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Energy Supply Security and Artificial Intelligence Applications

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ABSTRACT *There are various options and instruments to ensure energy security, which is very important in terms of accepting energy efficiency as a source of supply and implementing an innovative political perspective. When energy efficiency practices are supported by relatively rich renewable energy resources, it will be possible to reduce the energy import bill. In this process, coal, and nuclear options, as well as renewable energy, may play a prominent role on the supply side. In this context, the necessity of a well-functioning legal system, an independent decision-making authority, and a well-developed accountability institution to make the necessary investments remains important. In integrated cooperation with artificial intelligence, the internet of things, and machine learning technologies, it is possible to store, process, and manage data, which creates energy supply security, with less time and cost. Advanced technology continues to permeate every aspect of the modern world, and the energy industry is no exception. Artificial intelligence has all the capabilities that can radically change or even revolutionize the energy industry. This study predicts that in the near future AI will go from being a useful technological marvel to being the most influential decision-maker in the energy industry.*

Keywords: Energy Supply Security, Energy Market, Installed Capacity, Artificial Intelligence

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Introduction

Energy supply (ES) is a comprehensive concept that includes four important elements such as the availability, accessibility, and economic and sustainability of the energy source, and the existence of this basic element ensures energy supply security (ESS).[1] The energy market maintains its strategic importance all over the world as one of the most important supporters of economic and social development.[2] There are key indicators in the market such as energy consumption per capita, energy intensity as an indicator of energy efficiency, and carbon intensity of ES, which differ significantly between developed and developing countries. Smart Grids (SG) make great contributions to ES, which increases the importance of today's very important mega-trends such as climate change, electrification, industry 4.0, and efforts to make the energy sector more efficient, competitive, and sustainable. In this direction, the importance of public-industry interaction in the new period has been better understood and concepts such as better regulation and Artificial Intelligence (AI) have begun to be implemented.

Türkiye's energy demand is developing in parallel with its growing economy. While the annual electrical energy demand in the world increased by 3 percent on average between 2000 and 2020, this rate was approximately 4.5 percent in the country.[3] To safely meet this high demand growth is a key priority of energy policy. According to the Presidential 2022 Annual Program, Türkiye'sinstalled power was expected to reach 100,607 MW at the end of 2021and 102,423 MW by the end of 2022. Türkiye does not have rich reserves in terms of fossil fuels, excluding lignite and newly discovered natural gas in the Sakarya field, the import rate of primary energy resources in 2019 was 69 percent. In 2019, the share in the supply of primary energy resources was 25.7 percent natural gas, 28.6 percent oil, 29.1 percent coal, and 16.6 percent renewable resources. The main aim of the program is to continuously provide ES with high-quality, sustainable, safe, and bearable costs, the most optimal control of which is possible with AI-based models.[4]

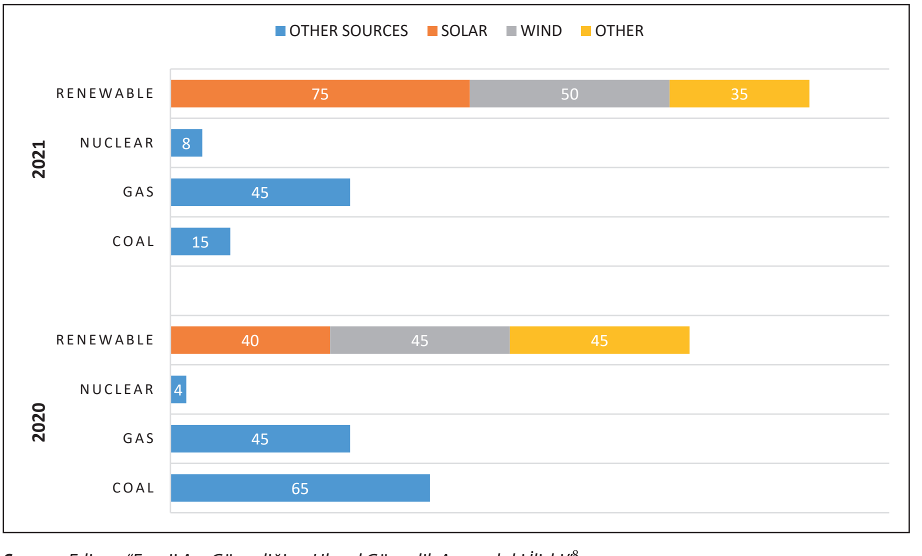
The concept of AI is that computers accurately and speedily do the work of humans. Machine learning, a broad sub-base of AI, is concerned with the design and development of algorithms and methods that enable computers to 'learn.'[5] The concept of learning means the software will make changes to the system that allow it to do the same job more efficiently next time. Generally, there are two types of inductive learning and deductive learning. The inductive machine learning method extracts rules and patterns from very large datasets. The foundation of machine learning is to calculate information from data and automatically extract it using statistical methods. Therefore, machine learning is directly related to data mining and statistics.[6] In the literature, supply reliability is generally provided by deterministic methods, and the control is made with autonomous machines. However, in this study, it is advocated to control with the AI approach in providing this security, which presents the necessity of a system that can control and make decisions in the face of unexpected events. In this study, general data and comparative analysis of installed power and production are presented in the second part. In the third part, the basic principle and requirements of energy supply security are expressed. Finally, the studies of AI as supportive methods of ES security are explained, and the dynamics of the power system have been determined.

