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RESEARCH ARTICLE

The state of the art of nuclear energy and its bibliometric analysis

Elanur Adar[1,*]

[1]Artvin Coruh University Environmental Engineering Department, 08100, Artvin, TURKEY

ABSTRACT

Nuclear power plants, which started to be used in the military field in the 19th century, began to be used in electricity generation due to the oil crisis and increasing electricity need. It has many advantages as well as some disadvantages. Commonly used fossil, hydraulic, wind and solar energy systems likewise have both advantages and disadvantages. The emission of nuclear radiation is the most important risk. If there is no radiation emission, it will cause a less bad impact even if an accident happens. Also, waste management will be easier. With the development of technology, the production of new generation reactors can ensure that some disadvantages are eliminated or minimized. When looking at the studies carried out in WOS, studies on nuclear energy are related to environmental issues (waste management and occupational health). However, more studies should be carried out on two problems (waste management and occupational health) that are important in the operation of nuclear power plants.

Keywords: Advantages, bibliometric analysis, disadvantages, nuclear energy, waste management

1. INTRODUCTION

Nuclear power plants started with the discovery of uranium at the end of the 19th century and are a technology developed and used primarily in the military field. As the infrastructure developed, the high heat energy generated as a result of fission reactions started to be converted into electrical energy. Especially after the oil crisis in the 1970s, interest in nuclear energy has increased. Today, 8.1% of the electricity needs are met in more than 30 countries with nuclear power plants operating over 440. The USA (99), France (58) and Japan (42) are the countries with the most nuclear power plants. Turkey is continuing the construction of nuclear power plants in Sinop and Mersin. It is planned to be built in Kirklareli. Nuclear energy is a method that provides high electrical energy. For example, all of Turkey's electricity can be provided with 26 nuclear power plants and is a technology that requires less space than conventional alternatives. In addition, the amount of waste and emission generated is low. Except that the investment costs of nuclear power plants are high and waste management is difficult, the possibility of being used as a nuclear weapon in the future decreases the confidence in technology. However, despite its negative aspects, it is a technology that continues to be built due to its advantages. Research studies are related to both reactor design and waste management. But especially the accidents in the past (Three Mile Island in the USA in 1979, Chernobyl in the Soviet Union in 1986, Tokai-mura in Japan in 1999, and Fukushima in Japan in 2011) make this technology difficult to accept by the public. In addition, an issue that makes this technology difficult to be desired by the public is waste management. These two issues have caused some countries to abandon the installation of nuclear power plants or to extend the construction period. Despite its negative aspects, various research studies are still being conducted [1].

The aim of this study is to consider the positive and negative aspects of nuclear energy and to compare it with the most widely used power plants. In addition, to present a bibliometric analysis of studies conducted with nuclear energy.

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2. NUCLEAR ENERGY

Nuclear energy is formed as a result of the reaction that takes place between atoms. The first use of nuclear reactors was in 1942. Reactors were first used for military vehicles, submarines, and ships, then began to be used for commercial, power/electricity generation and educational-research purposes. Commercial reactors are divided into two groups as fast and thermal. Thermal reactors are mostly used. Reactors are divided into 3 groups according to whether or not enrichment is made in terms of fuel. The most used reactors in the world are light-water reactors (pressurized water reactor and boiling water reactor). Pressurized water reactor is the most widely used reactor. Its operating conditions are 15 MPa pressure and 320◦C temperature. In these reactors, uranium fuel is enriched by 3-5% and water is used as a retarder/coolant [2]. The fuels used in nuclear power generation are mainly uranium, thorium and plutonium. Uranium and thorium occur naturally, while plutonium is artificially produced from uranium. Plutonium is also a nuclear weapon. Uranium is found in high amounts in Australia, Kazakhstan and Canada. Thorium is highly available in India, Brazil, Australia, and the USA [2].

