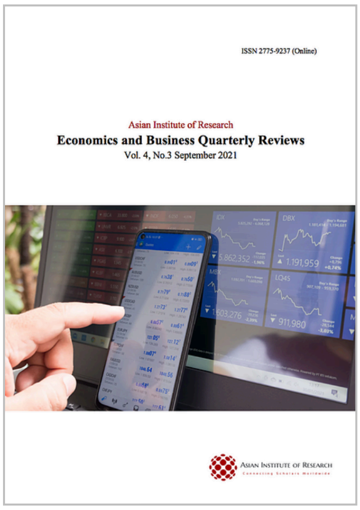

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A Comparative Study on Turkey's Science and Technology (S&T) Indicators

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Abstract
Science and technology (S&T) indicators are important in evaluating how successful countries are in factors described by endogenous growth models. Accordingly, the aim of this paper is to investigate S&T indicators of Turkey in a comparative and more hitherto comprehensive study and to present a guiding reference for researchers and decision makers working on innovation and technology policies. This study was carried out using online databases such as those of the OECD, World Bank, Eurostat, and TÜİK considering the criteria used in the literature to measure countries' R&D and innovation performances, and Turkey's innovative performance is presented in comparison with the world's by summarizations within the scope of the study. The results demonstrate that Turkey has made significant progress in the last 20 years in terms of R&D and innovation, but it is still far from reaching the indicators of developed countries. In particular, the increase in R&D and innovation performance has decreased due to the economic difficulties experienced in the world and in Turkey after 2012 and 2013. Based on the indicators evaluated in this study, some suggestions are given and prioritized to increase Turkey's innovation performance.

Keywords: Innovation, Science and Technology Indicators, Turkey's Performance, Research and Development

1. Introduction

Since Austrian economist Joseph Schumpeter defined innovation as the key driver behind social and economic development in the 1930s, it has been indisputably accepted by everyone that innovation plays a critical role in the development of industries and, thereby, in the economic growth of countries (Haneda & Ito, 2018). Both the diversification and rapid change of customer preferences and needs as well as the dizzying speed of technological developments and intensifying globalization, investigated in the scope of technological and market turbulence today, force industries to focus intensely on achieving innovation. It is also clearly observed today that advanced countries contribute to the welfare of both their own societies and the world, and that they influence the innovation policies of developing and less developed countries with the technologies they develop. For example, Industry 4.0, which is based on the rationale of integrating digital technologies into production processes, is spreading all over the world as a strategy of developed economies to regain and maintain their competitive power in manufacturing. This suggests that integrating the workflows of advanced technologies into continuous improvement methodologies will bring higher industrial performance (Dalenogare, Benitez, Ayala, & Frank, 2018). Industry 4.0 is a phenomenon that will influence the future of production. In this sense, it would not be wrong to say that the national innovative capacities of countries are indicators of their economic power in the world (Furman, Porter, & Stern, 2002).

As seen in Figure 1, Turkey is an upper middle-income country according to the classification by gross national income (GNI) per capita, using the purchasing power parity calculation (
Table 1). The literature acknowledges that countries stuck at this income level for more than 15 to 20 years have fallen into the middle-income trap (Bresser-Pereira, Araújo, & Costa Peres, 2020). The term "middle-income trap" indicates a country's inability to join the group of nations with high-income (Abdon, Felipe, & Kumar, 2012). This inability is mostly due to a country's failure to transition from low-value-added to high-value-added sectors. Countries experiencing the middle-income trap are those that have surpassed low-income levels and made substantial social and economic developments but have not yet reached the levels achieved by advanced countries.

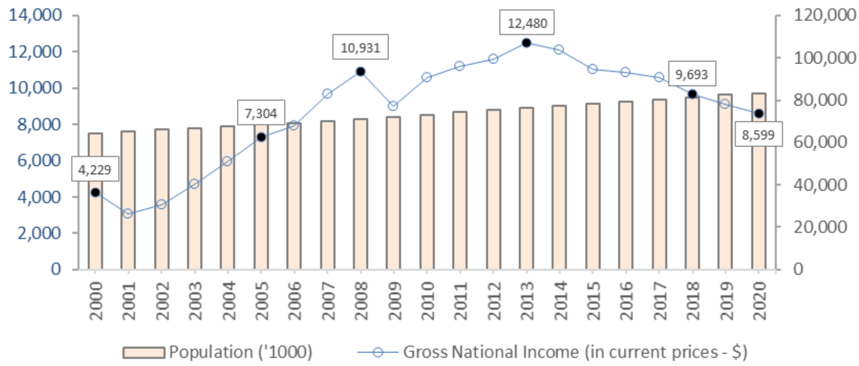


Figure 1: GNI per capita (USD) and total population in Turkey (TÜİK, 2021)

Since these countries do not have enough resources or capabilities to produce knowledge and develop innovative products, processes, and services in order to compete with highly skilled producers in developed economies, their economic growth slows down, and they end up trapped in the middle-income group (Yilmaz, 2014).

With the economic reforms initiated since the early 2000s, Turkey's GNI per capita has increased, and the country is now classified as an upper-middle income country (Figure 1). However, the advantages of having labor-intensive industries and the use of cheap labor, which are benefits while moving up from the lower-middle income level to the upper-middle income level, are gradually being lost. In fact, the relatively low growth rates in Turkey in recent years clearly demonstrate the disappearance of this advantage (1.8% in 2020, 0.9% in 2019, and 2.6% in 2018).

Table 1: World Bank classification of countries based on income (July 2020)
(Classification is updated each year on July 1st)

	Average Income per capita per year
Low-income level	$ 1,035 or less
Middle-income level	$ 1,036 to $ 12,535
– *Lower-middle income level*	$ 1,036 to $ 4,045
– *Upper-middle income level*	$ 4,046 to $ 12,535
High income level	$ 12,536 or more

(Serajuddin & Hamedah, 2021; Worldbank, 2020)

Most economists agree that Turkey has been stuck in the middle-income trap since 2008. Although a positive trend appeared to emerge in 2010 and 2011, it reversed in 2012 and 2013. However, arguing neither the notion of the middle-income trap nor whether Turkey is in the middle-income trap is the aim of this study. The main reason for mentioning this is that the steps Turkey must take to get out of the middle-income trap coincide with the steps that Turkey must take to become one of the top ten economies of the world.

Today, technological innovation is a major driver in the development of countries and the sustaining of competitiveness, which requires building powerful technological knowledge, conducting intense research and development (R&D) activities and supporting entrepreneurs and entrepreneurship (Gackstatter, Kotzemir, & Meissner, 2014; Raghupathi & Raghupathi, 2019). Accordingly, being Europe's 6th and the world's 13th largest economy as of 2020, Turkey should take strategic steps with R&D and innovation policies in order to rise to the level of advanced countries by developing its own technologies, allocating more financial and human resources to R&D and innovation, and improving its innovation ecosystem. With that aim, the Turkish government will need to embrace a proactive role in the design of the necessary incentive systems, invest larger volumes of resources in both R&D and education, support those industries that represent comparative advantages for the country, and increase its focus on capability accumulation and advancements in industrial upgrading (Gemici & Öztürk, 2020). In this paper, while investigating the selected science and technology (S&T) indicators of Turkey and other countries through a review of the statistics of the OECD (Organization for Economic Co-operation and Development), World Bank, Eurostat (Statistical Office of the European Union), TÜİK (Turkish Statistical Institute), and TPE (Turkish Patent Institute), we pursue insights that will reveal the matter of the innovativeness of Turkey and accordingly, its growth. Our approach in this article is to discuss the resources seen as inputs and the results seen as outputs, in search of the innovativeness of a country. Innovation inputs are the efforts in R&D, represented by financial resources allocated to R&D and available human resources to conduct R&D and achieve innovation. Innovation outputs, on the other hand, are assessed by patent applications and registrations and scientific publications originating from a country (Raghupathi & Raghupathi, 2019). At the same time, we will argue the role of government policies in innovation as considered as one of the determinants for enhancing the innovation capacity of countries.

