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Artificial Intelligence in the Energy Industry: Practical & Economic Analysis of Existing Uses

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ABSTRACT

This thesis will explore the vast potential of uses that artificial intelligence has in the energy industry. There is much existing literature describing the various uses of AI in energy, and the purpose of this thesis is to review this literature and highlight the most common uses of AI in energy, as well as the most promising potential uses for the technology. A variety of papers were utilized for this literature review, and the authors have a lot of diversity from which country's perspective they are writing from, and how they view AI's potential in energy. First, AI is defined both in its own terms and in the terms of the energy industry to set the precedent for how it is interpreted in the thesis. Throughout the paper, an overview of AI in multiple different energy sectors is done to show how its capabilities can be flexible throughout the industry. From renewables to fossil fuels, AI has a place in all types of energy. Main uses include optimization, forecasting, and efficiency improvements that can help to ensure that energy flows smoothly from extraction to end-use. Furthermore, this paper will dive into the economics behind AI use in the energy industry, discussing market effects, costs, and finances for companies that choose to utilize AI. The goal of this thesis is to demonstrate the growing literature and research being done on artificial intelligence in the energy industry, and to highlight its most significant capabilities.

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Chapter 1 Introduction

To keep up with the world's growing energy demand, the energy industry has rapidly evolved and grown in the past few decades. Attempting to balance meeting energy demands and reducing carbon emissions, energy companies have invested millions into their energy systems to incorporate more advanced technologies. Artificial intelligence (AI) is the most prominent of these technologies, as it has allowed the energy industry to grow significantly and become much more efficient and reliable. As highlighted by Chelliah et al (2023) in their book on AI in the fossil fuel sectors, AI makes it possible for energy providers to resolve complicated issues within their systems in a much quicker and more efficient way than they used to be able to resolve these issues before the integration of AI. Starting in the 1960s and 1970s, the development of AI technologies eventually led to the integration of these technologies into energy systems in the 1980s. By using artificial neural networks and different types of algorithms, artificial intelligence has significantly improved energy generation, trade, and consumption since energy companies began implementing it into their systems (Chelliah et al, 2023). In recent years, the long-term effects of artificial intelligence on the energy industry have begun to be researched to determine the benefits of AI integration and to study which specific applications of AI have been most successful within the industry. Among many areas of study, authors have commonly focused on both the integration of AI into the different energy sectors and the economic effects of AI on the energy market. This thesis is an analysis and review of existing literature, and it will examine the use of AI tools in the energy industry and their ramifications, including costs, benefits, and future outlooks. The energy sectors explored include electricity, natural gas, nuclear, crude oil and renewables; these prevalent energy sources have the most potential for utilization of AI tools, and have served as the blueprint for AI integration in energy. With the growing availability of data on energy systems using AI, researchers hope to continue to discover more ways for AI to be integrated into the energy industry to improve the efficiency of energy generation and the energy market.

The remaining sections will first define AI and discuss the popular forms of AI. Specifically, large language models will be discussed as they are one of the most relevant forms of AI in the energy industry.

Methods

With so much existing research on the energy industry and the technology used within the various sectors, it is important to set parameters for the selected literature in this paper. Only literature published from 2019 and onwards was selected in order to keep the scope of the research within recent years, where most AI development has taken place. Google Scholar was used to locate the majority of the literature, alongside the Penn State University Libraries database catalog to find the rest. Key search terms included “artificial intelligence,” “artificial intelligence in the energy industry,” and “economics of AI.” The articles were initially skimmed to ensure accurate and relevant information for the scope of this paper. The overarching goal was to locate and use all of the available literature on the specific topics of this paper, to provide a comprehensive and complete literature review on AI developments and uses in the energy industry.

Artificial Intelligence Overview & Definition

First created by the desire to replace human mental labor with machines, AI has become an advanced tool that has made its way into almost all careers and aspects of life. As explored by Jiang et al (2021) in their paper defining artificial intelligence, AI has endless application fields, the main ones including the following: speech recognition, image processing, natural language processing, smart robots, energy systems, autonomous vehicles, and healthcare. With so many widespread uses, definitions of AI itself can differ as highlighted by Jiang et al (2021). For example, in the Turing test, AI is defined as the ability for machines to communicate with humans without revealing their identity as non-human. One of the pioneers of AI, Marvin Minsky, defines AI as enabling machines to do tasks that require human intelligence. The National Renewable Energy Laboratory (NREL) (2025), defines AI as “the simulation of human intelligence processes by machines”. The International Energy Agency (IEA) (2023), another credible source of energy research and information, defines AI as a transformative, general-purpose technology capable of sensing, reasoning, adapting, and interacting. All of these definitions from various entities have their significant differences, so it is important to define a specific use and definition of AI for the scope of this paper.

After reviewing much of the literature written on artificial intelligence and its place in the energy industry, a detailed definition of its purpose and meaning can be synthesized. There are many existing definitions of artificial intelligence, however, most of them are very similar in communicating the general themes of the term “artificial intelligence.” Jiang et al (2021) summarized the core values found in almost all AI definitions: “the core of AI is widely believed to be research theories, methods, technologies, and applications for simulating, extending, and expanding human intelligence”. Building off of this statement, a definition of AI for this thesis is formulated. The general definition of artificial intelligence is as follows: the theory and development of computer systems and machines able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, and decision-making. To summarize, artificial intelligence is the technology that has the ability to replicate and speed up the thought processes of the human brain. AI is of special interest to the energy industry because its capabilities match the industry's constant need for optimization, prediction, and automation.