Nuclear power plants are similar to thermal power plants. The steam formed in both power plants is converted into electrical energy by means of tribunes and generators. The main difference between the two power plants is the way steam is obtained. A nuclear reactor consists mainly of fuel, retarder (moderator), cooler, control rods, reflector, reactor heart (core, boiler heart) and protector [3].

As a result of nuclear energy generation, waste that must be managed is created. Radioactive wastes are found in solid, liquid and gaseous forms. Safe management of nuclear waste; It consists of collection, separation, packaging, conditioning (concentration, solidification, compression, incineration), intermediate storage, transportation, long-term storage and/or disposal. The wastes generated are grouped according to their radioactivity content as very low, low, medium and high levels. Very low-level wastes are the group with activity concentrations less than about 100 times the clearance limits, and disposal of these wastes can be carried out in surface disposal facilities. Low (400-4000 Bq g^{-1}) and medium level wastes can be disposed of in near-surface, medium and deep disposal facilities depending on their radionuclide content. Low and medium level wastes are stored in an abrasion resistant, safe and sheltered structure. High-level wastes are disposed of only in deep disposal facilities. Small volume low and medium level wastes can be disposed of well type, while high level wastes cannot be disposed of well type. Wastes (gas or liquid) below the emission limit to the environment can be released directly into the environment. The volumes of low level solid wastes are reduced by compression and incineration methods, while the volumes of liquid wastes are reduced by evaporation and drying. It is then stored properly and kept waiting to reduce the radioactivity. High level wastes are stored either by dry/wet storage or after vitrification. Continuous control is required in dry or wet storage methods. Vitrification method is a difficult and costly option [2]. Countries such as France, Germany, England, Russia, Canada and Japan have active recycling facilities. Recycled plutonium is a nuclear weapon material. The acquisition of nuclear weapon material is a threat to the world [2].

In nuclear power plants, radiation is mostly emitted from radioactive waste and nuclear equipment rooms. Emitted radiation is a serious danger to human and environmental health. Regular radiation monitoring in reactor, storage units etc. should be done. Mladenov et al. [4] stated that radioactive waste management is technically difficult but can be managed more easily when there is sufficient funding and professional management behavior.

In addition to providing a sustainable electricity source, nuclear power plants will also produce new generation reactors with the rapid development of technology [5]. Of course, the development of the nuclear industry may be slow due to the public reaction. However, necessary support must be provided and qualified personnel must be trained to design, build and operate nuclear reactors. Nuclear energy that has no carbon emissions is a cheap and technologically advanced alternative. Today, 2nd and 3rd generation reactors are operated. 3+. Generation has begun to be used. With the development of 4th generation reactors, or the use of fusion reactors rather than fission, it would be a more attractive alternative. Fusion reactors prevent nuclear weapon.

It is the occurrence of accidents that have a serious impact on the slow development of the nuclear industry [6]. Of course, it is natural for the public to be anxious because of accidents. However, when the literature was searched, it was concluded that accidents occurred as a result of some measures that were not taken or natural disasters such as earthquakes. For example, while the reactors did not have a protective shell in the Chernobyl accident, the Fukushima accident was due to the earthquake. One of the reasons why the earthquake has a great impact is that some reactors do not have refrigerators.

Yes, there is risk. There is nothing in life without risk. Driving, flying, etc. is also a risk. Perhaps the biggest disadvantage of nuclear power plants is that it affects large areas, including where the system is located. But if we think in terms of Turkey, many of our neighboring countries are used nuclear reactors. Many countries have focused on developing their economy and producing their energy needs cheaply without considering this risk. For this reason, it is an alternative to be preferred to reduce its dependence on foreign development and meet the electricity needs of Turkey. Only good management, business plans should be created and qualified personnel should be trained. Nuclear power plants can be dangerous if not managed well and safely from the site selection process to the final stage [7].

