10. Future of artificial intelligence and energy demand

The close interrelationship between artificial intelligence (AI) and energy is at the centre of global attention. As a symbolic example, in recent years, the growth in the use of generative AI and digitalisation has triggered a major increase in the number of data centres, raising concerns that electricity supply facilities may fail to keep up with the pace of data centre construction in some places in the future.

There are also high expectations for AI to bring significant benefits to energy-use-related demand sectors. AI has the potential to transform energy use itself by improving productivity and saving energy in industry, transport and buildings. AI is expected to enable optimal plant operation by forecasting demand, improving productivity, and thereby enhancing the energy efficiency of plants. In the transport sector, AI will save energy through autonomous driving, namely by improving fuel efficiency through optimising the spacing between cars and route selection, and by shortening travel distances. For buildings, AI will save energy by optimising air-conditioning operations while maintaining comfort. In this way, the futures of AI and energy are closely interconnected.

This chapter provides an overview of the relationship between AI and energy, examines the energy savings potential of data centres, and assesses the current status and provides a future outlook, focusing on the role that AI can play in energy saving.

10.1 Relationship between AI and energy

Factors behind the soaring electricity consumption of data centres in recent years

AI is an area of computer science that refers to technologies for building machines and computers capable of simulating the cognitive functions associated with human intelligence. There are various types of AI, but when we focus on analytical techniques, they can be classified into 'rule-based AI', 'machine learning', 'deep learning' and 'generative AI'.

- **Rule-based AI**: AIs operate based on the rules given by humans.
- **Machine learning**: This is a method that enables computers to realise a mechanism equivalent to human learning. Based on a certain algorithm, the computer discovers patterns and rules from input data, and it applies these patterns to new data to identify and predict what they are.
- **Deep learning**: Machine learning performed using multi-layer artificial neural networks. An artificial neural network simulates the neural network of the human brain and enables higher accuracy than machine learning.
- **Generative AI**: Based on deep learning technology, generative AI generates new content using massive amounts of learning data.

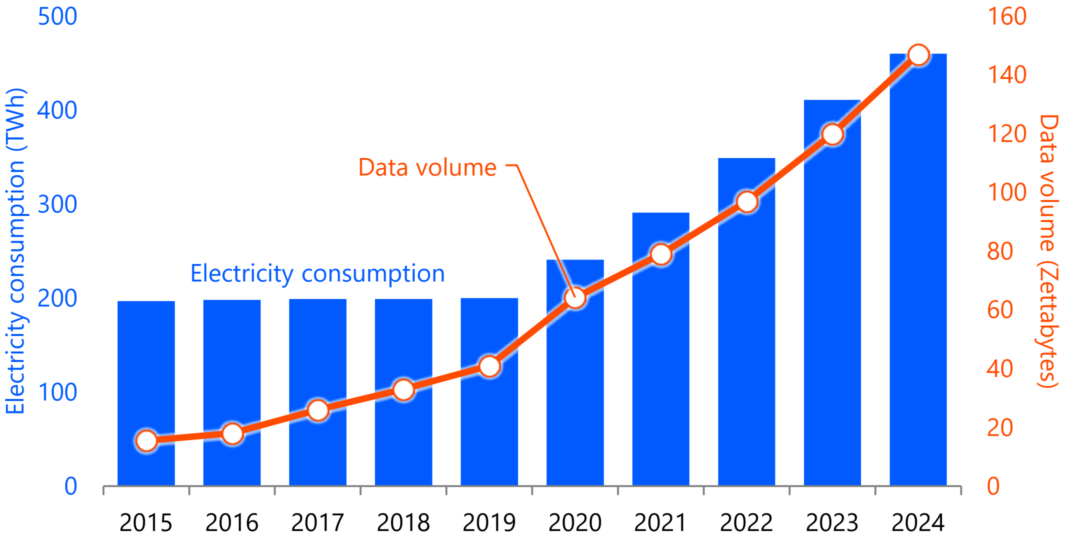
With the advent of generative AI in recent years, increases in data centres and their electricity consumption are raising the risk of local capacity constraints in transmission networks and electricity supply shortages at peak demand.

Currently, AI-related workload is estimated to account for 14% of the electricity consumption of data centres worldwide, cloud computing 54%, and conventional business-related workload from email and storage 32%[47]. AI uses significant amounts of electricity during the training and inference processes.

Meanwhile, if we look at the historical trends of data centres, electricity consumption remained mostly unchanged from 2015 through 2019, while the global data volume increased by a factor of 2.6 from 15.5 zettabytes. This was due to 1/ improved efficiency of servers, storage, networking, infrastructure and other devices; 2/ the transition from small-scale data centres to large-scale cloud and hyperscale data centres; and 3/ improved efficiency of the graphics processing unit (GPU) that processes images and videos.

However, global electricity consumption of data centres, which had previously remained stable, increased by 70% in the three years between 2020 and 2023. The factors behind it included the expansion in the use of generative AI and progress in digitalisation, the spread of remote work and workation during the pandemic, and the full-fledged development of the fifth-generation mobile communication system (5G) including in regions previously without coverage[48]. All these factors spread faster than improvements in the efficiency of data centre equipment and facilities.

Figure 10-1 | Global electricity consumption and data volume of data centres



Sources: Masanet et al. (2020), Cisco, International Energy Agency, Goldman Sachs Research

Improving the hardware and software efficiency of AI

In looking at the relationship between AI and energy, it is necessary to consider both the hardware and software aspects for future efficiency improvements. Specifically, 1/ the hardware aspects represent the performance of data centre information and communication technology (ICT) equipment that conducts computational tasks, and that of auxiliary facilities such as cooling; and 2/ the software aspects include differences in electricity consumption between computational methods and improvements in the efficiency of AI models.

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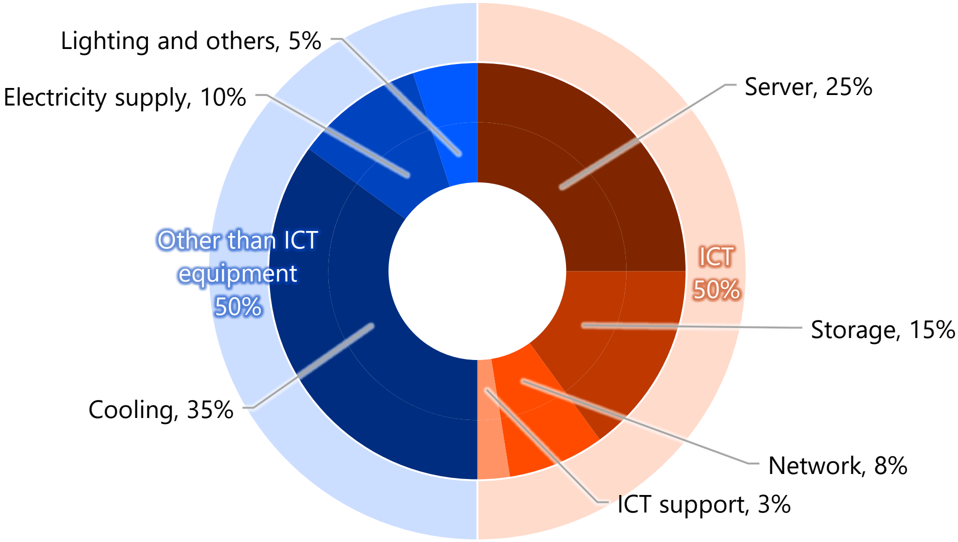
[47] https://www.goldmansachs.com/insights/articles/ai-to-drive-165-increase-in-data-center-power-demand-by-2030

[48] https://www.jaif.or.jp/en/news/7022#:~:text=Among%20other%20things%2C%20it%20showed,/%20floor%20area)%20as%20parameters

Data centre efficiency performance is often measured by power usage effectiveness (PUE). PUE is obtained by dividing the total electricity consumption of a data centre by the electricity consumption of its ICT equipment, and the energy efficiency is higher the closer the PUE is to 1. Data centre performance varies greatly depending on the scale, but the global average PUE is around 1.5. When PUE is 2, ICT equipment accounts for 50% of the total electricity consumption, followed by cooling, which accounts for around 35% (Figure 10-2). Often located near cities, data centres are experiencing rising ICT equipment density per rack for efficient land use. In some cases, efficiency is deteriorating due to operating air conditioners at full capacity to cool the heat emitted from ICT equipment.

Figure 10-2 | Breakdown of data centre electricity consumption (when PUE=2)



Source: Hongyu Zhu et. Al. (2023) "Future data center energy-conservation and emission-reduction technologies in the context of smart and low-carbon city construction. Sustainable Cities and Society" | VOL 89 | 2023 |

A generative AI system must conduct massive amounts of computation depending on the model (such as a large language model [LLM]) and data volume (several billion web pages). Learning is conducted over several weeks using supercomputers installed in data centres, sometimes with massive energy consumption.