2. Endogenous Growth Theory, Technological Innovation and R&D

According to the Oslo Manual published by the OECD, "innovation is defined as the implementation of a new or significantly improved product/service, process, marketing method, or organizational method in business practices, workplace organization, or external relations" (Oslo Manual, 2018). Despite this broad definition of innovation, today it is technological innovation that dominates the world, creates value, and drives economic growth. The process of a novel concept embodied in tools, methods, or procedures that are of practical use to society is referred to as technological innovation (Tornatzky & Fleischer, 1990). These are new products or processes and new technologies that include significant technological changes in products or processes and have profound effects on people's lives as well as contributing to the growth of countries (Carayannis, Samara, & Bakouros, 2015). Technological innovation emerges by matching a novel solution obtained from scientific and technological knowledge with a real or perceived need and makes that solution feasible and producible (Garcia & Calantone, 2002). Through the eyes of economists, technological innovation is considered as one of the main factors that lead to increased productivity and economic growth of countries.

Instead of neo-classical growth models that treat technological progress as an external factor and therefore cannot fully explain economic growth, so-called "endogenous growth models" have been developed in the world since the 1980s. According to endogenous growth theory, the forces that change economic structures and industry landscapes come from within the system. This kind of growth is driven by the internal forces governing the opportunities and incentives to create technological knowledge (Furman et al., 2002). In this regard, endogenous growth models emphasize that human capital, knowledge and technology are the main contributors to a country's innovation and economic growth, which need to be developed in-house (Raghupathi & Raghupathi, 2019). This perspective is also in line with Schumpeter's vision because he focused on endogenous factors to explain the economic system (Shane, 2009). The first economic growth model based on R&D and human capital was proposed by Romer (1990), and then that model was expanded by Grossman and Helpman (1991) and Aghion and Howitt (1992). The rationale behind these models is that every additional resource allocated to R&D and the presence of skilled human resources contribute to the development of new products and manufacturing techniques and the increase of countries' competitiveness by improving productivity and innovativeness, eventually leading to the economic growth of countries (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Romer, 1990). As a result of this approach, both developed and developing countries allocate more and more resources to R&D and develop a highly skilled workforce today.

Although innovation is acknowledged as "something new", "an invention", "a new idea" in various sources, in fact, it encompasses all processes, involving the effective transformation of ideas into action, including design and evaluation phases (Carayannis et al., 2015). In this sense, R&D activities, which are strong indicators of innovative efforts, constitute an important part of this process (Greenhalg & Rogers, 2010). R&D is described as any creative effort that is done in a methodical way to expand stock and apply knowledge to develop new applications (OECD, 2015). In fact, R&D constitutes a wide range that stretches from basic research targeting only the production of new knowledge without considering its utility to efforts that will enable the improvement of existing products or processes (Forbes & Wield, 2004). As seen in Figure 2, the innovation process comprises R&D, commercialization, and diffusion stages.

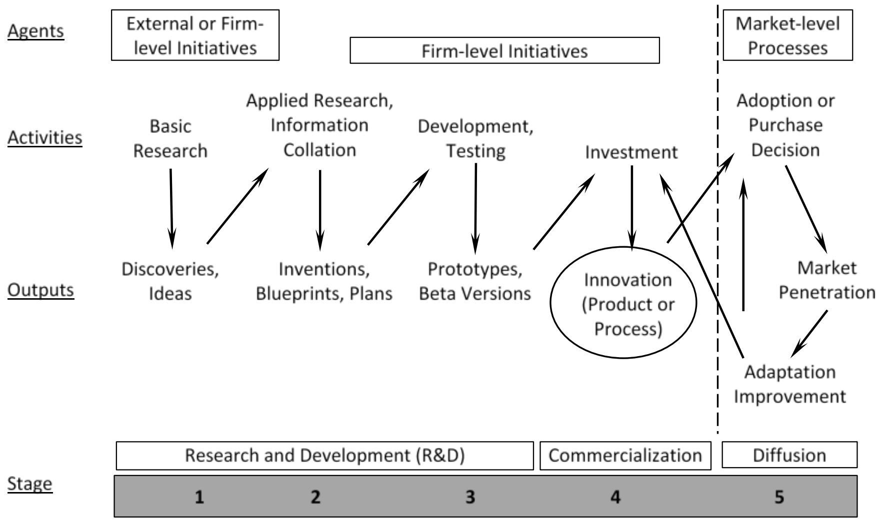


Figure 2: The Innovation Process (Greenhalg & Rogers, 2010)

Because the traditional aim of R&D is the creation of new goods and processes, R&D activities constitute an essential contribution to national innovation (Forbes & Wield, 2004; Raghupathi & Raghupathi, 2019). It is important to note here that, in developed countries, research (R) accounts for roughly half of overall government R&D expenditures, while development (D) accounts for two-thirds of R&D expenditure of industries. At the same time, most of the fundamental research is funded by the government and carried out at universities. In this sense, R&D is considered mostly as development (D) in business enterprises (Forbes & Wield, 2004). In advanced economies with high GNI per capita, it is observed that government incentives for R&D are increasing every year. The fact that high-income countries are ahead in science and technology is a result of this approach. Accordingly, most countries improve various support mechanisms in order to expand R&D activities throughout the country, which are considered strategic in terms of achieving economic growth, and to have R&D-based models of economic development.

3. Brief Historical Background of Strengthening Innovation and R&D in Turkey

As is known, countries that have high R&D expenditures as a percentage of GDP rank higher in the Global Competitiveness Index and this leads to sustainable welfare beyond growth. The post-World War II era saw the most rapid development in industrial R&D and R&D studies became routine in large companies, thus entering the innovation agendas of countries (Drejer, 1997). On the other hand, in developing countries, R&D efforts usually began in state-sponsored laboratories (Forbes & Wield, 2004).

Although Turkey did not follow aggressive policies that would penetrate at grassroots levels in promoting R&D

and innovation until the 2000s, we will review the steps taken in this regard in the history of the Turkish Republic. In Turkey, the Law for the Encouragement of Industries that was enacted in 1927 became the country's first encouragement law, as a result of the Industrial Development Initiative launched by the first Izmir Economic Congress in 1923. Later, the Urgent Industrial Plan in 1946, Economic Development Plan (also known as the Vaner Plan) in 1947, and Law No. 5821 on the Foreign Capital Incentive Law in 1951 were put into action. Up until 1973, some amendments were made to these laws. The Industrial Investment and Credit Bank was also established in 1963 to provide loans to industries (Ahmad, 1993). In addition, the State Planning Organization was established in the early 1960s. A planned development period having been initiated with the First Five-Year Development Plan in Turkey, it was aimed to encourage the private sector to invest in the country and adopt an import substitution strategy. In the same period, in 1963, TÜBİTAK (the Scientific and Technological Research Council of Turkey) was founded, and the first steps were taken toward a transition to a knowledge-based economy. Turkey implemented a mixed economic system until the decisions announced on January 24, 1980. After that, economic liberalism with an export-based growth model was adopted. Until 2009, incentive systems based mostly on investment were maintained to support growth and development. In that year, an incentive system was introduced based on R&D and aimed at narrowing regional disparities (Candan & Yurdadog, 2017).