The advantages and disadvantages of nuclear power plants are given below:

Advantages;

•It does not cause global climate change [8],

•Approximately 2 million times more energy is produced compared to fossil fuels,

•Less solid waste (300 thousand times by mass) is produced compared to fossil fuels

•Uranium is found in many countries (100-year reserve),

•It has no polluting effects on the environment during normal operation,

•Using less fuel compared to fossil fuels [9],

•Requiring approximately 3.5 times less space compared to thermal power plants,

•It can be operated day and night, regardless of climatic conditions,

•Not affected by fluctuations in fuel prices,

•Has a long operating life

•It can be reused after the radioactivity of the generated waste decreases [10],

•Risk of accident is very low due to the security measures taken.

•Its construction is cheaper than hydroelectric power plants.

•Provides stable energy production throughout the year [11, 12].

Disadvantages;

•Radiation emission harms the environment and people,

•Management is difficult and expensive due to the radiation contained in solid waste [13],

•The storage period of wastes is long and the need for space can be high [14],

•Plutonium produced artificially or as a result of the operation of a nuclear plant can be used as a nuclear weapon,

•More than 50% of the public do not accept it,

•Accidents with serious impact have occurred,

•Having high investment cost [12].

3. NUCLEAR ENERGY VS. OTHER ENERGY SOURCES

The main renewable energy sources used in addition to fossil fuels (coal and natural gas) are hydraulics, wind and solar. Nuclear energy is not a renewable energy source. However, as a result of the reaction, water vapor and H_2 are formed. So there is no greenhouse gas effect. Mainly used energy sources were compared in terms of different criteria (Table 1).

While $7.8x10^{13}$ J kg^{-1} of energy is released as a result of the burning of uranium used in nuclear energy production, $5x10^{7}$ J kg^{-1} of energy in fossil fuels is released. In other words, $1.5x10^{6}$ times more energy is produced from nuclear fuel compared to fossil fuels [17]. When nuclear and thermal power plants are compared in terms of fuel cost and waste amount, a nuclear power plant is both a cheaper and more environmentally friendly method. For a 1000 MW power plant, 25 tons of fuel are required annually for nuclear power generation and 1 ton of vitrified waste is produced annually. In thermal power plants, 3 million tons of fuel are required annually, 7 million tons of gas such as CO_2 and H_2S are emitted and 150-200 thousand tons of solid waste are generated [2]. In other words, 1 ton of uranium is equivalent to burning 16000 tons of coal or 80000 barrels of oil [18].

Energy generation costs are decreasing rapidly due to constantly evolving technologies, economies of scale, competitive supply chains, and increasing developer experience. This is valid for fast-growing alternatives. For example, the costs of solar and wind energy production decreased by 82% and 39% in 2019 compared to 2010, respectively [19]. In the 2020-2050 projection study, while no significant change is expected in the cost of nuclear (79-78 \$ $(MWh)^{-1}$) and coal (71-68 \$ $(MWh)^{-1}$) energy alternatives, it was predicted that there will be a decrease in the cost of solar (51-37 \$ $(MWh)^{-1}$) and wind (39-28 \$ $(MWh)^{-1}$) [19]. Installed capacity (2010-2020) and electric generation (2010-2018) data for renewable energy alternatives used both in the world and in Turkey is shown in Fig 1 [19]. As the installed capacity for all alternatives increased worldwide, electricity generation has also increased. In Turkey, there has been a rapid increase in production in all alternatives, especially solar energy, except hydropower.

Nuclear energy plants should also be established in areas with few fault lines, such as coasts, rivers and lakes. Hydroelectric power is reliable and cheap. However, it is insufficient to meet all energy needs. The yield varies according to the seasons and cannot be installed everywhere. Wind and solar energy are also weather dependent and are not stable alternatives.