Türkiye is very rich in terms of water resources, and by the end of 2021, hydraulic power plants (HPP) had the highest annual average electricity production share with 53,053 GWh

Installed Capacity, Generation, Consumption, and Foreign Trade of Electricity

The widespread use of clean energy technologies and, in this context, renewable resources, on the one hand, increases the rate of access to energy due to political engagements and economic developments for the realization of global sustainable development goals, on the other hand, it increases the network expansion and modernization requirements in almost every country. Figure 1[7] shows the change in global annual net electricity capacity increases in gigawatts from 2020 to 2021.

Figure 1: Global Annual Net Electrical Capacity Increases



Source: *Ediger, "Enerji Arz Güvenliği ve Ulusal Güvenlik Arasındaki İlişki."*[8]

Today, the share of electricity generation based on wind energy in the field of renewable energy in Türkiye is at high levels

In the period 2001-2019, the rate of electricity generation from natural gas in Turkey was between 30 and 50 percent. The share of natural gas in electricity production was 23.1 percent in 2020, and this rate is expected to rise to approximately 30.6 percent in 2022. Of the natural gas consumed in 2020, 28 percent was used in electricity generation, 26 percent in industry, and 46 percent for heating houses and other sectors. The installed power based on electricity generation from natural gas was 25,733 GW at the end of 2021 and it is calculated that it will decrease to 25,108 GW at the end of 2022. In this context, no increase is planned in the installed power of the thermal power plant.

While the installed power of domestic coal in Türkiye in 2020 was 11,336 GW, it is expected to remain the same at the end of 2022. Imported coal capacity was expected to remain constant at 10,307 GW in the 2021-2022 period. Within the scope of the national energy and mining policy, studies are continuing to increase the use of domestic coal. In this context, the use of large lignite reserves in electricity generation.

Türkiye is very rich in terms of hydroelectric resources and hydraulic power plants (HEPPs) have the highest annual average electricity generation share with 53,053 GWh at the end of 2021. With the Yusufeli Dam and HPP project, which will be the country's first and the world's third-highest dam when completed, the HPP installed power is expected to increase to 32,228 MW. In addition, rehabilitation investments continue in Keban, Karakaya, and Hirfanlı HPPs, which are publicly operated dams, to increase efficiency and availability.

Recently, the share of electricity generation based on wind energy in the field of renewable energy in Türkiye is at high levels. While the installed power capacity was 8,832 GW at the end of 2020, the average electricity production in this period was 24,828 GWh. In 2021, it was expected that the installed power of wind energy would be 10,100 MW and its production would be 29,137 GWh. It is foreseen to reach 10,900 MW installed power capacity in 2022.[9]

Türkiye is one of the most efficient regions in Europe in terms of solar energy.It was calculated that the installed power would reach 7,750 MW and the average generation power would be 13,211 GWh by the end of 2021. It is planned to reach 8,750 MW by the end of 2022.

The Akkuyu Nuclear Power Plant, which will be the nation's first nuclear power plant and whose foundation was set in 2018, is still being built. The

Muratlı, Borçka, Deriner and Artvin dams with hydroelectric power plants built on the Çoruh River, known as one of the fastest flowing rivers in the world, provided 2.5 billion TL to Türkiye's economy in 2021.

YUSUF OKUR / AA

power plant, which is expected to meet approximately 10 percent of Türkiye's electricity needs when completed, will consist of 4 units. The first unit of the power plant will be commissioned in 2023 and each unit will have an installed power of 1,200 MW and a total installed power of 4,800 MW. In addition to Akkuyu, research is ongoing in areas including site selection, location licensing, and collaboration with tech firms or nations for the construction of two more nuclear power stations. It was predicted that the installed power of geothermal, biomass and waste heat would increase to 3,435 MW at the end of 2021 and 3,536 MW at the end of 2022. The share of renewable energy sources in meeting electricity consumption was expected to be 35 percent in 2021. The low production in hydroelectric power plants due to drought plays a decisive role in this rate. It is predicted that this rate will increase to 40 percent in 2022.[10]

The diversification of primary energy sources, the decrease in reliance on foreign sources, and the improvement of energy efficiency through resource management are all covered under ESS policies. As a result, the goal is to provide a consistent and affordable supply of energy and raw materials.

