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Artificial Intelligence in the Power Sector

By Baloko Makala and Tonci Bakovic

The energy sector worldwide faces growing challenges related to rising demand, efficiency, changing supply and demand patterns, and a lack of analytics needed for optimal management. These challenges are more acute in emerging market nations. Efficiency issues are particularly problematic, as the prevalence of informal connections to the power grid means a large amount of power is neither measured nor billed, resulting in losses as well as greater CO_2 emissions, as consumers have little incentive to rationally use energy they don't pay for. The power sector in developed nations has already begun to use artificial intelligence and related technologies that allow for communication between smart grids, smart meters, and Internet of Things devices. These technologies can help improve power management, efficiency, and transparency, and increase the use of renewable energy sources.

The use of AI in the power sector is now reaching emerging markets, where it may have a critical impact, as clean, cheap, and reliable energy is essential to development. The challenges can be addressed over time by transferring knowledge of the power sector to AI software companies. When designed carefully, AI systems can be particularly useful in the automation of routine and structured tasks, leaving humans to grapple with the power challenges of tomorrow.

Access to energy is at the very heart of development. Therefore, a lack of energy access—which is the reality for one billion people, mostly in Sub-Saharan Africa and South Asia—is a fundamental impediment to progress, one that has an impact on health, education, food security, gender equality, livelihoods, and poverty reduction.

Universal access to affordable, reliable, and sustainable modern energy is one of the Sustainable Development Goals (SDGs). Yet it will remain just that—a goal—unless innovative solutions and modern technologies can overcome the many energy-related obstacles that plague emerging markets, from a lack of sufficient power generation, to poor transmission and distribution infrastructure, to affordability and climate concerns. In addition, the diversification and decentralization of energy production, along with the advent of new technologies and changing demand patterns, create complex challenges for power generation, transmission, distribution, and consumption in all nations.

Artificial intelligence, or AI, has the potential to cut energy waste, lower energy costs, and facilitate and accelerate the use of clean renewable energy sources in power grids worldwide. AI can also improve the planning, operation, and control of power systems. Thus, AI technologies are closely tied to the ability to provide clean and cheap energy that is essential to development.

For the purposes of this note, we follow the definitions and descriptions of basic, advanced, and autonomous artificial intelligence that were put forward in EM Compass Note 69.[1]

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AI refers to the science and engineering of making machines intelligent, especially intelligent computer programs. AI in this note is a series of approaches, methods, and technologies that display intelligent behavior by analyzing their environments and taking actions—with some degree of autonomy—to achieve specific targets in energy.

Toward a Smart Power Sector

The power sector has a promising future with the advent of solutions such as AI-managed smart grids. These are electrical grids that allow two-way communication between utilities and consumers.[2] Smart grids are embedded with an information layer that allows communication between its various components so they can better respond to quick changes in energy demand or urgent situations. This information layer, created through widespread installation of smart meters and sensors, allows for data collection, storage, and analysis.[3]

Phasor measurement units (PMUs), or synchrophasors, are another essential element of the modern smart grid. They enable real-time measurement and alignment of data from multiple remote points across the grid. This creates a current, precise, and integrated view of the entire power system, facilitating better grid management.

Paired with powerful data analytics, these smart-grid elements have helped improve the reliability, security, and efficiency of electricity transmission and distribution networks.[4,5] Given the large volume and diverse structures of such data, AI techniques such as machine learning are best suited for their analysis and use.[6] This data analysis can be used for a variety of purposes, including fault detection, predictive maintenance, power quality monitoring, and renewable energy forecasting.[7]

Innovation in information and communications technologies (ICT), cloud computing, big-data analytics, and artificial intelligence have supported the proliferation of smart metering. The widespread use of smart meters and advanced sensor technology has created huge amounts of data that is generated rapidly. This data requires new methods for storage, transfer, and analysis. For illustration sake, with a sampling rate of four times per hour, one million smart meters installed in a smart grid would generate over 35 billion records.[8]

The use of smart grids in EM countries lags advanced economies, but several EM countries have taken steps to adopt them, with various level of development. These include Brazil, China, Gulf Cooperation Council (GCC) countries, Malaysia, South Africa, Thailand, and Vietnam among others.