In nuclear power plants, technology is constantly improving and safety is increasing. But radiation emissions, fatal accidents have not yet been completely minimized. Although it is a clean and highly efficient energy source, it seriously affects the wide area in a long time for case of an accident. But, according to the statistics obtained from the World Health Organization and other sources, it is seen that approximately 4000 times more people die per unit of energy produced compared to nuclear energy in energy production from coal [8].

4. BIBLIOMETRIC ANALYSIS ABOUT NUCLEAR ENERGY

When Fig 2 is examined, the number of studies on nuclear energy has increased every year. Studies on nuclear energy started in 1975. Until today (20/07/2020) 105505 studies have been carried out. These studies were carried out mainly in the USA, Germany, China, Japan, and France. Environmental studies have been carried out since 1980. 3096 environmental studies have been carried out so far. The top five countries in which environmental studies are carried out are America, England, Germany, Japan and France. 815 of environmental studies are related

to occupational health. Studies on occupational health were also carried out by the same countries (USA, France, Japan, England, Germany). The first study about occupational health was carried out in 1980 in the USA. The number of studies that include the words nuclear energy and waste management as a topic in Web of Science (WOS) is 894. 30% of the studies were carried out in the USA. Other top five countries are France, Germany, England, and Japan. The first study was carried out in 1990 in England.

As can be seen in Fig 3, studies have been carried out on many issues. The most intensive studies are related to nuclear science technology, environmental sciences, and energy fuels [20].

Table 1. Nuclear energy vs. other commonly used energy sources [15*, 16]

Criteria	Nuclear	Fossil-Coal	Solar	Geothermal	Wind-Onshore	Hydraulic
Source	Local/Foreign	Local/Foreign	Local	Local	Local	Local
Carbon neutral	Yes	No	Yes	Yes	Yes	Yes
Dispatch	Baseload	Baseload	Intermittent	Baseload	Intermittent	Baseload
Efficiency	High	Medium	Low	Low	Low	Low
Environmtental impacts	High	High	Low	Low	Low	Low
Occupational heath and safety	High	Medium	Low	Low	Low	Low
Pollution	Low	Very high	Low	Low	Very low	Very low
Capacity factor (%)	90-91	66-83	39-68	85-90	38-55	-
Fuel cost ($ (MMBtu)$^{-1}$)	0.85	1.45	-	-	-	-
Total capital cost ($ kW^{-1})	6900-12200	3000-6250	6000-9100	3950-6600	1100-1500	1900-2600*
Fixed O&M cost ($ kW^{-1} yr^{-1})	108.5-133	40.8-81.8	75-80	0	28-36.5	-
Variable O&M cost ($ (MWh)$^{-1}$)	3.5-4.25	2.75-50	-	24-34	-	-
2017 capacity (GW)	11	70	98	-	52	19

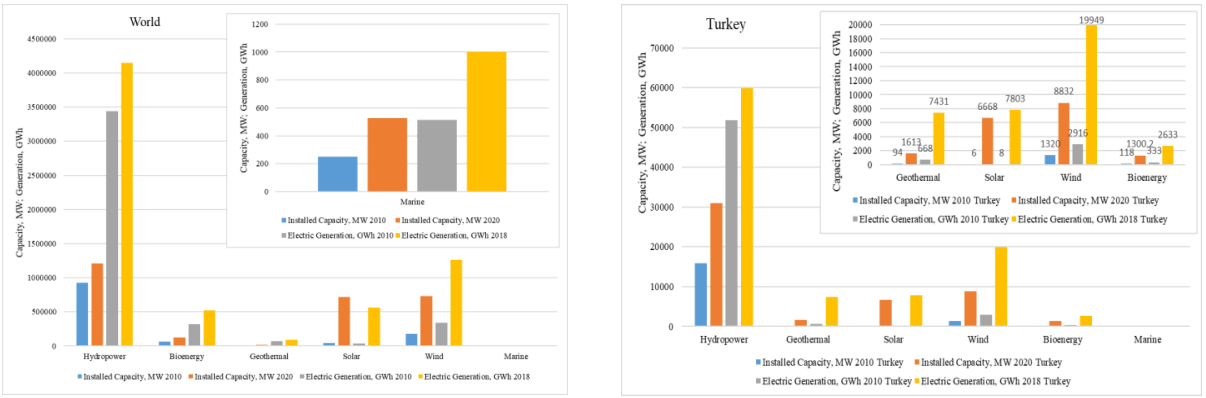

Fig 1. Installed capacity (2010-2020) and electric generation (2010-2018) for renewable energy alternatives used both in the world and in Turkey [19]