Taking this definition and applying it to the role of AI in the energy industry, a detailed definition of artificial intelligence in the energy industry is also useful to define. From the generation stage, through the transmission and transportation stages, and finally to the consumption stage, artificial intelligence has thousands of applications in the energy industry. To summarize its main uses, I consider its most important functions in each stage, many of which were highlighted in my selections of literature. In the generation stage, artificial intelligence aids in resource allocation and generative efficiency. In the transmission state, artificial intelligence helps maintain grid stability and reliability. Finally, artificial intelligence in the consumption stage most notably improves demand forecasting and consumer experience in the financial energy market. After breaking down the role that AI plays in each part of the energy industry, my definition for artificial intelligence use in the energy industry is as follows: Artificial intelligence in the energy industry aids in generative efficiency, energy systems stability, and demand forecasting, all of which benefit both consumers and producers in the energy industry; furthermore, AI analyzes market dynamics in energy trading, leading to a more stable market that promotes the innovation of new energy sources and sustainable development of the energy industry. These core uses of AI in energy point to a bright and successful future for the industry, and there are specific types of AI that can help make this longevity possible. Figure 1 highlights these main uses for machine learning and AI in the energy industry.

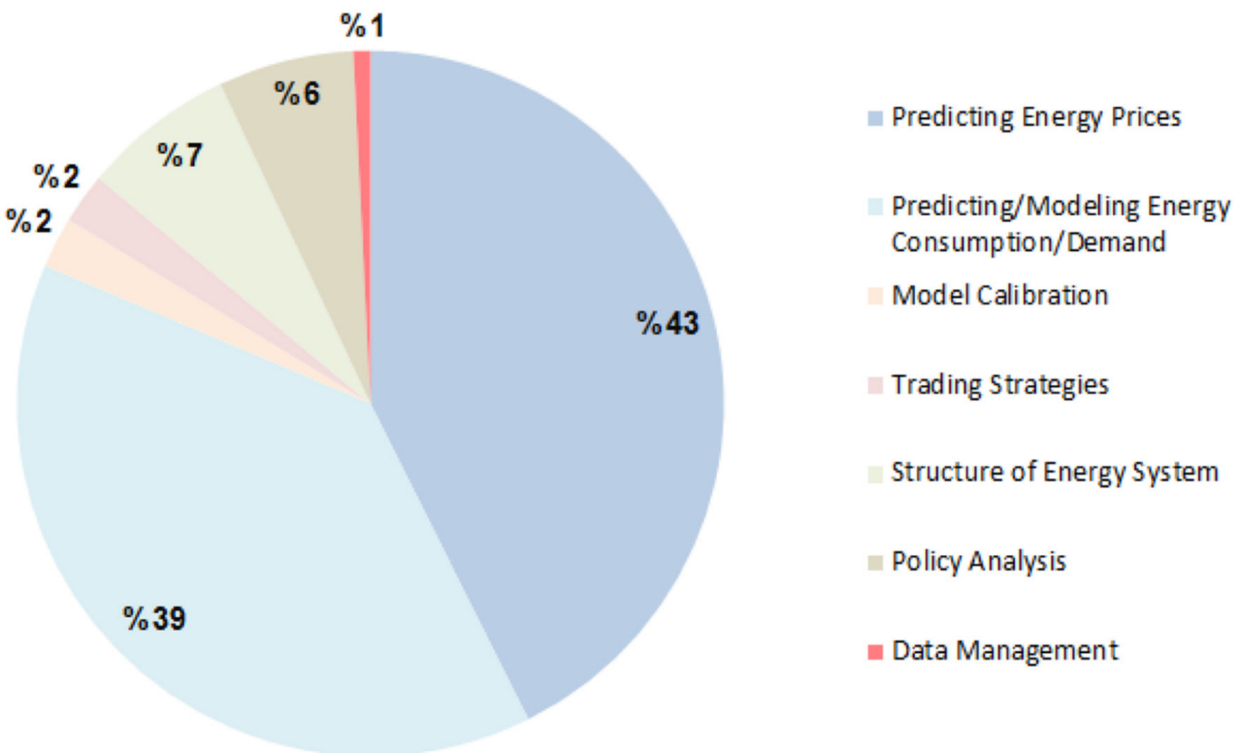

Figure 1: Relative frequency of application domains (Ghoddusi et al., 2019)

Large Language Models

Large Language Models (LLMs) are a specialized branch of generative artificial intelligence (GenAI) that consist of deep neural networks that leverage the self-attention mechanism to efficiently process and generate text (Liu et al, 2025). These pre-trained models excel in generating new content based on trained models and large-scale training datasets, which enable their wide range of generation powers. Many popular examples of LLMs include Open AI, ChatGPT, and Google Gemini, however, Liu et al (2025) dive into the uses of LLMs in energy applications in their research. Liu et al (2025) highlight how LLMs have the potential to transform traditional engineering fields by redefining workflows and improving outcomes. Their specific focus is the use of LLMs in large building energy systems. Much of the LLM potential in this sector remains untapped, and Liu et al (2025) highlights the untapped potential of LLMs to promote sustainability in the energy usage of buildings. The pattern recognition and data analysis capabilities of LLMs allow for the prediction and forecasting of energy consumption, occupancy, weather conditions, and system output for powering large buildings (Liu et al, 2025). These capabilities represent the use of LLMs in the end-use consumer phase of the industry, however, these LLMs can also have powerful effects on the producer end of the energy industry, which will be discussed further in this paper. First, it is important to understand how AI was originally integrated into the energy industry, and how its use has evolved over time.

