Green Technology Book Energy solutions for climate change in Asia and the Pacific

WIPO

In cooperation with our partners

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Contents

Foreword by WIPO

Home to over half the world's population and some of the fastest-growing economies, the Asia-Pacific region is a story of diversity, growth and transformation for countries at all stages of development.

This progress is driving a surge in energy consumption. Asia-Pacific now accounts for 47% of global energy demand, a share that continues to rise. Unsurprisingly, this has led to an increase in emissions. Across the region, CO_2 emissions from fuel combustion have increased by nearly 150% since 2000.

However, this challenge is also inspiring a new generation of innovators who are making the region a hub of innovation in clean energy and climate solutions. From electric vehicles and smart grids to large-scale renewable energy projects, efficient cooling systems, sustainable urban infrastructure and new water purification technologies, a wide array of solutions is being developed and deployed, aligning economic growth with environmental sustainability.

> A new generation of innovators are making the region a hub of innovation in clean energy and climate solution.

This special edition of WIPO's Green Technology Book supports these efforts. Published on the occasion of Expo 2025 in Osaka, Japan, it is designed as a practical resource for policymakers, practitioners, investors, researchers and the wider public, featuring technologies that are commercially available or nearing market readiness. All of these are accessible through the WIPO GREEN Database of Needs and Green Technologies, the largest green tech platform in the UN system, with over 140,000 technologies from more than 140 countries.

As in previous editions, this installment adopts an end-user perspective, highlighting practical technologies for energy use in cities, rural and agricultural areas, and energy-intensive service sectors such as hotels and shopping malls. These fast-growing sectors can benefit greatly from both existing solutions and innovations on the horizon.

In Asia-Pacific – as elsewhere – economic growth and sustainable development can go hand in hand. As the region pursues both, access to practical, proven and scalable solutions is essential. This is where we hope this publication, and the WIPO GREEN database, can make a meaningful contribution.

Daren Tang

WIPO Director General

Foreword by Partners

Climate Technology Centre and Network (CTCN)

This special Expo25 edition of the *Green Technology Book* highlights the critical role of energy efficiency in addressing the urgent climate and energy challenges facing Asia and the Pacific. With rising energy demand driven by the growth of middle classes and shifting lifestyles, the region must act decisively. However, it also leads in innovation, with several countries in the region, such as Singapore, the Republic of Korea, China and Japan, ranked among the world's most inventive. This edition focuses on high-impact green solutions across urban and rural sectors, from households and transport to agriculture and public services.

Over the past decade, developing countries around the world have increasingly turned to the CTCN for guidance on navigating the complex transition to sustainable energy systems. In particular, one in five technical assistance requests has focused on the energy sector, with a strong emphasis on renewable energy and energy efficiency.

This edition of the *Green Technology Book* showcases practical, scalable energy solutions tailored to the Asia-Pacific region – one of the world's most climate-vulnerable areas. From urban grids to clean cooking in remote communities, the case studies highlight how innovation can simultaneously drive mitigation and adaptation. Many of the technologies featured, such as micro-grids, solar energy, biogas, agrivoltaics and energy-efficient infrastructure, build resilience while cutting emissions.

In 2024, CTCN assisted Thailand in developing a national hydrogen strategy and action plan to advance its 2065 net-zero target. The project evaluated hydrogen production options, infrastructure and local resources, resulting in actionable roadmaps and institutional frameworks to guide implementation. Similarly, in Viet Nam, a 2023 feasibility study focused on converting livestock manure into biogas and fertilizer through anaerobic digestion. The project pinpointed pilot sites, analyzed viability and recommended policy support. The system targets to reduce over 51,000 tCO_2e annually and enhance sustainable waste management.

As countries prepare for their next round of climate commitments, WIPO's special Expo25 edition aims to support decision-makers, practitioners and innovators with practical knowledge and inspiration. Whether advancing national strategies or launching local pilot projects, the insights gathered here can help translate ambition into action where it matters most.

Ariesta Ningrum, Director of the CTCN

Academy of Scientific Research & Technology (ASRT)

We are living in an era when the consequences of climate change are no longer a distant threat but a present reality. The need for innovative and actionable solutions has therefore never been more critical than it is now. The WIPO *Green Technology Book* continues to be an indispensable resource in this global endeavor, providing a platform for the exchange of technologies that can mitigate and adapt to a rapidly changing environment. Egypt – one of the countries most vulnerable to climate change – is proud to stand alongside WIPO in this vital initiative.

The Expo25 special edition of the *Green Technology Book* is particularly significant in its zeroing in on innovative energy solutions for climate change in the Asia-Pacific region, especially in the energy sector, a domain that is both vast and essential to the fight against climate change. This edition takes an end-user-oriented approach. It focuses on tangible energy-related technologies that can be immediately implemented to address climate change mitigation and adaptation. From rural communities adopting bio-energy and solar solutions to industries optimizing heating, cooling and transport through innovative technologies, this edition offers practical insights and tools to drive sustainable change.

As the Asia-Pacific region continues to grow economically and demographically, the urgent need for sustainable, resilient and innovative energy solutions becomes ever more critical. This edition provides a roadmap for how energy technology can be harnessed to create sustainable, resilient communities. Whether it is through renewable-powered farming technologies, energy-efficient household appliances or advanced waste-to-energy systems, the *Green Technology Book* for Expo25 inspires policymakers, businesses and communities to embrace green technology as a cornerstone of progress.

I would like to express my deepest gratitude to WIPO, our partners, and all contributors who have made this edition possible. The collaboration between nations, organizations and individuals is the cornerstone of progress in the fight against climate change. By sharing knowledge, fostering innovation and accelerating technology transfer, we can collectively create a more sustainable future.

Egypt remains committed to supporting the *Green Technology Book* and to advancing global efforts toward a cleaner, greener and more equitable world. We invite all WIPO Member States and stakeholders to contribute their green technologies and innovations to this shared endeavor. Together, we can make a profound impact on this planet that we all share.

Professor Gina El-Feky, ASRT President

Acknowledgments

We are pleased to present the special EXPO25 edition of the WIPO *Green Technology Book*, putting the spotlight on energy technologies in essential areas of our lives with a particular focus on the Asia-Pacific region. This edition has been made possible through the collective efforts and contributions of numerous individuals and organizations. We extend our heartfelt gratitude to all those who have supported this project. This edition of the *Green Technology Book* has been generously funded by the Funds-in-Trust Japan Industrial Property Global, coordinated through the Japan Patent Office.

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Acronyms

3G-SHS	third-generation solar home systems
AC	air conditioner
AC	alternating current
AD	autonomous driving
ADB	Asian Development Bank
AHU	air handling units
AI	artificial intelligence
AnMBR	anaerobic membrane bioreactor
AnWT	anaerobic wastewater treatment
APAC	Asia-Pacific
APS	auto pressurization systems
ART	autonomous rail rapid transit
ASEAN	Association of Southeast Asian Nations
ASRS	automated storage and retrieval systems
AWD	alternate wetting and drying
BCM	billion cubic meters
BEMS	building energy management system
BESS	battery energy storage system
BEV	battery electric vehicle
BIPV	building-integrated photovoltaics
BLDC	brushless DC motors
CaaS	cooling as a service
CAV	constant air volume
CCA	Clean Cooking Alliance
CCFL	cold cathode fluorescent lamp
CFCs	chlorofluorocarbons
CIPP	cured-in-place pipe
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COP	Conference of the Parties
C-V2X	cellular vehicle-to-everything
DC	direct current
DCS	district cooling system
DCV	demand-controlled ventilation
DER	distributed energy resources
DFI	Development Finance Institution
DVI	Digital Village Initiative
ED	electrodialysis
EDI	electro-deionization
E-ferries	electric ferries
EMB	electric mini- and microbus
EMS	energy management system
ERD	energy recovery devices
ERP	enterprise resource planning
ERP	electronic road pricing

ERV	energy recovery ventilation
ESCAP	Economic and Social Commission for Asia and the Pacific
ETFE	ethylene tetrafluoroethylene
EU	European Union
EV	electric vehicles
EXPO25	2025 World Exposition
FAO	Food and Agriculture Organization
FBD	flatbed dryer
FCEV	fuel cell electric vehicle
FO	forward osmosis
GBI	green building index
GHG	greenhouse gas
GIS	geographic information systems
GPS	global positioning systems
GRE	green real estate
GSHP	ground-source heat pumps
GWP	global warming potential
HCFCs	hydrochlorofluorocarbons
HDV	heavy duty vehicles
HEV	hybrid electric vehicles
HFCs	hydrofluorocarbons
HRV	heat recovery ventilation
HVAC	heating, ventilation and cooling
HVLS	high-volume low-speed
IAS	irrigation advisory system
ICS	improved cookstoves
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IER	ion-exchange resin
ILR	ice-lined refrigerators
IMTA	integrated multi-trophic aquaculture
IoT	internet of things
IP	intellectual property
IPF	international patent family
IPR	intellectual property rights
IRENA	International Renewable Energy Agency
ITS	intelligent transport systems
kVA	kilovolt-ampere
kWh	kilowatt-hour
LCD	liquid crystal display
LCM	liquid crystal module
LDCs	least developed countries
LED	light emitting diode
LEED	leadership in energy and environmental design
LFP	lithium iron phosphate
Li-ion	lithium ion
LNG	liquefied natural gas
LPA	liquid pressure amplification
LPG	liquefied petroleum gas
LPWAN	low-power wide-area network
LTO	lithium titanate
MABR	membrane aerated biofilm reactors
MBRs	membrane bio-reactors
MCS	megawatt charging system
MDBs	multilateral development banks
MEPS	Minimum Energy Performance Standards
MFC	microbial fuel cells
MRL	machineroom-less
MSEs	micro- and small enterprises
MW	megawatt
MWh	megawatt-hour

Nb-IoT	narrowband internet of things
NCA	lithium nickel-cobalt-aluminum oxide
NDB	New Development Bank
NDC	nationally determined contribution
NEBP	National Electric Bus Program
NMC	lithium manganese cobalt oxide
NRW	non-revenue water
NSI	national system of innovation
NTO	niobium titanium oxide
OGR	off-grid refrigeration
OLED	organic light emitting diode
PA	precision agriculture
PCM	phase-change materials
PHE	plate heat exchanger
PHEV	plug-in hybrid vehicles
PMSMs	permanent magnet synchronous motor
PRVs	pressure-reducing valves
PSC	perovskite solar cells
PV	photovoltaics
RAS	recirculating aquaculture system
RCD	recirculating columnar dryer
RE	renewable energy
RO	reverse osmosis
RPM	revolutions per minute
SBD	solar bubble dryer
SCADA	supervisory control and data acquisition
SDD	solar direct drive
SDG	sustainable development goal
SHP	small hydro power
SHS	solar home systems
SRI	solar reflectance index
SRI	system of rice intensification
TRL	technology readiness level
UFAD	underfloor air distribution
UN	United Nations
UV	ultraviolet
V2I	vehicle-to-infrastructure
V2X	vehicle-to-everything
VAV	variable air volume
VAWT	vertical axis wind turbine
VIP	vacuum insulation panels
VMS	vessel monitoring system
VPP	virtual power plant
VRF	variable refrigerant flow
VSDs	variable speed drives
WGR	weak-grid refrigeration
WHS	wind home systems
WIPO	World Intellectual Property Organization
W/mK	Watts per meter-Kelvin
WRI	World Resources Institute
WWTPs	wastewater treatment plants
ZEH	zero-energy homes

Executive summary

Asia is leading the clean energy innovation

Asia and the Pacific region is emerging as a global leader in the clean energy transition, propelled by diverse technological advancements addressing the dual challenges of climate mitigation and adaptation across various sectors. The region is experiencing a surge of innovation, with countries like Singapore, the Republic of Korea, China and Japan (ranked according to the Global Innovation Index 2024) leading in clean energy inventions, from advanced batteries and electric vehicles to smart farming tools. However, many technologies such as electric vehicles (EVs) rely heavily on a green energy mix within the electricity grid to make a meaningful impact on climate change. Fortunately, several countries in the region are well-positioned to benefit from this, thanks largely to their significant hydropower potentials. This has enabled them to develop a relatively low-carbon electricity grid with a notable share of renewables. For example, Nepal generates 100% of its electricity from hydropower, while countries such as Myanmar, New Zealand and the Republic of Korea also obtain a significant portion of their electricity from renewable sources, creating favorable conditions for a cleaner energy transition.

The rise of smart cities through energy efficiency and electrified mobility

Across the Asia-Pacific region, urban households are changing, driven by technological advancements and a growing emphasis on energy efficiency. Rapid urbanization, rising living standards, resource constraints and climate pressures are accelerating the adoption of advanced technologies, from improved building materials to energy-efficient home appliances like smart home systems and inverter air conditioners. These innovations not only improve comfort and convenience but also significantly reduce energy consumption and carbon emissions. Smart thermostats and IoT-enabled appliances, for instance, offer real-time control and optimization, enabling households to align energy use with off-peak hours or renewable supply. The expansion of demand-response technologies and AI-driven home energy management systems are fostering a more adaptive, efficient urban energy landscape. At the same time, energy solutions are becoming more inclusive and sustainable. Cooling-as-a-service models, PAYGO (pay-as-you-go) cooking appliances, leasing arrangements and affordable smart home kits are helping lower-income households access modern energy technologies without high upfront costs.

Effective energy management, however, must begin at the design stage. The development of walkable urban centers, alongside buildings that leverage passive design strategies such as green roofs, cool roofs and natural ventilation, has an important potential for change. Supportive governance frameworks, like India's and China's national cooling action plans, demonstrate how integrated approaches to design, technology and policy can drive low-carbon, resilient urban development. Pioneering cities are further optimizing energy use across multiple sectors through interconnected digital solutions, including smart streetlights and intelligent transport systems (ITS). Nonetheless, many cities have yet to exploit these opportunities, and disparities in implementation capacity remain a persistent challenge.

Urban public transport systems are critical to the region's energy transition. As the demand for mobility increases due to the population increase and urban growth, there is an urgent need to reduce dependence on fossil fuels to curb projected emissions increases. Electrification of public

transport, including buses, trains, ferries and two/three-wheelers, offers a powerful path to decarbonization, if paired with low-carbon electricity from renewables like solar or hydropower. Vehicle-to-grid (V2G) charging infrastructure and battery swapping are making these systems more viable and efficient.

Yet, barriers remain. Grid capacity limitations, lack of charging and green hydrogen infrastructure, high upfront investment and urban space constraints can hinder widespread adoption. While technologies such as V2G integration, real-time traffic optimization and autonomous electric vehicles can improve operational efficiency, they do not resolve these fundamental issues. Overcoming these challenges will require coordinated efforts from policymakers, urban planners and technology providers, along with sustained investment in grid upgrades, public charging and space-efficient urban design. But the technologies exist.

Using technology to tackle Asia's water-energy nexus

The region is increasingly confronting the dual pressures of rising energy demand and escalating water scarcity. Energy systems account for nearly 10% of global freshwater withdrawals, while water supply, treatment and distribution are heavily energy intensive. Rapid urbanization, shifting rainfall patterns and aging infrastructure are amplifying vulnerabilities in both sectors. In many Southeast Asian cities, up to 50% of water is lost through leaks and inefficiencies, driving up energy use and operational costs. Addressing these losses is crucial for improving both energy and water efficiency. Improved water management through technologies like IoT-enabled sensors, smart meters and pressure control systems, paired with infrastructure upgrades and better governance, is proving effective. These technologies facilitate real-time monitoring and optimization of water distribution. For example, the cities Ho Chi Minh and Wellington demonstrate how targeted investments and community engagement can reduce non-revenue water, lower energy consumption and enhance the reliability of urban water services.

At the heart of water infrastructure and energy use are electric motors driving pumps and aeration systems. Adopting high-efficiency models, variable-speed drives and digital controls can cut energy use of these motors by up to 30%. Wastewater treatment is being transformed by energy-efficient technologies such as fine-bubble diffusers, membrane bioreactors (MBRs) and anaerobic systems that generate biogas. Emerging innovations such as microbial fuel cells are also helping turn wastewater into a source of both clean water and renewable energy. Meanwhile, in response to water scarcity and saltwater intrusion, countries like Singapore, India and China are expanding desalination capacity through advanced reverse osmosis (RO), electro-deionization and hybrid systems.

Renewable energy solutions are empowering rural communities amid energy challenges

Off-grid renewable energy technologies are rapidly advancing energy access across rural and underserved areas in the Asia-Pacific region, offering affordable and scalable alternatives to traditional grid expansion. Innovations such as mini- and micro-grids combining renewable energy, for example in the form of pico, micro and small hydropower, solar and wind home systems combined with battery storage and backup generators, are providing reliable electricity and improving quality of life. These solutions are especially valuable in disaster-prone areas and are emerging as cost-effective options for both developing and developed countries. Notable successes include Bangladesh's solar home system program electrifying around 20 million people and Pakistan's solar rollout in over 12,000 schools. These decentralized renewable solutions are integral to a broader shift toward clean, cheap and locally adapted energy ecosystems that support sustainable development and climate resilience.

Beyond electricity access, off-grid green energy solutions help improve health and livelihoods through clean cooking and improved water access. Despite progress, over a billion people in the Asia-Pacific region still lack clean cooking technologies, and rely on inefficient biomass fuels and kerosene, leading to harmful emissions and health risks. Biogas from organic waste, biomass gasifiers, improved cookstoves and solar cooking options are reducing fuel consumption

and emissions while empowering rural communities. Emerging third-generation mini-grids equipped with smart meters, mobile payments and real-time monitoring further improve reliability and customer engagement. However, scaling these technologies requires supportive policies, innovative financing and institutional collaboration to overcome cost barriers and integrate decentralized systems with national grids, enabling energy access for all.