Table 1: Electric Installed Power of Türkiye

INSTALLED POWER	Unit	2010	2015	2019	2020	2021	2022*
	MW	49.524	73.147	91.267	95.891	100.607	102.423
THERMAL	MW	32.182	41.541	46.500	46.309	47.633	47.008
- Local Coal	MW	9.161	10.085	11.317	11.336	11.336	11.336
- Imported Coal	MW	3.281	6.064	8.697	8.987	10.307	10.307
- Natural Gas	MW	18.213	24.945	25.904	25.675	25.733	25.108
- Other**	MW	1.526	446	312	312	258	258
RENEWABLE	MW	17.342	31.606	44.767	49.582	52.974	55.414
- Hydraulic	MW	15.831	25.868	28.503	30.984	31.688	32.228
- Wind	MW	1.320	4.503	7.591	8.832	10.100	10.900
- Solar	MW	0	249	5.995	6.667	7.750	8.750
- Other***	MW	191	986	2.678	3.098	3.435	3.536

* Data for the last quarter of 2022 are not taken into account.
** Other sources of petroleum derivatives (Naphtha, diesel, floil)
*** Biogas, geothermal etc.

Table 2: Electric Generation, Consumption, and Trade of Electricity in Türkiye

GENERATION	Unit	2010	2015	2019	2020	2021	2022*
	GWh	211.208	261.783	303.898	306.703	324.528	334.253
THERMAL	GWh	155.370	177.608	170.518	177.066	210.990	201.796
- Local Coal	GWh	40.515	36.180	52.499	43.306	49.722	50.571
- Imported Coal	GWh	14.532	39.986	60.506	62.506	61.759	70.410
- Natural Gas	GWh	98.144	99.219	57.288	70.931	99.189	80.451
- Other**	GWh	2.180	2.224	336	323	320	363
RENEWABLE	GWh	55.838	84.175	133.379	129.637	113.538	132.457
- Hyraulic	GWh	51.795	67.146	88.823	78.094	53.053	66.867
- Wind	GWh	2.916	11.652	21.731	24.828	29.137	30.643
- Solar	GWh	0	194	9.250	10.950	13.211	15.680
- Other***	GWh	1.126	5.183	13.576	15.764	18.137	19.267
IMPORT	GWh	1.144	7.136	2.212	1.890	1.290	2.303
EXPORT	GWh	1.918	3.194	2.789	2.484	3.317	2.303
CONSUMPTION	GWh	210.434	265.724	303.320	306.109	322.501	334.253

* Data for the last quarter of 2022 are not taken into account.
** Other sources of petroleum derivatives (Naphtha, diesel, floil)
*** Biogas, geothermal etc.

Energy Supply Security

It is necessary to define ESS to make the subject clear and to determine the scope of the future analyses we will make. At this point, several different definitions can be mentioned. It is important to remember that the definition of ESS has evolved while coming up with these definitions. The International Energy Agency (IEA) defines ESS as "the uninterrupted availability of energy resources at an affordable price."[11] According to the IEA, ESS has many dimensions. Long-term ESS means "investments made mainly to provide ES in line with economic development and environmental needs." On the other hand, short-term ESS is the ability to respond quickly to sudden changes in the supply-demand balance.[12] A definition of "supplying sufficient quality and clean energy at affordable prices and uninterruptedly" states that energy should be clean as well as sufficient.[13] In another study on Developing an Energy Security Index and assessing the ESS of East Asian Countries, ESS is defined as securing the amount of energy required for people's lives, economic, social, and defense activities, among other purposes, at a reasonable price level.[14]

Long-term energy planning is a strategic approach to how a nation will make structural changes that will affect its supply and demand, and it is also the guarantee of sustainable development

Energy imports constitute approximately one-fourth of Türkiye's total annual imports. This one-quarter of energy import items corresponds to three-quarters of the country's energy needs. Insufficient oil and natural gas reserves in Türkiye, insufficient use of renewable and alternative sources, and energy efficiency studies which have not been carried out effectively until recently all lead to this high foreign dependency in primary ES.

Meeting the energy need of a country is a roadmap that should be realized by taking into account many factors (such as society, technology, economy, and environment). Long-term energy planning is a strategic approach to how a nation will make structural changes that will affect its supply and demand, and it is also the guarantee of sustainable development.[15] An important indicator of the independence of countries is ESS. In ESS, renewable energy sources have an important place as well as electrical energy security and heat generation. Renewable energy sources (wind, photovoltaic, hydraulic, biofuel, etc.) constitute an important part of the energy sector, and these resources should be used most efficiently.[16]

ESS is affected by factors such as oil prices, primary ES, rate of renewable energy sources, carbon dioxide emissions, and per capita energy consumption. For this reason, to ensure ESS, it is necessary to increase the efficiency of existing resources with new technologies and to reduce their environmental impact, as well as to increase the use of renewable energy resources.[17]

Four-fifths of the world's energy needs are provided by fossil fuels, and the identified fossil fuels are expected to be exhausted after 70 years. Türkiye, a country with limited energy resources, imports the majority of the fuel used