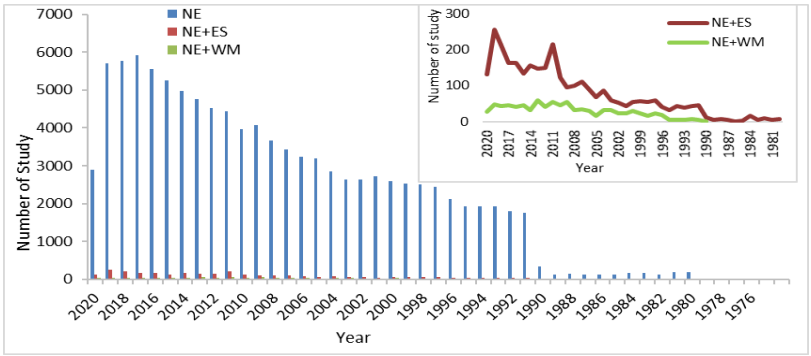

Fig 2. Bibliometric analysis on nuclear energy

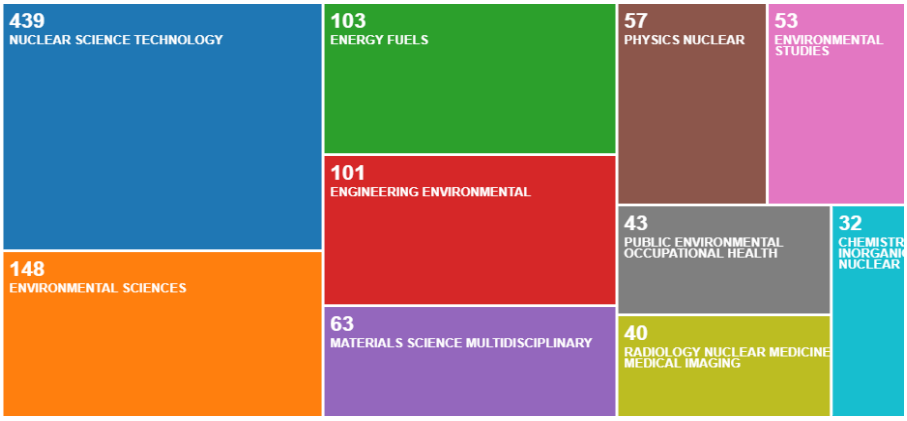

Fig 3. WOS categories in studies on nuclear energy and waste management

5. CONCLUSION AND EVALUATION

Nuclear power is an attractive source of electricity production. However, it is an energy generation system that must be operated with high precautions. It is a technology that can be used for electrical energy production, except that it is not used as a nuclear weapon. Various studies should also be carried out to optimize the negative effects of radiation emissions and waste management. Considering the bibliometric analysis results, it can be said that more attention should be paid to waste management and work safety issues. It is an alternative that can be preferred in terms of reducing dependence on oil and natural gas, reducing greenhouse gas, helping to solve the electrical energy problem, and helping the economy to develop.

REFERENCES

[1]. Turkish Academy of Sciences, Nuclear Energy Report (In Turkish), Editor: İbrahim Dincer, Turkish Academy of Sciences Publishing, Report No: 29, Ankara, Turkey. Available: http://www.tuba.gov.tr/tr/, 2019.