Energy-efficient innovations are driving Asia's agricultural transformation

Agriculture is a key contributor to climate change through greenhouse gas (GHG) emissions, particularly through livestock, fertilizer use and fossil fuel-powered irrigation and machinery. In Asia, rice cultivation contributes significantly to methane emissions. However, irrigation remains the largest on-farm energy consumer, largely powered by diesel and electricity. To meet growing food demand sustainably, a new green revolution is underway. Many Asian farmers are adopting solar-powered irrigation pumps and efficient methods like drip irrigation and alternate wetting and drying, which improve water and energy use. Innovations such as agrivoltaics (combining crop production with solar power) are new and expanding, boosting land productivity and supporting decentralized renewable energy access, while contributing to both climate mitigation and adaptation. Precision agriculture technologies using satellite images, IoT, AI and drones are growing to help reduce emissions and save water and energy, though adoption rates vary considerably between lower- and higher-income Asian nations.

Post-harvest stages also consume significant energy, particularly in rice milling, where Asia accounts for 90% of global output. Rural areas are increasingly turning to solar- and biomass-powered dryers, mills and cold storage to reduce losses and emissions. Cold chain logistics are rapidly modernizing, driven by urban food demand and e-commerce growth, and countries like Indonesia and Japan are leading with energy-efficient refrigeration. In key food sectors like dairy and tea production, innovations in heat recovery, solar-powered cooling, biomass heating and automated systems are lowering energy use and emissions while maintaining product quality. However, scaling solutions will require continued investment, enabling policies and affordable access for smallholders through innovative financing models like PAYGO, leasing and cooperative models.

Low energy pathways to more climate-friendly fisheries and aquaculture

In 2022, Asia contributed 75% of the world's total fisheries and aquaculture production, of which 185.4 million tonnes were aquatic animals. Global demand for aquatic products is expected to rise by 15% by 2030, with most of this rise coming from aquaculture, thus requiring a 35% to 40% increase in aquaculture production to meet future needs. Energy use is a major challenge throughout the sector, as both production, processing, storage and transport are highly energy intensive, making innovation and investment in energy efficiency essential for a more sustainable value chain. Additionally, small-scale fishers and farmers face significant hurdles, including limited access to quality inputs, financing and reliable energy, which restrict their productivity and sustainability.

Energy-saving technologies like fuel-efficient engines, hybrid and solar-powered boats, advanced fishing gear and digital navigation reduce emissions and improve fishing efficiency. In aquaculture, renewable solutions including solar- and wind-powered aeration, solar PV-powered cold storage and biomass-based feed processing are increasingly being adopted. Innovative technologies like aquavoltaics – where floating solar panels over fishponds generate electricity while maintaining optimal water temperatures and reducing evaporation – are gaining traction. This approach is particularly popular in China, India, Japan, the Republic of Korea and Taiwan Province of China, where land and water resource constraints drive the integration of energy and aquaculture systems. Smart IoT-based farm management, recirculating aquaculture systems (RAS) and integrated multi-trophic aquaculture (mimicking natural ecosystems which lowers energy usage and ecological footprint) further reduce environmental impacts and boost productivity. Pioneering projects like China's smart aquaculture vessel and offshore wind-powered fish farms highlight the sector's transition toward automation and sustainable energy.

Greening the service sector: technologies available for hotels and shopping malls

Hotels and shopping malls are two major pillars of Asia's fast-growing service sector and are central to both tourism and urban lifestyles. Shopping malls have become multifunctional hubs, offering not just retail, but also entertainment, dining, wellness and social spaces, essentially making them temperature-controlled community centers, especially in Southeast Asia. Likewise, hotels remain key to the region's booming tourism industry, serving millions of travelers year-round. Both types of buildings are among the highest energy users in urban settings, due to their constant demand for heating, cooling, lighting and water. As concerns over climate change grow, there is an urgent need for these high-energy hubs to adopt clean, energy-efficient technologies to reduce GHG emissions, meet sustainability goals and stay competitive by aligning with increasingly greening consumer expectations.

Both sectors are therefore turning to advanced energy solutions. Heating and cooling systems are among the largest energy users, making them a top priority for upgrades. Solutions like smart heating, ventilation and cooling (HVAC) systems, inverter air conditioners and heat pumps can cut energy use significantly. Inside hotels, energy-saving appliances, LED lighting, occupancy sensors and building energy management systems (BEMS) optimize overall performance. Shopping malls are incorporating zone-specific HVAC, variable-speed escalators and regenerative-drive elevators. Rooftop and parking-space solar panels and EV charging stations are becoming more common, while green façades and advanced building materials help lower energy demand. In supermarkets and food courts, low-global warming potential (GWP) refrigeration systems and heat recovery technologies are making operations more climate-friendly. These improvements not only lower energy bills but also enhance long-term resilience by aligning buildings with sustainability standards.

Water and waste systems also offer major efficiency gains. Biodigesters can convert food waste into clean energy, while low-flow fixtures, gray water recycling and smart water management help reduce both water use and energy demand. Hotel pools are increasingly heated with solar energy or energy-efficient heat pumps. Many hotels are now also engaging guests actively in sustainability efforts. Through room controls, behavioral nudges and reward programs, travelers are encouraged to use less water and energy, making them part of the solution. Such technologies demonstrate how innovation in everyday spaces can help drive a more sustainable future.

Financial solutions are catalyzing clean energy transition in the Asia-Pacific region

Multilateral development banks and climate funds are helping reduce investment risks and supporting both large and small clean energy projects in the Asia-Pacific region. At the same time, private sector investment is rising sharply, especially in East and South Asia, driven by the falling costs for solar, wind and other clean technologies. However, there are still big challenges. In many lower-income countries, clean energy projects are still too costly, and access to funding is limited. Furthermore, numerous developing nations in the region rely heavily on imported technologies and financial resources predominantly concentrated in developed countries. Despite these hurdles, Asia, with its immense potential and growing commitment to sustainable development, is poised for a transformative clean energy future if these financial and technological disparities can be effectively addressed. The unique vulnerabilities and isolation of Pacific Island nations also highlight the need for tailored solutions to ensure their equitable participation in this energy transition.

As with the other editions of the Green Technology Book, we hope that by showing what is already available, or close to being so, and that it is feasible, technically and financially, we can help pave the way for faster deployment of innovation and technology as part of the solutions to the climate change challenge. It is through inspiration that people looking for solutions will find the motivation to adopt and adapt a technology solution and thereby make it their own.

Key messages

Many solutions and high diversity are showing that change is possible

In carrying out research for the *Green Technology Books*, we observe a large diversity and magnitude of innovative solutions of all kinds. This fast-growing body of technologies and solutions is encouraging for our ability to meet some of the very serious challenges in relation to climate change. This innovation comes from public, private and civil society sectors alike, and is a testimony to the ingenuity found all over the planet. When these solutions are adapted to the local situation which is often required for them to function best, even more diversity is created, thus paving the way for successful implementation of new solutions.

Asia's strong position in innovation is making technologies more available and affordable worldwide

Asia has become a global powerhouse for inventing new and better ways to produce clean energy. Countries like China, Japan, the Republic of Korea and Singapore are high on the WIPO Global Innovation Index, constantly coming up with smarter technologies for energy sources such as solar panels, wind turbines and advanced batteries. Their sustained investment in research and development, coupled with robust industrial capabilities, positions them as essential engines for scalable clean energy solutions worldwide, making this a win for the entire planet. With the development of more efficient and affordable clean energy solutions, it helps bring down costs for everyone, making it easier and cheaper for countries around the world to switch from fossil fuels to cleaner, renewable power.

Efficient and affordable energy storage is key to unlocking Asia's renewable energy future

As renewable energy sources like solar and wind become more prevalent, efficient storage technologies are becoming crucial for managing supply intermittency, especially in the Asia-Pacific region which is particularly prone to extreme weather and unreliable grids. The significant reduction in costs of lithium-ion batteries, along with advancements in energy density, lifespan and efficiency, has made energy storage more accessible to both households and businesses. Additionally, emerging technologies like pumped hydro storage, and gravity-based systems are expanding storage options, especially in remote and mountainous parts of Asia. These innovations are not only improving energy security but also enabling greater integration of renewable energy into the grid, reducing reliance on fossil fuels, and supporting climate adaptation by ensuring reliable power during heatwaves, floods or erratic monsoons.

Targeted and locally adapted solutions are needed to bridge the energy and digital divide

While urban households in advanced Asia-Pacific economies like Australia, China, Japan, the Republic of Korea and Singapore are rapidly embracing smart home automation and energy-

efficient technologies, less-developed parts of the region continue to face significant barriers. In wealthier cities, growing electricity demand, supportive government policies and high consumer awareness are fueling the adoption of smart home automation, IoT-enabled devices and energy-efficient appliances that enhance comfort, cut costs and reduce environmental impact. However, in lower-income and rural areas across countries in Southeast Asia and South Asia, the high upfront costs of these technologies and limited infrastructure are slowing progress. This growing digital and energy divide highlights the need for targeted investment, inclusive policies, localized solutions and access to knowledge to ensure the benefits of smart technologies and energy innovation are accessible to all.

Innovative energy technologies boost Asia's climate resilience and food security

Renewable energy and energy-efficient technologies strengthen energy systems by integrating various renewable sources, boosting grid resilience and offering flexibility to manage extreme weather events. For instance, smart grids facilitate the integration of decentralized renewable energy, managing variable outputs and coordinating with other resources, which is vital for improving grid stability and contributing to climate change adaptation. Investing in renewable energy also stimulates local economies and creates jobs, enhancing community resilience to climate disruptions. Further, agrivoltaics optimize land use, enabling simultaneous energy production and crop cultivation, which is essential in areas where agricultural land is under pressure from climate impacts and urbanization. Similarly, aquavoltaics, which integrates solar PV with water bodies, provides off-grid fishing and aquaculture communities with affordable decentralized energy. In land-constrained regions of Asia, like China, India, Taiwan Province of China and Viet Nam, these innovations are enabling sustainable growth, reducing emissions and enhancing climate resilience.

Decentralized renewable energy enhances flexibility, resilience and diversity of energy access

Decentralized renewable energy infrastructures can play a crucial role in addressing the energy access challenges faced by rural and remote communities. In the Asia-Pacific region, with more than a billion people still lacking reliable electricity, off-grid renewable solutions, such as solar home systems, wind home systems, micro-hydropower, alongside mini-grids and microgrids, are providing affordable, scalable and sustainable alternatives to traditional grid-based power. These systems also enhance energy flexibility, enabling communities to manage energy demand more effectively and ensuring continuous access despite extreme weather events or grid failures. These innovations also contribute to reducing the environmental and health impacts associated with traditional energy sources.

Energy efficiency through advanced integrated system management

Technologies such as smart meters and automation are commonly used in both energy and water systems to improve efficiency. However, true energy savings come not just from the presence of these technologies, but from how well they are coordinated and optimized across systems. This system-level approach goes beyond the use of individual energy-efficient appliances and maximizes efficiency, which is especially important in large energy-intensive service sectors such as hotels and shopping malls, as highlighted in this publication. Heating, ventilation and cooling (HVAC) systems, lighting, and appliance loads are all now being monitored and controlled through centralized building energy management systems (BEMS). These systems allow for real-time optimization, adjusting operations based on occupancy and usage patterns. Similarly, efficient water management, using low-flow fixtures, gray water recycling and smart metering, reduces the energy needed for water pumping and heating. Without integrated management, the full potential of even the most advanced technologies remains untapped.

Sustainable, energy-efficient and climate-smart farming solutions to meet growing food demand

As Asia's population continues to grow, meeting future food demand with consideration for climate change and the environment will require adopting green and sustainable solutions rather than relying on traditional, energy-intensive practices. While past innovations boosted agricultural productivity, they also contributed to soil degradation, water pollution, biodiversity loss and greenhouse gas emissions through heavy use of irrigation, chemical fertilizers and pesticides. In the Asian context, these challenges are amplified by the region's vulnerability to climate change, water scarcity and rapidly changing consumer needs. But a new green revolution is underway, driven by emerging technologies that enhance the sustainability of agricultural practices. These include electric farm machinery, solar-powered irrigation systems, energy-efficient livestock and greenhouse ventilation and bio-based farm inputs. In addition, precision agriculture tools – like drones for crop monitoring and spraying, satellite-based data analytics and AI-driven farm management systems – are enabling farmers to apply water, fertilizer and pesticides more accurately, reducing waste and environmental impact. The post-harvest stage is also seeing innovation through solar-powered cold storage, electric transport and advanced refrigeration using low-climate-impact refrigerants. By embracing these innovations, Asia can sustainably increase food production, reduce environmental impact and build climate resilience for the future.

Transforming public transport is fundamental to ensuring sustainable, inclusive and low-carbon urban mobility

Asia's rapidly growing urban populations are placing immense pressure on public transport systems, leading to congestion, air pollution and social inequality in mobility access. To meet rising demand while reducing emissions, Asian cities must prioritize the transformation of public transport into a clean, efficient and affordable service. This includes investing in electric buses and rail systems, improving first- and last-mile connectivity, integrating digital ticketing and real-time data systems and ensuring accessibility for all segments of society. While cities like Singapore, Seoul, Tokyo and increasingly those in China and India have made significant strides, the pace and scale of transformation vary widely across the region, and both small and large or less wealthy cities still face implementation challenges. Strong policy frameworks, cross-sector collaboration and sustained public investment are crucial to making public transport the backbone of sustainable urban mobility across the region.

Scaling up clean energy investments is a critical priority for Southeast Asia's low-carbon future

Southeast Asia remains one of the world's fastest-growing regions in terms of energy demand, yet it continues to rely heavily on imported fossil fuels. While progress has been made in electricity access and clean energy technology development, domestic deployment still lags behind due to limited financing and investment. To align with global climate targets and reduce exposure to volatile fossil fuel markets, the region must accelerate its transition. This includes increasing annual clean energy investment fivefold by 2035 to around USD190 billion and advancing grid modernization, energy storage and renewable deployment (IEA, 2024e). Strategic policy reforms, stronger regional cooperation and private sector engagement for investments will be key to unlocking the full potential of sustainable, affordable and secure energy systems across Southeast Asia.

Accelerating clean technology adoption in underserved regions requires bold and inclusive financing approaches

As evidenced throughout the chapters, innovative financing approaches like pay-as-you-go (PAYGO), energy-as-a-service and leasing models are making clean energy technologies more accessible to low-income communities in semi-urban and rural areas across Asia. These models lower upfront costs and financial risk, allowing households and small businesses to adopt solar home systems, efficient appliances and even microgrids. In countries such as India,

Bangladesh and Indonesia, PAYGO models have helped scale solar access by enabling users to pay in small, manageable installments. Additionally, flexible financing options for farmers, such as cooperatives or leasing of solar-powered irrigation and energy-efficient equipment, are supporting the adoption of sustainable technologies without heavy capital investment. These solutions are proving vital for improving energy equity and fostering inclusive green energy transitions across the region.

Energy efficiency and demand-side management are critical to addressing growing energy consumption

As energy demand surges across the Asia-Pacific region, energy efficiency and demand-side management play a vital role in mitigating the region's growing consumption. While high-income countries are making significant strides in developing and patenting low-carbon technologies, many countries in the region still lack the necessary funding and infrastructure to adopt these solutions effectively. Renewable energy investments are essential, but they alone cannot keep pace with the rapid energy demand growth. The continued reliance on fossil fuels, combined with national subsidies and a rising energy appetite, highlights the urgent need for policies and technologies that prioritize energy efficiency, reduce consumption and foster innovation in appliance usage. Focusing solely on supply-side solutions without addressing efficiency could lead to further challenges, such as ensuring the availability of sustainable raw materials and exacerbating social inequalities through resource-driven conflicts.

Fostering behavioral change is essential for the adoption of clean technologies

Behavioral change and targeted training are crucial for the successful adoption of energy-efficient and clean technologies across Asia. Despite the availability of improved solutions, many rural households continue to rely on traditional energy sources, such as wood and charcoal for cooking, due to affordability, accessibility and lack of awareness about health and environmental consequences. This dependence has a severe impact on vulnerable groups, particularly women and children, who suffer the most from indoor air pollution from cooking, contributing to Asia's alarmingly high rates of respiratory illness and premature deaths. Governments can play a key role in providing access to improved technologies such as improved cookstoves, running awareness campaigns and subsidizing clean energy alternatives. Beyond cooking, similar behavioral shifts are needed in sectors like lighting, cooling and transportation, where people often use outdated or inefficient technologies because they are cheaper upfront or simply familiar. Addressing this requires not only better access to efficient technologies but also widespread education on their long-term economic and health benefits, incentives for upgrading equipment and government-led standards to phase out the most polluting products.

Methodology

The *Green Technology Book* special EXPO25 edition presents an assessment of the state of energy innovation for climate change in the Asia-Pacific (APAC) region. By showcasing concrete examples of technologies, we aim to make the energy transition debate tangible and inspire direct action. For this reason, the chapters are designed to target specific end-user groups, ranging from individual farmers to shopping malls and water utilities.

The *Green Technology Book* can be considered a climate technology catalogue meant for inspiration, but also a living project to which everyone can contribute. The publication links to the free public WIPO GREEN Database of Needs and Green Technologies, where users can create a profile and share their particular climate solutions and needs. All solutions related to the *Green Technology Book* can be found in the dedicated Green Technology Book Collection in the database.

The EXPO25 special edition of the *Green Technology Book* is the first to have a specific geographic focus, namely the APAC region. Such broad geographical groupings are not always consistently defined across international organizations. We here define APAC as comprising South Asia with Pakistan as the furthest western boundary, East Asia, Southeast Asia, and Australia and Oceania.

How we wrote the book

For the purposes of this publication, we considered a broad set of scientific articles and gray literature, as well as technology databases and webpages developed by private, public and civil society entities and organizations. Search strings included broad terms related to climate mitigation and adaptation paired with key terms for the three thematic areas, as well as key terms related to specific technologies (“efficient water pumps,” “immersion cooling,” “solar home systems” and so on). Translation engines enabled us to search articles in several languages to ensure a broad geographical spread.

Owners of the technologies identified were contacted, and all technologies uploaded to the WIPO GREEN Database of Needs and Green Technologies, either by the owner or by us.

Throughout the publication, we operate with three concepts: innovation, solution and technology. Although sometimes used almost interchangeably, they do have different meanings.