Türkiye's electricity generation capacity has shown a rapid increase, especially in recent years, mainly based on renewable energy

for electricity generation. In Türkiye, priority should be given to renewable energy sources, domestic coal should be made environmentally friendly, and nuclear energy and hydrogen energy should be prioritized.[18] The use of renewable energy sources has become attractive for the world economy, which is highly dependent on energy, in the production of electrical energy, with the limited fossil fuels and high costs, and the need to reduce greenhouse gas emissions. Globally, renewable energy sources have enormous potential, and it is anticipated that, with the development of smart technologies and power electronics, their contribution to meeting rising energy demand will rise in the years to come. In 2035, the share of renewable energy sources in electrical energy production is expected to be 31 percent, 6 percent in transportation, and 14 percent in heating.[19]

This study's objective was to create an ideal production planning framework for the period of 2012 to 2027. The installed power of renewable energy sources–including wind, geothermal, biomass, and solar energy, but excluding hydraulics–as a percentage of all installed power increased somewhat as a consequence of this study, rising from 8.92 percent to 8.94 percent. It is of great importance to create plans and strategies to ensure more efficient use of energy in all sectors in Türkiye, and to develop financial mechanisms for energy efficiency. For this purpose, it is seen that the implementation of energy efficiency obligations, one of the market-based energy efficiency policies which has started to be implemented in the EU, is effective in providing energy efficiency.[20]

The most important part of energy resource planning for the security of supply is the estimation of future electricity consumption in regional and national service areas.[21] Many future-oriented AI-based prediction techniques such as deep learning, machine learning, genetic algorithm, fuzzy logic, and artificial neural networks are used in the energy field in Türkiye the most used method being artificial neural networks.[22]

Investment in the sustainability of generation, transmission, and distribution, is of great importance to meet the electricity demand in safe, continuous, and competitive conditions. Türkiye's electricity generation capacity has shown a rapid increase, especially in recent years, mainly based on renewable energy.[23] Renewal and expansion investments in transmission and distribution networks continue in line with the development in production and the growth in demand. These investments should continue intensively in the upcoming period as well. In this context, the investments of Turkish Electricity Transmission

Corporation (TEİAŞ), which is the main backbone of the electricity system, should be continued in the most efficient way, necessary investment priorities should be implemented, master plans should be prepared similar to the examples in Europe, and generation development plans should be created based on AI in line with the transmission system development plans. In addition, the establishment of the electricity transmission system according to N-2 criteria (It means the simultaneous failure of two independent pieces of equipment of the transmission system due to faults) in regions where economic activities are intense, the development of high voltage direct current transmission line (HVDC-High Voltage Direct Current) projects to reduce transmission losses and increase operating efficiency within the scope of long-distance power transmission should be studied. Opportunities for cross-border trade and interaction with regional markets should be increased by developing electricity interconnections.[24]

A power system equipped with smart components creates the basis for cyber-attacks. Thus, cyber security is becoming more and more important in the network industries. Studies initiated to strengthen cyber security should be continued with the principle of meticulous and continuous improvement, in this context, a national Energy Management System SCADA software should be developed for TEİAŞ and AI-based models should be developed.

With the recently created TEİAŞ Electricity Power Quality and Network Monitoring System (TEKİS), automatic collection and storage of data pertaining to the electricity network, including transmission and distribution main feeders, is ensured. This system aims to monitor the entire network in a holistic structure using up-to-date software technologies, to analyze the data with various methods, including AI methods, and to automatically generate the necessary reports by this system. With the system to be developed, it will be ensured that power and power quality parameters are collected at the same time in different and high resolutions. It is planned to analyze these data using big data analytics methods. In addition to voltage events, it will be possible to detect power quality events on current and power. With the ability to determine the direction of the voltage dip, whether such events originate from the transmission network or the transmission system user, will be automatically determined using different methods of analysis. With the event classification capability that will use AI technologies, the causes of power quality events will be determined automatically.[25] TEKİS is a system developed by TÜBİTAK MAM Energy Institute for TEİAŞ. The R&D project in which TEKİS is being developed is an AI-oriented development supporting a variety of studies that started in April 2021.

Expectations on Energy Supply Security

Considering the changes and developments in the world, it is very important to research how to provide energy resources and technologies to Türkiye's increasing population, which are domestic, cheap and easy to obtain, reliable, and do not harm the environment. These studies have a significant economic impact on the country, and it is critical that all investigations are long-term. According to the "World Energy Outlook 2021" prepared by the IEA, global energy demand is expected to increase by 37 percent until 2040, but economic development is expected to be less energy-intensive. In 2040, it is expected that the world ES component will consist of four equal sources, namely oil, natural gas, coal, and low-carbon energy sources.[26] Resources such as renewable energy sources and nuclear energy, which are expressed as low-carbon energy sources, are among the energy source diversity of all developed countries around the world. In terms of increasing environmental awareness and local solutions in the world, renewable energy sources have in particular started to attract more attention.[27]