Deep learning techniques, a subset of machine learning, can help discern patterns and anomalies across very large datasets—both on the power demand and power supply sides—that otherwise would be nearly impossible to achieve. This has resulted in improved systems, faster problem solving, and better performance.

Advanced economies are leading the way in the application of AI in the power sector. For example, DeepMind, a subsidiary of Google, has been applying machine learning algorithms to 700 megawatts of wind power in the central United States to predict power output 36 hours ahead of actual generation using neural networks trained on weather forecasts and historical wind turbine data.[9]

Deep learning algorithms are also able to learn on their own. When applied to energy data patterns, the algorithms learn by trial and error. For example, in Norway, Agder Energi partnered with the University of Agder to develop an algorithm to optimize water usage in hydropower plants.[10] Water may appear to be a seemingly endless source of energy, however only a limited amount of it is available to produce hydroelectricity, so it must be used optimally.

In Canada, Sentient Energy, a leading provider of advanced grid monitoring and analytics solutions to electric utilities, was selected in 2017 to support power and natural gas utility Manitoba Hydro. Its *Worst Feeder Program* initiative is anticipated to allow Manitoba Hydro to speed up system fault identification and restore power to customers faster at the most critical points on its distribution grid.[11]

AI can also help with prediction issues in hydroelectricity production. In general, most countries do have reliable hydrology data collected over a 40 years period, and in some cases, longer, that facilitates the prediction of hydrology using proven stochastic dual dynamic programing tools. However, in the past year climate change has disrupted such predictions. Currently, the mathematical models underlying the operation of power production are approximately 30 years old and are generally incompatible with the current realities of the hydro power sector.[12] The increasing uncertainty of parameters such as future precipitation levels or pricing are among the many challenges to optimizing production and profit.

AI-Business Models in Emerging Markets

According to a November 2019 International Energy Agency (IEA) report, some 860 million people around the world lack access to electricity.[13] Around three billion people cook and heat their homes using open fires and simple stoves fueled by kerosene, biomass, or coal.[14] Over four million people die prematurely of illnesses associated with household air pollution. For these reasons, the provision of energy goes beyond mere power supply: It is critical to human health and safety.[15] Renewables will play an important role in increasing access to electricity, one of the United Nations Sustainable Development Goals (SDGs). According to World Bank data, the global electrification rate stood at 88.9 percent in 2017.[16] In terms of sustainability, while the share of energy from renewable sources (including hydroelectric sources) rose from 16.6 percent in 2010 to 17.5 percent in 2016[17], these sources of power have yet to be widely adopted. This is partly because renewables present a particular challenge to the power grid due to their intermittency and difficulty to plan for in real-time. AI tools' speed, robustness, and relative insensitivity to noisy or missing data can address this by improving the planning, operation, and control of the power system. In doing so, AI can facilitate the integration of renewable energy into power systems to create hybrid low-carbon energy systems.[18] Thus the shift to renewables can occur at a much faster rate with the use of AI.[19]

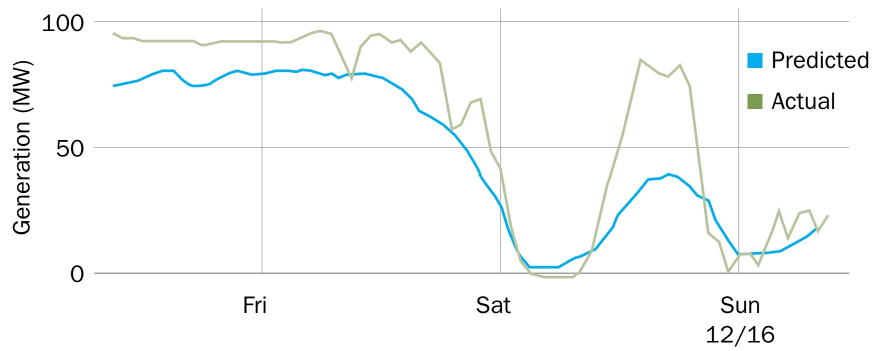

FIGURE 1 Example of DeepMind Predictions vs Actual in December 2018

The DeepMind System predicts energy output 36 hours ahead using neural networks, and recommends how to create optimal commitment on the grid. Source: Witherspoon, Sims and Will Fadrhonc. 2019. "Machine Learning Can Boost the Value of Wind Energy."