Chapter 2 History of Integration of Artificial Intelligence into Energy Systems

Over time, AI has been shown to greatly increase the growth rate of the energy industry in the following years after it was integrated into energy systems. This is highlighted in the case study of China's energy industry, a study done by Dong et al. (2021) at China University of Mining and Technology. Through the application of a comprehensive evaluation index, the authors were able to calculate the development index of the energy industries of 30 provinces in China from 2000 to 2017. With the development of AI in these industries throughout those years, an annual growth rate for the industries of about 20% was found. This growth rate represents promising results from the implementation of AI into regional energy markets in China. These results can help to justify the necessity for policies facilitating the integration of AI in China's local governments.

China currently faces a disconnect between its regions in terms of technological advancement and the presence of AI. Dong et al. (2021) suggest the synthesis of preferential tax policies for artificial intelligence enterprises. In addition, policies to attract artificial intelligence professionals and policies to develop the required skills needed to work with AI were also suggested as ways for AI to become more widespread throughout all regions in China. For these policies to be created, there needs to be cooperation between local and national governments as well as universities and other institutions. This case study of China highlights the effects of government involvement in the integration of AI into the energy industry. The energy industry is a crucial part of the global economy, and government policies and investment in the industry heavily influence the future of AI integration.

Integration of AI into the U.S. energy industry was also studied by Ahmad et al. (2022), where the advantages and setbacks of AI integration were compared in these authors' research. The authors found many benefits of AI in the energy industry, including improved demand forecasting, lower operational costs, improved quality control, and better workplace safety. These significant improvements that AI brings to energy systems help to overall improve the efficiency and ability of the energy industry. However, with its many benefits, AI also brings some expected setbacks to the industry. Ahmad et al. (2022) predicted that AI developments as a whole could jeopardize 47% of jobs in the United States. Furthermore, the application of AI proves to bring integration and compatibility issues to systems—an issue that 36% of industrial companies are worried about in the United States. The overview of these advantages and setbacks by the authors provides valuable insight into the possible consequences of AI integration for companies that have both already integrated AI and those that have yet to invest in AI technologies.

Chapter 3 Sustainability

As global energy demand increases, it is crucial for the energy industry to adapt in order to meet demand while reducing carbon emissions. This adaptation is studied by Shi et al. in their exploration of the sustainable development of China's smart energy industry. The authors focus on how artificial intelligence is a necessity for developing low-carbon cities. Shi et al. (2022) state that the purpose of artificial intelligence in sustainable development should be to both reduce resource consumption and replace pollution factors in the energy production process. The overall goal of the sustainable development initiative, both in China and globally, is to meet the energy demand needs of current generations while also not depriving future generations of their abilities to meet their environmental and energy needs. Furthermore, the authors highlight the importance of social benefits from sustainable development. One of the important goals of the integration of AI into the energy industry for the purpose of sustainable development is to achieve equity and ensure that everyone benefits from the development of the energy industry. This includes improved energy efficiency, more job opportunities, meeting the energy demands of rural areas, and improving energy security. All of these factors benefit the greater population, and this article emphasizes the importance of keeping these factors in mind when integrating artificial intelligence into the energy industry.

Another piece of literature by Ersoz et al (2022) highlights the trend in growing use of AI in renewable energy. The article highlights the plentiful benefits in modeling and control that AI has to offer in the renewable energy industry. As stated by Ersoz et al (2023), the increasing need for clean and sustainable energy has called upon AI as a required part of the transition to clean energy. Specifically, the article mentions "XAI," which is a method that allows users to trust the outputs produced by machine and deep learning models. By implementing technology that allows users to trust the outputs of AI in the renewable energy industry, AI is more easily integrated and put to use with less troubleshooting. This is a crucial part of the renewable energy industry, as it helps avoid adding more challenges onto the already difficult transition away from fossil fuels.

The Great Energy Transition

With the piling concerns in recent decades about energy consumption and fossil fuels, a movement often referred to as “the great energy transition” has come alive, aiming to transition our world from being completely fossil fuel dependent to being clean energy dependent. This is highlighted by Wang et al (2025) in their paper studying the role that AI could play in the energy transition. AI is emerging as a powerful tool to aid in the costly and difficult transition away from fossil fuels, providing crucial technologies that can serve as the foundation for this transition to happen efficiently (Wang et al, 2025). Many of the barriers surrounding the transition include cost and reliability issues with renewable energy, such as wind and solar. These renewable energy sources are limited by storage constraints, power grid issues, expensive build costs, and unpredictable weather patterns. AI is able to assist with many of these issues because of its algorithmic prediction capabilities. AI is also able to provide aid in grid stability, smart grid integration, energy efficiency, and deployment of renewable energy technologies (Wang et al, 2025). This research also highlights how large language models serve as the efficient, problem, solving technology that allows for this energy transition to happen as smoothly and quickly as possible.