[2]. A. Polatoglu, "Technoeconomical investigation of nuclear fuel and nuclear waste at nuclear power plants that planned to establish in Turkey," Firat University, Turkey, 2016.

[3]. M. Benedict, T.H. Pigford, and H.W. Levi, *Nuclear Chemical Engineering,* McGraw- Hill Book Company, USA, 1981.

[4]. A. Mladenov, T. Nonova, D. Dimitrov, and K. Krezhov, "Radioactive waste management at the nuclear scientific and experimental centre of the institute for nuclear research and nuclear energy–bas," *Radiation and Aplications,* Vol. 1 (3), pp. 193-198, 2016.

[5]. E. Aras, "The necessity of nuclear energy in Turkey: A comparison with hydropower energy," *Energy Sources, Part B: Economics, Planning, and Policy,* Vol. 8 (2), pp. 107-114, 2013.

[6]. C. Karakosta, C. Pappas, C. Marinakis, and J. Psarras, "Renewable energy and nuclear power towards sustainable development: Characteristics and prospects," *Renewable and Sustainable Energy Reviews,* Vol. 22, pp. 187-197, 2013.

[7]. I. Atiyas, T. Cetin, and G. Gulen, *Reforming Turkish Energy Markets,* Springer publishing, New York, 2012.

[8]. R.M. Harrison, and R.E. Hester, *Nuclear Power and the Environment,* RSC Publishing, London, UK, 2011.

[9]. K. Temurcin, and A. Agaoglu, "Nuclear energy and the reality of nuclear energy in the light of discussions," *Turkish Journal of Geographical Sciences,* Vol. 1(2), pp. 25-39, 2003.

[10]. Turkey Atomic Energy Agency website. [Online]. Nükleer enerji ve sürdürülebilir kalkınma. Gunumuzde Nukleer Enerji. Available: http://taek.gov.tr/nukleer-guvenlik/nukleer-enerji-ve-reaktorler/166-gunumuzde-nukleer-enerji-rapor/443-bolum-09-nukleer-enerji-ve-surdurulebilir-kalkinma.html, 2010.

[11]. H. Topal-Namli, and S.S. Namli, "Nuclear power in Turkey: Pros and cons," *in The 2014 WEI International Academic Conference Proceeding,* 2014, New Orleans, USA.

[12]. M. Eral. Nükleer güç santralleri ve ülkemiz. [Online]. Available: http://www.kmo.org.tr/resimler/ekler/1423037b0f99b51_ek.pdf, 2015.

[13]. H. Sokolsky, The high and hidden costs of nuclear power, *Policy Review,* vol. 162, pp. 53-68. [Online]. Available: https://www.taek.gov.tr/tr/ and https://www.hoover.org/research/high-and-hidden-costs-nuclear-power, 2010.

[14]. B.L. Cohen, *Before it is Too Late.* Springer Publishing, New York, 1983.

[15]. E. Koc and M.C. Senel, "Dünyada ve Türkiye'de enerji durumu," *Mühendis ve Makina,* Vol. 54(639), pp. 33-34, 2013.

[16]. Lazard's levelized cost of energy analysis. [Online]. Available: https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf (Accessed date: 05/04/2021), 2019.

[17]. W.M. Haynes, *CRC Handbook of Chemistry and Physics*, 92. ed., CRC Press, 2011.

[18]. D. Davis, "The necessary good that is nuclear power," *Electric Light & Power,* Vol. 89 (5), pp. 7-9, 2011.

[19]. IRENA Renewable power generation costs in 2019, International Energy Agency, Abu Dhabi. Available: https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019 (Accessed date: 05/04/2021), 2020.

[20]. Web of Science. [Online]. Available: https://apps.webofknowledge.com/WOS_GeneralSearch_input.do?product=WOS&search_mode=GeneralSearch&SID=E2TEkaaNbya8ihWb4iq&preferencesSaved= (Accessed date: 20/07/2020), 2020.