On the one hand, the growth of the country is encouraged with investment incentive policies, while on the other hand, some steps have been taken in science and industrial policies in order to manage the transition to a knowledge-based economy. Twenty years after the establishment of TÜBİTAK, in 1983, the Supreme Council for Science and Technology was founded for the purpose of assisting the government in determining long-term science and technology policies, setting goals, identifying priority areas, preparing plans and programs, deploying public institutions, cooperating with the private sector, preparing for law-drafting and legislation, helping to train researchers, leading the establishment of research centers, and ensuring coordination between industry and institutions. The reports entitled "1983-2003 Turkish Science Policy" and "1993-2003 Turkish Science and Technology Policy" were the first important steps taken by the Supreme Council for Science and Technology in the efforts of policy development. Since the desired path could not be achieved over time with these steps, a vision and a strategy for science and industry policies was determined with the aim of creating an ever-more innovative society through the "Vision 2023: Science and Technology Strategies" report in 2001 prepared by the Supreme Council for Science and Technology (TÜBİTAK, 2004). From this point on, Turkey has taken important steps in the fields of science and technology, its economy has developed, and it managed to be included among the upper-middle-income countries by exceeding gross national income per capita of $10,000. Indeed, the indicators discussed in this study demonstrate the increased momentum of Turkey in the 2000s. Now, it is necessary to set more result-oriented goals to get out of the middle-income trap and move up into the upper-income group of countries.

In the framework within EU-Turkey Customs Union & Policy Harmonization, the Turkish Patent Institute (TPE) and the Turkish Competition Authority were founded in 1996. In the same year, the Turkish Academy of Sciences (TÜBA), Technology Development Foundation of Turkey (TTGV), and National Metrology Institute (UME) was established (Candan & Yurdadog, 2017). These steps have been the premises of the advances of Turkey in the fields of science and technology in the 2000s.

4. Role of Government Policies in Innovation

The economic function of government appears to be divided between neoliberalism and statism, with the former advocating market-led development and the latter advocating government intervention (Wang, 2018). Although the same is true for innovation policies, the literature emphasizes the active role played by governments in steadily enhancing the national innovation capacities of countries. The argument has been made that by establishing clear standards and policies, governments can facilitate technological transformation and sustainable development (Patanakul & Pinto, 2014). Indeed, governments play a key role in supporting R&D and innovation through making policies, giving targeted incentives, enabling R&D collaboration, and undertaking coordination role (Raghupathi & Raghupathi, 2019). In this sense, most government intervention falls into one of two categories: directive intervention in which arrangements in investment and manufacturing models in certain industries are made with the goal of achieving specified results; and facilitative intervention aimed at providing public services such as infrastructure investments and education policy development programs in order to create a favorable climate for private firms. The government considers that some sectors and products are more vital than others, thus it uses directive intervention to strategically concentrate capital in certain businesses. On the other hand, the government's facilitative approach aims to encourage innovation by establishing institutions that support a healthy culture and focusing policy on removing barriers to private involvement in innovation (Wang, 2018).

Particularly, diverse needs, technological and market turbulence, and political uncertainties have put governments in the inevitable position of intervening in both social and economic fields. Both developed and developing countries adopt this approach effectively with the implementation of instruments such as direct or indirect and monetary or non-monetary grants provided to public institutions, the private sector, and research institutions for R&D and innovation. These incentives are classified based on their objectives (supporting R&D and innovation, increasing export volume, increasing investment, attracting foreign direct investment, ensuring inter-regional equity, accelerating economic development), their scope (general/special purpose incentives), their awarded time (pre-investment, during the investment, post-investment), and their tool used (in-kind, in-cash, tax incentives) (Candan & Yurdadog, 2017). All these incentives are defined as "grants and government supports" and are used as some of the most effective financial instruments by the government to influence the socio-economic realm in Turkey today.

Directly supporting R&D, offering tax incentives for investments in the field of sustainable technology, and applying further initiatives for technical assistance in the area of industrial policies can certainly help in creating a more fruitful environments for business (Patanakul & Pinto, 2014). Since the early 2000s, Turkey has implemented policies in line with improving the innovation ecosystem and started to give strong incentives for R&D to SMEs, large firms, and universities. In fact, going a step further, investment incentives and strategic investment programs have been created for the commercialization of R&D outputs and inventions, which are the most important part of innovativeness. With the Law on Technology Development Zones enacted in 2001, firms in technology development zones were provided a partial tax exemption for their R&D activities. Although the tax exemption was limited to 40% with Law No. 5228 enacted in 2004, this rate was increased to 100% afterwards. After a while, it was realized that these incentives were insufficient, and Law No. 5746 on supporting R&D activities was enacted in 2008. Also, there have been legislative updates regarding both laws over time. With these laws, strategic policies were determined, and grants were provided through TÜBİTAK to support both the development of human capital and R&D activities of private and public institutions. In addition, through the Small and Medium Industry Development Organization (KOSGEB), grants and credit advantages were made available to SMEs (Candan & Yurdadog, 2017).

5. Science and Technology (S&T) Indicators

S&T indicators are international measure, analysis, and comparison tools to support the awareness and evolution of R&D activities. Governments and researchers have been measuring S&T for more than 50 years in order to determine the strengths and weaknesses to reach national objectives in terms of the national capacity and performance of the countries (Benoît Godin, 2003).

Although S&T indicators are very diverse, in this paper, we will review the main indicators, namely financial resources devoted to R&D, the availability of skilled human resources, and patent and scientific publication statistics (Raghupathi & Raghupathi, 2019).

5.1 R&D expenditure (gross expenditure on R&D GERD)/R&D expenditure as a percentage of GDP

The most important factor for effective and efficient R&D is to allocate sufficient financial resources to this field. For this purpose, one of the most important criteria used to assess the R&D and innovation efficiency of a country is R&D expenditure. R&D expenditure is used to encourage innovation, economic growth and sustainable development and to offer a boost to a country's competitiveness (Benoit Godin, 2003). The changing of R&D expenditures suggests the evolution of long-term policies and strategies associated with innovation for the development of the economy.

In the late 1950s and early 1960s, economists were interested in linking R&D to economic growth. J.D. Bernal measured research budgets as a percentage of national income for the first time, comparing the UK's performance with that of the USA and USSR and he suggested that between one-half percent and one percent of the UK's national income should be spent on research (Benoit Godin, 2003). Later, R&D expenditure as a percentage of GDP started to be measured, which is particularly useful for making international comparisons. As stated in the first edition of the Frascati handbook, the American GERD/GNP ratio of the early 1960s, i.e. 3%, was supported as the percentage that OECD member countries would target. It was emphasized that a high level of R&D expenditure as a percentage of GDP is of great importance in terms of strengthening domestic industries and reducing foreign dependency.

As seen from Figure 3, from the early 2000s onwards, R&D expenditure as a percentage of GDP has been increasing each year in Turkey. However, when compared to other countries, it is clearly observed that Turkey needs to allocate more financial resources to R&D in order to gain a competitive edge in the field of advanced technology. For example, R&D expenditure as a percentage of GDP in Korea is remarkable. While this rate is around 3% in many developed countries, it is 4.64% in Korea. Accordingly, Korea has displayed extraordinary economic growth and global integration to become a high-tech industrialized country over the last years. Also, while many see China as only the world's manufacturing powerhouse, the same figure in China was 2.1% in 2019, which shows the innovative potential of the country. Scientific publications and the number of patent applications in China that we will review in the following figures (see Figure 15 and Figure 17) are also indicators supportive of this.