We utilize the term **innovation** to cover all intellectual creativity that can result in a solution.

Solution broadly means to deploy the output of this innovation to solve a specific challenge.

Technology is a broad term, but we apply it more narrowly to any physical entity or technique, with or without additional equipment, that is deployed to resolve a specific challenge.

We are primarily interested in a technology’s potential for mitigating and adapting to impacts from climate change. We therefore cover technologies broadly, ranging from the very simple

to the highly complex. Often the scope of climate technologies is expanded to include enabling mechanisms such as ownership and institutional arrangements that pertain to the technology in question (e.g., building codes or energy management systems). While recognizing the importance of such mechanisms, we focus primarily on tangible technologies or actual techniques.

It is important to emphasize that the technologies presented here have not been tested or in any way vetted by WIPO, and that we rely on publicly available material. Inclusion in the *Green Technology Book* is therefore not a recommendation of a particular technology. Technologies presented here should be seen as examples of a technology area, of which there may be many similar offerings which to our knowledge are in no way inferior. Photos illustrating the technologies are used with permission from the technology owners. Where permission could not be obtained, we instead use relevant stock-photos or AI-generated images. Photos of technologies may therefore not represent the actual technology in question.

The appropriateness of a technology is often highly context-specific and relates to factors other than geographical location. Therefore, no recommendations on where, when or how the technologies might be suitable are provided. Such an assessment should always be made with the involvement of local experts and stakeholders. Technology owners can freely upload their technology to the WIPO GREEN Database of Needs and Green Technologies and thereby become part of the collection.

The following criteria were used when selecting technologies for the *Green Technology Book*:

- relevance for climate change mitigation and adaptation
- relevance for the thematic areas

That these technologies pertain to:

- a product or service available for purchase or licensing
- a product or service available for free/open source
- a guidebook on the application of a method or technique
- a research project or similar (for horizon technologies).

In addition, the following factors were taken into consideration:

- anticipated impact from implementation
- availability of sufficient quality information or third-party endorsements
- market availability (for proven and frontier technologies)
- cost in relation to impact
- geographical balance
- business balance (large- and small-scale businesses, startups, research teams, non-governmental organizations and so on)
- no-harm principle.

We have divided technologies into three broad groups in order to indicate their maturity and availability. **Proven** technologies have been on the market for some time and therefore rely on a tried and tested concept. **Frontier** technologies are available, but still relatively new, and as such possibly less validated within a real-world setting. **Horizon** technologies are those new concepts being developed and expected to become available within a few years' time; that is to say, technologies that are realistic and likely to become available very soon. Additionally, technology maturity was broadly assessed according to the standard Technology Readiness Level (TRL) definition. According to this measure, horizon technologies have the lowest readiness level but are still close to full development (TRL 3–6), whereas proven and frontier technologies are validated and ready to be scaled-up if this has not already been done (TRL 7–9).

When presenting technologies, we have included a few classifiers as an easy guide to relevance for a reader. We have aimed for a broad representation of technologies at various stages of complexity and readiness. We classify technologies as either of a low, medium or high level of complexity. This is an indication only, and does not follow a strict definition of complexity. It reflects the relative level of human, material and monetary resources required to implement the solution.

Many more relevant technologies can be found in and added to the Green Technology Book Collection in the WIPO GREEN Database of Needs and Green Technologies. We welcome feedback and suggestions. These can be sent to us through the WIPO GREEN website or through email: info@wipogreen.wipo.int.

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1. Introduction

Photo: Unsplash/Getty Images

Green energy solutions for climate change in the Asia-Pacific

Energy drives everything. In today's societies oil, gas and coal are the standard sources for the energy we need to live, work, move around and consume. But this is changing, and the shift is both necessary and urgent. Our reliance on fossil fuels must come to an end, or at least be severely limited, if we are to have a chance of avoiding the worst climatic changes and impacts. This critical need was acknowledged on the global stage at the 28th Conference of Parties (COP28) of the United Nations Framework Convention on Climate Change (UNFCCC) in 2023, which closed with an agreement officially marking the beginning of the end to fossil fuels and paving the way for a rapid energy transition. This ambition must be sustained.

The team behind the Green Technology books is admittedly somewhat techno-optimistic, and we do see progress even though it is too slow. The pace of deployment of new technologies is not on par with the gravity of the climate change challenges, but there is progress and not least a plethora of innovation and new technology which is already available and feasible. The Green Technology Books, and the WIPO GREEN Database of Needs and Green Technologies to which they link, are our modest contributions to help speed up the deployment of much-needed solutions. By showing what is available, and what is coming very soon, we hope to bridge the perceived knowledge gap between needs and solutions. The WIPO GREEN database is an active matchmaking tool and through the link to the database, the Green Technology Books also become active matchmaking tools. Both are free UN resources, and we strongly encourage you to explore what they have to offer.

> The pace of deployment of new technologies is not on par with the gravity of the climate change challenges

The *Green Technology Book* has, since its inauguration in late 2022, been published in three editions. In the first, we presented the technologies available for climate adaptation, an area which we found did not receive enough attention. We closely examined technologies for agriculture, cities and water, including coastal protection. The second edition focused on climate change mitigation technologies, as well as agriculture and cities, but also the hard to abate industries steel and cement. The third edition focused specifically on energy technologies for climate change with chapters addressing urban areas, rural communities including agriculture, and the service areas of water, supermarkets and data centers. Common to all the *Green Technology Books* is a simple and accessible style and short, concise sections describing various technology developments and trends in the focus areas, followed by a listing of technology examples. We divide these into three groups: proven technologies, which have been on the market for some time and hence are well established; frontier technologies that are available but relatively new; and horizon technologies, which are expected to become available soon. We have designed the books to help anyone curious about the potential of technology easily find the areas and solutions most relevant to them. In the digital version, it only takes a click to go to the WIPO GREEN database and find more details and a link to the solution provider. We would be grateful if you could let us know (email: info@wipogreen.wipo.int) whether you find what you are looking for or share how you are using our work.

The World Intellectual Property Organization (WIPO) is a UN specialized agency, established in 1967 with the mandate to promote invention and creativity for the economic, social and cultural development of all countries through a balanced and effective international intellectual property (IP) system. In WIPO GREEN and the *Green Technology Books*, we focus on showing how innovation and technology are part of the solutions to climate change, food security and the environment. By doing so we support the national systems of Innovation (NSI) and technology transfer, both of which are based on and enabled by the international IP system.

This edition of the *Green Technology Book* was created as a special EXPO25 edition of the Energy Solutions for Climate Change edition. It builds on many of the same technology areas but applies a specific Asia-Pacific focus. The 2025 World Exposition (EXPO25) *Designing Future*

Society for Our Lives takes place in Osaka, Japan (EXPO25, 2025). The Funds-in-Trust Japan Industrial Property Global through the Japan Patent Office has generously funded this EXPO25 special edition.

The Asia-Pacific climate change focus

The Asia-Pacific region is remarkable for many reasons, one being the spectacular economic growth in several countries. It is a region with stark contrasts and is home to both some of the richest and poorest countries in the world. Additionally, it boasts high population growth in some countries and is home to the world's most populous nations. High economic growth coupled with large and growing populations also mean an increasing demand for energy. Changed demographic strata, notably emerging large middle-classes with new food and living style preferences, increase pressure on natural resources and the demand for energy to support new home appliances and transport needs. But it is also a region which is home to some of the most innovation-capable countries in the world, with Singapore, the Republic of Korea, China and Japan in the top 13 countries in that order in the 2024 WIPO Global Innovation Index (WIPO, 2024b).

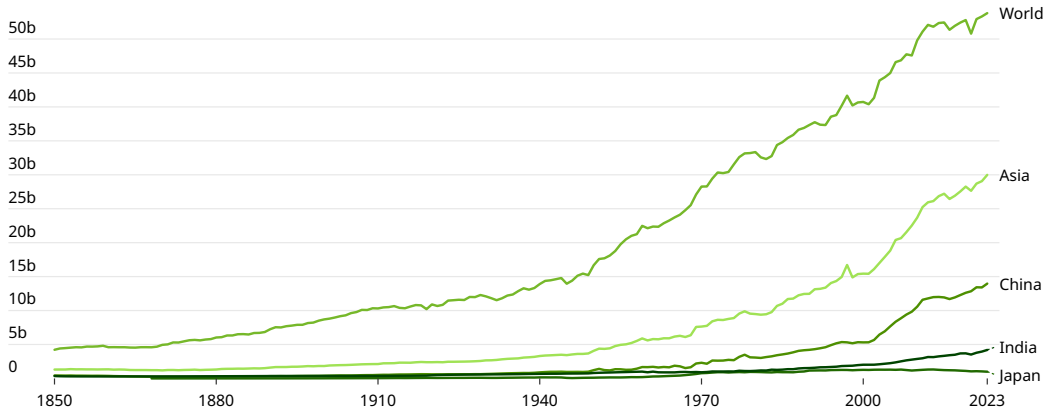
> Asia-Pacific is a region which is home to some of the most innovation-capable countries in the world

Reflecting the trends in the region as well as some of the sectors where the potential for green technology transformation is high, we have chosen to focus this edition on urban households, public spaces, transport and water utilities, in rural areas on households and communities, fisheries and aquaculture, agriculture on-farm and post-harvest, and hotels and shopping malls as service areas. For more details on how we create the book, select technologies etc., please refer to the methodology section.

Fossil fuels still dominate the energy and GHG emissions landscape of the Asia-Pacific region

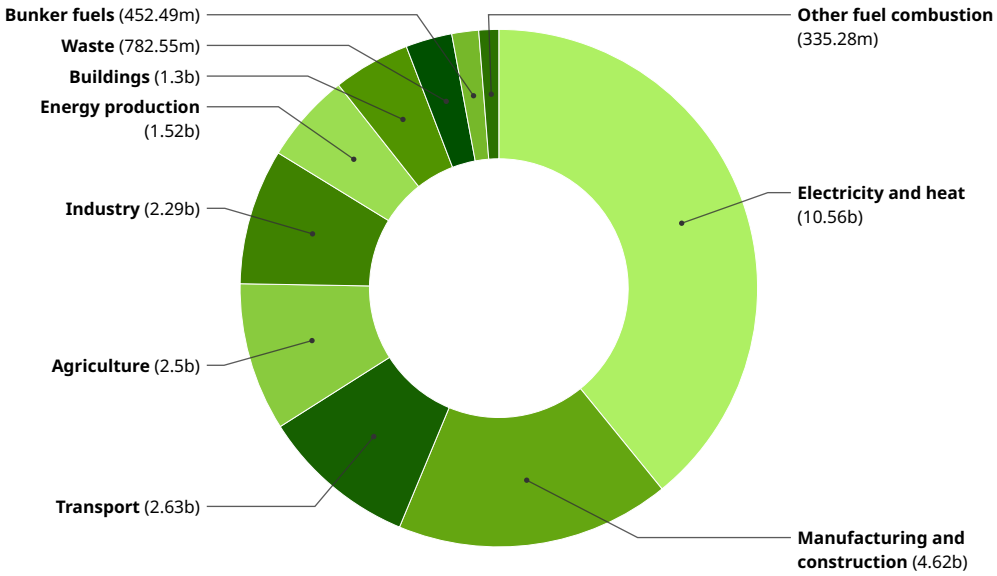
The region consumes approximately 46% of the world's energy (Ritchie *et al.*, 2024b). Of this, around 83% still originates from fossil fuels (Ritchie *et al.*, 2024b; Ritchie and Rosado, 2024b) rendering the region responsible for around 53% of global GHG emissions in 2023 (Ritchie *et al.*, 2024c). Figure 1.1 summarizes GHG emissions trends in the Asia-Pacific as compared to world emissions while calling out the region's largest economies of China, India and Japan. Figure 1.2 illustrates how each economic sector contributes to emissions in the region. Electricity generation and heating are dominating, with manufacturing and construction, industry, agriculture and transport also being major emission sectors.

Figure 1.1 GHG emissions (World, Asia, China, India, Japan), 1850-2023



Source: Ritchie *et al.* (2024c).

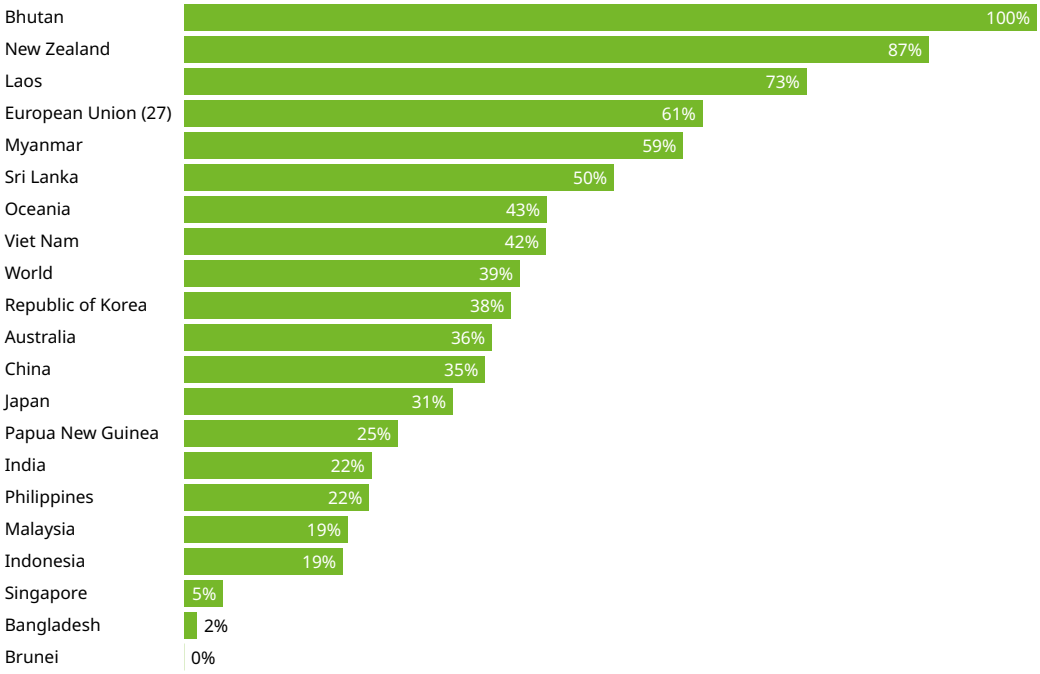
Figure 1.2 GHG emissions by sector, Asia 2021



Source: Ritchie *et al.* (2024a).

As the region is highly diverse, rural connectivity to national electricity grids also varies considerably. The electricity grid is key for many of the low-carbon solutions that are being implemented, simply because they are electricity driven with many requiring frequent recharging. This means that they are not greener than the electricity that feeds them. The region benefits from a significant hydropower potential in many countries which contributes to greening the energy mix in the electricity grid. Major investments in other renewable energy sources, especially solar PV and wind, are resulting in a positive trend toward greener grids, not least spearheaded by the very large and rapid solar PV investments in China. Figure 1.3 illustrates the large regional diversity in low-carbon energy (renewable and nuclear) in the electricity mix. It ranges from countries with almost no low-carbon energy in the mix to extreme cases like Bhutan, New Zealand and the Lao PDR with massive hydropower resources.

Figure 1.3 Share of electricity from low-carbon sources, Asia-Pacific, 2022-23



Note: Low-carbon electricity is from nuclear and renewables (solar, wind, hydro, biomass and waste, geothermal, wave and tidal)

Source: Ritchie and Rosado (2024a).

Technology available for a region vulnerable to climate change

The region is highly vulnerable to climate change impacts. This stems from a combination of factors: several poor countries with limited resilience capacity, large populations or even whole countries that are prone to flooding and other extreme events, and climate systems which are vulnerable to disturbances from climate change such as the yearly monsoon pattern. This implies that climate change adaptation is crucial, and for some countries by far the most important factor. This edition of the *Green Technology Book* focuses on energy technologies that are often associated with climate change mitigation. However, as was also observed in the adaptation and mitigation editions of the *Green Technology Book* and is pointed out repeatedly in the following chapters, many solutions have dual advantages in that they may help bring down GHG emissions while also reducing vulnerability and increasing resilience – in short, supporting climate change adaptation.

> The region benefits from a significant hydropower potential in many countries which contributes to greening the energy mix in the electricity grid

The Sharm El Sheikh Adaptation Agenda, introduced at COP27, established a target for energy plans to include climate adaptation perspectives for energy generation, transmission and distribution infrastructure at national and sub-national levels. Here, the focus is often on enabling decentralized energy systems through extended battery storage capacity and transmission and distribution networks. The targets also consider how transport infrastructure can become resilient to climate hazards through the adoption of new technology, design and materials. While these technologies are not specified, and there is a global lack of standards on the topic, the *Green Technology Book* adaptation edition presents a number of adaptation solutions.

With regard to the incorporation of energy resilience into national adaptation planning, the International Energy Agency (IEA) has found that even where countries have national strategies or adaptation plans, pressing needs for climate resilience in the electricity sector have not been addressed, evidenced by the fact that more than half of the 31 IEA member countries have limited or no information on the climate resilience of electricity systems (IEA, 2020).

Understanding the link between energy access and climate adaptation is crucial, and yet this is often overlooked. Energy services themselves, such as cooling and back-up energy and water supply, are essential to respond to climate change impacts including drought, temperature rise and natural disasters (Malekpoor *et al.*, 2019). The potential role of reliable and affordable modern energy services in bolstering adaptation to climate change impacts has not been widely acknowledged in policy or practice (Sharma, 2019). Increasing the distribution of renewable energy solutions and diversifying energy sources builds resilience for individuals and communities whose lives have been impacted by climate change. Deploying and scaling up specific technologies that both enable energy access via renewable energy and energy efficiency, such as solar panels and biogas digesters, achieves multiple benefits for vulnerable populations and builds resilience to climate impacts.

Agriculture and renewable energy production can successfully coexist using agrivoltaics. Maximizing land and water use via agrivoltaics and aquavoltaics (energy technologies that allow for simultaneous agricultural or aquacultural use alongside energy production) achieves synergies between mitigation and adaptation for rural communities, boosting both renewable energy supply and food production. This co-location provides solutions for land constraints, which will be increasingly important as the population grows and productive land becomes scarcer.