Chapter 4 Renewable Energy Systems

AI is being used in renewable energy industries such as hydropower and solar power to improve supply and demand forecasting and improve the reliability of green energy. Jiang et al. (2021) explored the use of AI technology in the fields of solar and hydropower generation as well as supply and demand management control. They explored recent advances in AI technology in the energy industry. The authors found that AI outperforms traditional models in controllability, big data handling, cyberattack prevention, smart grid optimization, energy efficiency, predictive maintenance, and computational efficiency. These effects shown in the research conclude that AI is crucial to the energy industry and market because of its ability to enhance operation efficiency and performance of renewable energy systems.

Similarly, Sozontov et al. explored how artificial intelligence could benefit renewable systems through weather forecasting. Solar and wind energy can greatly benefit from artificial intelligence algorithms, which are compared with weather data to predict the production of these renewable energy stations. Being able to predict the output of these stations overall increases efficiency and can help optimize energy consumption. Sozontov et al. (2019) highlight the use of artificial intelligence neural networks by the British company Deep Mind Technologies Ltd, which were able to reduce energy consumption by 40% for the company through the optimization provided by artificial intelligence. Additionally, the researchers found that General Motor’s use of artificial intelligence algorithms increased the efficiency of their wind turbines by 5% and reduced maintenance costs by 20%. These statistics show reduced energy consumption and improved efficiency within renewable energy systems, shining light on the many potential benefits that artificial intelligence can have when integrated into energy systems.

Chapter 5 Nuclear Energy

Nuclear power plants are an energy source that face much risk and danger due to their complex integration system of machines and operators. Zhong et al (2022) explores this topic in their paper on AI applications in nuclear energy. They highlight that while nuclear energy digitalization has been attempted, it still uses a lot of traditional control and operation methods that can often be dangerous for operators. AI is now being explored for use in nuclear power software development, automatic control, health management, reactor design optimization, and nuclear safety management (Zhong et al, 2022). A specific example is a neural network-based data-driven model to predict the bubble departure diameter in subcooling boiling flow. Integrating AI into nuclear energy shows a promising path for safer and more reliable generation, as highlighted in the piece by Zhong et al.

Another source by Nassar et al (2025) explores the integration using AI of nuclear-hybrid renewable energy systems used for electricity distribution networks. The author highlights how smaller nuclear power plants show promise as viable renewable energy alternatives for clean electricity. By using AI to increase the demand forecasting of the electrical grid, smaller nuclear generators could be used more heavily to power the grid, reducing both costs and GHG emissions (Zhong et al, 2025). These studies highlight how AI use is being researched in all sectors of energy, and its usefulness also expands into the oil field.

Chapter 6 Electricity

A significant part of the electricity sector is load forecasting, where generators and utilities must try to determine the electricity demand for a given time period. When load, or demand, is incorrectly estimated, it can lead to mass outages and stress on the electricity grid. These outages have been outstanding problems for both consumers and producers, and many upgrades made to the power grid over the past few decades aim to increase reliability and decrease the change of outages and grid issues. In their paper studying AI models in the context of bulk energy consumption control, Ahmad et al (2019) focus on the use of AI over traditional data-mining and machine learning technologies for electricity management. Their study uses two AI techniques to help utilities plan decisions on generation, purchasing, infrastructure, and load switching in the power grid. The study found that two AI models were successful in bulk load demand forecasting, load planning, and grid management, and provided higher flexibility and accuracy in grid planning (Ahmad et al, 2019). These technologies are an example of the promising AI models that can help optimize energy utilization with higher flexibility to allow for grids to remain more stable and to prevent power outages. There are several examples of real-life implementations of AI in the electricity sector, and the next section will specifically focus on the California ISO.

In July 2025, the California ISO announced that they were going to be utilizing AI in their grid management system. They chose to utilize Open Access Technology International, which is a well-known provider of AI technology in the energy industry. The ISO cited that they intend to use large language models to aid in decision-making and management of the California electricity grid (California ISO, 2025). The main issue targeted by the new technology is processing and managing the thousands of maintenance requests put in by various facilities in the state every year. Because every single request must be reviewed and verified, the CAISO operators and engineers are often overwhelmed. With the new integration of AI, the maintenance review requests can be automatically processed and reviewed based on historical data and operating procedures that are taught to the AI model. This tool will allow for more efficient grid management that prevents outages, long maintenance request times, and overall improves grid efficiency. This integration is just the start of AI being widely used amongst the electricity grid. Other fossil fuel industries are more focused on troubleshooting transportation issues with AI, such as the natural gas industry.