The subsidies given to fossil fuels in the world energy sector, which is predominantly fossil fuel, hinders investments in renewable energy sources and energy efficiency. Nuclear energy, which is widely used especially in developed countries, is expected to continue to be at the center of national energy strategies. Nuclear energy is an alternative energy source that can both reduce CO_2 emissions and provide base load energy, and it is an energy source that can replace other production methods. When the renewable energy market (electricity, heating, and transportation) is analyzed around the world, remarkable growth has been observed in the last five years. Table 3 shows the amount and rates of electricity generation from renewable energy sources around the world, and a 2.7-fold growth is expected between 2010 and 2035. While heat production from renewable energy sources was 337 million tons equivalent of oil (Mtoe) in 2010, it is predicted to be 604 Mtoe in 2035. The use of biofuels worldwide is expected to reach 4.5 million barrels of oil equivalent per day by 2035.[28]

Table 3: Renewable Energy Use in the World

	2010	2020	2035
Electricity Generation (TWh)	4.206	6.999	11.342
– Bioenergy	331	696	1.487
– Hydraulic	3.431	4.513	5.677
– Wind	342	1.272	2.681
– Geothermal	68	131	315
– Solar	34	382	1.124
– Wave	1	5	57

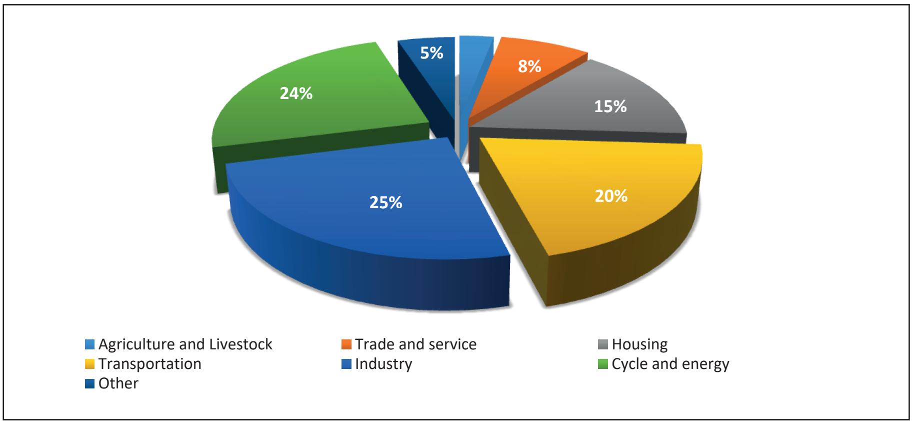
Source: *Ediger, "Enerji Arz Güvenliği ve Ulusal Güvenlik Arasındaki İlişki."*[29]

In the field of renewable energy, there are developments and expectations in Türkiye close to global standards. According to the 2019-2023 Strategic Plan

Türkiye's renewable energy potential is theoretically sufficient to meet the electricity demand in the medium term

prepared by the Ministry of Energy and Natural Resources, Türkiye aims to increase the ratio of the electricity installed power based on domestic and renewable energy sources to 65 percent of the total installed power to ensure sustainable ESS.[30] Türkiye's sectoral energy consumption is seen in Figure 2; industry at 25 percent with 24 percent stand out as the sectors with the highest energy consumption. These are followed by the transportation sector with 20 percent. Considering these rates, the importance of energy efficiency studies in sectors with high energy consumption is increasingly obvious.[31]

Figure 2. Sectoral Energy Consumption in Türkiye



Source: *Ediger, "Enerji Arz Güvenliği ve Ulusal Güvenlik Arasındaki İlişki."*[32]

Türkiye's renewable energy potential is theoretically sufficient to meet the electricity demand in the medium term.[33] However, considering the nature of the country's renewable energy resources, the constant supply-increasing pressure from the supply-demand balance, the duration of the use of renewable resources, their intermittent generation, financing constraints, and the need to strengthen the grids, in the short term, there is a need for a purely renewable energy resource. It does not appear possible to construct an electrical energy grid. As a result, an integrated system planning should be carried out in the next term, with renewable energy sources receiving top priority on the supply side, while also taking into consideration the goal of acquiring a specific technology and developing industrial infrastructure.

Thus, with the outputs to be obtained from the well-designed (Renewable energy resource area) YEKA model, on the one hand, it will be possible to significantly increase the share of renewable energy resources in both primary

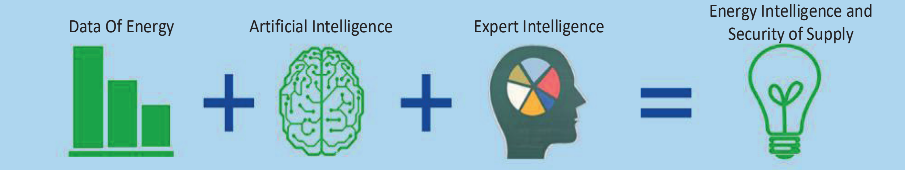
Energy companies need to predict demand changes, system overloads, and potential failures as precisely as possible

ESand electrical energy production, and on the other hand, thanks to the competitive advantage to be provided by domestic equipment production, those who want to benefit from renewable energy resources, especially in the countries in our hinterland, will have the opportunity to penetrate the country's markets. In this context, it is important to produce technologies compatible with the aforementioned AI model with national resources or by localization.