According to an analysis of electricity demand for generative AI use by Dutch researcher Alex de Vries, ChatGPT may consume 564 MWh of electricity per day to operate. According to the analysis, if Google were to use AI to conduct about 9 billion searches a day, 29.2 TWh of electricity would be needed per year, which is equivalent to the annual electricity consumption of Ireland.

Meanwhile, the generative AI tool Gemini, which Google released in 2025, consumes just 0.24 Wh per prompt, which is almost the same as the electricity consumption of a common search. Considering that a generative AI search was said to be 10 times as electricity intensive as a common search, electricity savings have made rapid progress.

Table 10-1 | Relationship between data centres, AI and energy: present and future

		Present	Future
Hardware (data centre)	ICT equipment Server, storage and ICT auxiliary equipment	ICT equipment is the most electricity-intensive and accounts for 50% of the total data centre electricity consumption. Often located near cities, data centres are seeing rising ICT equipment density per rack for efficient land use. In some cases, efficiency is deteriorating due to putting air conditioners in full operation for cooling.	Optimise rack layout. Shift from company data centres to hyperscalers. Migrate to edge computing for some purposes. Optimal use of servers such as shifting from GPU to CPU. Improve the efficiency of integrated circuits and storage.
	Auxiliary facilities Cooling, backup electricity supplies, lighting, etc.	Cooling demand is rising as computation volume soars and ICT equipment density rises. Cooling-related electricity consumption accounts for around 35% of the total.	Improve efficiency by switching from air cooling to rear door cooling, liquid cooling and immersion cooling.
Software	Computation Generative AI, Data processing, Software	Computation by generative AI consumes 10 times as much electricity as common search operations. However, a search operation by the latest generative AI only consumes almost as much electricity as a common search operation.	Reduce energy demand per task through innovative algorithms. Models are ‘optimised in scale’ to match different tasks.

10.2 Efforts of tech firms

Hyperscalers that own many large-scale data centres necessary for using artificial intelligence (AI) are setting ambitious net-zero targets (Table 10-2). Among the efforts to reach those targets, all companies set energy efficiency improvements that directly affect operating costs as their priority and are implementing various unique initiatives.

Table 10-2 | Efforts of tech firms

Hyperscaler	Net-zero target	Efforts to achieve net-zero		
		Data centre efficiency improvement	Supply chain decarbonisation	Electricity source development and support, carbon dioxide removal (CDR)
Amazon (Amazon Web Services)	2040 (Amazon as a whole)	Improve power usage effectiveness (PUE) by introducing efficient cooling systems. Develop efficient semiconductor chips.	Use low-carbon construction materials (steel, concrete). Utilise low-carbon fuels (sustainable aviation fuels (SAFs), renewable diesel).	Invest in renewable energies; electricity purchase agreements (PPAs). PPAs with battery systems, actively utilise proprietary systems. Nuclear power generation PPAs, support for the development of small modular reactors (SMRs).
Microsoft (Microsoft Azure)	2030 (Microsoft as a whole; hourly matching)	Use of energy-saving operations such as standby mode. Develop advanced cooling technologies.	Use low-carbon construction materials (steel, concrete, wood, etc.) Utilise low-carbon fuels (SAFs, renewable diesel). Cooperation with suppliers (requiring the use of decarbonised electricity).	Invest in renewable energies; PPAs. Nuclear PPAs (including nuclear restarts). Provide support for implementing decarbonised energies using proprietary technologies.
Google (Google Cloud Platform)	2030 (Google as a whole; hourly matching)	Optimise cooling systems by utilising machine learning. DR through task shifting. Optimise data centre design.	Cooperation with suppliers (requiring the use of decarbonised electricity). Utilise low-carbon construction materials.	Invest in renewable energies; PPAs. Provide support for implementation of decarbonised energies using proprietary technologies.

Hyperscaler	Net-zero target	Efforts to achieve net-zero		
		Data centre efficiency improvement	Supply chain decarbonisation	Electricity source development and support, carbon dioxide removal (CDR)
Meta	2030	Monitor workload and optimise electricity profile. Highly energy-efficient hardware design. Improve cooling efficiency using outdoor air and direct evaporative cooling.	Cooperation with suppliers (aim to have at least two-thirds of all suppliers set emission targets by 2026). Utilise decarbonised fuels (SAFs, biofuels)	Invest in renewable energies and batteries; PPAs. Provide support for developing CDR technologies.

Efforts to achieve net-zero (cross-company efforts)
iMasons Climate Accord (ICA): a framework to decarbonise the digital infrastructure run by industrial group iMasons, which consists of digital infrastructure firms, mainly big tech firms.
Semiconductor Climate Consortium (SCC): a framework for decarbonising the semiconductor industry.
ZEROgrid: A framework consisting mainly of large-scale users to decarbonise electricity grids and improve their reliability.

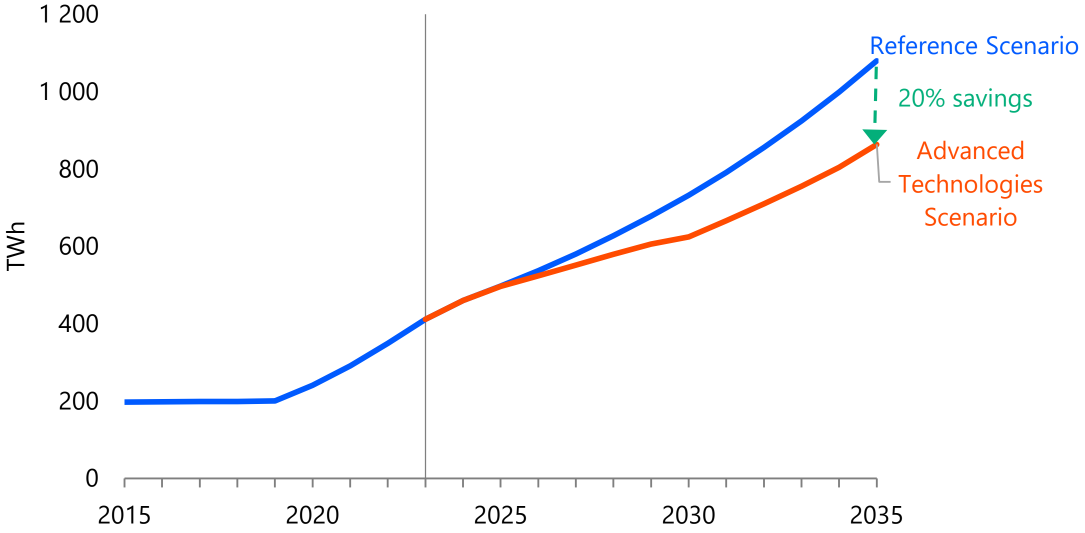
To lower the power usage effectiveness (PUE) by improving the efficiency of non-information and communication technology (ICT) equipment such as cooling systems and the facilities as a whole, efforts to raise operating temperatures to reduce the amount of necessary cooling are in progress, alongside efforts to improve cooling systems using innovative technologies and AI. Improvements in data centre efficiency through data centre design optimisation, strengthened workload monitoring, and AI utilisation are also underway. In addition, measures to improve data centre flexibility, such as task shifting, though not directly linked to improving the energy intensity, are receiving attention as they contribute to demand response (in which electricity consumption is adjusted depending on the balance between grid electricity supply and demand), and in turn help decarbonise the grid.

To improve the efficiency of central processing units (CPUs), graphics processing units (GPUs) and other ICT equipment that perform computations, alongside efforts such as offloading CPU computations and energy-saving operations such as a standby mode, big tech companies are developing their own AI-specific semiconductor chips, such as Amazon Web Services’ Trainium, Google’s TPU, Meta’s MTIA and Microsoft’s Maia 100.

10.3 Electricity demand and energy savings potential of data centres

Based on the Reference Scenario, the electricity demand of data centres worldwide will increase by 2.1 times from 497 TWh in 2025 to 1 080 TWh in 2035 (Figure 10-3). The amount of data will grow by 2.9 times from 230 zettabytes (ZB) to 660 ZB in the same period.