Chapter 7 Fossil Fuels

Natural Gas

The natural gas industry's function and success is heavily reliant on the operations of natural gas pipelines. The pipeline systems of the U.S. span thousands of miles and are owned by hundreds of different companies. With so many regulations, tight scheduling deadlines, and weather impacts, pipeline issues are not uncommon in the industry and can be an issue for both producers and consumers. Awuku et al (2023) published a study focused on using AI to decrease the frequency of pipeline issues and to improve the system as a whole. The purpose of their research is to predict natural gas pipeline failures caused by natural forces by using climate change data and incorporating it into pipeline incident data (Awuku et al, 2023). They used records containing pipeline failure datasets to feed into the model, which produced predictions on whether the pipeline damage was caused by natural forces or by other issues. This AI model was able to produce a predictive accuracy 92.3% for pipeline damage caused by natural forces (Awuku et al, 2023). This result suggests AI as a solution for pipeline companies to manage their pipeline systems and avoid dangers and leaks caused by natural force damage, demonstrating the unique benefits that AI has to offer to the natural gas industry.

Another significant and emerging part of the natural gas industry is Liquefied Natural Gas (LNG). Worldwide demand for LNG is rapidly increasing, as countries turn to natural gas as a transition fuel towards renewables. As stated by Serrano et al (2019) in their study of AI use in LNG shipping, LNG is an emerging component being evaluated for use as fuel in large shipping because of its cleaner burning and reduced emissions qualities. The article highlights that currently, very few ships are using LNG as fuel, as there is much uncertainty about the consequences of making such a drastic change in fuel sources with shipping. Serrano et al (2019) wanted to help ease some of this uncertainty, and adopted AI use to help run scenarios of the most important variables and challenges that need to be resolved with LNG being used as a widespread fuel. Their AI algorithm identified that infrastructure factors and political resistance were amongst some of the largest barriers with transitioning to LNG as a shipping fuel (Serrano et al, 2023). By uniquely utilizing AI, the authors were able to help identify what is preventing LNG, a cleaner fuel, from being used for shipping. This is a fantastic example of AI's unique ability to help troubleshoot challenges and identify barriers in both the natural gas industry and the energy industry as a whole.

Crude Oil

Similar to natural gas, crude oil is a nonrenewable resource whose industry and market rely heavily on predictions of resource reserve lifespans. There is abundant technology and effort put into investigating the crude oil reserves thousands of feet below the surface. Soromotin et al (2025) focuses on a crucial rock characteristic in geologic oil formations: permeability. Permeability is one of the most important oil reservoir characteristics, as it affects oil production, well completion, and oil recovery methods. Soromotin et al (2025) decided to use various machine learning methods to create algorithms that would predict well permeability. The model that resulted from this study was able to predict well pressure recovery curves in real time during active well operation. This was able to reduce downtime associated with traditional well-testing procedures, and it led to a more cost-effective reservoir development system, showing the optimization that AI can provide to the oil industry (Soromotin et al, 2025).

Another author, Gunel et al (2025) researches the use of machine learning in estimating solids content of drilling fluid. Drilling fluid is a large part of crude oil extraction, and solids content is used as a parameter for the success of a drilling operation. Gunel et al (2025) used machine learning models to analyze drilling fluid contents from 130 wells around the world. The models were trained to recognize patterns and create algorithms for estimating solids content automatically. The end model was capable of automating the estimation of solids in fluid in real-time during drilling operations. Typically, standard solids analysis can take up to 2 hours on site, so this development is yet another example of the strong efficiency capabilities that AI has to offer to the energy industry (Gunel et al, 2025).

Chapter 8 Economic Effects of Artificial Intelligence in the Energy Industry

In addition to playing a role in the operations of energy systems, artificial intelligence plays an equally important role in the financial market. This application of artificial intelligence in finance is reviewed in an in-depth analysis by Professor Longbing Cao (2020). His analysis is a unique study on the effects of artificial intelligence on the financial market. Professor Cao focuses on the abilities of artificial intelligence to solve issues in the financial market in a more efficient way than humans could normally solve these issues. Some of the areas of finance where AI could be implemented include modeling economic-financial mechanisms, financial market analysis and forecasting, and smart markets operated by artificial intelligence. One of the most notable of these abilities is modeling economic-financial mechanisms, which Longbing Cao (2020) explains as modeling a real market ecosystem and being able to predict hypothetical prices, trading interactions, and the effect of different environmental factors on the financial market. The importance of being able to simulate the effects of these economic factors on the financial market lies in the accurate prediction of future economic trends, which can help keep the market stable and avoid sudden changes that could affect large sums of consumers and producers. Furthermore, the ability of artificial intelligence to predict market movements benefits consumers by helping them to make better energy consumption decisions and aid them in deciphering what all goes into the prices that they receive on their energy bills.

In the energy market, the ability to simulate future trends is extremely important, as the energy market can be extremely vulnerable to rapid changes from weather conditions, geo-political factors, domestic and international economies, and demand factors. The more AI can accurately predict changes to these factors, the more stable the financial market can remain.

Professor Cao's analysis of these uses for AI in the financial market proves to be a very detailed and potentially valuable source for the future integration of AI into the financial energy market.

Economic Benefits of AI for Energy Companies

While Professor Cao's analysis of AI in the energy market focuses mainly on the benefits for consumers in the market, Lei et al. focus on the potential benefits of AI use for firms in the energy market. The authors highlight how AI can help traditional energy companies keep up with the current energy trends through economic resilience predictions. Economic resilience, which is the ability of companies to remain financially stable under sudden changes in the economic state of the industry, is extremely crucial to firm development. Companies are more hesitant to develop and evolve if they are unsure of their ability to survive a constantly changing market environment. Lei et al. (2023) constructed a new prediction model based on support vector machine technology utilizing artificial intelligence. The authors concluded that this prediction model, and other potential models using artificial intelligence, can be highly effective for producers to improve their economic analysis and prediction of their firm's development. When these companies invest in digital transformation through the incorporation of AI, they enhance their ability to deal with economic development disturbances both internally and externally. This ability to deal with these setbacks and disturbances allows for economic resilience and gives the companies a chance to sustain development over a long period of time.