Micro-grids are increasingly useful to populations impacted by natural disasters such as bush fires, storms and flooding whose frequency and severity have been exacerbated by climate

change. Conventional micro-grids relying on diesel generators contribute to GHG emissions and are costly. Local smaller-scale renewable energy sources can deliver more reliable services while mitigating climate change.

Energy efficiency measures are often an underutilized opportunity. The ambitions for build-back-better following the COVID-19 pandemic looks increasingly like a missed opportunity as we return to pre-pandemic habits and procedures. The current (mid-2025) tense geo-political situation, along with many countries being forced to allocate larger budgets for defense, risks derailing and delaying climate action otherwise well underway. However, climate change will not go away, even if we are preoccupied with other priorities, and any delay will only worsen its consequences. That is why we talk of delay. Climate change can only be ignored in the short term and the impacts will continue to become worse as CO_2 content in the atmosphere increases, and global temperatures and sea levels rise.

Technology transfer in all directions

The international and national systems of innovation are highly efficient in producing new solutions. Innovation is still predominantly originating in the more developed and affluent countries as innovation can be expensive and often requires highly specialized skills as well as other factors important for an efficient innovation ecosystem. For a more thorough understanding of this, we encourage you to visit the WIPO Global Innovation Index and discover the many factors included in the innovation ecosystem assessments.

But innovation is also taking place in much less developed and affluent countries. It may not always be as high-tech or advanced as other solutions, but it may be exactly what is needed in a specific context. It is one of the ambitions of the team behind the *Green Technology Books* to bring this innovation to the forefront. We believe that there is huge potential for South–South technology transfer where many solutions may be more easily adaptable to the local situation. Innovation is also a matter of being able to adapt solutions originating elsewhere to local conditions, and this factor may be hugely important. It looks like technology adaptive capacity is often overlooked or underappreciated. It can be challenging to find such technologies as often they are not as visible, market-oriented or competitive as technologies from developed countries which often are emerging in a highly competitive space. We do our best to uncover local solutions, but we know we are only seeing a fraction of what is taking place. Finally, it should be noted that South–North technology transfer is something we should expect to see more of in the coming years. We hope that by showing the solutions that are available or rapidly becoming available, also from developing countries, we can help contribute to speeding up this process. We need all available solutions, and we need to implement them fast. This is, in a nutshell, what we hope to help achieve.

> Innovation is taking place in less developed and affluent countries. It may not always be as high-tech or advanced, but it may be exactly what is needed

Make climate change good business through innovation

Maybe the political will to fight climate change is waning among some, but this does not stop developments in innovation and technology developments which are increasingly making climate change solutions good business. Already solar and wind are energy sources competitive with fossil fuel, meaning that it simply makes sense economically to go green. The best guarantee for rapid green transition is to make it good business, also for the individual company, farmer and household. There is no need for short-lived government sponsored support programs if a solution is good for the bottom line. It may take support initiatives in various forms to reach that point, but this is not new and holds true for many new solutions, be that in climate change or not. Do not expect that a company or a farmer with narrow margins will transition to green technology

just to reduce emissions. Even if they want to, they may not be able to afford the risk associated with change. But if a solution is reducing emissions and/or increasing resilience while also increasing earnings, then climate change ambitions and economic considerations are pulling in the same direction. This is what we must achieve, and this is what we are looking for. In the *Green Technology Books* we of course cannot guarantee that the solutions we show as examples are economically beneficial, as this will always depend on the individual context. But we can show what is there and is available and it is then up to the reader to explore whether it is also economically feasible. There is increasingly a good chance that it will be.

Climate finance and corporation in the Asia-Pacific region

Unlocking climate funds for inclusive clean energy growth

Climate finance refers to local, national or international funding, sourced from public, private or alternative channels, that is used to support climate change mitigation and adaptation efforts. It can be mobilized through mechanisms under the UNFCCC or through bilateral and multilateral institutions. Climate funds continue to play a critical role in supporting renewable energy and energy efficiency projects across the Asia-Pacific region.

The Climate Investment Funds (CIF) serve as an umbrella mechanism to promote low-carbon and climate-resilient development in developing countries. As of 2019, the Clean Technology Fund (CTF), Green Climate Fund (GCF), and Global Environment Facility (GEF) were the largest multilateral climate funds by total investment volume, providing significant financing to countries in the region (see Table 1.1). The GCF supports clean energy and energy access initiatives, while the GEF focuses more on climate adaptation and sustainable development. The GEF had the broadest reach, with 168 active projects as of February 2019, while programs like the Scaling Up Renewable Energy Program (SREP) focus on fewer, larger-scale infrastructure investments. Between 2003 and 2017, just three countries, China, India and Indonesia, accounted for 53% of the climate finance received in the region, reflecting the scale and maturity of their economies and energy markets (REN21, 2019).

Table 1.1 Flow of clean energy-related climate finance in the Asia-Pacific region, 2019

Region	Country	Funding amount approved (million USD)	Number of Projects	Major Funding Source
Northeast Asia	China	222	24	GEF
	Mongolia	73	9	GCF
South Asia	Bangladesh	79	5	SREP
	India	1 077	34	CTF
	Pakistan	10	6	GEF
	Sri Lanka	6	2	GEF
South east Asia	Indonesia	538	22	CTF
	Myanmar	14	4	GEF
	Philippines	104	8	CTF
	Thailand	125	9	CTF
	Viet Nam	136	12	GCF
Pacific	Fiji	1	1	GEF
	Tonga	33	2	GCF
	Others	415	60	
Regional		1 212	45	

Source: Adapted from ADB (2022b).

Recent data indicate a strong post-COVID-19 surge in global investment in energy transition technologies. In 2022, global investments in these technologies reached USD 1.3 trillion, an increase of nearly 70% from pre-pandemic levels in 2019. Asia has emerged as a key destination for this capital, with East and South Asia alone receiving over three-quarters of global investments in renewable energy technologies. This trend reinforces the region's growing importance in the global clean energy transition (IRENA, 2023).

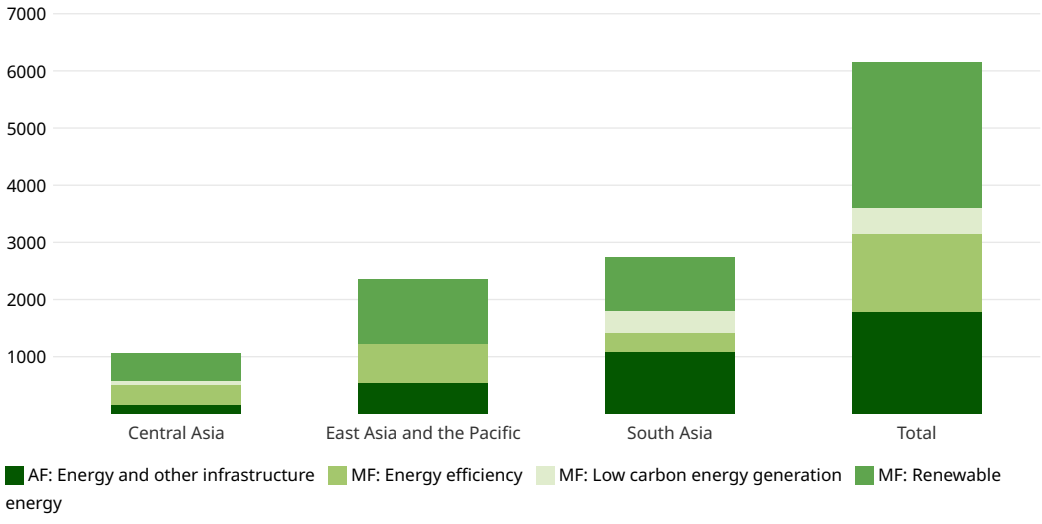
Several other global programs with dedicated clean energy mandates are active across Asia, such as the Global Climate Partnership Fund. These funds are well-positioned to support project preparation and mobilize investment.

However, although climate funds are well established in the region, many focus on large-scale projects and often face challenges in developing pipelines for smaller, decentralized initiatives due to high transaction costs. This poses a barrier for smaller economies, especially in the Pacific and parts of Central Asia, where energy markets remain relatively underdeveloped. To bridge this gap, there is a strong need for investment facilitation mechanisms that help viable smaller projects, also in the private sector, meet funding criteria. Enhancing access to these funds could significantly accelerate clean energy deployment in the region (REN21, 2019).

Multilateral development banks driving and de-risking investment in Asia's energy finance landscape

Multilateral Development Banks (MDBs) have been pivotal in advancing clean energy across Asia, particularly in the early phases of renewable energy deployment. Initially, development finance institutions (DFIs) led investments in the region, supporting capacity building, technology transfer, feasibility studies and technical cooperation. As utility-scale solar and wind projects became more bankable, private sector participation increased markedly after 2010, with MDBs continuing to play a complementary role by de-risking investments and strengthening enabling environments. This is reflected in the scale and focus of MDB climate finance flows to the region. As seen in figure 1.4, in 2019 alone, the region received over USD 6 billion in MDB funding, 44% of which went to South Asia and 38% to East Asia. Approximately 53% of this financing was allocated to renewable energy and 31% to energy efficiency initiatives (ADB, 2022b).

Figure 1.4 Energy related MDB climate finance in Asia (in million USD), 2019



Source: Adapted from ADB (2022b).

The World Bank and the Asian Development Bank (ADB) are the primary MDBs supporting clean energy investments in the region. The European Bank for Reconstruction and Development (EBRD) is also active, particularly in Central Asia. New MDBs such as the Asian Infrastructure Investment Bank (AIIB) and the New Development Bank (NDB), established in 2016, have increasingly contributed to clean energy and sustainable transport. By the end of 2019, the NDB had committed USD 3.5 billion to clean energy initiatives (ADB, 2022b).

Between 2009 and 2016, Southeast Asia attracted about USD 6 billion in development bank investments, largely in the form of loans (73%), concessional loans (10%) and equity (3%). The World Bank, ADB and Japan Bank for International Cooperation (JBIC) were the largest contributors. Hydropower has been a focus of many MDBs, especially in South and Southeast Asia, while AIIB has emphasized large-scale renewable projects (REN21, 2019).

Private sector offers promising opportunities for clean energy investment in Asia and the Pacific

Private financing originates from individual and corporate sources and is channelled into investments through a range of financial intermediaries. Since 2010, there has been a noticeable shift toward private financing for utility-scale clean energy projects across the region. East Asia and the Pacific have led this trend, mobilizing around USD 100 billion annually, while South Asia has attracted approximately one-tenth of that amount. Most of this investment has remained domestic, with about 90% directed toward solar and wind technologies, reflecting their technological maturity and bankability (ADB, 2022b).

In earlier stages, venture capital played a key role in advancing renewable technologies. In 2019, venture capital and private equity invested USD 3 billion in renewable energy, with 60% allocated to solar PV. India emerged as the largest recipient, securing USD 1.4 billion (ADB, 2022b). Similarly, networks such as PFAN-Asia (Private Financing Advisory Network), a network of more than 200 investors and financiers that secures renewable energy and energy efficiency investments for both the private sector and governments, leveraged more than USD 200 million in finance across the region since its inception (REN21, 2019).

However, as solar and wind technologies have matured and now dominate the renewable energy market, funding dynamics have shifted, with many companies increasingly conducting research and development internally. In contrast, emerging clean energy solutions such as freshwater and near-shore floating solar PV still require substantial support from venture capital and private equity. Ocean-based technologies, including marine and tidal energy, are gaining attention, yet face similar challenges. Likewise, progress in biofuels, including production of green hydrogen and marine energy, has been less than anticipated. As a result, investment in these areas remains limited, underscoring the need for targeted venture capital and innovation-focused financing to help bring these next-generation technologies to scale (ADB, 2022b). Additionally, several alternative sources of financing may potentially support clean energy in the region (Box 1.1). Green hydrogen is, however, an energy storage technology that has been and still is strongly promoted in, for example, China and Japan. Standards are being developed which can lead the way for the required mainstreaming infrastructure, but it is still to be seen what place there will be for green hydrogen alongside other fast developing options, especially new battery technologies (Xie *et al.*, 2022).

Private sector banks and financiers also represent major potential sources of funding, often investing directly in businesses across developing countries. However, emerging low-carbon technologies face higher financing hurdles due to uncertainties in performance, supply chains and profitability. To support their development, governments and development finance institutions can offer risk-sharing mechanisms, concessional finance and guarantees (REN21, 2019).

Box 1.1 Alternative and innovative sources of financing

A new trend is emerging, where a pool of capital from foundations is being used for specific purposes. For example, four United States of America (US)-based foundations – the William and Flora Hewlett, John D. and Catherine T. MacArthur, and David and Lucile Packard Foundations, and Jeremy and Hannelore Grantham Environmental Trust – have jointly supported multiple initiatives in India, including the US–India Catalytic Solar Finance Program, to support development of risk mitigation vehicles for the renewable energy sector. This trend extends to a global pool of institutional or private funds, who are willing and prepared to support India's renewable energy transformation over the next decade.

(Excerpt from (ADB, 2022b)

Renewable energy dominates climate finance in the Asia-Pacific region

In 2022, 302 cities across Asia-Pacific reported through the CDP-ICLEI[1] Track, with 79 cities in 16 countries disclosing 201 climate-related projects, 169 of which were actively seeking funding. Renewable energy was the top sector, with projects valued at USD 4.6 billion and nearly USD 1.4 billion in unmet financing needs. Buildings/energy efficiency (USD 529 million), and transport (USD 146 million) were among other key sectors (CDP, 2025a).

Investment in renewable energy has been increasing at a rate of 34% in the Asia-Pacific region since 2004, although much of it is in China and India (KPMG, 2025). China leads renewable energy investment in East Asia and globally, with sustained growth in solar deployment driven by domestic banks and government-backed lenders. Technological advancement and cost reduction are key drivers behind the growth. Most renewable energy projects are in the early stages in South and Southeast Asia, while more advanced projects are found in East Asia. In South Asia, the investment trend leans heavily toward smaller-scale systems like mini-grids and rooftop solar, aimed at improving energy access and reducing infrastructure costs. MDBs are playing a key role in expanding access to energy and promoting technologies like smart metering. India's government-supported Energy Efficiency Services Limited (EESL) has helped scale up energy-efficient lighting and appliances through mass procurement programs, while Bangladesh is making progress with off-grid solar solutions such as solar home systems, backed by IDCOL, the largest facilitator of renewable energy financing (Oksen, 2020). Many of these projects still depend on low-interest financing, often through local banks that receive funding from development banks and other international donors (REN21, 2019).

In Southeast Asia, solar PV and solar thermal are gaining investor interest, but investment patterns vary across the region based on resource availability, demographics and national priorities. For example, in countries with abundant hydroelectric resources, like Cambodia and the Lao People's Democratic Republic, international funds have primarily supported hydropower development. Indonesia, by contrast, has focused heavily on geothermal energy, far outpacing investments in solar and wind power.

Despite growing interest, access to finance for large-scale renewable energy projects remains a key challenge in Southeast Asia. Barriers include permission and ownership restrictions, grid limitations and underdeveloped financial institutions in lower-income countries. While some local and development banks are engaged, many domestic banks lack the expertise or investment-ready projects to participate fully. Strengthening institutional capacity and creating more bankable projects are essential for scaling up investments (REN21, 2019).

Overall, cities are prioritizing mitigation over adaptation, despite rising climate risks. As explained in the introduction section of this chapter, many energy technologies have both mitigation and adaptation qualities. Between 2018 and 2019, mitigation finance, especially in the energy sector, dominated climate funding in the Asia-Pacific region, totaling USD 472.5 billion, or 91% of the total flow (CDP, 2025b). This was largely driven by investments in solar photovoltaic (PV), wind and hydropower projects in China and India. Table 1.2 provides the technology breakdown for China, India and other developing countries in the rest of Asia and the Pacific. Financing for low-carbon transport also grew quickly, supported by increased investments from corporations and public sector actors in rail, transit and the rising adoption of electric vehicles by households. However, as climate risks intensify, adaptation efforts will need stronger support and financing. Analysis of climate finance flows also reveals a funding gap between developed and developing countries, underlining the need for stronger multi-stakeholder cooperation to address barriers and expand access to climate finance (CDP, 2025a). Accepting responsibility for historical GHG emissions, developed countries have committed to providing USD 100 billion a year of climate finance to developing countries by 2025. However, delivery has fallen short, even as climate-related costs continue to rise. Estimates suggest that developing countries and emerging markets (excluding China) will need around USD 1 trillion annually through 2030 to meet their external climate finance needs, making equitable and coordinated global financing efforts more critical than ever (WIPO, 2023).

1 The CDP-ICLEI Track is a unified reporting platform that allows cities, states and regions to disclose their environmental data, including emissions, climate actions and risks, through a standardized process. It is jointly operated by CDP and ICLEI-Local Governments for Sustainability, to streamline climate reporting and increase transparency and accountability in local climate action.

Table 1.2 Renewable energy investment in Asia (in billion USD), 2019

Technology	China	India	Other developing countries in Asia and the Pacific
Solar photovoltaic	26	7	5
Wind	55	2	9
Small hydro/geothermal	1	0	0
Biomass and waste	2	0	0
Biofuels/others		0	1
Total	83	9	15

Source: ADB (2022b).

Pacific Island states face challenges accessing both technology and financing for the energy transition

Achieving energy security remains a major challenge for Pacific Island states due to their geographic isolation, relatively small economies and reliance on costly imported fuel. While renewable energy offers a promising alternative, many islands are exposed to cyclones, corrosive marine environments and difficult logistics, making infrastructure deployment costly and technically complex.

Despite the constraints, the Pacific region is seeing growing interest in small-scale renewable energy solutions, especially off-grid and micro/mini-grid solar systems (REN21, 2019). Several countries have committed to achieving net-zero by 2050 and 100% renewable energy transitions. Fiji, the Solomon Islands and Vanuatu, for instance, aim to achieve 100% renewable energy by 2030. Overall, renewable energy capacity in the Pacific grew by 30% between 2014 and 2022 (WEF, 2024).