Figure 10-3 | Electricity demand and energy savings potential of data centres



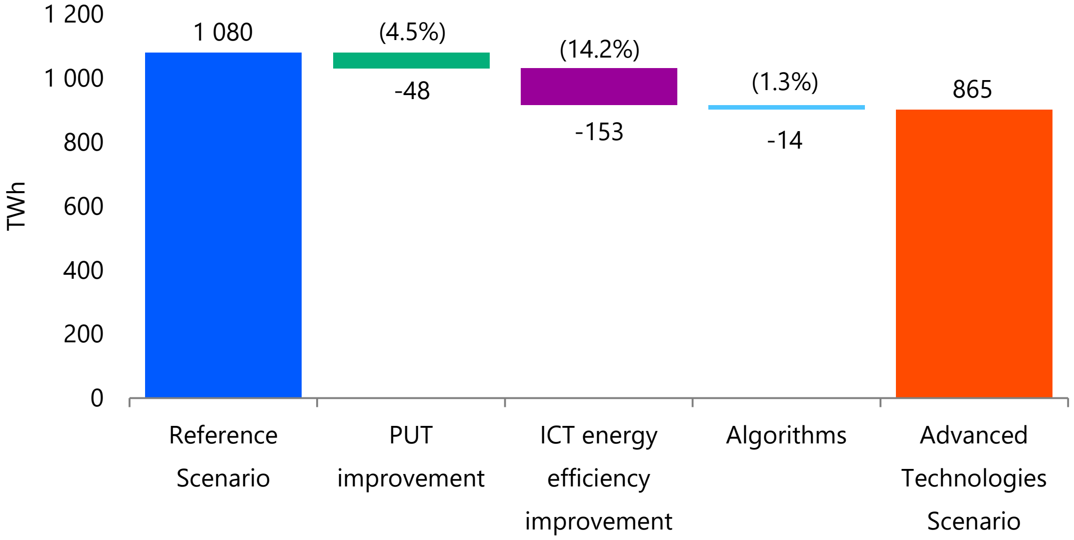
The growth is driven by electricity consumption for artificial intelligence (AI) computations at data centres, which will double from the current 14% to 30% of the data centre total in 2035. Meanwhile, the pace of increase in data centre electricity consumption will ease somewhat from 17.5% per year in 2020–2024 to 8.1% in 2025–2035. Recently, electricity consumption soared as AI learned new data from scratch over weeks for large language models. However, as AI systems will learn more efficiently by shifting to differential learning and only learning updates, or by updating only some parameters, the increase in data centre electricity consumption is expected to ease in the future.

Based on the Advanced Technologies Scenario, data centre electricity consumption will be 20% lower than that of the Reference Scenario in 2035. This saving is due to improvements in power usage effectiveness (PUE) through the introduction of high-efficiency cooling technologies in new data centres, and improvements in the efficiency of information and communication technology (ICT) equipment and computations.

The current average global PUE of data centres is estimated to be 1.5. This will improve to 1.38 in 2035 based on the Reference Scenario, and further to 1.28 based on the Advanced Technologies Scenario thanks to the wider adoption of liquid cooling and immersion cooling (an electricity saving of 4.5% from the Reference Scenario). ICT has an even greater energy savings potential, and the Advanced Technologies Scenario can save 14.2% more electricity than the Reference Scenario. Efficiency is improved by various technological factors such as more efficient central processing units (CPUs) and graphics processing units (GPUs), non-von Neumann computers, more efficient storage equipment, shorter transmission pathways between memory and processors, and the replacement of some volatile memory functions with non-volatile memory (that can retain data when electricity is cut off).

An electricity saving of about 1.3% can be expected from improvements in computation efficiency (by 2035). The number of searches by generative AI is expected to more than double by 2035 from the current 3 trillion searches a year, but higher-efficiency models are likely to be adopted to some extent.

Figure 10-4 | Electricity demand and energy savings potential of data centres (comparison with the Reference Scenario) [Advanced Technologies Scenario, 2035]



10.4 Energy saving using artificial intelligence (current state analysis)

Overview

There are concerns that the widespread use of artificial intelligence (AI) will drive up data centre electricity consumption and trigger national, regional and local electricity supply shortages. Meanwhile, AI is also expected to bring various benefits to the energy sector, such as an expanded use of renewables through weather forecasts, optimal electricity grid operation, energy savings and efficiency improvements in other demand sectors and the development of new materials. As demand sectors have greater energy consumption than data centres, the application of AI to these sectors can result in greater net energy savings overall.

AI can play various roles in the demand sectors. These roles can be summarised based on four keywords: ‘detection’, ‘prediction’, ‘simulation’ and ‘optimisation’.

One possible application is to optimise the processes from sourcing to production, not for one manufacturing plant but for the whole company or even several companies, thus optimising and planning the production for the entire supply chain. Weather forecasting by electricity retailers and the optimal supply of renewable energy have been put into practice. It is also possible to guide users to control the timing of heat storage by heat pumps and the discharge of electric vehicles (EVs) to match the supply of variable renewable electricity.

The following sections focus on AI’s contribution to energy savings in each sector, provide an overview of its roles, discuss the potential and challenges, and forecast the future.

Industry

The use of AI technology is already underway in the industry sector for applications such as failure detection, production management and demand forecasting. For example, it can forecast optimal production capacity while allowing for demand fluctuations and optimise energy consumption across entire supply chains.

AI also plays an essential role in energy saving. It can produce additional energy savings of a few percent in the industry sector without special facility upgrades. Facility upgrades are needed, however, if further energy savings are to be explored. The industry sector is a so-called 'hard-to-abate' sector, and even a contribution of a few percent from AI would be valuable for reducing remaining heat demand, as well as supporting electrification.

Conventional digital control was performed based on the difference between the target and actual values. For example, when controlling the heat temperature in a factory, control operations stop when a target temperature is reached. This causes a gradual deviation from the target temperature over time and the need for a correction.

Figure 10-5 | Energy saving using AI in the industry sector

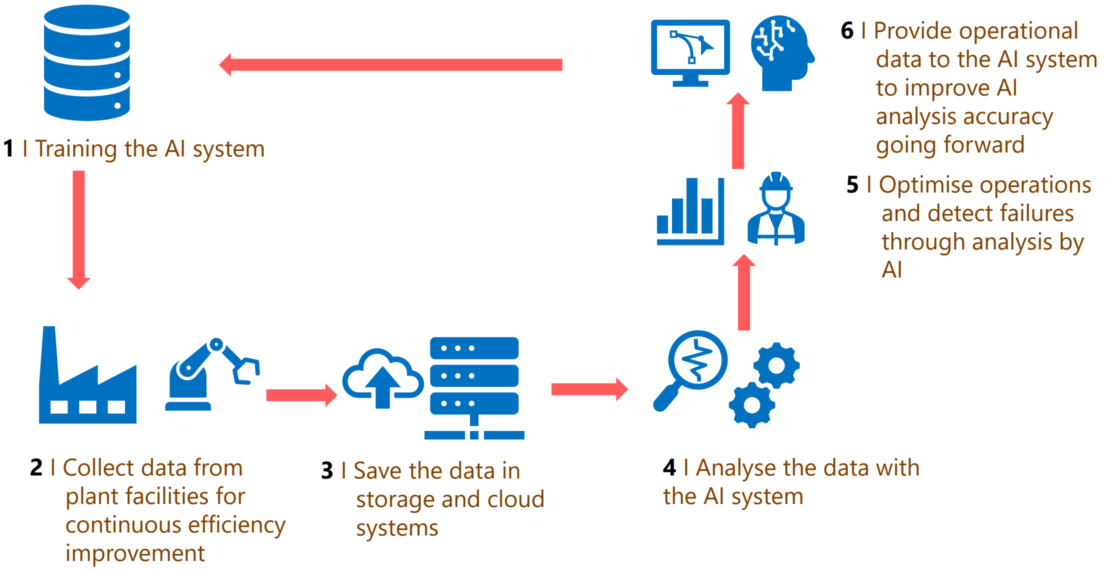
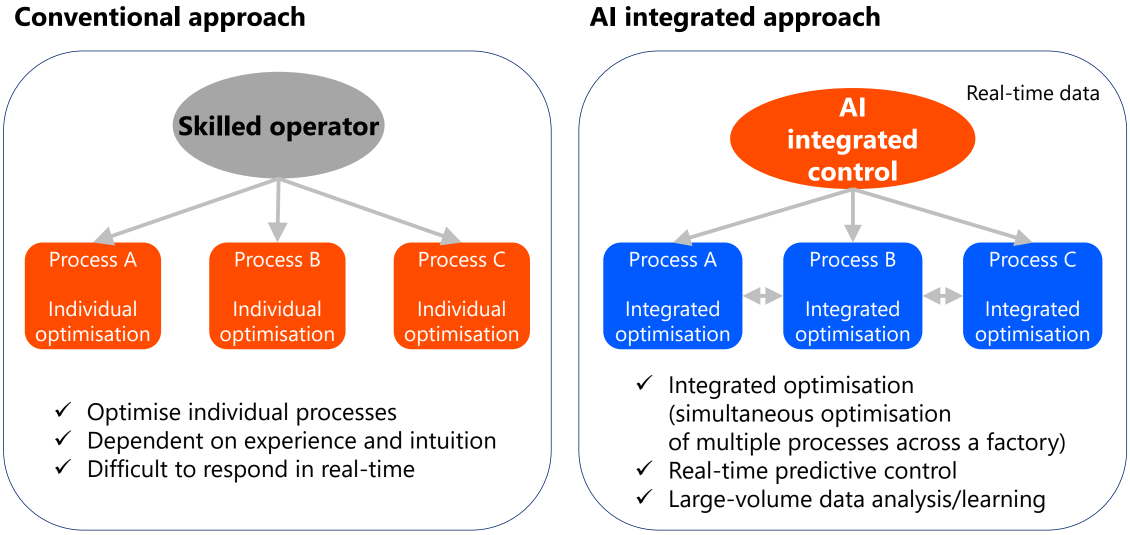


Figure 10-6 | Energy saving in the industry sector: Comparison between the conventional approach and AI integration approach



AI control learns from past operational data and performs a control operation before a deviation occurs. For heat temperature control, once the target temperature is reached, control is performed focusing on 'what kind of control is needed to avoid deviating from the target value'.