On the other hand, R&D expenditure as a percentage of GDP in the EU has not significantly increased since 2000. This situation may occur because while the new members of the EU increase the EU's total GDP, the R&D expenditures of those members do not contribute to the total R&D expenditure at the same rate. However, as is known, the EU is making considerable efforts to increase its R&D potential, particularly with the Framework Programmes for Research and Technological Development. The Framework Programmes, which encompass practically all scientific fields, have been the principal funding mechanisms through which the EU has supported research and development activities. Also, the rate of economically active Germany within the EU is similar to that of the USA, which is around 3% since the 2010s. Furthermore, Germany's government has now targeted this figure at 3.5%, which can be achieved by 2025 ("Germany Trade&Invest," 2021).

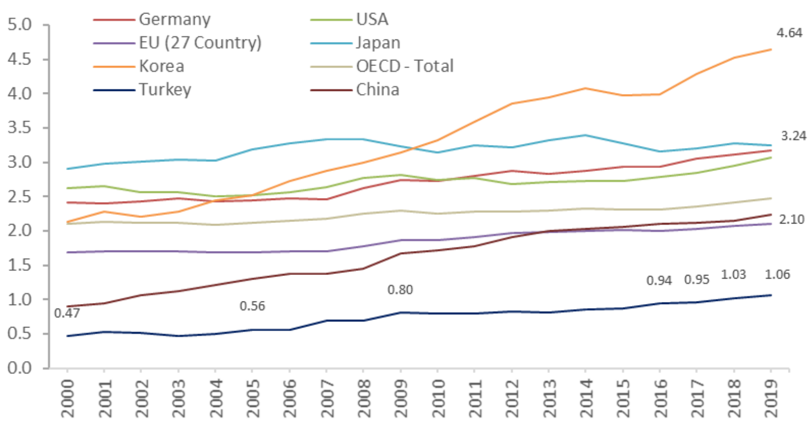


Figure 3: R&D expenditures as percentage of GDP (%) (OECD, 2021)

Turkey's R&D allocations over the years offer significant findings. While R&D expenditures of approximately 800 million Turkish lira (TL) were made as 0.47% of GDP in 2000, this value was approximately 46 billion TL as 1.06% of GDP in 2019 (Figure 4). During this period, R&D expenditures increased about sixty times. Although R&D expenditures have increased considerably, the fact that the share did not increase is due to the concurrent significant increase in GDP. However, these figures are far from the target of 3% R&D expenditure specified in "Vision 2023: Science and Technology Strategies" by TÜBİTAK (TÜBİTAK, 2004). Considering that the GDP target set for 2023 is 2 trillion USD, the amount of expenditures required for R&D, which is 3%, is 60 billion USD.

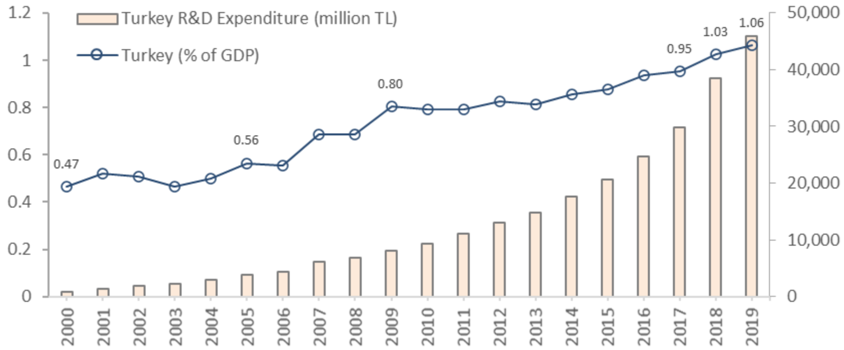


Figure 4: R&D expenditure as a percentage of GDP and total R&D expenditure in Turkey (million TL) (OECD, 2021)

In addition to a steady increase in R&D spending in Turkey over the years, the distribution of R&D expenditure by sectors offers important insights. Gross domestic expenditure on R&D (GERD) is the sum of the R&D expenditures of four sectors: business enterprise, government, higher education, and non-profit (Raghupathi & Raghupathi, 2019). Business enterprise R&D expenditure (BERD) is key in measuring the contribution of businesses to innovation. There is no doubt that business enterprises are important actors in bringing out new products, processes, and services. Although every effort toward R&D does not yield positive results, commercially, the commitment of firms to the generation and implementation of new ideas is an important indicator. At the same time, higher education institutions are also important players in a modern knowledge economy, performing basic and applied research. In this sense, higher education expenditure on R&D (HERD) is the component of GERD that is incurred by entities in the higher education industry. On the other hand, GOVERD stands for government R&D expenditures, which is a component of GERD incurred by government sector (OECD, 2015). For a country to have a say in high technology fields in the world, state R&D expenditures are necessary. This is also important for the R&D transformation of industries. In this way, human resources will develop and the government will act as a role model. In addition, it is important for the government to act as a catalyst by incurring R&D expenses itself, especially in high-risk industries.

In the following figures, we will review the distribution of the three main sectors in GERD. As seen from Figure 5, R&D expenditures in Turkey have been increasingly undertaken by business enterprises over time. This demonstrates that the R&D awareness of business enterprises has increased over time. The share of overall R&D expenditure of business enterprises increased from 0.16% in the 2000s to 0.68% in 2019. Business enterprises increased their R&D expenditures more than four times during this period.

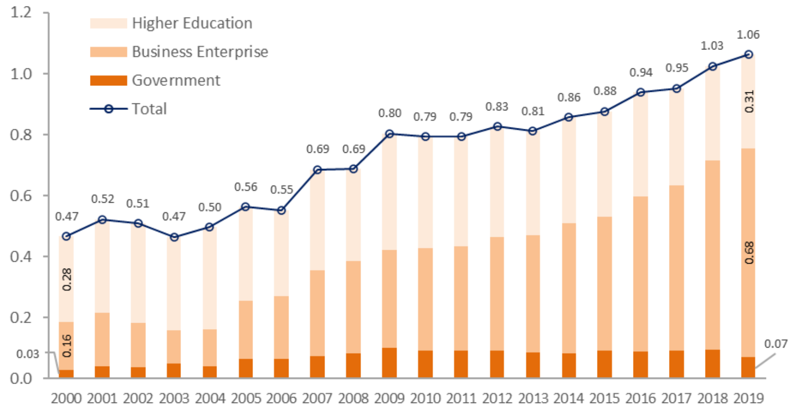


Figure 5: Distribution of R&D expenditure by sectors in Turkey (OECD, 2021)

On the other hand, Figure 6 shows the levels of R&D expenditures for the private sector funded by governments in selected countries. In Turkey, this rate has increased every year since 2000. As can be seen from Figure 6, unlike other countries, the funding of R&D expenditures for the private sector by the government is in an increasing trend in Turkey, and this rate is almost twice that of other countries. This shows that the state is exerting significant effort to direct business enterprises toward R&D culture.

Also, in order for the private sector to not abandon R&D activities, during the times of crisis in 2008 and 2009, particularly Turkey, Korea, and the USA increased their R&D support for business enterprises.