> Despite the constraints, the Pacific region is seeing growing interest in small-scale renewable energy solutions, especially off-grid and micro/mini-grid solar systems

However, financing remains one of the biggest hurdles in transitioning to clean energy in the Pacific. Shifting from centralized diesel systems to solar, wind or hydroelectric plants involves significant capital investment, which many countries in the region cannot afford on their own. In addition, private sector investment in renewable energy in the Pacific is quite modest (ADB, 2021). Private investors are often reluctant to commit to long-term renewable energy projects due to high perceived risks and the lack of access to affordable, long-term financing options.

ADB is a major funder of renewable projects in the region, including through the Pacific Renewable Energy Program (PREP), a financing structure that is designed to finance a series of renewable energy projects in the small Pacific Island states. ADB has also supported the long-standing Promoting Energy Efficiency in the Pacific initiative, which has helped catalyze energy efficiency investments across the region. Improving energy efficiency can also ease the cost of fuel imports and help existing power systems meet demand more affordably and thereby may result in reduced investment needed for the expansion of electricity generation (ADB, 2021).

International climate finance and technology cooperation must go hand in hand

At COP28, countries committed to tripling renewable energy capacity and doubling energy efficiency improvements –an ambition that places energy efficiency at the heart of global and regional energy policymaking (UNFCCC, 2023). For many developing countries in Asia, this signals an urgent need to integrate energy efficiency and renewable energy solutions into national investment strategies, supported by international climate finance and effective technology cooperation. Several Asian countries have reflected this in their Nationally Determined Contributions (NDCs), which prioritize renewable energy (RE) and energy efficiency (EE) measures. However, aligning with a Paris Agreement-compatible transition scenario will require significantly increased ambition, policy clarity and implementation capacity, especially through the 2025 NDC updates, which offer a crucial opportunity for countries to raise their targets (Tachev, 2025).

> Most financial resources are held by developed countries, making it hard for many Asian nations to attract the large investments needed for big changes

The region holds a window of opportunity to leapfrog into cleaner, more sustainable systems. Yet progress is often hindered by structural barriers, including high upfront costs of clean technologies, limited access to affordable finance and dependence on imported technologies (IEA, 2023d). While some countries like China and India are becoming technology exporters, many other Asian economies still rely heavily on foreign innovation and imports for low-carbon technologies.

A key challenge lies in the global imbalance in financial and technological resources. Most financial resources are held by developed countries, making it hard for many Asian nations to attract the large investments needed for big changes. Moreover, most climate technologies are developed by and exported from developed countries, with China being a notable exception (Yu, 2023). As a result, many Asian countries depend on strong partnerships and technology-sharing systems to access the latest solutions.

Strengthening international and regional cooperation is therefore essential. Enhanced South–South and triangular cooperation, including between more technologically advanced Asian countries and their neighbors, can play a significant role in bridging gaps in capacity and access. Initiatives like the India–EU Clean Energy and Climate Partnership, and regional platforms under the Clean Energy Ministerial involving Asian countries such as China, India, Indonesia and Japan, offer valuable pathways for knowledge exchange and collaborative innovation.

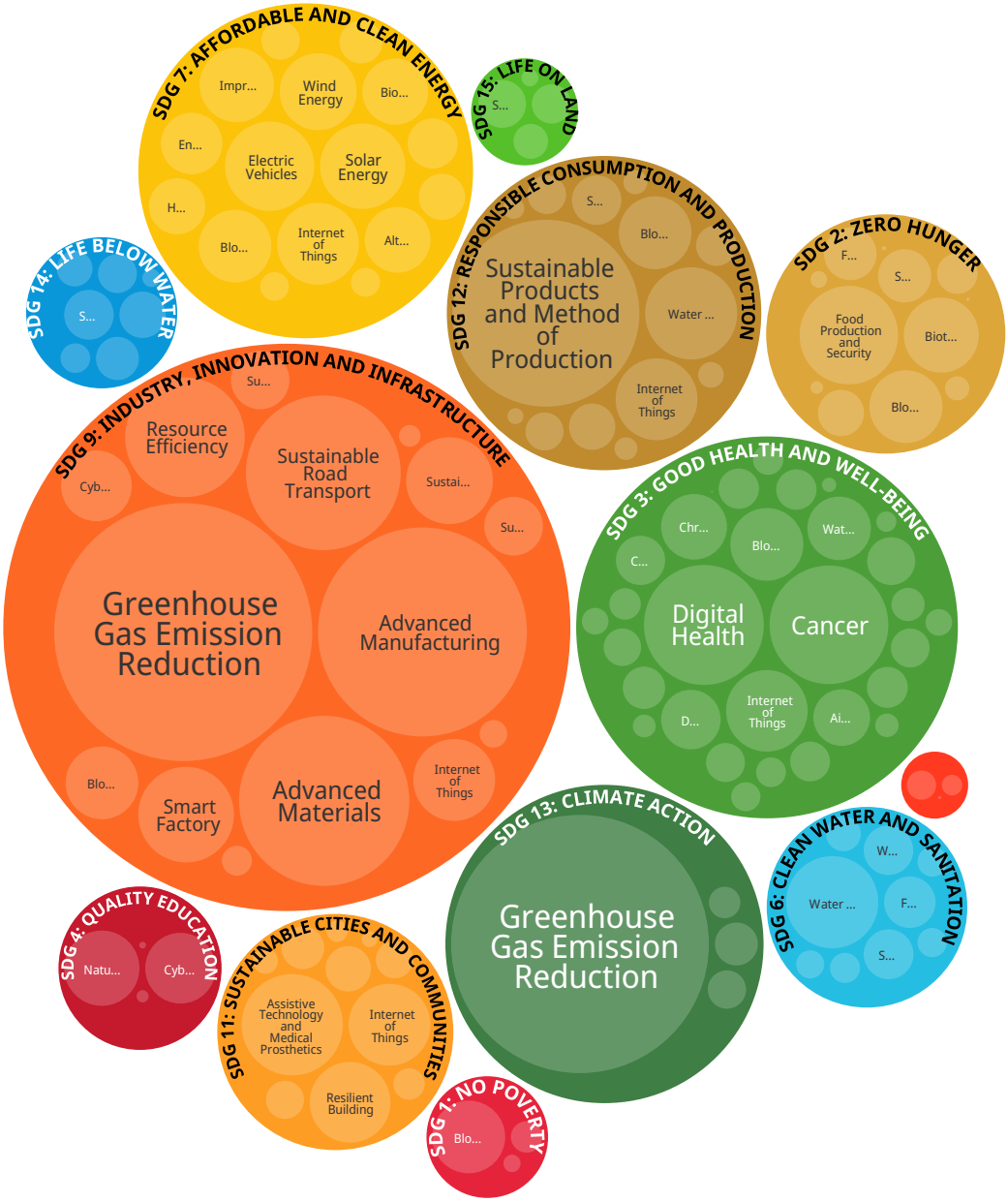
The role of innovation and intellectual property rights for clean energy technologies

Innovation for a sustainable future: Asia's commitment to the Sustainable Development Goals

Globally, innovation linked to the Sustainable Development Goals (SDGs) has seen steady growth, with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) showing particularly strong upward trends compared to most other SDGs. This is driven by technological advances in RE and efforts to cut greenhouse gas emissions. It reflects a growing awareness of and consumer preference for cleaner alternatives, aimed at improving energy efficiency and reducing carbon emissions (figure 1.5). Patent applications can be a good proxy for relative innovation activity levels in various sectors. Analyses of patenting patterns show that some technologies contribute to multiple SDGs; for instance, "Greenhouse Gas Emission Reduction"

falls under both SDG 9 (Industry, Innovation and Infrastructure) and SDG 13 (Climate Action). While SDG 13 focuses on technologies directly aimed at reducing emissions, SDG 9 includes broader innovations like upgrading infrastructure and retrofitting industries to improve energy efficiency and sustainability (WIPO, 2024d).

Figure 1.5 SDG-linked technologies (circle size is proportionate to number of active patent families)



Source: WIPO (2024d).

The Asia-Pacific region mirrors this trend, with a sharp rise in clean energy patenting activity reflecting strong alignment with these two SDGs. In China, the innovation landscape is led by companies like CATL, a major innovator and producer of batteries, who owns the second-largest share of SDG-related patents among the top 25 patenting companies in China, underscoring the active innovation in advancing storage technologies essential to clean energy deployment. Japan also demonstrates significant patent contributions toward the SDGs, especially from its top corporate innovators. Toyota Motor has shown a consistent upward trend in SDG-related patent activity, surpassing Panasonic in 2013 to become the country's leading filer. These patent trends highlight the strategic focus of Japanese industry on low-emission mobility, hydrogen technologies and energy-efficient manufacturing (WIPO, 2024d).

> Patent applications can be a good proxy for relative innovation activity levels in various sectors

In the Republic of Korea, Samsung, the country's largest patent holder, maintains a vast SDG-related portfolio, accounting for about 25% of its total patents. However, this share has remained stable as the company's overall patent activity grows across multiple sectors. Other Korean firms, including Hyundai Motor, LG Chemical, LG Electronics and Kia, have shown more varied but generally positive growth trends, particularly in sectors tied to electric vehicles, battery storage and energy-efficient electronics. Overall, the Korean landscape appears more diverse, presenting a mix of company sizes, SDG patent shares and growth trajectories, that range from highly positive to highly negative. This diversity likely stems from market consolidation within the Republic of Korea, where a few major players hold the majority of patents (WIPO, 2024d).

Although energy patent trends may not directly reflect market demand or predict the commercial success of a technology, analyzing them offers valuable insights into technological advancements, industry trends and regional innovation hubs. For further discussion on the innovation ecosystem for climate change technologies and intellectual property systems, refer to Chapter 2 of the *Green Technology Book* adaptation edition as well as WIPO patent landscape reports and the WIPO Global Innovation Index. More details on intellectual property rights are highlighted in Box 1.2.

Renewable energy (RE) boom in the Asia-Pacific region

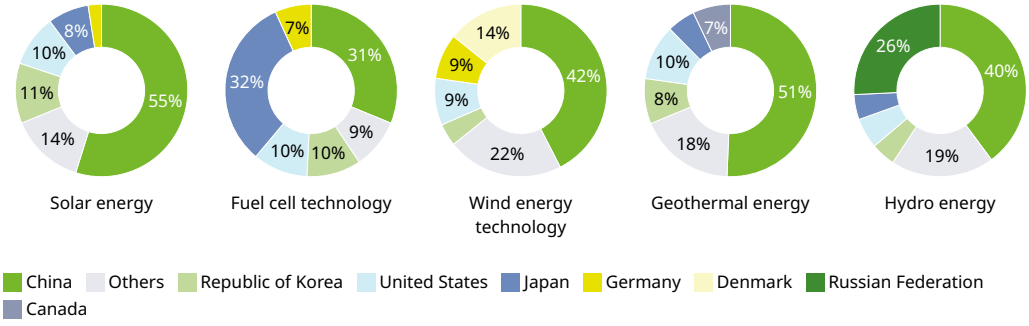
Technological advancements are playing a pivotal role in accelerating the adoption of clean energy across the Asia-Pacific region. Innovations in energy storage, grid modernization and RE generation technologies are significantly improving the efficiency, reliability and scalability of clean energy systems. The declining costs of solar panels, wind turbines and energy storage technologies have made RE more accessible and economically attractive, prompting substantial public and private sector investment. By 2024, utility-scale solar photovoltaic (PV) systems in the Asia-Pacific region had become the most cost-competitive globally, with RE generation proving approximately 13% cheaper than coal. Alongside leading the world in solar PV and onshore wind deployment, the Asia-Pacific region, led by China, is also set to accelerate the deployment of and further increase innovations in alternative clean energy technologies such as offshore wind, floating solar and green hydrogen (imarc, 2024).

> Energy patent trends may not directly reflect market demand or predict the commercial success, analyzing them offers valuable insights into technological advancements, industry trends and regional innovation hubs

This momentum is mirrored in the region's innovation landscape and patent activity. From 2007 to 2022, global patent filings for clean energy technologies, covering solar, wind, fuel cells, hydro and geothermal, grew from approximately 29,400 to 44,700 per year. Asia-Pacific countries, particularly China and Japan, have emerged as global leaders in this space. As shown in figure 1.6, China accounted for the highest share of global patent applications in four of the five technologies, including a dominant 54.9% in solar energy and 39.9% in hydro. Meanwhile, Japan

led globally in fuel cell innovation, contributing 32.1% of related patents. From 2020 to 2022, solar energy represented more than half of the energy-related patent filings worldwide (54.4%), followed by wind (19.4%), fuel cells (13.2%), hydro (11.4%) and geothermal (1.5%). Here, notable innovation trends include a focus on technologies that enable more cost-effective installation and manufacturing, and new types of organic PV cells design that enable solar integration into windows, wearables and other objects (EPO and IEA, 2021). These trends highlight the Asia-Pacific region's growing role as a hub of clean energy innovation, with strong potential to shape the global shift toward a more sustainable and low-carbon future (WIPO, 2024e).

Figure 1.6 Share of patent applications in energy-related technologies for the top origins, 2020–2022



Source: WIPO (2024e).

Box 1.2 Intellectual property rights

Intellectual property rights (IPR) are central for innovation. International agreements have created the foundations of an IPR system that allows for the protection of innovators' rights almost worldwide. Multi-territorial protection is crucial for cross-border technology transfer and technology marketing. It is also a cornerstone in the innovation ecosystem as discussed briefly in the introduction section. It is the mandate of WIPO as a UN specialized agency, to ensure that this system is functional and developing, ultimately for the benefit of global development. In relation to technology, patenting is the dominant way to secure IPRs. The system is based on rights granted by national or regional authorities for their respective territories, and there is no such thing as a global patent. While the Patent Cooperation Treaty (PCT) does not provide for centralized patent granting, it does simplify and make more cost effective the process of seeking patents in multiple countries.

A patent provides the innovator with rights to authorize or prevent the use of the invention in a certain territory for a certain period, typically 20 years from filing the application. In exchange, the innovator has to disclose detailed information on the invention publicly available so that anyone can understand, make and further develop an invention when it falls into the public domain. A technology protected by a patent of course cannot be used commercially in a country where a patent is still in force. In countries where no patent was granted, however, such use cannot be prevented by the holder. This significant quality of the IPR system has created an enormous repository of detailed technological information which is made publicly available in several very large patent databases. For example, WIPO's PATENTSCOPE database contains more than 120 million patent documents. The WIPO GREEN Database of Needs and Green Technologies contains a small selection (>135,000) of green technology patents. A patent contains the description of an invention, but it cannot be known from the patent document whether it is available on the market or even whether it was developed into a solution. WIPO GREEN has therefore created a special search function "Patent2Solution" which uses AI to search for an available solution based on the specific patent document. It can be launched from the patent description in the WIPO GREEN database. Patents can be analyzed for trends and geographical distribution and much more. It is to some degree a measure of innovation and numerous patent studies are published regularly, e.g. the *WIPO Patent Landscape Reports*, the *Global Innovation Index*, the *World Intellectual Property Indicators* and the *WIPO Technology Trends Report*. Often these analyses are based on patent families which are a group of patents that cover the same invention in different territories and share the same "original" application.

Asia's dominance in clean transport innovation and market growth

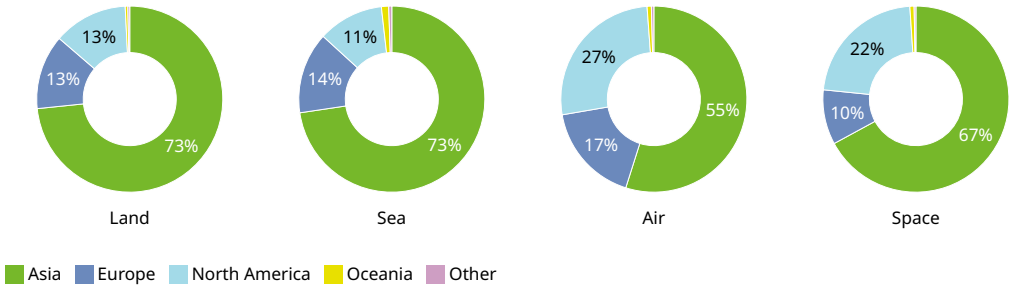
The global transportation sector is undergoing a profound transformation, driven by the rapid rise of electric vehicles (EVs), sustainable fuels and smart mobility solutions. As more EVs hit the roads and alternative fuels such as biodiesel, sustainable aviation fuel and green hydrogen gain traction, fossil fuel dependency is beginning to decline (Shan, 2025).

> Across all major transport modalities Asia leads in patent activity, with China, Japan and the Republic of Korea among the global top five countries

Innovation plays a central role in this transition. The global transportation sector has accounted for more than 40% of international patent families (IPFs) in low-carbon energy (LCE) technologies between 2000 and 2019. EV-related patents – including those for fuel cells and charging infrastructure – have surged, overtaking all other road transport technologies by 2011. Additionally, technologies aimed at improving energy efficiency in transport represent nearly one-third of all end-use technology patents, underscoring the sector's broader push toward sustainability (EPO and IEA, 2021).

Asia has emerged as the dominant region in transportation innovation. Across all major transport modalities – land, sea, air and rail – Asia leads in patent activity, with China, Japan and the Republic of Korea among the global top five countries (figure 1.7). Since 2018, China has emerged as the primary engine of innovation in this space, with its number of annual patent families nearly doubling from 38,900 to 76,000 by 2023, reflecting a robust 14.3% annual growth rate and underscoring the country's strategic investment in next-generation transport technologies (WIPO, 2025a). Despite China's rapid growth in land transport technologies, Japan remains dominant among top patent holders. Six of the top ten patent holders including Toyota, Denso, Honda, Panasonic, Nissan and Hitachi are Japanese. Toyota leads by a wide margin, with over 37,000 patent family publications from 2000 to 2023, more than double that of Denso, the second-highest (WIPO, 2025a).

Figure 1.7 Regional breakdown of patent families in different transport modalities



Source: WIPO (2025a).