AI can achieve greater energy savings as it is capable of not only optimising the operations of a single facility but also optimising multiple processes simultaneously across a factory, performing dynamic control based on real-time forecasts, deriving optimal solutions from large amounts of data, and coordinating approaches among several factories.

One example of energy saving using AI is the case of Toshiba. There are multiple boilers, turbines, generators and chillers operating in one factory, and it is necessary to supply electricity, steam and cold and hot water. Toshiba provides a digital platform for optimising plant operations and minimising costs by using a mathematical model, which is built based on demand forecasts generated by AI using outdoor temperatures and production plans[49].

Azbil Corporation provides technologies for updating models for factory control[50]. The accuracy of advanced factory control depends on how accurately plant operations are modelled. Meanwhile, a model's error can widen after implementation due to changes in the plant's operational characteristics, such as ageing, facility repairs and modifications, and can affect the model's performance related to control and optimal operation. The company provides technologies for updating models so that models remain up to date with changes in the plant.

Iron and steel

The iron and steel industry is an energy-intensive sector that accounts for 8% of the world's final energy consumption and 7% of the carbon dioxide (CO_2) emissions of the energy sector, and its production processes are hard to decarbonise[51]. By collecting and analysing data using AI, benefits can be expected, including improving product quality, reducing raw material costs and enabling preventive maintenance of equipment, which in turn leads to reduced energy use and lower CO_2 emissions, as well as improving production efficiency.

The major European steel company ArcelorMittal is working on saving energy at its plants using Energiency's industrial energy performance software. This software platform evaluates the energy performance of plants in real-time using AI algorithms. With the help of Energiency, Luxembourg's Belval plant has reduced its energy consumption by 9 GWh, saving 150 000 euros or over 3% in electricity tariffs[52]. Belgium's Geel plant is also aiming to cut its annual energy consumption by at least 5%[53].

Japan's JFE Steel has built a cyber-physical system (CPS) that reproduces the status of the steel mills' blast furnaces in virtual space. CPS visualises the status of blast furnaces using real-time image data from inside the furnaces, in addition to temperature and pressure data collected with sensors. Optimal controls are performed by forecasting the future using AI and conducting

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[49] "Optimisation of private power generation facilities": Toshiba Energy Systems & Solutions Corporation (2021) https://www.global.toshiba/jp/company/energy/topics/digital-transformation/dx008-210324.html

[50] "Plant model automatic update technology using parameter probability distribution": Azbil Corporation, https://www.azbil.com/jp/corporate/pr/library/review/pdf/Review2025_05.pdf

[51] https://www.iea.org/reports/iron-and-steel-technology-roadmap, https://unece.org/climate-change/press/cop27-un-report-shows-pathways-carbon-neutrality-energy-intensive-steel

[52] https://innoenergy.com/uploads/2023/01/success-story-arcelormittal-energiency-eng.pdf

[53] https://belgium.arcelormittal.com/en/arcelormittal-chooses-energiencys-artificial-intelligence-to-save-energy-in-steel-coils-processing/

analysis with various models[54]. Digital twin technology is a core component of CPS and is being used to optimise incineration in parts of the furnaces. This technology has been implemented at the company's West Japan Works and has reduced fuel use by 5% and CO_2 emissions by 6 600 t/year compared with previous levels[55].

Cement

The cement industry is an energy-intensive sector that accounts for 8% of the global CO_2 emissions and 4.5% those of Japan[56]. The uses of AI related to cement proposed to date include heat optimisation using sensors during clinker production[57] and optimising concrete mixes (ratio of cement, sand, water, fly ash, etc.)[58].

Carbon Re, a venture from Cambridge University, is optimising the heat of plant operations during clinker production. The company creates a high-accuracy digital twin based on cement plant operation data to realise real-time process optimisation and reduce fuel use in the preheater and kiln (baking) processes. The digital twin technology can be added to existing plants and can be linked with advanced process control (APC) systems such as ABB's Expert Optimizer and FLSmidth's ECS/ProcessExpert, allowing operations to be adjusted automatically by AI. The Mokra plant of Heidelberg Materials has reduced its energy-related CO2 emissions by 2% by introducing this AI on a trial basis.

Paper

The paper industry mainly produces paper and paperboard using wood (pulp) and recycled paper as raw materials and is an energy-intensive sector that requires large amounts of electricity and heat from steam during the manufacturing process. The manufacturing process is divided into the pulping process for producing the raw materials and the papermaking process, in which pulp is processed into paper.

Paper and paperboard production requires substantial amounts of steam heat and electricity. Paper mills around the world are starting to introduce AI to reduce energy consumption and CO_2 emissions. AI is expected to be used in a variety of areas such as improving the efficiency of drying processes, optimising shipping plans for raw material purchases and predictive maintenance.

One best-practice example in the paper industry shows that electricity costs were cut by 5% per year and CO_2 emissions by 20 kt by switching to load-levelling operations suggested by AI[59].

Chemicals

The chemicals industry is divided largely into the petrochemical, polymer chemical and inorganic chemical industries. Among these, the petrochemical industry is particularly energy-intensive, as it involves high-temperature processes such as thermal cracking using naphtha obtained from crude oil as feedstock. Energy consumption in chemical processes occurs mainly in the reaction (such as thermal decomposition), separation and purification (such as distillation), drying and

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[54] https://www.jfe-steel.co.jp/products/solution/data-science/01-blast-furnace.html

[55] https://www.jfe-steel.co.jp/release/2023/07/230710.html

[56] Takafumi Noguchi 'The Challenge of Concrete for Achieving Carbon Neutrality by 2050', Japan Institute of Country-ology and Engineering, September 2022

[57] Carbon Re, https://carbonre.com/. Retrieved 19 August 2025

[58] Meta, 16 July 2025. https://engineering.fb.com/2025/07/16/data-center-engineering/ai-make-lower-carbon-faster-curing-concrete/

[59] https://newji.ai/supplier/manufacturing-industry/paper-industry-dx-strategies-and-ai-iot-application-examples/

concentration, transport and mixing and other processes (such as auxiliary facilities), and the reaction and separation and purification processes are particularly energy-intensive. For example, the decomposition furnace, which is the core facility of an ethylene plant, accounts for the majority of the total energy consumption[60, 61].

In the petrochemical industry, energy-saving initiatives including catalyst improvements to increase low-temperature activity and selectivity, waste heat recovery and reuse, heat integration, and high-efficiency furnaces and distillation columns have been implemented. Previously, operations used to be based mainly on static optimisation assuming an as-designed, steady state and rely on the experience and knowledge of skilled operators. However, combining operations with AI has made possible an integrated approach that can optimise multiple processes simultaneously across a factory, dynamic control based on real-time forecasting and data-driven operation that derives the optimal solution from vast amounts of data, raising the likelihood of simultaneously achieving stable quality and higher yield while saving energy.

Published case studies report energy savings of a few percent[62] through unit-to-plant optimisation, with certain units (such as rotary kilns) indicating savings in the high double digits (for example, 4%[63] fuel savings for chemical manufacturers and 15%–30%[64] fuel savings for rotary kilns). However, the effect varies significantly depending on the scope of introduction, operational conditions, and the baseline. While this is a limited case, a petrochemical ethylene plant has reported a 40% reduction in fuel consumption through visualisation and optimal control achieved by combining internet of things (IoT) sensors with AI[65].

Other industries

So far, we have discussed energy-intensive industries such as steel, cement, paper and petrochemicals. Meanwhile, there are also other industries that consume significant amounts of energy. Among such industries are food and tobacco, non-ferrous metals and machinery manufacturing[66].