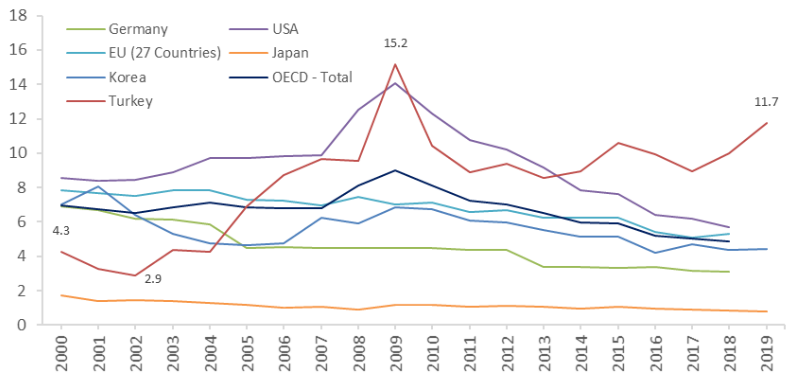


Figure 6: Ratio of Private Sector R&D Expenditures funded by governments (OECD, 2021)

In addition, Figure 6 tells us that as the development levels of countries increase, the support of the state to the private sector in terms of R&D decreases or stays stable. On the other hand, Japan differs from other countries in this regard. Although a decreasing trend has also been observed in Japan, the rate of private sector R&D expenditures funded by the government there has been lower than that of other countries since 2000, which demonstrates the high R&D awareness of the companies themselves. Furthermore, in Korea, which hosts giant technology brands, government funding of R&D expenditures made by the private sector has started to decrease, especially since 2010.

As can be seen from Figure 7, the major contribution to the total R&D expenditures of countries comes from business enterprises. For example, while R&D expenditure as a percentage of GDP was 4.64% in Korea in 2019, a very large part of that rate, 3.73%, was contributed by business enterprises (Figure 7). Meanwhile, only 4.4% of this expenditure was funded by the government (Figure 6).

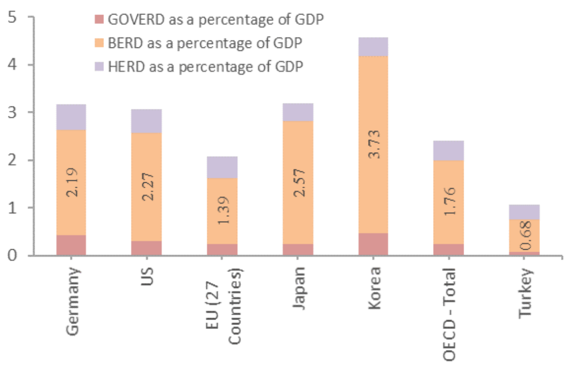


Figure 7: R&D expenditures by sectors (2019) (OECD, 2021)

5.2 Human resources in science and technology

Individuals' knowledge, skills, abilities, and traits that promote the building of personal, societal, and economic well-being are referred to as human capital (Keely, 2007). The degree of human capital in a country has an impact on its national innovation performance (Suseno, Standing, Kiani-Mavi, & Jackson, 2020). Accordingly, skills development is a constant priority for governments in both developed and developing nations in order to promote the enhancement of human capital for their nations' productivity, economic success, and wealth (Cannon, 2000). HRST are defined according to the Canberra Manual as people with tertiary education or who work in a scientific and technology occupation that requires a high level of qualification and has a high level of innovation potential (OECD, 1995). Human resources in science and technology (HRST) are accepted as major actors in innovation. If a country is lacking in highly skilled scientists or engineers who are able to conduct their work with the newest technologies, that country will probably not be producing significant amounts of innovative output (Furman et al., 2002). The level of national innovation and the potential for scientific and technological advancement is determined by the amount, structure, and efficiency of HRST in a country. Accordingly, when looking at developed countries such as Germany, the USA, and North European countries, it is seen that there is a large volume of educated and skilled human resources in the innovation ecosystem.

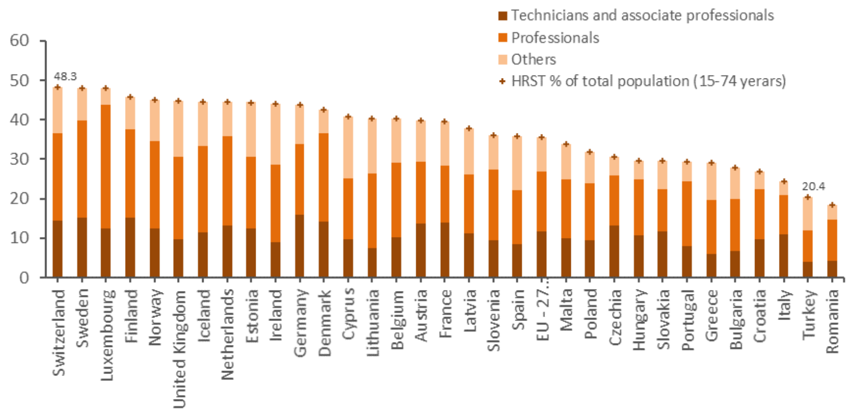


Figure 8: Share of persons with tertiary education and/or employed in science and technology (%, 2020) (Eurostat, 2021a)

Figure 8 clearly shows that developed countries have great potential for innovation because almost fifty percent of their total populations have received tertiary education or are already employed in science and technology (Note 1). At the same time, Germany stands out with its rate of technicians and associate professionals, which is a natural consequence of being an advanced industrial country. Considering that Germany is the most populous European country, it can be said that Germany has successfully managed its human resources. On the other hand, unfortunately, both the rate of HRST in the total population and the rate of technicians and associate professionals in HRST are quite low in Turkey compared to other countries. This indicates the difficulty of today's manufacturers in Turkey in finding intermediate-level employees. For Turkey to become a productive industrial country, the number of intermediate-level employees should be increased rapidly. At the same time, it is seen that Turkey aims to increase the rate of tertiary education in HRST by increasing the number of universities. Of course, the quality of education is a separate topic of discussion.

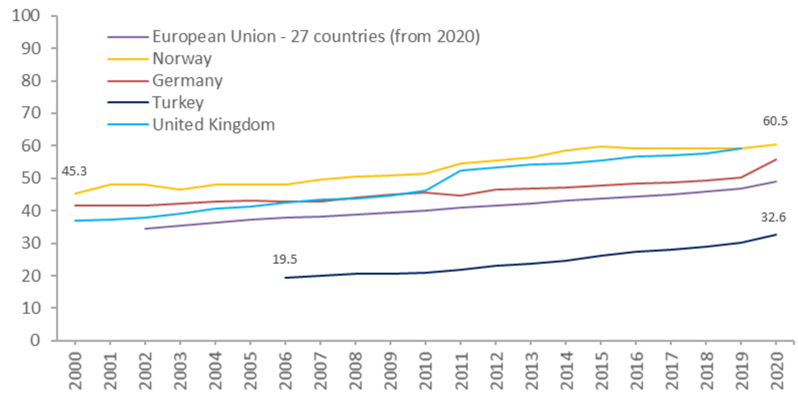
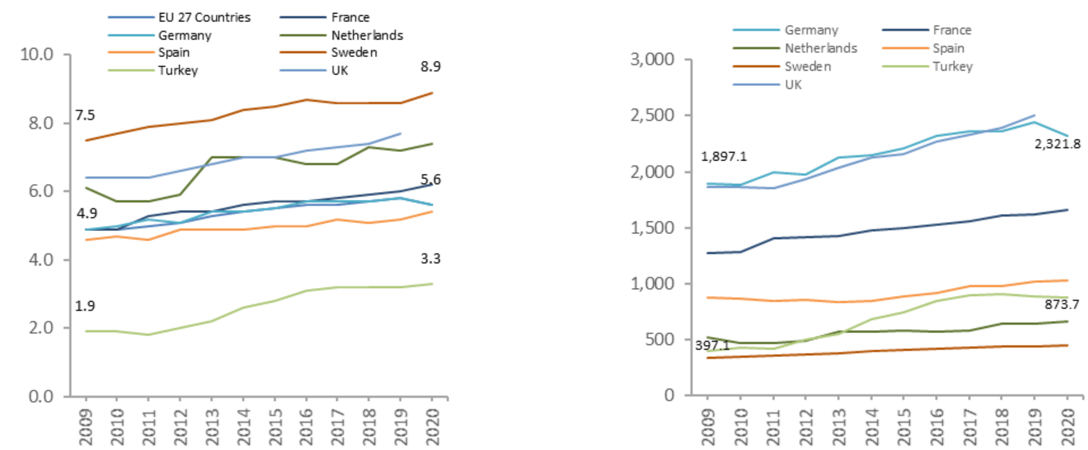


Figure 9: Share of science and technology employment in the active population (25-64 years) (Eurostat, 2021c)

Figure 9 shows the development of the active population in the age group of 25-64 that is classified as HRST (i.e., having successfully completed an education at the tertiary level or being employed in the fields of science and technology) as a percentage of the total active population aged 25-64 for some selected countries.