While patent data reveals the scale of innovation, market dynamics provide a broader context. The global transportation market is a multi-trillion-dollar industry, with the Asia-Pacific region holding the largest and the fastest-growing share. This growth is propelled by rapid urbanization, population growth and major infrastructure investments, particularly in China and India. Additionally, the sector is being reshaped by the rise of e-commerce, advancements in automation and autonomous vehicles, and shifting regulatory frameworks aimed at sustainability and efficiency (WIPO, 2025a).

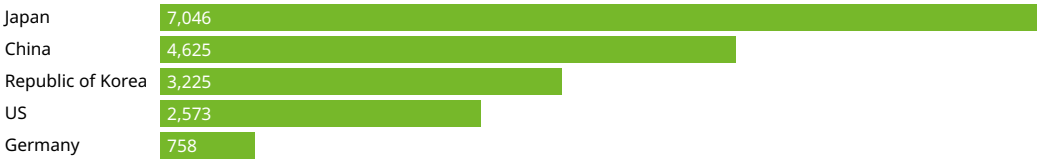
China and Japan dominate global patenting activity in sustainable propulsion, particularly in battery and electric drive technologies

A key sub-sector within this broader transformation is smart transportation, which integrates advanced technologies to improve mobility efficiency, safety and sustainability. Valued at USD 33.4 billion in 2024, the global smart transportation market is expected to reach USD 46.4 billion by 2029, growing at a compounded annual growth rate (CAGR) of 6.8%. Though it currently represents just 0.5% of the overall transportation industry, its role is expanding rapidly. Asia-Pacific is projected to experience the fastest growth, fueled by increasing traffic demands, governmental efforts to reduce greenhouse gas emissions and the emergence of megacities. Key enablers of this growth include technologies such as the internet of things (IoT) and artificial intelligence (AI), which are instrumental in advancing autonomous vehicles, intelligent traffic management systems and integrated mobility platforms. Recent developments highlight growing global collaboration in building smart infrastructure and integrating these technologies into real-world transport systems (WIPO, 2025a).

Sustainable propulsion systems are central to addressing the transport sector's climate, air quality and energy security challenges. China and Japan dominate global patenting activity in sustainable propulsion, particularly in battery and electric drive technologies driven by robust national strategies, industrial capabilities and R&D ecosystems. China leads with over 44,000 patent family publications in electric propulsion from 2000 to 2023, while Japan follows with more than 31,000.

Among corporate players, Toyota Motor leads in patent family publications for batteries, electric propulsion and hydrogen/fuel cells with more than 26,000 patent families published since 2000, while China is the technology leader in device-to-device communication, navigation and cloud technologies. Patent activity in solid-state batteries has surged over the past decade, driven by growing R&D efforts across industry and academia, especially in China, Japan and the Republic of Korea. With over 7,000 solid-state battery patent families published between 2000 and 2023, Japanese inventors accounted for nearly 40% of all filings in this field (figure 1.8).

Figure 1.8 Patent family publications in solid-state batteries, 2000–2023



Source: WIPO (2025b).

In parallel, Asian inventors are actively exploring alternative sustainable fuels – including biofuels, synthetic fuels and liquefied natural gas (LNG) – which can complement electrification by reducing emissions in sectors less suited to battery power (WIPO, 2025b).

Rapid ascent in predictive and autonomous technologies for precision agriculture

Patents within the agrifood sector comprise more than 3.5 million published patent families (inventions) filed over the past 20 years. Asia continues to assert its leadership in agricultural innovation. Interestingly, with respect to energy technologies, recent patent growth within the AgriTech subdomain (one of two under agrifood, alongside FoodTech) is driven by rising interest in automation and IoT-based solutions. The most dynamic areas of innovation include connectivity, sensors, smart farming systems, precision agriculture and mapping/imagery. Japan, second only to the United States of America, is a leading inventor location in multiple

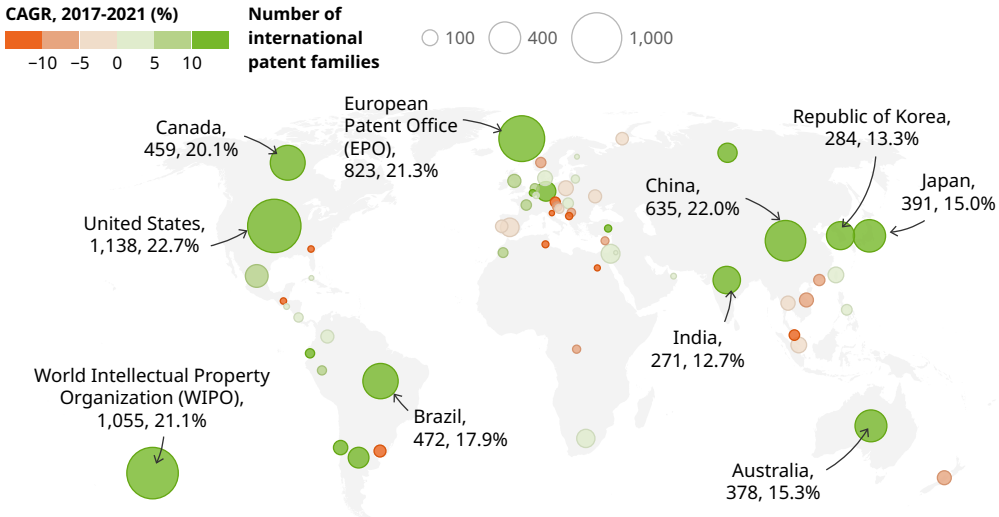
IoT-related technologies such as robotics and drones, economic and whole farm management software, livestock management and carbon farming, thus demonstrating its pivotal role in the digital transformation of agriculture. Patent filing data reflects this momentum as China leads Asia with 137,000 international AgriTech patents, followed by Japan (107,709), the Republic of Korea (64,099) and India (53,766). These are largely driven by agricultural machinery makers, agrochemical firms and tech giants such as Sony, LG and Samsung (WIPO, 2024a).

Asia continues to assert its leadership in agricultural innovation

One of the top four key research hotspots in AgriTech identified by WIPO is precision agriculture, including advancements in robotic/autonomous agriculture vehicles and automation through AI and software. Data analysis from 1,500 IPFs in the predictive models in the precision agriculture field shows a significant recent annual growth rate of 27.1%, underscoring increasing global interest within the topic sector. Figure 1.9 shows that Asia is a strong contributor to this trend, with China leading at 635 international filings, followed by Japan (391) and the Republic of Korea (284). Australia also stands out regionally with 378 filings. These innovations reflect Asia's growing commitment to sustainable and data-driven agriculture. Countries such as Bhutan, India and Viet Nam, are actively promoting digital technologies and smart farming systems – ranging from AI-driven advisory apps and carbon footprint tracking to weather warning platforms and digital traceability systems – to modernize agriculture and enhance productivity across diverse agro-ecological zones (WIPO, 2024a).

In the domain of autonomous devices in precision agriculture, Asia is a key player, with rapidly growing use of technologies in soil management, crop harvesting and food processing

Figure 1.9 Top filing authorities in the predictive models in precision agriculture field



Source: WIPO (2024a).

In the domain of autonomous devices in precision agriculture, Asia is a key player, with rapidly growing use of these technologies in soil management, crop harvesting and food processing to enhance efficiency and productivity across the sector. China tops the list with 1,379

international patent filings, followed by Japan and the Republic of Korea. Regionally, R&D output in Asia is substantial, with 1,177 IPFs focusing on autonomous agricultural technologies. The strong momentum in both predictive models and autonomous devices indicates Asia's strategic investment in agricultural automation and smart farming, positioning the region as a hub for future-ready agrifood systems (WIPO, 2024a).

2. Green urban energy solutions in the Asia-Pacific region

Photos: Unsplash/ Sandi Benedicta, Tyler Zhang

Low-carbon energy solutions in urban households

The Asia-Pacific region is home to rapidly growing cities as a result of general urbanization and population growth. This, coupled with improved living standards, leads to increasing demand for household energy technologies. From solar power systems and smart grids to energy-efficient appliances and demand-response technologies, cities in the Asia-Pacific region are embracing innovative approaches to address both energy challenges and sustainability goals. These technologies play a crucial role in shaping the future of urban living and fostering sustainable development across the region.

This chapter examines the diverse energy solutions implemented in urban households with an emphasis on enhancing energy efficiency and on minimizing costs and environmental impact. Energy is essential for heating, cooling, lighting, cooking and other daily needs. Growing consumer awareness is driving a competitive market for low-carbon technologies, supported by policies and standards to guide consumers toward real impact.

> Cities in the Asia-Pacific region are embracing innovative approaches to address both energy challenges and sustainability goals

While this chapter focuses on households with electricity access, it's important to note that around 700 million urban residents in Asia live in slums with limited access to reliable, affordable electricity, sanitation and water (Rowe, 2022). Many of these households still depend on unsafe, inefficient sources like firewood and kerosene for cooking and lighting, which pose health and environmental risks. Chapter 3 (Green rural energy solutions) discusses technological solutions to address such challenges, including clean cookstoves, solar lanterns, biogas and distributed renewable energy.

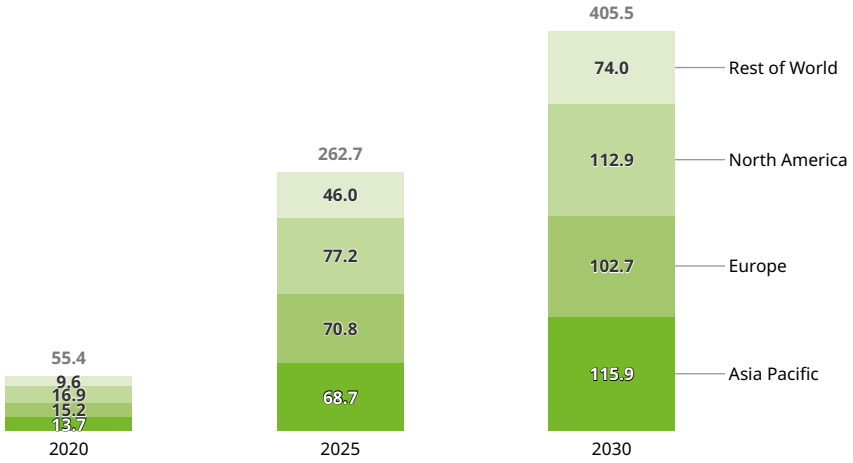
Technological development and trends

Asia's cities are at the forefront of smart home automation systems

A smart home system refers to a home setup of interconnected devices like lights, heating, cooling and ventilation (HVAC), and home appliances that can be controlled and monitored remotely via the internet, often through a smartphone or tablet, to enhance performance and save energy.

Driven by increasing urbanization, technological innovation and growing consumer awareness, smart home systems in Asia and the Pacific are evolving rapidly. The region is projected to lead the global smart home market by 2030, accounting for more than 25% of global market share (figure 2.1). This growth is fueled by the increasing adoption of smart devices and development of innovative technologies by Australia, China and Japan, with other big economies such as the Republic of Korea and Singapore also playing a key role. Governments across the region are actively accelerating the adoption of smart home technologies through both financial and non-financial incentives. These include subsidies for smart energy devices, tax incentives for smart appliances, and regulations that promote energy efficiency standards in new residential construction. For instance, in Singapore, government-backed programs like the Smart Nation Initiative offer grants and pilot projects to integrate smart technologies into public housing (Smart Nation Singapore, 2025). Meanwhile, in China, government investment and support for 5G and Internet of Things (IoT) infrastructure have led to widespread smart home implementation at the household level (Narcotta, 2024).

Figure 2.1 The global smart home market by region (in billion USD)



Source: Adapted from ATKearney (2016).

The popularity of products like Amazon Alexa, Google Assistant and Apple Siri is further driving smart home companies to deploy voice-enabled smart devices using the latest AI-powered technologies. With a growing middle class and higher disposable incomes, the region's tech-savvy consumers are increasingly embracing app-based control of smart home devices. Homeowners can now use smartphones or voice commands to control lighting, turn off heating in an empty home or start a dishwasher during off-peak energy hours which may lead to significant energy savings. A substantial 36% energy reduction is possible in homes with IoT-enabled solutions (Context, 2023).

> Demand for air conditioning is projected to increase to 60% by 2040, with nearly two AC units per household in the region

However, the challenge of high upfront costs, security concerns, strong data connectivity and consumer affordability remains a key barrier for smart home adoption in the region, especially in developing countries of South and Southeast Asia. To include a broader demographic, companies are innovating affordable smart home kits and flexible payment models which have seen a notable increase in sales (Context, 2023). As renewable energy and decentralized systems expand in urban areas, integrating solar panels and mini-grids with smart home systems is also becoming feasible, which improves energy efficiency and sustainability greatly through demand-response and home energy management systems.

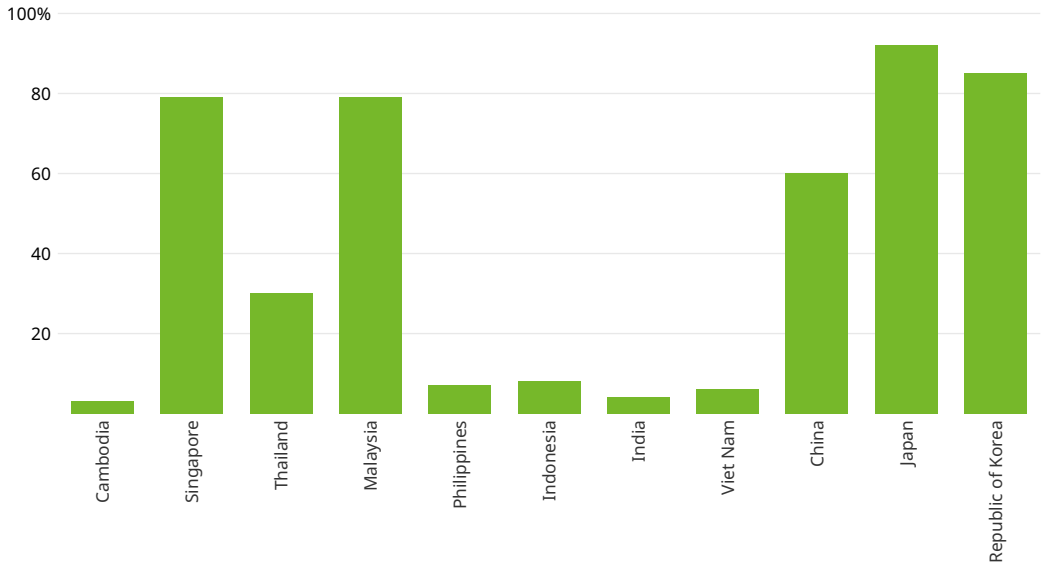
Space cooling is a major energy consumer for urban households in Asia

Cooling represents an increasing portion of household electricity demand in Asia, and without stronger policies, peak cooling demand could place significant pressure on power systems (IEA, 2019). As 83% of Southeast Asia's electricity generation mix is based on fossil fuel, more cooling leads to increased greenhouse gas (GHG) emissions.

Air conditioning is the most prevalent cooling technology in the whole region. The heat generated from air conditioners (ACs) contributes to the heat island effect and further increases the demand for cooling systems. In Australia and New Zealand, cooling accounts for 20% to 50% of energy consumption, depending on the climate zone (IEA, 2019). Meanwhile, in Southeast Asia, demand is soaring. Over the next two decades, an estimated 300 million new air conditioners will be installed, increasing the electricity demand from space cooling to 300 TWh in 2040 – surpassing India's current annual household energy use (IEA, 2022c).

However, there is a significant variation in air-conditioner ownership across Southeast Asia: over 80% of households in Brunei, Malaysia and Singapore owned an air-conditioner unit in 2017, compared to less than 10% in Cambodia, Indonesia, and Viet Nam (figure 2.2). Nevertheless, as incomes rise, demand for air conditioning is projected to increase to 60% by 2040, with nearly two AC units per household in the region (Cava, 2023).

Figure 2.2 Share of households using air-conditioning systems in 2017



Source: Adapted from IEA (2022c).

Hence, efficient cooling is necessary to save energy. One such technology is an advanced inverter that can adjust the compressor speed to match the cooling or heating demand, providing more consistent temperature control. This can reduce power consumption by 30 to 50% compared to non-inverter units (Raiz, 2024). The residential inverter air conditioner market is growing rapidly in Japan.

A simple thermostat can monitor a household's temperature and regulate heating and cooling. However, technological advancements such as smart thermostats go beyond simply regulating temperature. With the help of AI-driven automation and sensors, they can anticipate user preferences and adjust heating/cooling settings accordingly based on the time of day, occupancy patterns and even weather forecasts to save energy. This is often enabled by wireless connectivity and IoT technologies which allow for easy control through smartphone apps. More details on thermostat technology are available in the energy edition of the *Green Technology Book.*

> In Indonesia, 78 to 91% of households own stand fans, while in India more than 90% of households rely on ceiling fans for ventilation

An affordable and low-energy cooling alternative in Asia is household fans. They use up to 10 times less electricity than air conditioners (IEA, 2022c). Although fans do not lower room temperature like an AC, they can provide significant comfort in well-designed and energy-efficient buildings. In Indonesia, 78 to 91% of households own stand fans, while in India more than 90% of households rely on ceiling fans for ventilation (Surahman *et al.*, 2022).

Additionally, the integration of thermal storage and heat pumps, along with efficient energy management and operations, can contribute to energy savings.

Thermal storage and heat pumps: a key to reducing energy consumption

Adding thermal storage systems with renewable energy sources like solar photovoltaics (PV) in residential buildings can effectively manage space heating/cooling demand by storing excess energy during times of high renewable generation. The system powers devices such as heat pumps or electric heaters/coolers, which convert electricity into stored thermal energy (heat or cold), typically held in materials like water, ice or special phase-change materials (PCM) which store and release thermal energy by changing their physical state. This stored energy is then used to heat or cool the building when needed, reducing reliance on grid electricity and improving overall energy efficiency. One study showed that in Brisbane, Australia, a space cooling system in residential houses with thermal storage coupled with a solar PV system and a domestic heat pump, reduced summer grid electricity demand by 79% (Yuanyuan *et al.*, 2020).