Energy Supply Security and Artificial Intelligence

There are some applications behind the new world trend, which include big data, machine-to-machine communication, AI, and learning machines. In all sectors, especially the energy sector, everything becomes customer-oriented, and behind these studies are AI and machine learning (ML). Data for companies has now become as valuable as oil. With AI, big data focuses on what to do with it rather than how much knowledge is gained. It takes data from any source and analyzes it to find answers that save money and time, new project development and optimized proposals, as well as smart decision-making. While companies that analyze and interpret this data correctly and create value-added services are growing, it is obvious that companies that cannot keep up with innovations and developments will shrink and disappear over time. Algorithms created by AI between energy-based data and expert knowledge create supply reliability and an intelligent energy system, as shown in Figure 3.

Figure 3: AI between Energy-based Data and Expert Knowledge



Learning in AI is basically Statistical Learning (Bayes, Clustering, Hidden Markov Model, Nearest Neighborhood Model, etc.), Neural Learning (most used), and Evolutionary Learning (Genetic Algorithm, Particle Swarm Optimization, Ant Colony Optimization, Bee Swarm). Hybrid methods in AI combine two or more ML and/or soft computing methods for higher performance and optimum results and are grouped into three categories: neural networks and fuzzy logic, neural networks and genetic algorithms, and fuzzy logic and genetic algorithms. AI in renewable energy is widely used in wind, solar, geothermal, hydro, ocean, bio, hydrogen, and hybrid energy systems. It is used for design, optimization, estimation, management, distribution, and policy determination in renewable energy types.

Applications of Artificial Intelligence in the Energy Sector

Today, due to the large amount of data that energy companies have to manage, there are serious problems with many issues such as the cost of energy, production, and distribution. Chief among these problems is the inconsistency in carbon footprint and energy efficiency. In an integrated collaboration with AI, the internet of things, and machine learning technologies, it can store, process, and manage this data with less time and cost. Furthermore, it is not restricted to these; rather, it can produce fresh insights that might fundamentally alter the way the sector functions. The energy industry is ripe with opportunities for AI.

Predictive Analysis

The continuity of modern industries and global population growth have an ever-increasing energy demand. In order to overcome these problems, it is thought that the analytical and predictive ability of AI will be a savior for humanity. Energy companies have problems that require complex data systems to reduce costs, conserve power, be prepared for changing conditions, and provide better customer service. These problems can only be addressed through highly accurate forecasting and analysis, and today the only technology with this potential is AI. All of these issues may be solved with the aid of AI machine learning by optimizing the use of predictive data in the energy business. Energy companies need to predict demand changes, system overloads, and potential failures as precisely as possible. The cost of error for any deviation from these estimates is quite high for the energy sector. The predictions that AI will reach as a result of the data it processes seem to leave these problems behind.[34]

Resource Management

The next step in the predictions that AI achieves is resource management. Through the analysis of these forecasts, energy companies will be able to better allocate their resources, prepare for energy demands in advance, anticipate problems, and save resources. For end consumers, it will be possible to achieve results in the form of power savings, lower bills, and customized services with AI.

Storage of Energy

Efficient storage of energy is a very difficult and complex issue. As the amount of power to be stored increases, additional capacity and new management systems are needed. AI can optimize the industry's energy storage. In addition, the storage of clean and renewable energies (for example, wind energy) is quite problematic. Combining renewable energy with AI-powered storage can streamline storage management and minimize power losses.

Prevention Services

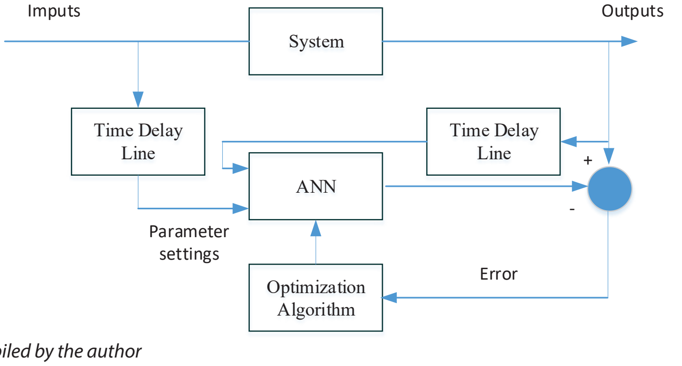
Energy is a powerful resource that can be very dangerous if misused.[35] For example, the deadly wildfires in California were caused by faulty transmission lines in 2019. If AI-enabled systems are used, system overloads can be predicted and operators would know about potential transformer failures in advance.