In the final energy consumption of the manufacturing sector, electricity accounts for 30%, while heat and other uses account for 70%[67].

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[60] https://research-portal.uu.nl/files/691692/NWS-E-2006-3.pdf

[61] https://www.sciencedirect.com/science/article/abs/pii/S0360544218309083

[62] https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-potential-of-advanced-process-controls-in-energy-and-materials

[63] https://c3.ai/wp-content/uploads/2024/05/C3-AI-Case-Study-Chemical-Manufacturer-Energy-Efficiency.pdf

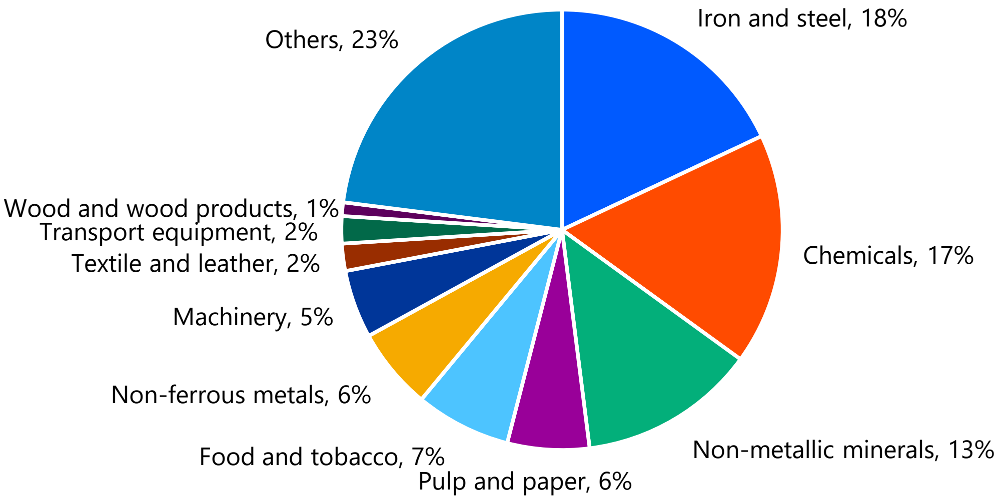
[64] https://imubit.com/oxbow-case-study/

[65] Yokogawa Electric Corporation, https://www.yokogawa.co.jp/news/press-releases/2023/2023-03-30-ja/

[66] International Energy Agency (2024) “World Energy Balances”

[67] International Energy Agency (2024) “World Energy Balances”

Figure 10-7 | Final energy consumption of the global manufacturing sector



Source: International Energy Agency (2024) "World Energy Balances"

As an example of the energy-saving effects of AI utilisation in factories, Yokogawa Electric reduced energy consumption by 3.3%. This was done by using a manufacturing data analysis AI to establish energy-saving metrics, then combining these with a general-purpose AI that performs optimisation and control[68]. Fuji Electric states that by utilising AI to optimise the operation of electricity and heat supply equipment, energy savings of 5% to 7% can be expected[69, 70]. Similar initiatives are underway at overseas companies; Schneider Electric Industries SAS says that by employing AI for analysis and proposal generation, energy consumption in the utilities sector can be reduced by 10% to 15%[71].

Residential

Energy savings using AI are achieved in the residential sector by having AI learn and analyse each household's energy usage patterns and human activity levels, so that appliances and devices can operate with optimal energy efficiency. By using AI controls to conduct upward and downward demand response (DR) based on the electricity prices and the share of renewable electricity sources, it is possible to use the resources within the residential sector as grid-balancing

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[68] Agency for Natural Resources and Energy (Yokogawa Digital Corporation), "The hearing materials in Document 4 for the 48th Energy Efficiency and Conservation Subcommittee of the Committee on Energy Efficiency and Renewable Energy, Advisory Committee for Natural Resources and Energy", https://www.meti.go.jp/shingikai/enecho/shoene_shinene/sho_energy/pdf/048_04_00.pdf

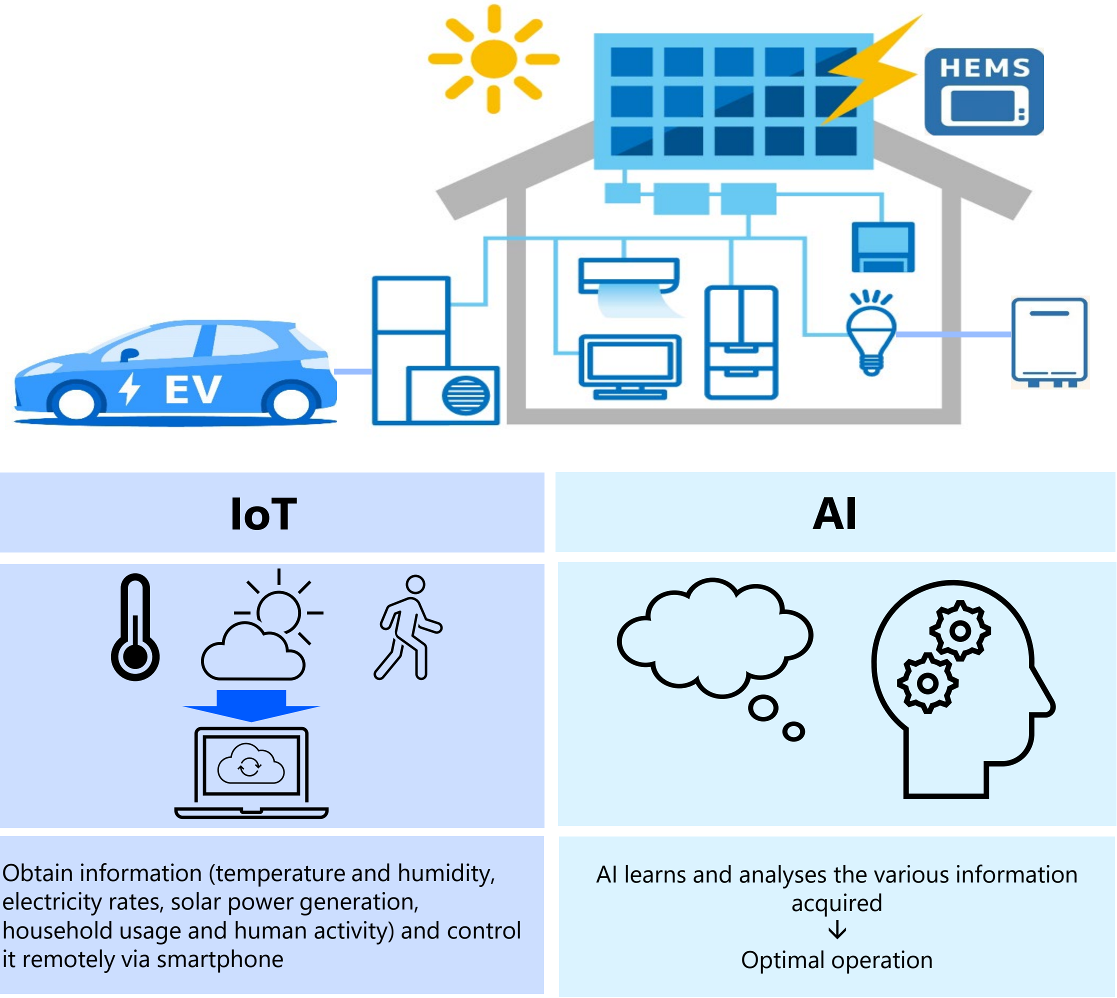
[69] Kyushu Renewable Energy and Environmental Industry Promotion Association (2024), "148th Eco School: Energy-saving solutions that create competitiveness: Introducing an energy management system that utilises DX and AI technologies (Fuji Electric Co., Ltd.)", https://k-rip.gr.jp/wp/wp-content/uploads/2024/06/3e78a0a6d967afb90ef0174efdcd55c7.pdf

[70] Fuji Electric Co., Ltd., "AI Technology Solutions List", https://www.fujielectric.co.jp/products/blue_navigation/energy_conservation/solution_list_energy_conservation_ai.html

[71] Schneider Electric Industries SAS (2024) "EcoStruxureTM Industrial Advisor - Predictive Energy", https://download.schneider-electric.com/files?p_Doc_Ref=PEB_99823549329&p_enDocType=Brochure&p_File_Name=EcoStruxure+Industrial+Advisor+-+Predictive+Energy+e-brochure.pdf

capacities. Various cases of AI use in the residential sector include savings of 14% for air conditioning[72], 15% to 35% for water heating[73] and 21% for washing and drying[74].