According to the data regarding "HRST" prepared based on the 1995 Canberra Guide by the OECD, the share of the workforce in S&T fields in Turkey (graduates of higher education or those working in the fields of science and technology) in the total active population (population aged 25-64 years old) rose to 32.6% in 2020 from 19.5% in 2006. Although this value is below the European average of 49%, the growth rate over the past decade in Turkey is more than twice the average European growth rate (Figure 9). When compared to Germany, which is an industrial society and has a population size close to that of Turkey, it is seen that it is not sufficient. However, it was stated in the report prepared by the Department of Science, Technology, and Innovation Policy of TÜBİTAK that it is very important to direct young people toward the field of R&D, improve their career opportunities, and accordingly increase their income and train human resources in the fields of science and technology in line with the R&D activities of industries and the country (TÜBİTAK, 2010).

While the graphs above show the potential of a country to realize and contribute to innovation, those below present the statistics regarding the people working in the fields of science and technology.



(a) (b)

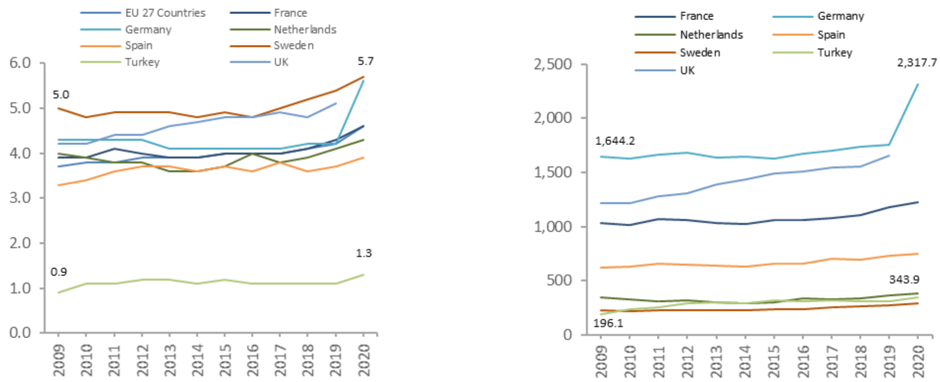
Figure 10: Employment in technology and knowledge-intensive sectors: a) Percentage of total employment (%), b) Number of employees (thousands) (Eurostat, 2021b)

When looking at the employment in technology and knowledge-intensive sectors, there is an increase in all countries, Figure 10. This shows that today's businesses are shifting toward technology-intensive areas. Although a significant increase in the employment in technology and knowledge-intensive sectors has been observed in Turkey since 2010, it is about half of the EU average. It is necessary to draw attention to an important issue here. Although Turkey has a rate half that of the EU average, the country has more human resources employed in technology-intensive sectors than some developed countries. For example, as of 2020, a total of 873,700 people worked in technology and knowledge-intensive sectors in Turkey; this figure is twice that of Sweden and 50% more than that of the Netherlands. This shows that Turkey can close the gap by increasing its technological output rapidly. On the other hand, the number of people working in technology and knowledge-intensive sectors in Turkey is almost one-third of that in Germany, which has a similar population. This shows that more steps need to be taken in this field.

Another indicator concerning technology and knowledge-intensive sectors is the number of employees in the field of advanced technology and their share in total employment. As seen from Figure 11, although it seems that the number of employees in the field of high technology in Turkey has increased over time (from 196,100 to 343,900 people), the share of total employment is well below that of developed countries. An important result emerging from Figure 11 is that there was a significant increase in all countries in 2020, and in Germany this increase was much higher.

Also, the number of employees in the field of high technology in Turkey is at the same level as in Sweden and the Netherlands. This is an important indicator in terms of the extent of employment in the field of high technologies in these countries, which have one-fifth of Turkey’s population.

In short, Turkey should create more business volume in the field of high technology.

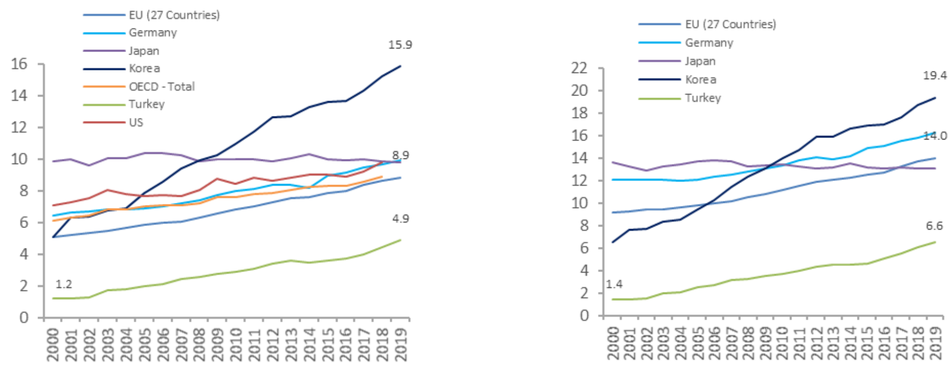


(a) (b)

Figure 11: Employment in high-technology sectors (high-technology manufacturing and knowledge-intensive high-technology services): a) Percentage of total employment (%), b) Number of employees (thousands) (Eurostat, 2021b)

Although the number of employees in the field of high technology in Turkey is more than that in the Netherlands and almost the same as in Sweden, those countries are much more assertive in technological innovativeness and have more GNI per capita, accordingly. This highlights the importance of the innovation ecosystem.

Similarly, the share of R&D employees and researchers in total employment in the fields of science and technology is considered as one of the performance indicators of a country. According to the Frascati Glossary, R&D personnel are defined as all persons directly engaged in R&D, whether employees of this entity or contributors from outside the company who are fully integrated into the R&D operations of the business, as well as those who provide direct support for R&D, such as managers, administrators, technicians, and clerical workers in an R&D function, are included in this entity. Researchers, technicians, and other support employees are all classed as R&D personnel based on their R&D role. Researchers are those who are involved in the development or conceptualization of new knowledge. They conduct research and develop or refine concepts, build theories and models, explore issues, and predict trends. When we look at the number of R&D personnel in total employment, it is seen that all countries except Japan have increased the number of R&D personnel and researchers in recent years, and Korea has far more employment in this area than any other country.



(a) (b)

Figure 12: a) Total researchers per thousand in total employment, b) Total R&D personnel per thousand in total employment (OECD, 2021)

It is further observed that Turkey has also increased its R&D employment in parallel with the increasing trend of the European Union and has been above the EU trend in the last few years in particular (Figure 12). It is understood that the law on technoparks for R&D and the law on R&D centers, implemented in Turkey in the last 15 years, have yielded results. Considering the rates of the EU average, Germany, and Korea, Turkey should employ more researchers.