Some examples of solutions to possible disturbances that come with development include improving customer service, operating efficiency, and collaboration with the energy market. AI can point out the weaknesses in these areas within a company and allow the company to fix these issues during periods of development, ultimately leading to economic growth. One of the most common reasons for energy firms' hesitating to switch to new, renewable systems is the potential financial burden and instability that they could face during the transition. When companies have an enhanced ability to keep their economic growth stable during development, they are more likely to integrate these new renewable energy systems that will reduce carbon emissions and are therefore much better for the environment. The research and data from Lei et al. can be a very powerful tool for communicating the benefits of investing in AI to energy producers and encouraging them to consider implementing AI into their economic analysis processes.

Economic Analysis

While the implementation of artificial intelligence into the energy industry proves to have many benefits for the industry, it is important to also consider the economic impacts of widespread AI integration. The integration of new technologies, specifically AI, is an expensive transition for energy companies to make. Many traditional energy companies may be hesitant to integrate AI into their systems, as it may require a budget of millions of dollars to successfully complete. Furthermore, AI being integrated into the entire industry as a whole can have drastic effects on the energy market and prices. Using the economic analysis methods that I learned in this course, I will analyze these effects of AI integration for both consumers and producers in the energy market, and what they mean for the long-term economic state of the energy industry.

Market Demand & Supply

In the economic model for a market economy, it is important to consider the different roles that both consumers and producers play in the market. In the energy market, consumers are the end users of energy produced by firms. Consumers rely on their energy supply being reliable, and producers need efficient energy systems in order to meet the varying demands of consumers. Consumer demand in the energy market is affected by many different factors, including weather, energy policy, and consumer preferences. The energy market prices are determined based on the quantities of energy demanded by consumers, and prices can fluctuate heavily with unforeseen demand falls or spikes. It can be very difficult to predict these periods of significantly increased or decreased demand, which highlights the importance of AI integration. Artificial intelligence has the ability to simulate real-world scenarios and how they would affect the energy market. Furthermore, AI can use its rapid data processing abilities to predict when market-altering events will happen. Using weather data and economic forecasting, AI can predict periods of very high or low demand. Predictions like these can help prevent market failures and unforeseen price spikes. This overall improvement in market stability makes a strong case for why AI should be utilized more in the energy industry.

While AI proves to have much potential for improving the state of the energy market, it is equally important to analyze how the process of AI integration itself can affect market supply and demand. New technology integration and policies can be very expensive and can affect the development of energy companies. When an energy company invests in new AI applications in their systems, the company may have to temporarily raise budgets for technology and allocate more capital into AI integration. This temporary increase in costs for energy companies could reduce net profits, however having AI can give companies market advantages that make the investment well worth the money in the long run. Furthermore, companies using AI could also help to lower energy prices for consumers as the companies' efficiency increases. Lower energy prices from AI use would also increase energy demand for consumers, and these consequences of AI are important to consider when evaluating the market effects of AI integration.

Market Equilibrium

With the changes in market supply and demand that are caused by AI in the energy market come changes in market equilibrium. Shifts in supply and demand curves caused by factors such as new technology also cause shift in the market equilibrium. Market equilibrium is the set of the price and quantity values at the intersection point of the supply and demand curves. At equilibrium the market is stable, and the levels of equilibrium price and output will not change with market disturbances. When the point of equilibrium is shifted due to shifts in supply and demand, the price and quantities needed for a stable market will increase or decrease. When applied to the scenario of AI use increasing in the energy market, the change in market equilibrium can be analyzed by the shift of the demand curve. For example, if AI predictions of the future state of the market indicate that the market will become weak in the future, this expectation of the state of the market may cause consumers to exit the energy market and sell their shares. This demand decrease would cause the demand curve to shift left, therefore decreasing the equilibrium price and quantity.

Another example of AI integration affecting the market equilibrium is the renewable energy sector. AI is known for its forecasting abilities and its ability to predict future weather patterns. These predictions allow for energy producers to determine if the weather conditions will allow for renewable energy production to be efficient. Solar and wind power rely heavily on specific weather conditions to produce a valuable amount of output. Since renewables are expensive build and have high capital costs, they must have conditions for a sufficient projected output to be operated. AI can help predict these periods of sufficient production. If the AI technology for a solar panel system determined that there wouldn't be enough sunlight to operate the panels for a long time, the energy firm may choose not to produce solar energy at all for that period. This sudden decrease in energy supply would shift the supply curve left, therefore decreasing the equilibrium price and quantity. Overall, these examples show how the forecasting abilities of AI can shift supply and demand curves, therefore shifting market equilibrium in the energy industry.