India, in particular, has been recognized for its efforts to expand renewable energy production. Currently, India has an installed capacity of 75GW from various renewable energy sources (wind, solar, etc.), and it has a target of 175GW from renewable sources by 2022.[20] Despite regulatory efforts aimed at incentivizing clean energy investments, the diffusion and expansion of renewable energy remains a challenge. AI is being considered as a potential solution to boost renewable energy adoption.[21]

BOX 1 Anti-Theft Technology in Brazil

Ampla, an electric power distribution subsidiary of Brazil's Enel Group, an IFC client, operates in 66 municipalities of the State of Rio de Janeiro and serves nearly seven million inhabitants and 2.5 million customers. It is one of the largest power distributors in Brazil, responsible for 2.5 percent of the nation's energy turnover and 27.8 percent of the state's. It serves an area of 32,608 square kilometers, some 73.3 percent of the state territory. The Ampla market has a residential profile, with 80 percent of its clients in low-density, high-complexity areas.

Ampla has long been plagued by loss of power due to fraud and theft, with more than half of it concentrated in five municipalities, all of which are populous favelas with high rates of urban violence and drug trafficking. The high rate of non-technical losses (i.e., via theft) damages the quality of Ampla's services, the safety of the population, and also pushes national energy production above levels needed by the market and the formal economy, causing waste.

To address these theft and power-loss issues, Ampla deployed an Anti-Theft Machine Project for medium voltage customers. The system gathers all the elements of power use measurement through digital meters into a single device that connects to Ampla through a remote management system using cellular communication networks. The devices are intelligent modules with diverse functionalities, and once a day, they transmit accurate consumption information to Ampla for efficient remote management of supplies, disruptions, and reactivations. Artificial intelligence is used in the control center to identify unusual patterns relative to customer profiles located in similar areas. This data is also used to anticipate consumer behavior and predict which customers are likely to have informal connections to the power grid. This information can then be used to curb such connections and cut waste. Brazilian business magazine *Exame* named Ampla's anti-theft system one of the top ten innovations of the last decade in Brazilian industry.

The increasing expansion of intermittent wind and solar generation, together with variable electrical loads such as electric cars and buses, energy storage (batteries), and decentralized renewable power such as rooftop solar PV systems, will need a more stable grid or smart grid.

A smart grid is able to learn and adapt based on the load and amount of variable renewable energy flowing into the grid.

AI-Supported Models in Fragile and Low-Income Countries

New business models built on AI are emerging that target underserved geographical areas where access to electricity remains a daily challenge. For example, Power-Blox is a distributed energy system fitted with battery cubes that can store 1.2 kilowatt-hours of solar or wind energy, and a single unit can serve several people. This solution can be scaled to multiple units to power an entire village.

FlexGrid is another example that builds an off-grid solution for rural villages. The company secured a grant from Electrifi, a European funding body, to establish a testing site in a remote community in Southern Mali where more than 10,000 villages lack access to the electrical grid. Customers are charged a fixed rate in a tiered pricing structure, which is based on their ability to pay, and payments are made using a text-based system. Currently, Power-Blox is being integrated with Internet of Things (IoT) protocols to integrate remote control of the boxes.[22]

How Can AI Support Large Integration of Renewable Energy?

Excess solar or wind power is stored during low-demand times and used when energy demand is high. As a result, AI can improve reliability of solar and wind power by analyzing enormous amounts of meteorological data and using this information to make predictions and decisions about when to gather, store, and distribute wind or solar power. On the other hand, AI is also used in smart grids to help balance the grid. AI analyzes the grid before and after intermittent units are absorbed and learns from this to help reduce congestion and renewable energy curtailment.[23]

AI is also gaining ground in Latin America. Argentina has embarked on a modernization effort of its power grid infrastructure by investing in automation of power distribution, remote reading of energy meters across several cities, and the implementation of renewable energy generators.

In Baja California, IFC is helping CENACE (Centro Nacional de Control de Energía) model the effect of cloud coverage on solar generation to help balance the grid with batteries. The AI algorithms developed help the ISO react in seconds to provide primary regulation to stabilize the grid.