Figure 13 demonstrates the share of doctorate holders by educational attainment in the years 2009, 2016 and 2019. The rate of those who have a doctorate degree among the educated population is 0.4% in Turkey in 2019, while this rate is around 2% in the US. Particularly, in northern countries, it is observed that the number of doctorate students has increased rapidly over the years, and it is understood that these rates coincide with the employment rates in the field of high technology. There was more than a twofold increase in Turkey between the years of 2009 and 2019. However, when compared to developed industrial countries, more doctoral researchers should be trained, similar to the above inferences.

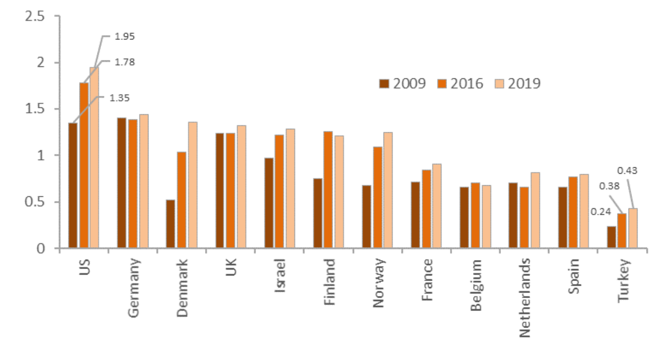


Figure 13: Share of doctorate holders by educational attainment (OECD, 2020b)

This verifies that scientific and technological activities can create more innovative results if they are carried out with competent employees. For example, one in three people with a doctoral degree in Denmark, the USA, and Belgium works in the industry (OECD, 2020a).

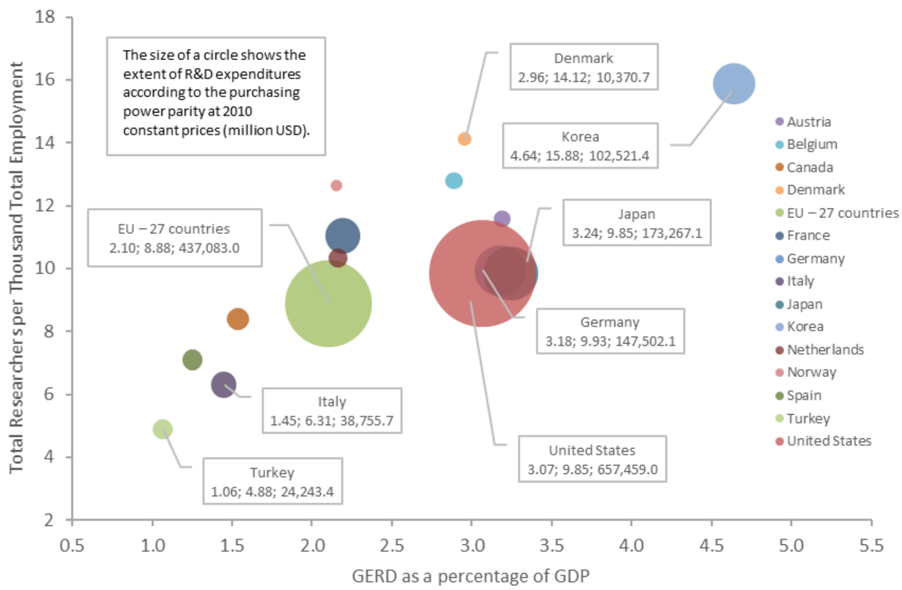


Figure 14: R&D expenditures of countries in 2019 (million USD), share of the number of Researchers in Total Employment (‰), and R&D expenditures as percentage of GDP (%) (OECD, 2021)

Figure 14 shows countries by total R&D expenditure, with the share of the number of researchers in total employment and R&D expenditures as a percentage of GDP in one shot. As can be seen from Figure 14, the USA and Japan are the two countries with the largest R&D expenditures in the world, at 657 billion USD and 173 billion

USD, respectively (R&D expenditures in the chart have been shown according to 2010 constant prices and purchasing power parity). Therefore, these countries are the first countries that come to mind when talking about technology, innovativeness, and, ultimately, social welfare. It is also a remarkable and important fact that the total R&D expenditure of the USA alone is higher than that of the EU (27 countries). Turkey is far behind the developed countries at approximately 25 billion USD of R&D expenditures (adjusted for purchasing power parity), 1.06% R&D expenditure as a percentage of GDP, and 4.9% researcher rate. This graph, which is a summary of the graphs given in detail above, gives an idea at a glance in terms of the R&D and innovation capacities of the countries.

5.3 Patents and scientific publications (outputs)

The financial and human resources mentioned above constitute the basic inputs of R&D and innovation activities. When we look at the outputs produced by these inputs, it is seen that developed countries are far ahead. Patents, which are the products of industrial activities, and scientific articles, which are the products of academic activities, are the main outputs that we will review in this section.

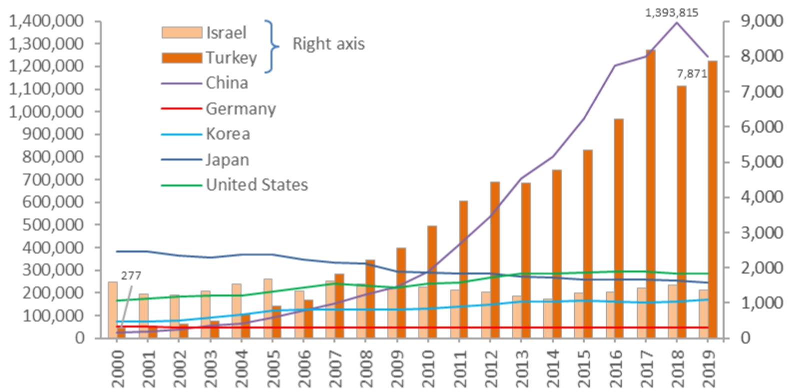


Figure 15: Number of local patent applications by Countries (Worldbank, 2021a)

Figure 15 demonstrates that China is far ahead in the number of patent applications despite a slight decrease in 2019. This figure shows us that China will increasingly have a voice in innovativeness. Although the number of patent applications is still high in the USA and Japan, this trend has been decreasing over the years. Despite a significant increase in the number of patent applications in Turkey, the very low numbers of applications indicate that the output of innovative efforts is not yet enough. For example, in Korea, the number of patent applications was around 170,000 in 2019, whereas it was only about 7,900 in Turkey.

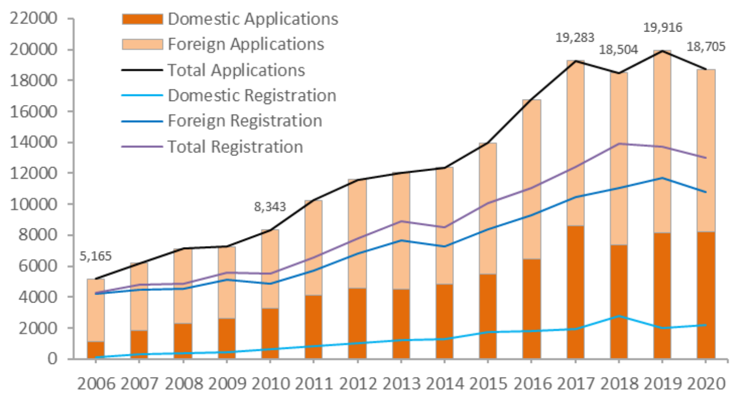


Figure 16: Number of total applications and granted patents in Turkey (TPE, 2021)

Although the significant surge in the number of patent applications in recent years shows that R&D activities have yielded results in Turkey, these are not sufficient when compared to the patent numbers of developed countries. When comparing the applications of developed countries with those of Turkey, local patent application numbers remain low. Also, when considering the number of patents in Turkey, the number of domestic applications must be evaluated because foreign patent applications are made to protect technology in Turkey that was developed abroad. On the other hand, there is a fourfold difference between the number of local patent registrations and the number of local applications. This difference means that a significant number of applications cannot be patented. Therefore, it is understood that the patent quality should also be increased (Figure 16).