Artificial Intelligence Applications according to the Energy Production Model

AI is widely used in wind power plants, in terms of wind power and speed estimation, data mining methods, probability models, neural network models, fuzzy logic, support vector machines, Adaptive Neuro-Fuzzy Inference System (ANFIS), principal component analysis, genetic algorithms, error diagnosis, Artificial neural networks (ANN) and Wavelet Transform. The most widely used method of AI in Solar Energy is known as ANN, which is used in the estimation of the amount of radiation of the Sun, power estimation in a photovoltaic system, and genetic algorithm (for parameter optimization).

AI Applications in Smart Grids (SG)are used to solve some difficult problems where it is difficult to model the nonlinear, time-varying nature of the power system with conventional methods. ANN is used to monitor changing parameters. Data centers today use 2 percent of all energy. With the increased usage of the internet and AI, demand for data centers and energy will rise. The flowchart showing the Determination of Power System Dynamics is shown in Figure 4 below.

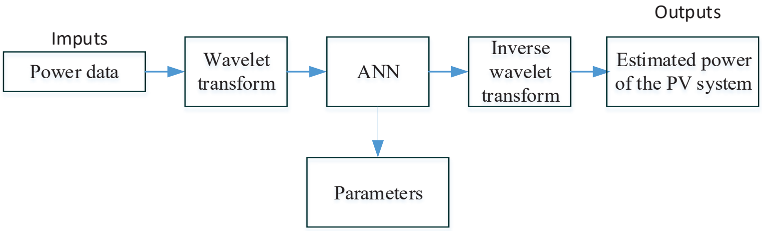
Figure 4: Determination of Power System Dynamics



Source: *Compiled by the author*

Energy estimation of photovoltaic systems Requires differential equation solution using a large amount of meteorological data. Artificial neural networks are useful in this field, the flowchart used for this is shown in Figure 5.

Figure 5: Energy Estimation of Photovoltaic Systems



Source: *Compiled by the author*

Energy efficiency, which has started to be accepted as a source of supply, has significant potential for the country. The Energy Efficiency (EE) Strategy Document (Published by The Energy Efficiency Opportunity in the UK), which covers the actions for the realization of this EE Action Plan, states energy efficiency as an energy security opportunity, controlling energy input costs, increasing efficiency in the fight against climate change and protecting the environment. In addition to its contribution, it also includes a perspective of acquiring know-how. In this respect, it is thought that the determination and meticulous implementation of the AI-supported EE Action Plan will provide more gains than expected with the synergy it will provide. To support this, efforts should be continued to create accurate price signals in consumption, a smart grid equipped with modern technologies will be used more effectively, AI-based decision-making mechanisms and forecasting, competitive and predictable energy market structures should be made more functional.

In the future, on the supply side of the energy sector, it is envisaged that large regional grids will be replaced by private microgrids that more precisely manage local energy needs

Potential development opportunities focused on software and new technologies should be identified in areas such as big data, data mining, distributed optimization, machine learning, AI, and mechanisms should be established to ensure the most effective use of institutional capacities in these areas.[36] Rapidly advancing technology poses very different risks and opportunities for energy infrastructure. Technological developments should be closely monitored in order to keep the risk at a minimum level and to make the most of the opportunities, and these developments should be taken into account in all aspects during the determination of long-term and large-scale energy infrastructure investments. It is important to establish and develop innovation and R&D capabilities in a way that will contribute to the competitiveness and growth of the energy sector. In this framework, there is significant potential for the development of an ecosystem that encourages innovation and the intersection of various investment opportunities with energy strategies. Research in domains such as artificial intelligence, digitalization in energy, high-efficiency fuel cells, electricity storage, and electrical charging systems should be fostered.

Possible Challenges of Artificial Intelligence Application in the Energy Sector

In the next ten years, the technologies that come with the concept of AI are not just energy, with robotic developments it is expected to seriously affect various sectors. It is possible to see the traces of AI-derived applications in the sector in the devices that come into use with SG and in the advances in demand management.[37] The management of distributed energy resources, smart infrastructures, sensors, and meters are topics that have been on the agenda of the energy sector for a long time since the creation of SG.[38] It is planned that today's smart devices, which reduce energy consumption by automatically detecting the demand levels in the network, will be powered by AI, be recorded with the blockchain, and securely interact with each other. However, all these applications bring with them some challenges.

Lack of Theoretical Knowledge

One of the reasons for the slow adoption of AI in the energy sector is the lack of knowledge among decision-makers about AI. Many companies do not have the technical background to understand how to leverage AI applications. Conservative stakeholders prefer to stick with proven methods rather than risk trying something new. As more industries tap into the potential of AI, the energy industry is turning its attention to this technology.

Lack of Practical Expertise

AI is still a new technology and very few professionals specialize in it. Although there are many experts with in-depth theoretical knowledge, it is extremely difficult to find experts who can develop new AI software with practical experience. Because the cost of error is high in the energy industry, many companies are reluctant to try new approaches.

Old Infrastructure

Outdated infrastructures are the biggest obstacle to the use of AI in the energy sector. Companies that provide public energy services find themselves immersed in the mass of data they collect and have no idea how to deal with it. The energy sector suffers great losses due to the security vulnerabilities of outdated systems.