In much of Sub-Saharan Africa, access to home electricity remains a challenge. Africans spend as much as $17 billion a year on firewood and fuels such as kerosene to power primitive generators.[24] There are glimmers of hope, however. Azuri Technologies developed a pay-as-you-go smart-solar solution used in East Africa and Nigeria. Azuri's HomeSmart solution is built on AI. It learns home energy needs and adjusts power output accordingly—by automatically dimming lights, battery charging, and slowing fans, for example—to match the customer's typical daily requirements. The company recently secured $26 million in private equity investment to expand its solutions across Africa.[25]

AI Applications in the Power Sector

Fault prediction has been one of the major applications of artificial intelligence in the energy sector, along with real-time maintenance and identification of ideal maintenance schedules. In an industry where equipment failure is common, with potentially significant consequences, AI combined with appropriate sensors can be useful to monitor equipment and detect failures before they happen, thus saving resources, money, time, and lives.[26]

Geothermal energy, which yields steady energy output, is being discussed as a potential source of baseload power (the minimum amount of power needed to be supplied to the electrical grid at any given time) to support the expansion of less reliable renewables. Toshiba ESS has been conducting research on the use of IoT and AI to improve the efficiency and reliability of geothermal power plants.[27] For example, predictive diagnostics enabled by rich data are used to predict problems that could potentially shut down plants. Preventive measures such as chemical agent sprays to avoid turbine shutdowns are optimized (quantity, composition, and timing) using IoT and AI. Such innovations are important in a country like Japan, which has the third largest geothermal resources in the world, especially in the face of decreasing costs of competing renewable sources such as solar power.

Maintenance facilitated by image processing. The United Kingdom's National Grid has turned to drones to monitor wires and pylons that transmit electricity from power stations to homes and businesses. Equipped with high-resolution still and infrared cameras, these drones have been particularly useful in fault detection due to their ability to cover vast geographical areas and difficult terrain. They have been used to cover 7,200 miles of overhead lines across England and Wales. AI is then used to monitor the conditions of power assets and to determine when they need to be replaced or repaired.[28]

Energy Efficiency Decision Making. Smart devices such as Amazon Alexa, Google Home, and Google Nest enable customers to interact with their thermostats and other control systems to monitor their energy consumption. The digital transformation of home energy management and consumer appliances will allow automatic meters to use AI to optimize energy consumption and storage. For example, it can trigger appliances to be turned off when power is expensive or electricity to be stored via car and other batteries when power is cheap or solar rooftop energy is abundant. With population growth and urbanization in emerging markets and resulting expanding cities, artificial intelligence will play a pivotal role in this effort by using data—including grid data, smart meter data, weather data, and energy use information—to study and improve building performance, optimize resource consumption, and increase comfort and cost efficiency for residents.[29]

Furthermore, in deregulated markets such as the United States, where consumers can choose their energy providers, AI empowers consumers by allowing them to determine their provider based on their preferences of energy source, their household budget, or their consumption patterns. Researchers at Carnegie Mellon University have developed a machine learning system called Lumator that combines the customer's preferences and consumption data with information on the different tariff plans, limited-time promotional rates, and other product offers in order to provide recommendations for the most suitable electricity supply deal. As it becomes more familiar with the customer's habits, the system is programmed to automatically switch energy plans when better deals become available, all without interrupting supply.[30] Such solutions can also help increase the share of renewable energy by helping consumers convert their preference for renewables into realized demand for it, and can be used to signal to producers the level of consumer demand for renewable energy.

AI can help improve forecasts of electricity demand and generation, improving production decision making. This is particularly important in the transition toward renewables, as they are often inconsistent due to their dependence on weather, wind, and water flows, and their reliance on fossil fuels for backup. AI-based forecasts combined with energy storage infrastructure can reduce the need for such backup systems.[31]

Finally, the spread of distributed generation means that consumers will now contribute to power generation, effectively acting as producers (prosumers). As these prosumers become more important players in the system, AI will facilitate decision making about optimal times for distributed generation to contribute to the grid, rather than draw from it. AI can also assist traditional producers and system operators who will now have to balance increased intermittent renewables, distributed generation including prosumers, and new demand-side trends such as the increase in electric vehicles (EVs).