The heat pump is an emerging technology among the myriad energy-efficient options in Asia. Technologically similar to air conditioners and often combined in the same unit, it is more energy efficient than boilers or electric heaters as it transfers heat instead of generating it. Moreover, new types of refrigerants are gradually decreasing the negative atmospheric heating effect of traditional refrigerants (see the *Green Technology Book* mitigation edition). Box 2.2 describes more about the heat pump.

Box 2.2 Heat pump technology

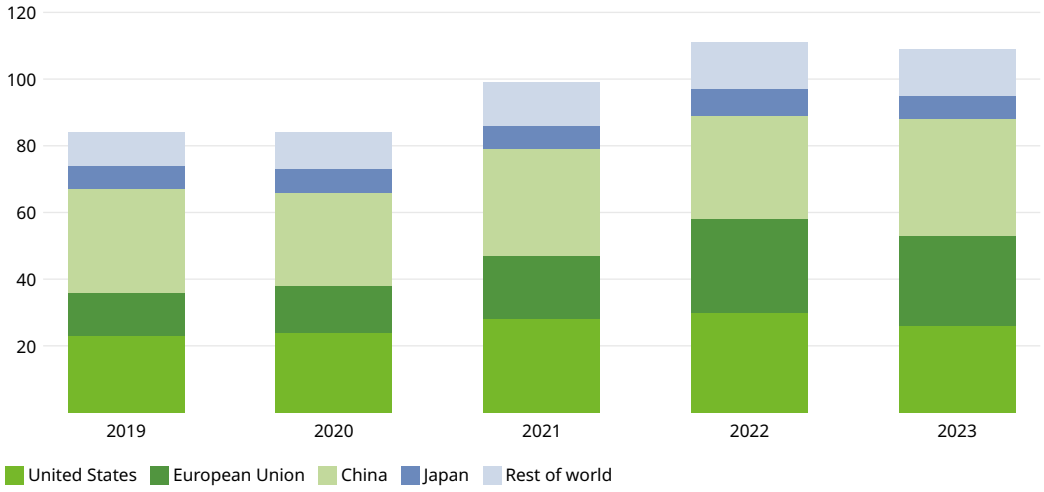
A heat pump transfers heat using a refrigeration cycle with four main parts: evaporator, compressor, condenser and expansion valve. The evaporator absorbs heat from the air, water or ground, turning the refrigerant into a gas. The compressor then compresses and heats the gas, which then moves to the condenser releasing heat into a home or water heating system. Finally, the expansion valve lowers the pressure, cooling the refrigerant back into a liquid to repeat the cycle. A typical household heat pump generates four times more heat than the electricity it uses for its operation (IEA, 2022b).

An air-to-air heat pump transfers heat between indoor and outdoor air, warming spaces in winter by absorbing heat from outside and cooling them in summer by removing indoor heat. These systems are commonly used for space heating and cooling through ducts or wall-mounted units. An air-to-water heat pump extracts heat from the air and transfers it to water for use in radiators, underfloor heating or hot water. It works well with low-temperature heating systems. While more expensive initially, they become cost-effective over time. In China, app-controlled smart air-to-water heat pumps are gaining popularity.

Solar-assisted heat pumps (utilizing solar energy captured via solar thermal collectors, to heat the refrigerant) are gaining popularity. Ground-source heat pumps (GSHP) are also being researched. They use geothermal energy transferred from the subsurface to the pump using closed-loop pipes.

However, this technology currently meets only about 10% of the world's building heating needs (IEA, 2024c). The adoption of heat pumps also varies across Asia-Pacific. In the urban landscape of East and Southeast Asia, like Tokyo, Taipei and Ho Chi Minh City, heat pump technology is ubiquitous. In Japan, 90% of households are equipped with combined heat pump and air conditioners, which are also being used in new applications e.g. clothes dryers. China currently holds the largest share of the global market for heat pumps for buildings (figure 2.3).

Figure 2.3 Heat pump sales by country or region, 2019–2023 (capacities, GW)



Source: Adapted from IEA (2024c).

Passive cooling strategies – the promise of cool and green roofs

Research indicates that 70% of the total heat gain in a building is generated through the roofing structure, which leads to increased energy use for cooling, accounting for around 15% of a building's total energy consumption (Ling Ho *et al.*, 2024; Al-Obaidi *et al.*, 2014). Therefore, sustainable roof design is drawing considerable attention to the energy conservation of a building, especially for vulnerable populations in hot climate areas. Technologies like cool roofs and green roofs can help mitigate the urban heat island effect by lowering the energy consumption of a building's air conditioning and reducing carbon emissions.

A cool roof is a roofing system designed to reflect more sunlight and absorb less heat than standard roofs. This is typically achieved using reflective materials such as slate or tile, white concrete and clay tiles, etc. or by applying coatings with infrared reflective pigments. Cool roofs are suitable for a variety of applications, including flat and low-slope roofs, pitched roofs, new construction or retrofitting. The Asia-Pacific region leads the cool roofs market, holding the largest share at over one third, while China and India are the top producers globally, contributing 30% and 20% of total production, respectively (Hardman and Well, 2023).

> China and India are the top producers of cool roofs globally, contributing 30% and 20% of total production

High-albedo coatings, such as those with cementitious or elastomeric binders, typically have reflective thermal properties and are usually white. They keep the surface temperatures only about 5°C warmer than the air, whereas conventional roofs can reach 40°C above air temperature. More details are given in Box 2.1. Ongoing research aims to create innovative coatings in non-white colors to maintain building aesthetics. However, in Southeast Asia, research and adoption of highly reflective roofs are still modest (Dahim *et al.*, 2022).

A green roof is a rooftop covered with vegetation, soil and a drainage system. It helps reduce building energy consumption by providing natural insulation and keeping buildings cooler in summer and warmer in winter. Green roofs also absorb rainwater and release moisture through evapotranspiration, which can further cool the surrounding environment. They are commonly used in cities like Singapore to maximize space utilization and lower energy costs. More green roof technologies are described in the next sub-chapter on public spaces and transport.

Box 2.1 Cementitious or elastomeric binders

Cementitious binders are made from cement, lime, or mineral-based materials. They help maintain a cooler building temperature when used in roof coatings or tiles. They are fire-resistant, weatherproof and moisture-resistant, and suitable for various climates.

Elastomeric binders, derived from acrylic, silicone, or polyurethane, offer flexibility to accommodate thermal expansion and contraction. Applied as a liquid, they form a durable, rubber-like layer that adheres to different roofing materials, including metal, concrete and polyurethane foam. They withstand sun, rain and temperature changes, with minimal maintenance.

In China, cool roofs reduced energy use by 12.6%, while green roofs saved 9.3% in hot summer, warm winter regions (Zhao and Zhang, 2023). Other passive cooling strategies include efficient building design such as better insulation, high-performance windows, airtight construction and solar shading, which reduce AC demand.

Building energy codes are a powerful tool in reducing energy-related emissions

A combination of passive and mechanical cooling strategies is essential to reduce energy use and emissions in buildings while ensuring comfort (UNEP, 2021). Building energy codes (regulatory standards applied during design and construction) are key to achieving this, as they regulate the building envelope, HVAC systems, lighting and water heating to reduce energy consumption. By incorporating passive cooling and enhancing mechanical efficiency, these codes can control up to 80% of a building's energy load. In China, enforcing these codes across urban, commercial and residential sectors could cut energy demand by 13 to 22% by the end of the century (UNEP, 2021). While codes set minimum requirements, building energy ratings assess actual or expected energy performance, offering guidance for owners and buyers. In Asia, several countries have adopted building rating systems, such as BCA Green Mark in Singapore, or BEE Star in China and India's Building Energy Label, to encourage higher energy efficiency in buildings.

Cooling as a service (CaaS) for energy-efficient solutions

CaaS is an innovative and cost-effective business model. Under the CaaS model, customers pay for cooling on a subscription or pay-per-use basis rather than purchasing and maintaining cooling equipment themselves, which is a major issue in many developing countries in Asia. The service provider handles all operations and maintenance, which also enables them to secure financing for energy-efficient systems. For example, in Elpro Business Park in Pune, India, a Singapore-based company, Kaer, implemented a CaaS model to supply an energy-efficient and smart cooling solution to residential, office and community spaces using a centralized chilled water system powered entirely by solar energy. Beyond commercial projects, CaaS also supports small-scale, off-grid refrigeration, reducing emissions and benefiting local communities.

Policy initiatives to boost energy efficiency in cooling

A range of policy packages such as Minimum Energy Performance Standards (MEPS), labeling programs and incentives form the foundation for progress on efficient, sustainable and affordable cooling options across the Asia-Pacific region (IEA, 2022c). MEPS have significantly influenced the efficiency and innovation of the air conditioner market in Australia and New Zealand. Energy labels also help encourage the uptake of better technologies. In many countries of Southeast Asia, inaccurate labeling of ACs makes it difficult for the consumer to identify the best option.

Another initiative like India's Cooling Action Plan, covering space cooling in buildings, AC technology, cold-chain and refrigeration, and transport air conditioning, seeks to reduce cooling energy requirements by 25% to 40% by 2038. Again, under China's Green Cooling Action plan, major cooling products are targeted to be at least 30% more efficient by 2022 (IEA, 2019).

Solar energy integrates with grid power for urban living

In many Asian cities, solar energy is increasingly integrated with grid power to meet the rising electricity demand for heating, cooling and everyday appliances in the households. Rooftop solar panels, building-integrated photovoltaics (BIPV) on façades and roofs, and community solar projects (enable multiple users to share a large solar installation eliminating the need for individual rooftop systems), are helping residents reduce reliance on conventional grid electricity while lowering energy costs and carbon emissions. The International Energy Agency (IEA) projects that by 2030, around 100 million households will rely on rooftop solar PV globally (IEA, 2022a). Tools like the Solar City Simulator can support this transition by helping urban households assess their potential to generate electricity with rooftop solar PV systems (IRENA, 2025). This web-based application developed by IRENA combines ultra-high-resolution three-dimensional building footprints with solar irradiation data to estimate energy output and calculate likely savings compared to other power sources.

> With CaaS, customers pay for cooling on a subscription or pay-per-use basis rather than purchasing and maintaining cooling equipment themselves

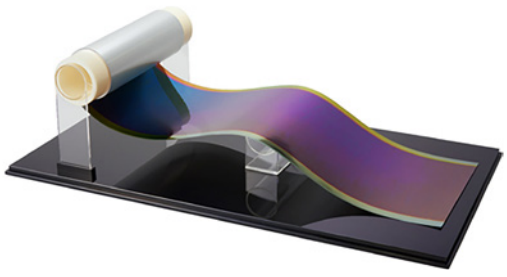
Many urban dwellers now combine solar panels with battery storage, allowing them to act as 'prosumers' of energy (a combination of producer and consumer of energy), where they can produce their own decentralized energy, optimize self-consumption of the generated electricity, store for later use or sell the unused electricity back to the grid. As a result, solar energy is not just an alternative but a complementary source to urban grid power, enhancing energy resilience and sustainability.

Perovskite solar cells: a promising next-generation solar technology

Recent advancement in solar technology is perovskite solar cells (PSC) – a very thin, lightweight and flexible technology that can even be painted to a structure to generate electricity (figure 2.4a and b). The cells are made from crystalline 'perovskite,' a material capable of converting a broader spectrum of sunlight into electricity. Combining with different solar cells, PSC technology can achieve high conversion efficiencies, which is not possible by traditional crystalline silicon solar cells (Zhao, 2024). In addition, PSC technology enables low-cost production through special coatings, making them a promising next-generation solar power technology that could be more affordable.

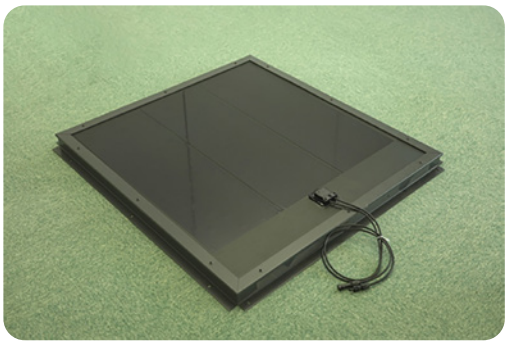
Commercial scalability of perovskite solar cells remains uncertain due to their shorter lifespan and environmental concerns over lead content. Sekisui Chemical company, based on their house research, has mounted the first film-type perovskite solar cells on the exterior walls of its Osaka Head Office building in Japan, designed to achieve stable power generation for 20 years (Sekisui, 2023).

Figure 2.4a Power generation layer of film-type perovskite solar cells



Source: Sekisui, 2023.

Figure 2.4b Building material panel of film-type perovskite solar cells



Source: Sekisui, 2023.

Increased focus on residential batteries as energy storage systems

As Asia prepares to transition to renewable energy, battery energy storage systems (BESS) have come to the fore, particularly for residential use. These systems store electricity from the grid or solar panels, provide backup power during outages and even integrate with electric vehicle (EV) chargers. Lithium iron phosphate (LFP) batteries, a type of Li-ion battery, are becoming popular due to their longer lifespan and safety, as they are less prone to fires or thermal runaway.

BESS can be retrofitted to existing electrical setups, offering energy savings even without solar panels by taking advantage of time-of-use tariffs. These reduced off-peak rates, commonly available in countries like China, India, Japan, the Republic of Korea and Singapore, allow consumers to charge batteries during low-demand hours and use the stored energy during peak hours. Smart-controlled batteries, integrated with energy apps, can further optimize savings by automatically coordinating the use of solar power, battery storage and time-of-use tariffs. An AC coupled or hybrid inverter communicates between the solar panels, battery and home to convert the power from DC to AC for home supply.

> As Asia prepares to transition to renewable energy, battery energy storage systems have come to the fore

Portable power stations or plug-and-play home battery systems are also widely used. They work like a large power bank for home appliances, such as phones, air conditioners, refrigerators, ovens, microwaves etc. serving as home backup power during outages. They simply plug in to a standard, dedicated wall socket with its own circuit breaker, ensuring safe integration with home electrical systems. Their ease of use makes them ideal for apartments and homes without complex electrical setups or rooftop solar installations.

LED is the most efficient and rapidly advancing lighting technology

Standard LED bulbs have become a staple in households across Asia, replacing incandescent and compact fluorescent lamp (CFL) bulbs. They consume significantly less energy and have a longer lifespan, making them cost-effective over time. Compared to a conventional incandescent bulb, residential LED bulbs consume at least 75% less energy and last up to 25 times longer (US Department of Energy, 2024). China, Japan and the Republic of Korea are leading in LED technology in Asia. In Hong Kong, China and Singapore, recessed LED ceiling lights and downlights are getting popular, especially with smaller apartments, as they provide bright, affordable and space-saving solutions in addition to energy saving.

Rising household incomes have driven a surge in demand for advanced kitchen appliances like convection ovens and smart microwaves

In some countries of Asia, energy efficiency policies encourage widespread adoption of LEDs in residential areas. For instance, in India, programs like the UJALA scheme promote energy-efficient LED bulbs for households at subsidized rates, with millions of LED bulbs distributed to reduce energy consumption. The estimated energy saving from this shift has reduced GHG emissions by 112 billion tons of CO_2 per year, while 20GW of electricity generating capacity has been avoided (Oksen, 2020)

Efficient and smart cooking appliances are in demand

In Asia's urban households, clean and efficient cooking solutions like electric stoves are gaining popularity. However, affordability remains a challenge, especially for low-income families in semi-urban areas. In countries like Bangladesh, high import costs further limit access to modern cooking appliances. To address this, innovative business models are emerging. Social enterprises like ATEC introduced PAYGO (pay-as-you-go) models, allowing households to pay just USD5 per month for energy-saving electromagnetic induction stoves (IRENA, 2024a). These eCook stoves function at over 90% efficiency, offering lower running energy costs than liquefied petroleum gas (LPG). However, although they are safer, cleaner and well-suited for urban homes with reliable electricity, their adoption can be constrained by cultural cooking practices and cookware preferences. For example, some traditional dishes that require high heat or the use of clay pots may not be compatible with eCook stoves. Addressing these limitations requires adaptable stove designs, user education and behavioral change, and community engagement to ensure long-term uptake.

Meanwhile, in wealthier urban households, smart cooking appliances are transforming kitchens. Smart rice cookers are trending in countries like China, Japan, the Republic of Korea and in Southeast Asia where rice is a staple food. Smart rice cookers with built-in sensors optimize cooking times while reducing energy use. IoT-enabled stoves, air fryers and slow cookers allow real-time energy monitoring and remote control via smartphone apps. Air fryers cut energy consumption compared to traditional ovens, while slow cookers operate on low wattage, reducing electricity costs while enhancing flavors. Across income levels, energy-efficient cooking technologies are shaping the future of home kitchens. Rising household incomes in India and Southeast Asia have driven a surge in demand for advanced kitchen appliances like convection ovens and smart microwaves, with purchases increasing by 15 million units between 2020 and 2023 (Tiwari, 2024). Several governments in the region are partnering with the private sector to develop and promote smart kitchen appliances. However, high costs remain a significant barrier to broader adoption. For instance, high-efficiency induction stoves in Australia can cost two to three times more than conventional models, often exceeding USD 1,200 per unit (Tiwari, 2024). This price gap may limit mass adoption, particularly in price-sensitive markets like India, where many households find these appliances unaffordable.

Innovation examples

Japan's Green First ZERO energy house

Source: Sekisui House

Sekisui House's Green First ZERO (ZEH) homes are gaining popularity for their energy-saving and energy-generating capabilities, reducing CO_2 emissions without sacrificing comfort. The Sha-Maison Green First model, launched in 2013, offers low-rise rental apartments with photovoltaic systems, allowing tenants to reduce utility costs and sell surplus electricity. ZEH standards vary, offering up to a 100% reduction in energy consumption. Sekisui House also developed disaster-resilient Green First HYBRID homes, which combine photovoltaic panels, fuel cells and an emergency power supply board. In case of power outages, HYBRID homes can maintain power to essential appliances, unlike homes with only solar panels or fuel cells. These homes offer 88% CO_2 emission reduction compared to standard homes, making them a strong option for both sustainability and disaster preparedness (Sekisui, 2020).