Government Intervention in the Energy Market

The energy market, while not a perfectly competitive market, is a market where many different firms have the chance to compete for consumers. In the energy market, consumers have the opportunity to choose energy providers that best fit their needs. This creates competition amongst firms, especially as more and more consumers are beginning to take sustainable and green energy into consideration. Consumers who care more about reducing their carbon footprint will choose suppliers that are more sustainable and use more renewable energy types. The turnover of traditional energy companies producing non-renewables to producing more renewables has been significantly influenced by government intervention in the market. Renewable energy production is much more expensive than traditional fossil fuel energy production, and artificial intelligence is one of the technologies that has allowed these companies to produce more renewable energy more efficiently. With growing demands for more powerful data systems to manage advanced renewable energy grids, the energy industry has harnessed the benefits of AI technology to help increase renewable energy production. However, the integration of AI proves to be very expensive for energy companies, so government intervention can play a significant role in incentivizing the production of renewable energy for energy companies. There are several types of intervention that the government can use to try to get more firms to produce renewable energy and to try to get producers to consume more renewable energy over non-renewable energy sources, many of which have been utilized in the more recent years in the rapidly growing industry.

One of the most significant strategies of government intervention in the energy industry is subsidies. Subsidies are a price instrument implemented on a type of commodity by the government. Since 2020, governments worldwide have allocated 1.34 trillion towards the renewable energy industry. According to the EIA (2023), in 2022 alone, about half of the government's energy subsidies were allocated to the renewable energy industry, resulting in $15.6 billion in subsidies for renewable energy producers. With these subsidies, the government's goal is to increase the quantity of renewable energy demanded and to increase the quantity supplied, therefore allowing the price of renewable energy to be less expensive for producers and consumers. This price decrease allows for companies to integrate the necessary systems to produce renewable energy, like artificial intelligence and machine learning systems. When they are able to integrate renewable systems and technologies with less financial ramifications, energy companies are more likely to switch to green energy. Additionally, when consumers can switch to consuming renewable energy at a lower cost, they are more likely to consume sustainable energy and therefore decrease their carbon footprint. These reasons are why governments introduce renewable energy subsidies into the energy industry, and these subsidies can be very effective for promoting the use of renewable energy and decreasing a country's carbon footprint.

Externalities

In the energy market, externalities exist with the cost of producing energy. Externalities fall under a class of market failures where a market is incomplete. Externalities exist in a market whenever an individual or a firm takes an action that impacts another individual or firm and they are not compensated, and the firm or individual that took the action does not pay. In the energy industry, a main type of externality is pollution, which is a negative production externality. Pollution is an externality because we do not have a market for pollution. One way to fix the issues of missing a market for negative energy production externalities in the energy industry is to either assign a price to the externality through tax, or to create a cap and trade system that limits emissions of energy companies. Because the externality of emissions is caused mainly by the fossil fuel energy industry, another way of reducing this externality of by reducing fossil fuel energy production. With a higher tax on fossil fuel emissions from production and more subsidy for renewable energy production, the government can help to reduce the emissions externality. This transition to more renewable energy would require more advanced technology like AI. However, it is important to consider that the increased integration of AI in the energy market could create another externality in itself.

One of the main concerns of AI use is that it can take away jobs from the energy industry by automating processes that used to be done with human labor. Therefore, if there is more widespread integration of AI into the energy industry with the global transition towards green energy, a large number of jobs could be taken out of the market. This could be considered a pecuniary externality, which is a spillover effect caused by market forces due to AI integration. The integration of AI could create a shock in labor markets, creating high numbers of unemployment. This shock in the market is considered a negative production externality from AI integration. This means that the energy industry would externalize increased unemployment through the widespread use of AI in energy systems. However, on the other hand, the production efficiency gained by companies using AI could offset the effects of this externality. Additionally, with the creation of negative externalities from AI comes the creation of positive externalities from using AI in energy systems. An example of a positive externality from AI integration in the energy industry is increased efficiency. This is a positive externality because AI integration can reduce the costs of producing energy, and it can aid in effective resource allocation. It is important to consider both types of externalities that come with integrating AI into the energy industry, as AI can have both positive and negative effects on an industry.

Chapter 9 Challenges, Risks, and Future Outlooks

After analyzing the economic effects of artificial intelligence use in the energy industry, it is important to consider the future of AI integration. Many of the ways that AI could be potentially integrated into the energy industry revolve around improving the sustainability of energy production and consumption in order to overall reduce the energy industry's carbon footprint. AI has rapid data processing abilities that can help energy systems process complex data in an efficient way. This feature of AI can be used to regulate and monitor carbon emissions of energy systems. AI can collect and analyze the data from power plants and industrial facilities to track emissions and help to develop carbon emission reduction strategies. Another use for AI in the industry is aiding in renewable energy integration. By forecasting solar and wind generation, AI can help coordinate the dispatch of renewable energy systems to help optimize renewable energy generation. The optimization of renewable energy production can help to reduce the price of renewables for both producers and consumers, incentivizing the use of clean energy. These potential uses all contribute to the reduction of emissions from the energy industry.

AI can also assist in improving consumer experience in the energy industry. An example of this is artificial intelligence's ability to forecast demand. AI can use data processing to predict period of high and low demand, therefore allowing prices to remain more stable for consumers and helping to prevent price spikes in the energy market. Another way AI could help keep prices stable is by helping the market to respond to demand more efficiently. AI can adjust energy consumption automatically in response to changes in energy prices, helping to balance supply and demand.