Disaster Recovery. When Hurricane Irma struck South Florida in 2017, it took 10 days to restore power and light, as opposed to the 18 days needed for the region to recover from a previous hurricane, Wilma. This time reduction was due to new technologies such as AI that can predict the availability of power and ensure it is delivered where it is most needed without negatively impacting the system. Furthermore, AI systems can improve assessments of damages and optimization of decision making thanks to faster access to imagery and information—within the first 12 to 24 hours—after the disaster has subsided.[32]

Prevention of Losses Due to Informal Connections. Losses due to informal connections constitute another challenge for the power sector. AI could be used to spot discrepancies in usage patterns, payment history, and other consumer data in order to detect these informal connections. Furthermore, when combined with automated meters, it can improve monitoring for them. It can also help optimize costly and time-consuming physical inspections. For example, Brazil, which has been suffering from a high rate of nontechnical losses that include informal connections and billing errors, has benefited from such solutions. Furthermore, the University of Luxembourg has developed an algorithm that analyzes information from electricity meters to detect abnormal usage. The algorithm managed to reveal problem cases at a higher rate than most other tools when applied to information over five years from 3.6 million Brazilian households. The technology is slated to be deployed across Latin America.[33]

Looking to the Future

While AI holds considerable potential to improve power generation, transmission, distribution, and consumption, the energy sector in both emerging markets and advanced economies continue to face multiple challenges in terms of efficiency, transparency, affordability, and the integration of renewable energy sources in power systems.

First, AI companies have expertise in math and computer science, but they often lack the knowledge needed to understand the specifics of power systems.[34] And this problem is more acute in emerging markets. While the potential applications of AI in the power sector are multiple and varied, there is a need to educate the AI industry more deeply on the aspects of the power sector. For example, cloud-based applications are widespread and central to AI solutions, but there are regulatory restrictions on their use in the power industry. This is changing, however, as the benefits of AI cloud applications become more evident.

Second, the reliance on cellular technologies limits AI's potential in rural and other underserved areas in many emerging markets, particularly low-income countries. Smart meters rely on constant data communication, so a lack of reliable connectivity is a substantial impediment in areas where cellular network coverage is sparse or limited.

Third, the digital transformation of the power grid has made it a target for hackers. The world's first successful attack of this kind happened in Ukraine in 2015, leaving thousands without power.[35] Successful cyberattacks on critical infrastructure can be as damaging as a natural disaster. The growing threat from hacking has become common and a matter of significant concern, particularly due to the fact that smart metering and automated control have come to represent close to 10 percent of global grid investments, equivalent to $30 billion a year dedicated to digital infrastructure.[36]

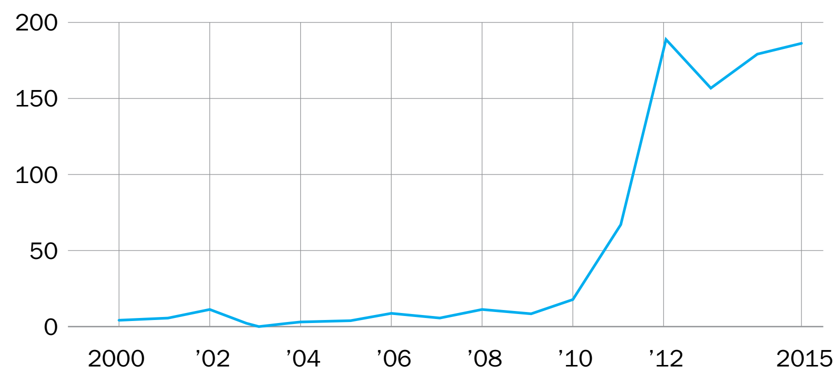

FIGURE 2 **Cyber Vulnerabilities**

Identified cyber vulnerabilities in industrial-control systems have spiked in recent years. Source: Kaspersky Labs. Fickling, David. 2019. "Cyberattacks Make Smart Grids Look Pretty Dumb." Bloomberg.com, June 17, 2019. https://www.bloomberg.com/opinion/articles/2019-06-17/argentina-blaming-hackers-for-outage-makes-smart-grids-look-dumb.