Figure 10-8 | An illustrative example of AI-driven energy savings in the residential sector



Obtain information (temperature and humidity, electricity rates, solar power generation, household usage and human activity) and control it remotely via smartphone

AI learns and analyses the various information acquired
↓
Optimal operation

With air conditioners, AI assesses factors such as lifestyle and ambient temperature to automatically regulate settings, maintaining comfort while achieving energy savings. For instance, by learning the time to wake up or to come home, as well as the room thermal characteristics, the air conditioner learns to start up gradually, reducing the electricity

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[72] When comparing the power consumption of Sharp air conditioners with and without AIoT control. Sharp Corporation 'More energy savings with AIoT!' https://jp.sharp/aircon/aiot-saving/ (Accessed on 13 August 2025)

[73] Case studies featuring Panasonic's AI EcoNavi-equipped water heaters and wood pellet water heaters from ÖkoFEN (Austria). 'AI EcoNavi' by Panasonic https://sumai.panasonic.jp/hp/2point/2_11.html (Accessed on 13 August 2025), ÖkoFEN (2025) "Product catalogue pellet heating" https://www.oekofen.com/assets/download/DeutschMA/Drucksorten/Drucksorten_aktuell_EN/oekofen_catalogue_pellets_2025.pdf (Accessed on 13 August 2025)

[74] Case studies featuring Panasonic's AI EcoNavi-equipped washing machine. 'AI EcoNavi' by Panasonic https://panasonic.jp/wash/feature/LX/econavi.html (Accessed on 13 August 2025)

consumption during startup. It can also reduce electricity consumption by automatically adjusting the temperature based on when occupants are leaving the house and proactively controlling the temperature based on weather information collected by AI. These AI-based controls reduce electricity consumption by 14% compared to systems without AI.

For water heaters, energy can be saved mainly by detecting people entering and leaving the bathroom when the bath is in automatic reheating mode and by reducing the energy consumption for automatic reheating when no one is bathing. Furthermore, by learning bathing patterns, AI can heat bath water at the optimal time. This can save energy by up to 35% compared with systems without AI.

Washing machines and laundry dryers can save energy by having AI determine the optimal operating conditions based on the water temperature, load size and fabric type detected by sensors. For instance, when the water temperature is high or the load size is small, the washing time is automatically shortened to save energy. When drying, the drying time is reduced to save electricity when there are many items that dry quickly. There are reports that AI control has reduced electricity consumption by up to 8% for washing alone and by up to 21% for the combined washing and drying cycle.

AI can be utilised not only in individual appliances but also in Home Energy Management Systems (HEMS) to reduce energy consumption. This mechanism involves using AI to predict solar photovoltaic power generation and electricity usage, control appliances within the home, and thereby reduce electricity consumption.

By connecting to the internet, IoT appliances support functions such as remote on/off switching via smartphone, remote monitoring of usage status and operation according to preset schedules, temperatures and other parameters. AI-equipped appliances learn from collected data and optimise operations more autonomously.

For example, they can perform more precise control by collecting past usage data using the sensors in the IoT appliances, transferring the data to the cloud or servers for storage, and then having AI learn and analyse this data by cross-referencing it with weather data and other information.

However, while these AI-equipped appliances and devices are technically capable of saving energy, their widespread adoption remains a challenge. AI-equipped devices tend to be more expensive than conventional products, which can be a barrier to adoption.

Commercial

Energy conservation in the commercial sector primarily focuses on improving the efficiency of installed equipment, and the energy savings effect can be limited depending on the actual operating conditions after installation. However, a combination of factors, including recent progress in AI technology, the falling costs of networked sensors and cloud computing, and innovations in construction and building materials, could drive a significant improvement in energy conservation in the commercial sector.

Energy efficiency in the commercial sector should be approached in stages. First, at the building design stage, with AI technology, it will be possible to utilise large amounts of historical data to create more efficient designs, beyond just fulfilling the current energy efficiency standards. At the operation stage, it will be possible to optimise lighting, air conditioning and power control using data on the flow of people and the weather collected via sensors, and to simultaneously achieve efficient energy use and comfort for the whole building. Furthermore, through integration with the surrounding buildings, energy savings can be expected at the community level.

There are several instances of AI-driven energy-saving initiatives like these. First, Daikin Industries implemented an initiative in which it used a Building Energy Management System (BEMS) to visualise the energy usage of a Yamaha office building, and it then used AI to analyse the accumulated data and save energy by 21% through optimisation[75]. In a similar example, NTT Data (2025) applied NTT's computing technology for optimal air conditioning control scenarios to the office lobby of JR Shinjuku Miraina Tower and demonstrated a 50% reduction in energy consumption in the summer[76]. Additionally, Zhao et al. (2023) have demonstrated that the winter heating energy consumption of the Osaka University campus can be reduced by at least 30% through automatic air-conditioning control using AI. Similarly, outside of Japan, Vattenfall (2023) has demonstrated a 30% reduction in the energy consumption of residential buildings by using AI to analyse their energy consumption and optimise their operation[77].

Even when a building energy-saving plan is created, it is difficult to adjust the discrepancy between the target and actual results daily. Mitsubishi Electric's system uses AI-based control to achieve planned targets, saving energy without the involvement of building managers[78]. The key point of this system is that it uses machine learning to analyse the incoming electricity and energy demand patterns for air conditioning, estimate energy-saving effects, and on that basis, sets targets and manages energy savings.

Even with AI control, results for air-conditioning temperature can deviate from targets depending on weather conditions; any such deviations are carried over to the next day's target to achieve annual performance targets. Compared with the electricity consumption of the previous year, energy savings of 1% to 5% have been achieved.

AI control can contribute to the energy management of not only individual buildings but also entire regions. Taisei Corporation is developing a cloud-based Community Energy Management System (CEMS)[79]. In this system, AI creates optimal operation plans based on weather forecasts, building usage and past operational data. The system is deployed through the installation of data

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[75] Daikin Industries (2025) "Achieving energy savings in air conditioning through artificial intelligence (AI) | Automatic energy tuning using heat load prediction" https://www.daikin.co.jp/tic/topics/feature/2025/20250507#:~:text=%E2%80%95%E2%80%95%E3%83%A4%E3%83%9E%E3%83%8F%E6%A7%98%E3%81%A7%E3%81%AF21%EF%BC%85%E3%80%81BMW%EF%BC%88%E3%82%BF%E3%82%A4%EF%BC%89%E6%A7%98%E3%81%A7%E3%81%AF16%EF%BC%85%E3%81%AE%E7%9C%81%E3%82%A8%E3%83%8D%E6%80%A7%E8%83%BD%E3%82%92%20%E7%99%BA%E6%8F%AE (Accessed on 13 August 2025)

[76] NTT DATA Japan Corporation (2021) "Demonstrating the simultaneous achievement of energy savings and comfortable environments through feedforward AI air conditioning control using small-scale learning" https://www.nttdata.com/global/ja/news/release/2021/110100/ (Accessed on 13 August 2025)

[77] Vattenfall (2023) "Yes, AI will improve energy efficiency—Essentially all buildings can benefit from this technology" https://group.vattenfall.com/press-and-media/newsroom/2023/yes-ai-will-improve-energy-efficiency--essentially-all-buildings-can-benefit-from-this-technology#:~:text=The%20properties%27%20heating%20system%20is,total%20of%20about%2030%20percent (Accessed on 13 August 2025)
https://www.taisei.co.jp/about_us/wn/2025/250711_10553.html

[78] Mitsubishi Electric Corporation (2023) 'An automated energy-saving solution for building air-conditioning systems "Smart Energy-Saving Assist"'
https://www.giho.mitsubishielectric.co.jp/giho/pdf/2023/2311106.pdf

[79] "Japan's first introduction of cloud-based CEMS utilising AI in an existing high-rise complex.": Taisei Corporation (2025)

collection devices in buildings. Furthermore, because it can control multiple buildings, it can be used not only to save energy but also as a grid-balancing capacity, such as by shifting demand to another building depending on the grid's supply-demand balance.

Meanwhile, digitising buildings for higher efficiency may not produce results that match the anticipated savings potential because of the installation of numerous networked sensors, higher on-site energy consumption for processing the collected data, or increased demand for data centres. Responses to possible sensor failures and events such as electricity outages must also be considered.

Transport

Road

One area where AI can improve energy efficiency in road transport is the optimisation of services such as parcel delivery, where large volumes of packages are delivered using numerous trucks. The issue is route optimisation, in other words, how multiple delivery operations should be connected and what routes should be taken to maximise energy efficiency for delivering packages from an unspecified number of senders to their respective receivers. This is a complex problem, particularly in urban areas with well-developed road networks, where numerous options exist; using AI increases the likelihood of selecting a better route. By considering factors such as traffic congestion predictions, in addition to the length and slope of the road and the speed limit, an optimal route with a greater energy-saving impact can be selected. Such efforts to use AI to improve the efficiency of truck transport networks are already underway in Japan by Yamato Transport[80] and other companies.