New trends, smart grid models, and energy diplomacy, which are gaining more importance day by day, affect the shaping of general foreign policies as well as the energy sector

Financial Pressure

Implementing AI technology may be the smartest thing to do. But it's definitely not the cheapest. Finding an expert software services provider, building and modifying software, and administering and monitoring all take a significant amount of time and effort. Before enjoying the benefits of implementing AI, machine learning, and deep learning into their strategy, businesses in the energy industry must be ready to commit to a sizable budget and incur the risks of replacing outdated systems.

In the future, on the supply side of the energy sector, it is envisaged that large regional grids will be replaced by private microgrids that more precisely manage local energy needs.[39] These grids will be paired with new battery technologies that allow energy to flow continuously, even if severe weather conditions cause interruptions to the power system. On the demand side, demand and supply will be continuously monitored for end consumers, including homes and workplaces, thanks to smart meters and sensors on transmission lines. Box-sized devices will measure the flow of electricity through the grid in real-time, allowing operators to manage and prevent outages. With smart calculations, there will be significant reductions in electricity bills that consumers will pay.

Conclusion

The unchanging paradigm of the energy sector is to ensure supply security. For Türkiye, which meets more than two-thirds of its energy needs through imports, ensuring the security of supply is not just a matter of energy policy. It is also an important component of foreign policy, industrialization, urbanization, transportation, and development policies. In this context, the contributions of AI and energy diplomacy in ensuring energy supply security are gaining more importance day by day.

The integration of modern systems into the grid and the search for determining or affecting the conditions of access to energy have become more frequent day by day. In particular, the instability in the geographies close to the South and East of Türkiye causes global repercussions in terms of influencing and ultimately being affected by the developments in this region, which is rich in energy resources. In this process, while interstate relations become more privatized than ever before in ensuring ESS and securing energy trade, it is witnessed that state-like reflexes are developing in inter-company relations. In this context, new trends, smart grid models, and energy diplomacy, which are gaining more importance day by day, affect the shaping of general foreign policies as well as the energy sector.

It is vital to adopt the following principles stressed by Türkiye's Ministry of Development in order to ensure energy security in our national power system:

i. Accepting energy efficiency as a source of supply and increasing energy efficiency through comprehensive and systematic planning and implementation,
ii. Diversification of countries and routes in terms of energy sources,
iii. Increasing the share of domestic and renewable energy resources,
iv. Meeting the base load requirement free from continuous resource input by making use of nuclear energy in the safest way,
v. Creating multidimensional value by creating a regional trade center in energy,
vi. Accelerating the transition to the Smart Grid model,
vii. Adoption of the Dynamic Market model,
viii. Designing AI-based models and ensuring their widespread use in forecasting,
ix. Using machine learning methods to design a market model using deep learning methods,
x. Using AI-based optimizations supported by stochastic methods instead of deterministic methods used in Ancillary Services, which is a decisive service in the energy quality and frequency regulation,
xi. Optimizing works of great importance such as the capacity mechanism with AI-supported designs to the national power system with expert teams to be formed,
xii. Coordination of loading and unloading instructions at the National Load Dispatch Center based on AI on the SCADA model,
xiii. Carrying out projects and R&D studies for the widespread use of AI-based monitoring and estimation algorithms that will be integrated into the TEİAŞ Electric Power Quality and Grid Monitoring System and will basically ensure supply security,

The realization of the above will have positive effects in almost every sector since energy based on modern technologies is a sector/element that cuts horizontally. For Türkiye, which has to create employment for its young population, the energy needs of the economic sectors, especially the industry, must be met with high quality, uninterrupted, and at reasonable prices. To avoid any bottleneck in meeting the energy demand, the energy system should be made more flexible and a smart supply system should be established in which domestic and renewable energy resources are at the center. This AI-based model can be achieved by handling natural gas imports, electricity generation, electricity, and natural gas transmission and distribution infrastructure with a holistic and smart modern approach. The synergy that will be created in this way will be reflected in all sectors, and in turn, it will strengthen the Turkish national power system in global competition.

Nonetheless, demand-side policies are gaining prevalence as much as supply-side policies in ensuring supply security. Energy efficiency and forecasting are at the center of demand-side management policies. Energy efficiency is often perceived as energy saving by the general public. Creating the necessary social awareness of energy efficiency, which has a conceptual content in itself, will contribute to the increase of rationality in energy supply and consumption. For this, energy saving, and energy efficiency should be included in formal and non-formal education programs and the public should be informed through suitable channels, in the final analysis, efficient use of energy is also of great importance in terms of evaluating energy resources and energy infrastructure with an optimal understanding, minimizing the impact of energy production on the environment and therefore using Türkiye's natural resources more efficiently and sustainably. As a final point, accurate demand forecasting will allow for accurate load planning, which will then allow for accurate production setup in intraday and day-ahead market models. The most proactive steps in this regard are demand-side management algorithms built on AI.

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