Another significant contribution that AI can make to the energy industry is aiding in energy production for firms. An example of a potential way that a firm could utilize AI is to help with grid and cybersecurity. AI algorithms, when implemented into an energy system, could detect and respond to cyber threats and breaches to energy infrastructure. This can help to ensure stability and reliability of energy systems for firms. Furthermore, in the fossil fuels industry, AI can help producers optimize their exploration processes and production by optimizing drilling, analyzing geological data, and detecting problems with equipment. These uses for AI are just a few of the many ways that AI can be integrated into the energy industry in the future, and there are many more uses that could be discovered with more research and data on AI.

Trusting AI

One of the greatest challenges with widespread use of AI in the energy industry is its reliability. Many energy leaders and operators remain skeptical of AI. In a publication by Siemens (2020), a large German technology empire, the opinions of energy leaders on AI were gathered. 117 senior energy industry leaders were asked to imagine their company installed a new AI model called Maintain-AI. The model assesses machinery and determines if improvements can be made to increase efficiency. In this scenario, the model evaluated the machinery at the company and suggested high-cost refurbishment. The participants were then told that the head of operations rejects the AI model’s suggestions, insisting the equipment is as efficient as it can be (Siemens, 2020). The 117 professionals were asked to evaluate this scenario and choose if they would side with the AI or the head of operations (Siemens, 2020). About half the participants chose to side with the head of operations, showing a clear discrepancy in the trust of the AI model. The participants were then informed that the AI model was proven to outperform the organization's strongest leaders, however 44% still chose to side against the AI (Siemens, 2020). This represents the bias towards AI faced by almost half the population, and this bias can be a significant barrier in the progression of companies through AI use. However, as AI is slowly integrated into more and more energy companies, there is potential for this bias to be eliminated through proof of AI making the industry safer, more reliable, and more efficient.

AI Energy Usage

One of the main issues with general AI use is the intense energy consumption that comes with powering AI. Much of this energy consumption is attributed to data centers, the massive storage facilities for AI data, information, and models. Mahmut Kandemir (2025) published an article highlighting this energy use. The author states that data centers consumed 4.4% of U.S. electricity in 2023, and that number could triple by 2028 (Kandemir et al, 2023). This is a growing concern because as the use of large language models grows with the changing needs for AI functions, the energy consumption is only going to increase. Large language models require significant computational power because of the training they must undergo before they are functional (Kandemir et al, 2023). The training materials for these such as graphics processing units (GPUs) lead to high levels of electronic waste, and rapid consumption of rare earth minerals for the building of GPUs. The energy usage from AI is not sustainable without mitigation techniques, especially because it will only keep growing.

To help mitigate the effects of AI usage, a lab at Penn State University created an AI-powered cooling startup to boost data center efficiency. Katie Defiore (2025) highlights this startup and how it can help data centers reduce power use: “NexDCCool Technologies is developing a platform powered by AI that aims to optimize the cooling system in data centers, helping to maximize IT capacity by reducing cooling demand.”

Another team of researchers at the university is also aiming to make AI-powered systems more efficient, as highlighted by Mallorie Mcllwain (2025). The team is using a selective learning approach where only necessary data is collected for a specific problem. By applying this approach to AI, the systems can become more efficient and avoid unnecessary power use from computation that is not necessary (Mcllwain, 2025).

These projects are examples of the vast research that is going on to help reduce the impact and power use from AI. By trying to mitigate the effects of AI, these researchers allow for more widespread and efficient usage of AI that is sustainable over time, and eventually these data center consumption issues could be resolved.

Chapter 10 Conclusion

In a world of rapidly advancing technology, it's important for industries like energy to adapt and harness systems like artificial intelligence to keep up with the changes brought by technological evolution. Throughout all of the research reviewed on artificial intelligence in the energy industry for this thesis, there is recurring theme that shows promise for the future of the energy industry with the growing integration of AI. While, like any new upgrades to a system, the integration of AI has its challenges, the benefits that it reaps make its integration well worth it. Drastically improving efficiency, stability, and reliability of energy systems, AI improves the energy industry for both energy consumers and producers. Furthermore, it helps the energy market remain efficient, preventing price spikes and allowing one of the most influential financial markets in the world to remain stable and beneficial for traders and firms. As more focus is put into studying the consequences of AI, the more it can be used to benefit society and the planet.

Future Research Directions

There is still so much more research that can be done on artificial intelligence and the many different areas in which it can be applied, and this broad field of study allows for many more exciting discoveries about AI to come in the future. As more data becomes available over time for systems that recently integrated AI, more research can be conducted to study the effects of AI. Furthermore, as more and more traditional energy companies incorporate AI into their systems, the overall change in the state of the energy market can be studied to determine the economic benefits or ramifications of AI. Additionally, it is predicted that AI integration will lead to increased use of renewable energy. The effect of this market turnover caused by AI on global carbon emissions can be studied to determine if AI integration is a big step towards more sustainable energy consumption and a smaller carbon footprint. Sustainability is the future of our planet, and artificial intelligence has the potential to play a major role in our ability to live sustainably. Therefore, because of its many potential benefits, artificial intelligence deserves to be studied and researched more.

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