Furthermore, for long-distance truck transport, fuel consumption is an issue not only during delivery but also when empty trucks travel after delivery. For higher energy efficiency, it is desirable for trucks to carry loads on both outbound and return trips, to reduce the number of empty trucks and increase delivery efficiency. Energy efficiency can also be improved by loading as many packages as possible to minimise empty spaces in the loading compartment while trucks are in transit. It is desirable to combine multiple delivery jobs with overlapping or nearby delivery routes and transport them together on a single truck. Such energy-saving efforts are already underway at companies such as Kao[81] and Lion[82]. In addition, the New Energy and Industrial Technology Development Organization (NEDO) is working on a programme called 'Program to Develop and Promote the Commercialization of Energy Conservation Technologies to Realize a Decarbonized Society', in which the Air Business Club and the University of Shiga Prefecture are studying ways to improve transportation efficiency using AI, including mixed-load trucks[83].

The above are examples related to planning freight transport, but AI can also optimise the operation of individual vehicles, that is, enabling eco-driving. For example, new types of 'connected and automated vehicles' (CAVs) that can communicate with surrounding vehicles and nearby traffic lights are being proposed and considered. CAVs monitor the surrounding road conditions through communications and use this information to optimise their driving speed and adjust the electricity distribution of their drivetrain (for example, adjusting the balance between the engine and motor). This reduces energy consumption and achieves eco-driving. Not all control technologies installed in CAVs are AI applications, but the knowledge and algorithms

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[80] Yamato Transport Co., Ltd., https://www.yamato-hd.co.jp/news/2021/newsrelease_20210803_1.html

[81] Kao Corporation, https://www.kao.com/jp/newsroom/news/release/2025/20250122-001/

[82] Lion Corporation, https://doc.lion.co.jp/uploads/tmg_block_page_image/file/10377/20241225_02.pdf

[83] NEDO, https://www.nedo.go.jp/koubo/DA3_100318.html

obtained through machine learning are expected to be useful, for example, when incorporating traffic light conditions into vehicle control[84].

Table 10-3 | Energy saving in the road sector using AI

Purpose	Energy conservation through AI in the road sector
Demand forecast	The loading efficiency and passenger efficiency of cargo trucks, taxis, etc. are improved based on weather and traffic information.
Route decision	Through machine learning, AI suggests optimal routes considering the driver's travel preferences and, for cargo trucks, delivery efficiency.
Maintain distance between vehicles	By keeping a constant distance between vehicles through autonomous driving, vehicles can move without congestion, improving fuel efficiency. Platooning also reduces air resistance, contributing to improved fuel efficiency.

Aviation, shipping and railways

Air, sea and rail transport face challenges similar to road transport. First, they must reduce the energy consumption of aircraft, ships and vehicles during flight, navigation and operation—in other words, optimise their operation, akin to eco-driving in automobiles. Furthermore, airlines and shipping companies with large fleets operating air and sea transport networks need to combine operations and develop plans for efficient transport across multiple airports and ports. This problem is structurally similar to that of vehicle transport, and AI is expected to improve efficiency. In fact, in the aviation industry, Alaska Airlines is using AI to optimise flight routes[85], and in the shipping industry, Cosmo Oil is using AI to plan domestic vessel allocations, reducing fuel consumption[86].

10.5 Scenario analysis related to energy savings using artificial intelligence

Energy savings potential of artificial intelligence in the industry sector

The energy savings potential of artificial intelligence (AI) in the industry sector will be equivalent to 2% to 6% under the Advanced Technologies Scenario in 2035 (Figure 10-9). In the short to medium term (2025 to 2035), the introduction of AI will be primarily focused on retrofitting existing facilities to optimise operations and improve efficiency.

By industry, the energy savings in the chemical industry will be the largest at 26 Mtoe, followed by the steel, cement and paper industries at 21 Mtoe, 11.5 Mtoe and 4 Mtoe, respectively. In addition to these, there will be a 68 Mtoe effect in non-energy-intensive industries such as the machinery industry.

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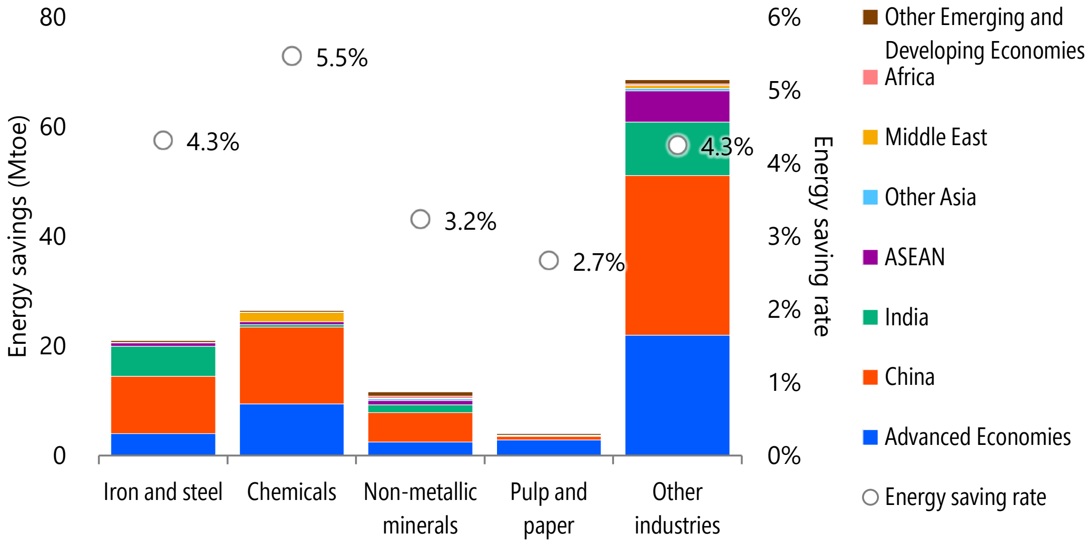
[84] Paper on CAV, https://doi.org/10.1016/j.rser.2023.114025

[85] Alaska Airlines, https://www.alaskakouku.com/2021/06/airspace-intelligenceai.html

[86] Cosmo Oil Co., Ltd., https://www.cosmo-energy.co.jp/ja/information/press/2025/250415-01.html

Figure 10-9 | Energy savings potential of using AI in the industry sector (compared with the Advanced Technologies Scenario) [2035]



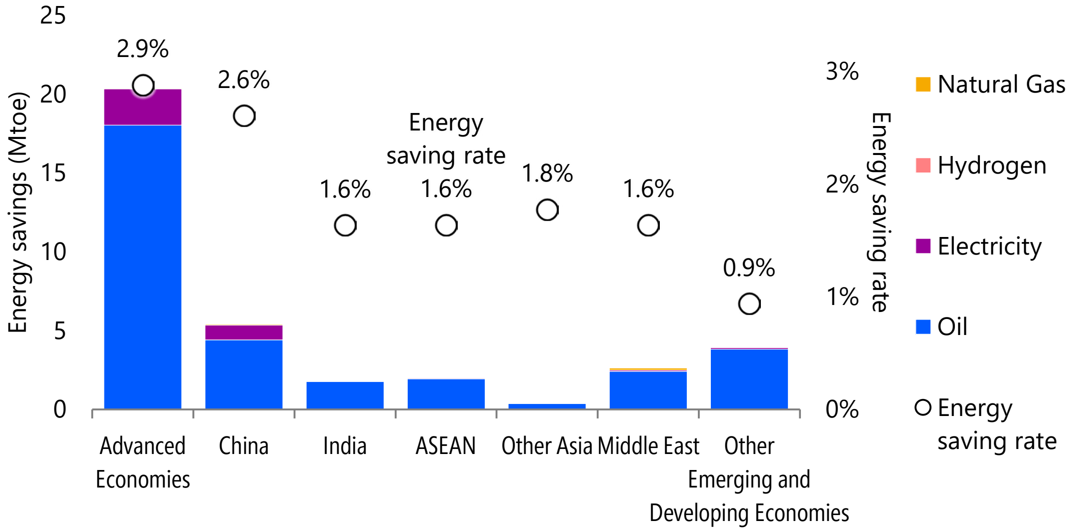
By region, AI will be adopted from early on in the Organisation for Economic Co-operation and Development (OECD) countries thanks to their abundant capital and digital infrastructure. China will see a high rate of AI adoption from the early stages, driven by its national strategy to actively promote digitalisation, as well as new builds and large-scale expansions. India, the Association of Southeast Asian Nations (ASEAN), other Asian countries, Africa and other Emerging and Developing Economies will initially lag behind, but adoption will accelerate due to rapid industrial development and the need to improve cost competitiveness. From 2035 onwards, they are expected to benefit from their late-comer advantage and introduce the latest AI more efficiently when expanding facilities or building new ones.