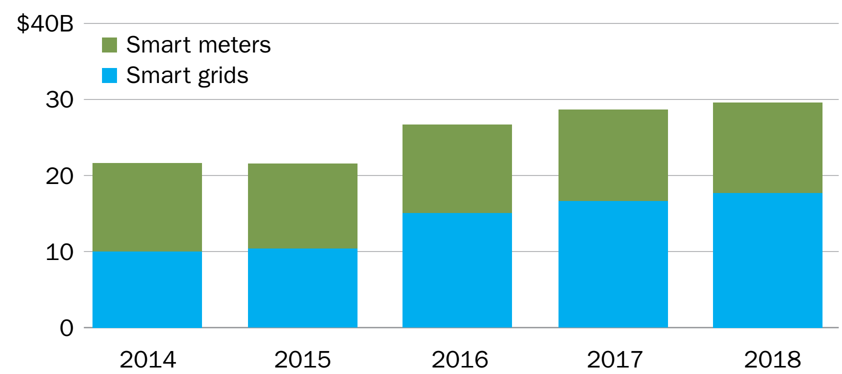

FIGURE 3 **Smart Grid Expenditure from 2014–2019 ($ billions)**

Source: International Energy Agency. Mahendra, Ravi. 2019. "AI is the New Electricity." Smart Energy International. May 11, 2019. https://www.smart-energy.com/industry-sectors/new-technology/ai-is-the-new-electricity.

Fourth, integrating different data sources and ensuring representativeness given the diversity within the data will be challenging. Other challenges may also arise as a result of a low volume of data for machine learning models to learn from. Contextualization and transfer of learning of two similar tasks could prove to be difficult. Furthermore, these models could be susceptible to inaccurate data. These challenges are being partly addressed through reinforcement learning.[37]

Fifth, AI-based models are essentially black boxes to their users, the majority of whom do not understand their inner workings nor how they were developed, which constitutes a security risk. And given that existing models are far from perfect, it is necessary to have safeguards in place when incorporating them into energy systems. When combined with better analytics, sensors, robotics, and IoT devices, AI can be used for automation of simple tasks, allowing humans to focus on the unstructured challenges.[38]

Sixth, there has been an imbalance in priorities and therefore, investments in smart meters compared to smart grids. As Figure 3 demonstrates, much of the attention has fallen on Smart meters. Smart meters are decision making tools for customer choice. Customers can decide when to turn their power on or off, or change their consumption habits, during peak times for example.

Smart grids, by contrast, are less about the consumer and more about making quick adjustments to ensure the electricity flows as efficiently as possible, for instance in case of disruption due to a faulty line, or imbalances brought along by variable renewable energy penetration.[39]

Finally, similar to other sectors that are increasingly applying AI technology, the power sector will need to address challenges such as governance, transparency, security, safety, privacy, employment, and economic impacts. AI is certain to play an important role in reducing distribution losses in emerging markets and in helping with maintenance and reliability issues. AI will also help with integration of intermittent renewables into the grid and will give operational autonomy to distributed energy resources and micro grids. Given the fact that AI innovation is being driven primarily by the private sector, IFC could play an important role in bringing AI to the power sectors of emerging markets.

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Please see the following additional reports and EM Compass Notes about technology and its role in emerging markets: *Reinventing Business Through Disruptive Technologies—Sector Trends and Investment Opportunities for Firms in Emerging Markets* (March 2019); *Blockchain: Opportunities for Private Enterprises in Emerging Markets* (January 2019); *Developing Artificial Intelligence Sustainably: Toward a Practical Code of Conduct for Disruptive Technologies* (Note 80, March 2020); *Accelerating Digital Connectivity Through Infrastructure Sharing* (Note 79, February 2020); *Artificial Intelligence and the Future for Smart Homes* (Note 78, February 2020); *Artificial Intelligence and 5G Mobile Technology Can Drive Investment Opportunities in Emerging Markets* (Note 76, December 2019); *How Artificial Intelligence is Making Transport Safer, Cleaner, More Reliable and Efficient in Emerging Markets* (Note 75, November 2019); *Bridging the Trust Gap: Blockchain's Potential to Restore Trust in Artificial Intelligence in Support of New Business Models* (Note 74, Oct 2019); *Artificial Intelligence: Investment Trends and Selected Industry Uses* (Note 71, Sept 2019); *The Role of Artificial Intelligence in Supporting Development in Emerging Markets* (Note 69, July 2019).

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