry, Analytical	68	2.7

9	Electrochemistry	59	2.4
10	Optics	49	2.0
11	Engineering, Electrical & Electronic	49	2.0
12	Engineering, Chemical	47	1.9
13	Pharmacology & Pharmacy	43	1.7
14	Materials Science, Coatings & Films	41	1.6
15	Metallurgy & Metallurgical Engineering	41	1.6
16	Physics, Atomic, Molecular & Chemical	36	1.4
17	Materials Science, Ceramics	34	1.3
18	Instruments & Instrumentation	34	1.3
19	Physics, Multidisciplinary	32	1.3
20	Materials Science, Biomaterials	30	1.2

1. # Records

2. % of Publications in Each Subject Category

Source: Based on Thompson Reuters Web of Science-SCI using Arora et al. (2013) nano search definition.

The subject categories of nanotechnology publications in Turkey for the period 1990-2012 are presented by comparing all Turkish nanotechnology papers to Turkish papers co-authored with EU institutions (Table 6). In the analysis, it is found that nano-related papers have been published in 99 out of the 175 subject categories in the Web of Science database. Going deeper into the analysis of Turkey's research output, findings show that 4 subject categories dominate the Turkish nano-related publications which are on materials science, physics, chemistry and engineering. The results on Web of Science subject categories of Turkish nano-related publications shows a similar trend with the study of Youtie and Shapira (2009) which indicate that materials sciences, physics, and chemistry subject categories dominate the listing during the period 1991-2008.

In a similar manner, in the collaboration with the EU, the same subject categories dominate the listing. However, collaboration with the EU researchers in biotechnology seems to have less importance. On the contrary, in the fields of pharmacology and pharmacy physics, atomic, molecular and chemical, and instruments and instrumentation, the papers produced by Turkey-EU collaboration is higher relative to Web of Science subject cate-

gories in all Turkish publications. This difference may be an encouraging factor for Turkish researchers to focus more on such areas.

5. Conclusion

This paper analyses the evolution of Turkey in nanotechnology research by taking into account the academic publications to observe the general trend and the leading actors and subject categories in the systems of nanotechnology innovation. In this sense, the aim is to show both the trend of nanotechnology research and Turkey's collaboration patterns in the relevant research sub-fields with the EU member states. Thus, the search for the potential of Turkey to collaborate with the advanced group of countries such as the EU in nanotechnology and identify the sub-fields of common interests lies at the heart of this paper. Turkey's growth of research output is increasing rapidly and it is also necessary to increase international collaboration. The findings are expected to be particularly useful for developing the future areas of research in nanotechnology domain in collaboration with the EU countries.

As a consequence of the fast pace of developments in nano-related activity and research, the number of publications has started to increase by mid-2000s in Turkey. In this respect, one of the key aspects of increasing the international scientific influence of Turkey in nanotechnology is to increase international collaboration. The most frequent collaborators of Turkey in nano-related scientific publications are mostly with advanced EU countries -Germany and the UK- which are considered as nanotechnology leaders. Moreover, Turkey has strong collaboration networks with the EU countries that seven out of top twenty collaborative countries are from the EU. However, the level of scientific collaboration with the remaining EU countries still remains low.

It indicates that the results of collaboration among two parties will be correlated with the Web of Science subject categories. The subject categories of nanotechnology publications in Turkey are also presented by comparing all Turkish nanotechnology papers to Turkish papers co-authored with EU institutions. Going deeper into the analysis of Turkey's research output by taking into account the Web of Science subject categories, findings show that four subject categories dominate the Turkish nano-related

publications which are on materials science, physics, chemistry and engineering. The results show a similar trend with the subject categories that dominate the global nano-related research. Another important finding is that, in the fields of pharmacology and pharmacy physics, atomic, molecular and chemical, and instruments and instrumentation, the papers produced by Turkey-EU collaboration is higher relative to Web of Science subject categories in all Turkish publications. This difference may be an encouraging factor for Turkish researchers to focus more on such areas.

Türkiye'nin AB Ülkeleri ile Bilimsel İşbirliği: Nanoteknoloji Örneği

Özet: Nanoteknoloji araştırma ağları gelişimini analiz etme konusunda artan bir motivasyon bulunmaktadır. Bu makale, nanoteknoloji yenilik sistemlerinde genel eğilimi, önde gelen aktörleri ve konu kategorilerini belirlemek için akademik yayınları dikkate alarak, Türkiye'nin nanoteknoloji araştırmalarındaki gelişimini ortaya koymaya çalışmaktadır. Bu çalışmanın iki amacı vardır; (i) nanoteknoloji alanındaki araştırma eğilimlerini sunmak ve (ii) Türkiye'nin AB ülkeleri ile gerçekleştirdikleri işbirliklerini ilgili araştırma alt dalları kapsamında vurgulamaktır. Bu çerçevede, bu çalışma Türkiye'nin gelişmiş ülkelerden oluşan AB ülkeleri ile işbirliği yapabilme kapasitesinin olup olmadığı ve Web of Science kategorileri kapsamında ortak çalışma yapılan alt konu dallarını göstermeyi amaçlamaktadır. Elde edilen bulguların gelecekte AB ile hayata geçirilecek nanoteknoloji araştırma konularına yararlı olması beklenmektedir.

Anahtar Kelimeler: Nanoteknoloji, Türkiye-AB Bilimsel İşbirliği, Bibliyometrik Analiz
Jel Kodu: C89, O30, O38

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