Energy savings potential of AI for road transport

The energy savings achieved by autonomous driving using AI in passenger cars, buses and trucks will reach 36.5 Mtoe in 2035 (Figure 10-10). The energy savings effect will be around 2.9% higher than that under the Advanced Technologies Scenario in Advanced Economies and 2.6% in China. Meanwhile, in other Emerging and Developing Economies, autonomous driving will not see significant progress in the short to medium term (2025 to 2035), and the energy savings will be around 0.9% to 1.8%.

Autonomous driving technology is not limited to electric vehicles (EVs) and can be applied to internal combustion engine vehicles (ICVs) as well. There are expectations that autonomous driving will spread to trucks, buses, taxis and other commercial vehicles, for which EVs are considered more difficult to deploy widely. This can lead to energy savings by improving loading efficiency and passenger efficiency based on weather and traffic information. Furthermore, transportation distances will be shortened by avoiding traffic congestion and selecting optimal routes. Autonomous driving will also improve fuel efficiency by maintaining a consistent distance between vehicles.

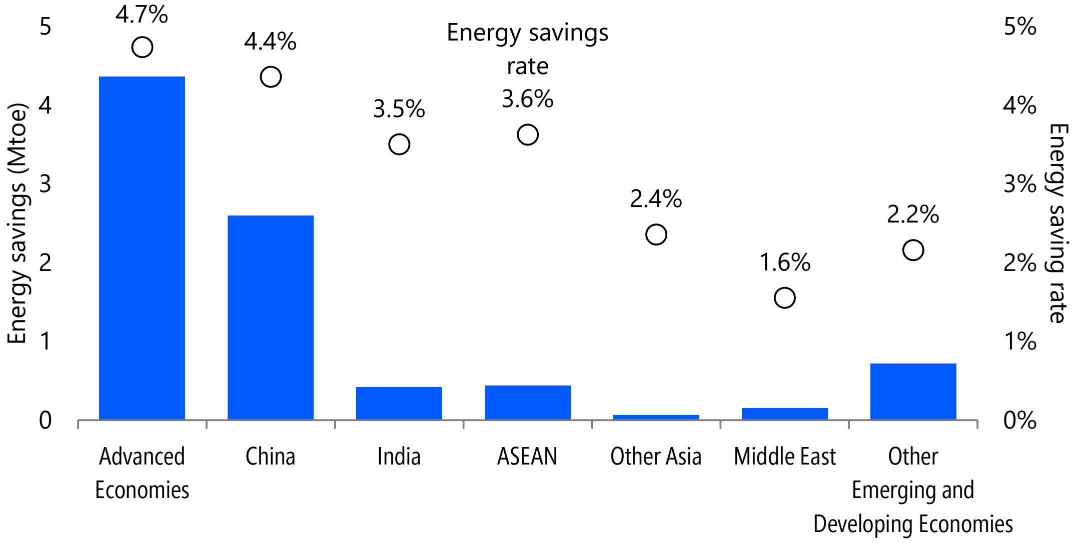
Figure 10-10 | Energy savings potential of AI for road transport (compared with the Advanced Technologies Scenario) [2035]



Energy savings potential of AI in the commercial sector

The energy savings potential of AI for heating, cooling, ventilation and lighting in 2035 is 8.8 Mtoe (102 TWh) compared with the Advanced Technologies Scenario (Figure 10-11). This is roughly a 10% reduction in data centre electricity demand in 2035. The energy savings potential of AI is 4.3 Mtoe in Advanced Economies and 2.6 Mtoe in China. In Emerging and Developing Economies, the adoption of AI will be limited to the latest buildings in the short to medium term.

Figure 10-11 | Energy savings potential of AI in the commercial sector (compared with the Advanced Technologies Scenario) [2035]

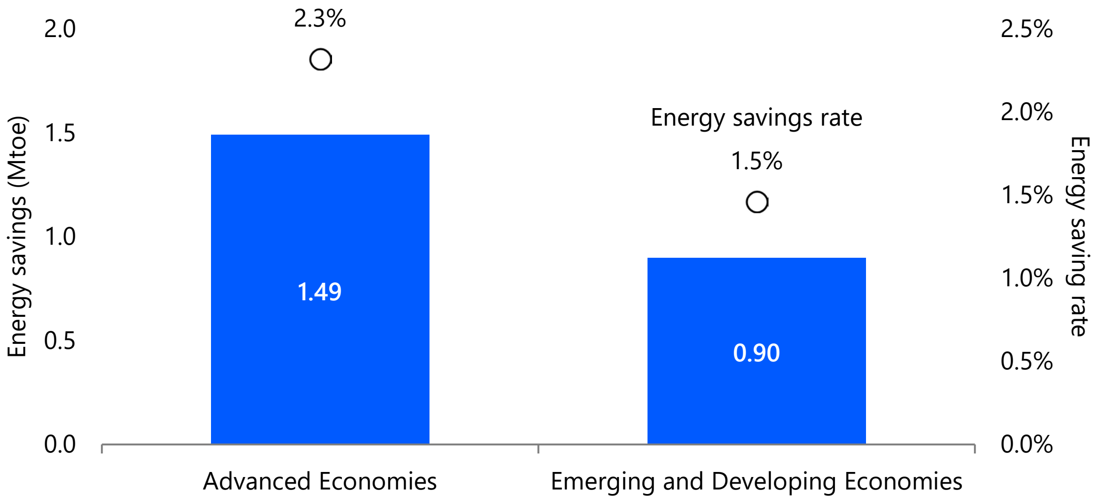


In Advanced Economies, digital control using Building Energy Management System (BEMS) has already become standard in large buildings of over 10 000 m². BEMS manages a building's energy based on predefined rules. By adding AI learning and prediction functions to this mechanism, more autonomous management of a building's energy will be possible. AI can improve the energy efficiency of an entire building without upgrading existing equipment, namely by installing sensors to collect data on the movement of people, temperature, and so on, and maintaining comfort through optimal control of lighting, air conditioning and power. In Emerging and Developing Economies, AI is expected to spread in the long run (after 2035), after first going through a stage of digitalisation.

Energy savings potential of AI in the residential sector

The energy savings potential of AI-equipped air conditioners and water heaters is 1.5 Mtoe compared with the Advanced Technologies Scenario (a 2.3% saving) for Advanced Economies and 0.9 Mtoe (a 1.5% reduction) for Emerging and Developing Economies in 2035 (Figure 10-12). Since AI-enabled technologies are high-end products that require a high initial investment, their adoption rate will be relatively low compared with that in other sectors in the short to medium term. AI air conditioners, for example, can save energy while maintaining comfort by performing proactive control that takes weather forecasts and human behaviour into account. For wider adoption of AI, it is necessary to promote understanding of its benefits.

Figure 10-12 | Energy savings potential of AI in the residential sector (compared with the Advanced Technologies Scenario) [2035]



For further widespread adoption

The use of AI on the demand side has many possibilities, including improving productivity and achieving energy savings in the industry sector, improving fuel efficiency and reducing travel distances for automobiles, and improving energy efficiency while maintaining comfort in the buildings sector. By 2035, an additional energy savings potential of several percent compared with the Advanced Technologies Scenario can be expected.

However, there are many obstacles to the introduction of AI in the energy demand sectors. First is the shortage of skilled personnel who can utilise AI in the industrial, commercial, road and other sectors. For example, factory equipment operators often rely on their experience. It is essential to raise awareness among factory workers about what AI can do.

Another issue is the lack of data that can be used. The more data there is, the higher the accuracy of predictions, which in turn enables more efficient operations. In other words, data preparation is essential before AI can be put into operation.

On the other hand, we must be careful of rebound effects, such as increases in energy consumption due to higher productivity. Efforts are currently underway to mitigate the rebound effects by having AI learn human behaviour and energy use patterns and apply predictive control. Sharing efforts like these is also important to promote the use of AI in the demand sectors.

Policy measures that need to be taken include sharing best practices to develop human resources and raise awareness and providing incentives to promote widespread adoption. To maximise the impact of AI, it is also necessary to standardise data and establish rules for data input and interoperability. Measures must also be implemented during the operation of AI, such as ensuring cybersecurity.

The energy savings potential of data centres depends significantly on improvements in information and communication technology (ICT) efficiency. Therefore, in addition to improving cooling efficiency, which has traditionally been the focus, measures and strategies to improve the efficiency of ICT equipment are needed. This will require additional evaluation of ICT efficiency as an indicator of data centre energy efficiency (in addition to power usage effectiveness [PUE]). It will also be important to cooperate not only with data centre operators but also with various stakeholders such as semiconductor manufacturers and ICT-related manufacturers.