Considering the number of scientific publications, China has shown a great increase (Figure 17). China even surpassed the USA in 2016. The number of publications that originated in China in 2019 was 528,263 and in the USA, it was 422,808. However, according to the last available data for Turkey, it was just 33,536 in 2018. The high number of patents and scientific publications of developed countries can be evaluated as an indicator of their development. However, China stands out with its population; it is an exceptional country that shows high performance in these two areas, but it cannot be considered a fully developed country.

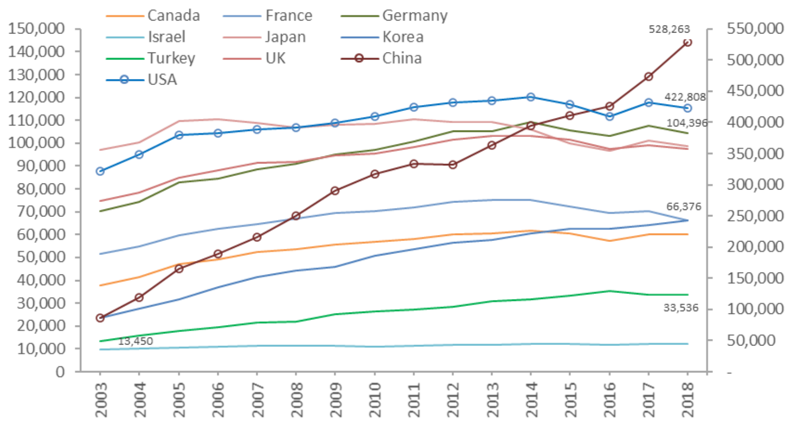


Figure 17: Number of scientific publications by countries (Worldbank, 2021b)

Although the number of scientific publications has continuously increased in Turkey from 2003 to 2016, a decreasing trend has been observed since 2016. This demonstrates that it is possible to increase the number of publications only up to a certain point with publication incentives, but to increase more, there is a need for increasing both the numbers of researchers and the R&D budgets and an ecosystem that will support all these, as seen in developed countries.

6. Conclusion

In this study, reviewing the relevant sources and drawing from related empirical studies in the literature, we have looked at the S&T indicators of Turkey, comparing the country with the world. Although Turkey has covered considerable ground in recent years, its current position is not sufficient for it to move up into the high-income group and increase its social welfare. As clearly stated for all indicators in S&T fields, Turkey has not yet achieved satisfactory performance in its R&D and innovativeness activities.

First, Turkey should focus more on high value-added industries, restructuring its manufacturing. High value-added industries focus on activities that result in large profit margins between the final price of an item or service and the cost of the inputs needed to manufacture it, resulting in larger profits for firms and higher pay for workers. Therefore, it is necessary to prioritize policies for the generation of the research infrastructure, technological infrastructure, and skilled human resources required by high value-added industries.

The growth of Turkey only through service industries, such as software or tourism industries, will not be sufficient for the employment needed and will not contribute enough to the GNP target. The average dollar value per kilogram in exports is an important indicator in this regard. For example, in the last 5 years, the depreciation of average dollar value per kilogram in exports in Turkey decreased from 1.44 dollars to 1.23 dollars. While exports per kilogram are close to 4 dollars in Japan, this figure is 3.7 dollars in Germany, 2.54 dollars in Korea, and 2.53 dollars in the USA. The two industries that saw increased average dollar values per kilogram in exports in Turkey are defense and aerospace. Therefore, it is imperative to invest particularly in advanced technology fields. In addition, policies should be developed to train intermediate-level employees in Turkey to meet the needs of the industrial sector.

Second, having a say in the field of advanced technology is only possible for countries that develop their technological capabilities in that field. In recent years, incentives have been given for technology-oriented sectors in Turkey and some investments have been made. For example, the state has demonstrated its desire for the development of the defense industry and similarly, incentives and investments have been made available for the automotive sector. Production investments in specific areas such as solar energy were also encouraged. However, these initiatives can only reach a certain stage with the financial incentives of the state. Human resources and, of course, the university ecosystem must be developed in parallel in order to ensure sustainable value creation. For example, many new engineers and technicians were required for the National Combat Aircraft Project of TAI-TUSAŞ in the defense industry, and it was inevitable to establish close cooperation with universities in order to achieve that. Therefore, the state should undertake a catalyst role including universities into the agenda of industries. To do this, universities may be included in the incentives opportunities given to industry. Operating models should be developed that will enable industry to make R&D investments primarily in universities. Training R&D personnel within industry requires much higher costs, while it is possible to generate more economic value by guiding the human resources already trained in universities.

Third, due to the limited resources, it is important to prioritize the areas to be invested in and that the prioritized areas support each other. For example, if investments are made in the field of health, investments should also be made in the creation of competencies in health technologies in universities. Likewise, while investing in the fields of defense and aviation, it is very important that universities also invest in these fields and train human resources in this direction. For example, Korea, whose income level was similar to Turkey's in the early 1990s, outpaced Turkey with heavy investments in S&T and has thus set a good example for Turkey to follow. The government of Korea has been particularly proactive in its efforts to apply sector-specific policies to increase the country's industrial success in interconnected production areas such as metals, machinery, and chemicals.

Fourth, it is important that all postgraduate studies, and especially those of technical universities, work in association with industry and be designed in a way that creates industrial output. As advisors from industry may be assigned to each graduate thesis, it should also be considered that the outputs of these theses can be turned into spin-off companies. It is critical to direct, raise awareness among, and, of course, encourage academic in order to achieve this. Instead of incentive systems that only target output, it is necessary to support methods that will produce these outputs.

Finally, more effective use of the funds given by the state for R&D activities should be ensured. For this, incentives should be given to the institutions that can use the resources correctly, and in order to achieve this, first of all, human resources must be trained to make use of such opportunities. In other words, personnel who know how to work in the fields of R&D should be trained first, and then the relevant resources and infrastructure should be designed. In this sense, R&D and technology management training should be a part of education in universities, and industrialists should be required to take such training programs in order to gain this competence. For example, such training could be made one of the incentive application requirements.

In conclusion, innovation should be a basis of any policy or strategy for Turkey. Just as governments play an active role in the formulation of these policies and strategies, the spread of these policies to the grassroots level and the cooperation of public institutions, firms, and individuals in line with these policies and strategies can only be achieved with government intervention.

The long-term growth of any country is intrinsically linked to that country's levels of innovation and technological advancement. Accordingly, to ensure the growth and development of any country, including Turkey, R&D strategies must be created and implemented, human capital must be fostered, innovation ecosystems must be developed in a way that unites financial and human resources with the national infrastructure, university-industry collaborations must be intensely promoted, key strategic fields must be determined and target-oriented incentives for those fields must be offered, the outcomes of all offered incentives must be tracked, support for this entire process must be guaranteed with appropriate mechanisms from the first step to the last, and, finally, bureaucratic obstacles must be removed to make these things possible.

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Notes

Note 1. Only professions are covered by the HRST data given in this study. Professionals and technicians, as described by the International Standard Classification of Occupations (ISCO-88) major groups 2 and 3, fall under this category of employees. For more detailed information please see https://www.ilo.org/public/english/bureau/stat/isco/isco08/index.htm