Singapore's energy saving "Tree House"

Source: City Developments Limited

One innovative green wall in a residential building in Singapore is the "Tree House" condominium, located in the Bukit Timah area. The Tree House is home to one of the world's largest vertical gardens, earning a Guinness World Record for its impressive size in 2014. Spanning 2,289 square meters and 24 stories high, the garden is expected to save over $500,000 annually in energy and water costs. It features heat-reducing windows and motion-sensor lighting for added efficiency. Designed by City Developments Limited (CDL), the green wall filters pollutants and carbon dioxide, reducing the estate's carbon footprint and cooling energy needs. The vertical garden serves as a "Bio-shield," enhancing greenery continuity with the surrounding environment while lowering solar radiation. Additionally, three layers of sky gardens on the 7th, 13th and 19th floors, adorned with climbing plants, provide extra green space and shade for residents, further contributing to the building's sustainable design (City Developments Limited, 2014).

Technology solutions

Proven technologies

Energy efficiency: CoolRoof® System

BMI Malaysia

Source: Getty Images/beekeepx

The BMI CoolRoof® System naturally reduces indoor heat by limiting heat transfer through the roof. It combines radiant heat reflectivity with a ventilation gap to optimize roof performance in hot, humid climates. Research in Malaysia and Europe showed that buildings with the system can be up to 10°C cooler than those with conventional roofs. Its five key elements (roof tiles, ThermaFoil®, counter battens, CompactRoll® Plus and pest guard) reduce heat build-up, promote natural airflow and lower indoor temperatures, leading to reduced air conditioning use and energy savings. Additionally, the system requires no maintenance as it operates without electricity or mechanical components.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Malaysia
- Availability: China, India, Indonesia, Malaysia
- Contact: WIPO GREEN Database

Energy efficiency: SEAL-N-COOL acrylic waterproofing coating

Dolphin Floats (Pvt) Ltd.

Source: Getty Images/Toa55

Source:SEAL-N-COOL coating significantly reduces solar heat gain at the terrace slabs and concrete walls, enhancing comfort and lowering air conditioning usage and electricity costs. Field tests show a reduction in terrace slab temperatures by 15°C to 17°C. In addition, it waterproofs slabs and walls, withstanding up to 45 feet of water pressure. The product's UV and heat resistance, along with anti-fungal properties, contribute to its durability. With a white, lustrous finish, SEAL-N-COOL also serves architectural purposes, offering both functional and aesthetic benefits.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Low
- Place of origin: India
- Availability: India, Lebanon, Qatar
- Contact: WIPO GREEN Database

Energy efficiency: nano-modified heat-reducing floor paint

Starshield Technologies (Pvt) Ltd.

Source: Getty Images/towfiqu ahamed

Star Cool Shield-Floor is a state-of-the-art nano-modified energy-saving coating designed for metal roofs, granite floors and marble floors. With an outstanding Solar Reflectance Index (SRI) of 130, it reflects up to 97% of solar heat, effectively reducing indoor temperatures and lowering air conditioning costs by 19.2%. Its heat-reflective technology of high-albedo paint maximizes solar heat deflection, offering a powerful solution for roof cooling. In addition to energy savings, the coating is highly durable, capable of withstanding extreme weather, UV exposure and corrosive elements, ensuring long-lasting protection with minimal maintenance.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: India
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: smart home automation

Home-A-Genius

Source: Getty Images/Thitima Uthaiburom

The Home-A-Genius Smart Home Hub is a smart home system allowing homeowners to connect and control a wide range of devices – such as air conditioners, refrigerators, lights, TVs, washers, CCTV, blinds and more – through a single app. It fits in the palm of the hand. Built with (2) 3.0 ports, the smart Hub allows for direct LAN connection with the home router, ensuring the most optimal network performance and stable connectivity of almost any smart devices, eliminating the need for multiple apps. By using sensors, timers and custom programming, Home-A-Genius enables automated control of appliances based on user preferences or preset conditions. It also incorporates smart meters and sensors to track real-time energy consumption, helping homeowners identify opportunities to reduce energy usage and make efficient adjustments.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Singapore
- Availability: Singapore
- Contact: WIPO GREEN Database

Machines and appliances: energy-efficient smart induction cooktop

Samsung

Source: Getty Images/PaulVinten

Samsung's smart stainless steel induction cooktop combines energy efficiency with cutting-edge technology, transferring up to 90% of heat directly to cookware for minimal energy loss. Featuring Flex Zone technology, it adapts to pots of various sizes and shapes. The Virtual Flame™ LED display mimics the appearance of gas flames, giving users a familiar visual cue while delivering the precise temperature control and efficiency of induction cooking. Bluetooth connectivity syncs fans and lights with active burners for seamless operation. It connects to SmartThings, which is Samsung's home automation application that helps users to activate home appliances through smartphones.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Republic of Korea
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy storage: all-in-one balcony solar energy storage system

Huntkey Grevault

Source: Huntkey Grevault

The Huntkey Grevault 2.5KWh all-in-one balcony solar energy storage system is a solution for homeowners seeking greater energy independence and reliable power. It is designed for high efficiency and ease of use. With a built-in battery and plug-and-play functionality, the system is simple to install – whether mounted on the wall or placed on the ground. The entire setup takes less than 30 minutes. The energy storage unit provides power during nighttime or rainy conditions, ensuring a stable electricity supply even when solar power is not available.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: Bathbox, a tankless water heater system

AOS Bath Pte Ltd

Source: Getty Images/MileA

AOS Bathbox is a revolutionary tankless water heater that combines space-saving design with energy efficiency, making it an ideal investment amid rising electricity costs. Its sleek, minimalist appearance allows it to seamlessly fit into small bathrooms without exposed pipework, addressing aesthetic concerns for homeowners, especially in Housing and Development Board (HDB) units. HDB flats are the most common form of housing in Singapore, accommodating a significant portion of the population. Unlike conventional smaller heater tanks that often lead to insufficient hot water supply, the Bathbox offers automated temperature settings, eliminating the need for manual adjustments. By reducing heat loss typical of tank systems, users can save up to $124 annually by switching off the storage water heater after use. Although it is not an instant heater, the Bathbox allows users to select their preferred showerheads without compromising water pressure, providing an eco-friendly and customizable showering experience.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Singapore
- Availability: Singapore
- Contact: WIPO GREEN Database

Energy storage: next-generation hybrid energy storage system with AI-based control

Smart Star

Source: Smart Star

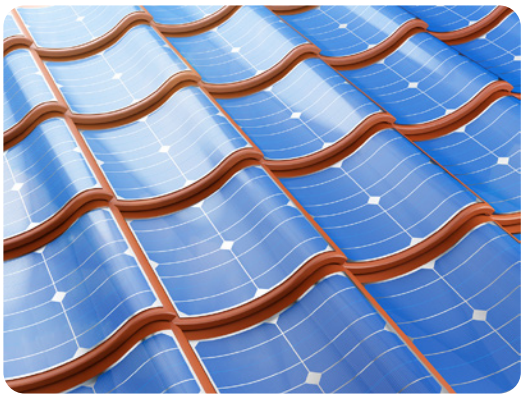
The Smart Star series is a next-generation home energy storage system, integrating AI-powered GridShare software to optimize battery performance. By learning household energy use patterns and forecasting solar power generation using weather data, it intelligently manages battery charging and discharging for maximum efficiency and cost savings. The system supports both photovoltaic and storage operations, ensuring reliable and economical power usage. With a 9.5kWh capacity, it can cover a typical household's daily energy needs and power multiple appliances simultaneously, including 200V devices like air conditioners and induction cookers, even during outages. Users can monitor and control the system anytime via the dedicated app.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Frontier technologies

Energy supply: curved solar roof tiles

San-gobuild



Source: Getty Images/Iaremenko

Source:Those who want to keep the house aesthetics while having clean energy, can opt for Apollo Tiles. Unlike traditional solar panels, these curved solar roof tiles integrate directly into the roof structure, serving as both a roofing material and a solar energy generator. Measuring 586 x 400 mm, these solar tiles feature a sleek and compact design that integrates seamlessly into the roofing while enhancing aesthetics. Weighing only 5 kg, they are lightweight and easy to handle, facilitating straightforward installation. Each panel provides a peak power output of 35 watts, ensuring maximum energy efficiency by effectively harnessing sunlight for sustainable electricity generation. With a lifespan exceeding 25 years, these panels offer a durable and reliable energy solution with long-term value.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy supply: bifacial solar panel for home

Namkoo Power

Source: Getty Images/Ivan Koliadzhyn

For those considering building sunrooms or conservatories to maximize natural sunlight while enhancing energy production from building-integrated photovoltaic systems, such as building façades, bifacial solar panels offer an ideal clean energy solution. The panel efficiency is 320W ~ 460W and allows energy generation from both sides simultaneously, which significantly enhances power efficiency. These panels are equipped with high-efficiency Passivated Emitter and Rear Cell (PERC) technology in a half-cell configuration, resulting in higher power output, better performance in varying temperatures, reduced shading impacts, lower risk of hotspots and enhanced mechanical loading tolerance. Traditional monocrystalline silicon cells have a light conversion efficiency of around 19%, but these new bifacial solar cells can achieve efficiencies of 20% to 30%. Unlike mono-facial panels, bifacial solar panels utilize direct sunlight on the front and reflected sunlight from the back, making them more effective in energy production. Additionally, they require less space than conventional single-sided panels, as they can generate power without needing additional land, although they perform best when installed over light-colored surfaces.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: nano glass coating transparent paint

Heatcure

Source: Getty Images/Aleksandr Potashev

Suitable for all the glass surfaces such as windows, glass roofs and doors, this is a solution to combat the increasing heat. HeatCure is a transparent, cutting-edge nanotechnology-based liquid glass coating designed to enhance home interiors by improving heat protection. Being transparent, it also allows 75% more natural light than conventional paint or coating. It offers durability, comfort and energy savings. Its innovative design blocks 99% of UV rays, protecting furnishings from fading, and blocks 98% of infrared rays, reducing heat transfer through glass to maintain a stable indoor temperature. By blocking 85% of heat, it helps lower air conditioning costs and improves overall comfort. The coating dries quickly, reaching full cure within 3-4 hours, and can cover 300–400 square feet per day, ensuring minimal disruption during application. It helps keep homes cooler in summer by reducing heat transfer and warmer in winter by retaining indoor heat. By regulating the temperature between the glass and the room, it creates a more consistent and energy-efficient indoor climate.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: India
- Availability: Worldwide
- Contact: WIPO GREEN Database

Machines and appliances: front loading washer/dryer with heat pump

Hitachi Global Life Solutions

Source: Getty Images/PaulinaOK

The Big Drum, a front loading high-capacity washer-dryer, uses heat pump technology for high-speed airflow and powerful ventilation to dry clothes while reducing wrinkles. The heat pump system saves time and energy, with front-directed airflow ensuring a polished finish. The low-temperature drying, around 65°C, gives clothes a soft, gentle feel. The washer-dryer also detects the humidity inside the drum to prevent uneven drying and stops before over-drying, helping to reduce energy consumption and protect clothes. By creating a highly humid environment and blowing air at high speeds, it not only minimizes wrinkles but also removes odors – making it a practical solution when ironing is not an option before heading out. The “Rakuhaya Wind Iron” and “Steam Iron” features further reduce wrinkles, though effectiveness varies by load and fabric type. Compared to traditional models, this washer-dryer cuts electricity use by 37% and water by 25%.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Space heating and cooling: R290 DC inverter air source heat pumps

SPRSUN

Source: SPRSUN

R290 heat pumps offer efficient, eco-friendly heating and cooling, and hot water solutions for a variety of homes, including single-family houses, apartments, villas and residential complexes. The new R290 heat pump combines natural refrigerant R290 with inverter heating technology, enabling it to operate efficiently across a wide temperature range from -25°C to 45°C while maintaining a high Coefficient of Performance (COP) and stability. It can heat water up to 75°C without relying on auxiliary electric resistance heating and utilizing only its DC inverter-driven heat pump cycle to enhance low-temperature heating performance. In cold climates, it delivers 30% more heating capacity than traditional heat pumps. R290 refrigerant offers exceptional energy efficiency due to its low freezing point and high latent heat of evaporation, speeding up cooling and minimizing energy consumption. The unit can reduce energy usage by 15% to 35% and, with a GWP as low as 3.3, it contributes significantly to lowering carbon emissions. Rated with an A+++ energy label, it saves 50% to 80% more energy than comparable systems. Featuring WiFi-enabled smart controls, it allows remote operation via an app and includes intelligent defrosting and smart grid (“SG-Ready”) integration for optimized energy use.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Machines and appliances: smart rice cooker

Tiger Corporation

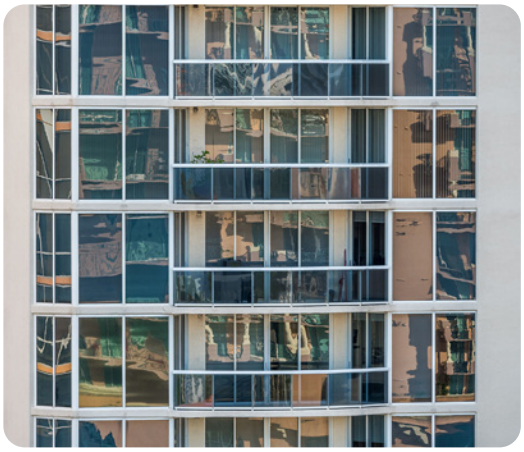
Source: Tiger Corporation

Driven by induction heating technology, the smart rice cooker is a brand-specific cooking function that reflects the intentions of rice producers, accounting for variations in rice taste due to brand, season and harvest year. It can adjust water and heat based on rice conditions, and updates its cooking programs to ensure optimal results. Users can monitor rice cooking history, electricity usage and calories via a smartphone app, which also allows adjustments to Eco Keep Warm settings, and quick steaming times. The cooker operates at around 106°C and utilizes an inner pot designed for high thermal efficiency and heat retention, mimicking the quality of rice cooked in a ceramic pot. The cooker employs a “pot-encasing IH” technique, heating a larger surface area for improved energy efficiency and flavor. With settings for easy preparation of side dishes and the flexibility to adjust cooking times, it accommodates changes in plans seamlessly. The five-layer inner pot ensures heat distribution and rapid transfer of high temperatures to the rice. Additionally, the digital display tracks cooking time and maintains a high energy conservation standard.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: low-e coated energy-saving window glass

AGC Glass Asia-Pacific



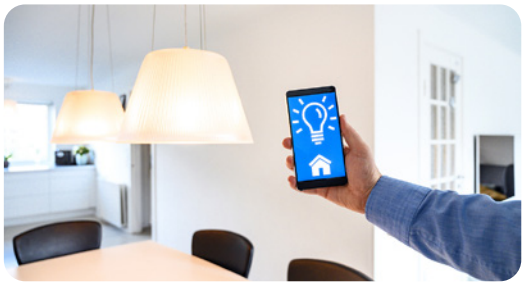
Source: Getty Images/aoldman

Solar control and low-e coated glass is a energy-efficient glass solution in residential buildings. AGC's range of energy-saving glass products feature these advanced coatings. The coatings are specifically designed to minimize temperature fluctuations within living spaces, which are often caused by heat transfer through traditional clear glass windows. The choice of glass depends on the climate, as different conditions require different approaches to temperature control. In tropical climates, a combination of solar control and low-e coatings helps block external heat, while in colder climates, low-e coatings paired with double glazing prevent heat loss, keeping the interior warm. By selecting the appropriate glass solution, households can reduce the energy needed for air conditioning or heating, boosting energy efficiency and lowering CO_2 emissions.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: smart LED lighting solution

Xiaomi



Source: Getty Images/mikkelwilliam

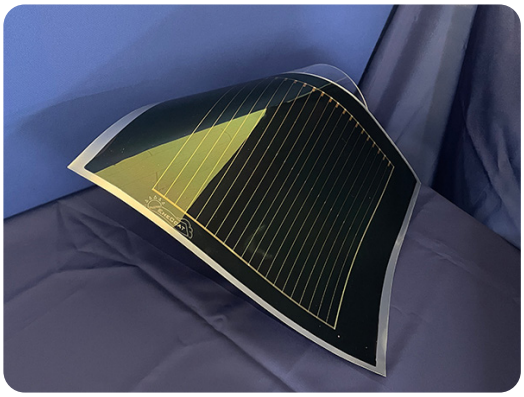
Smart LED lights are innovative lighting solutions designed to enhance convenience, energy efficiency and user experience. These lights can be controlled remotely via a mobile app or voice commands, making it easy to adjust brightness and color temperature based on individual needs. The integration with smart home systems allows for automation and customization of different lighting settings during the day or nighttime. The smart LED Bulbs have a lifespan of up to 25,000 hours (about 10–12 years with average use), providing low-power lighting. Its customizable settings, mobile app compatibility and modern design provide an energy-efficient home lighting system.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Horizon technologies

Energy supply: perovskite solar cells for housing

Mitsui Fudosan Residential Co., Ltd. and EneCoat Technologies



Source: Mitsui Fudosan Residential Co., Ltd.

Mitsui Fudosan Residential Co., Ltd. and EneCoat Technologies Co., Ltd., a spin-off company from Kyoto University involved in development of high energy-efficient perovskite solar cells, have partnered to conduct joint research on integrating perovskite solar cells into housing. This collaboration, in conjunction with Kyoto University's Wakamiya Lab, aims to accelerate the practical application of perovskite solar technology in residential environments. Perovskite solar cells are being researched for their high efficiency, thin and lightweight structure and lower production energy requirements. They offer a cost-effective alternative to traditional silicon-based cells. The project will test these cells in Mitsui Fudosan's apartments, incorporating them into well-designed lighting and furniture in the common areas as well as in the interiors of condominiums it supplies, to store solar energy during the day for use at night.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Energy efficiency: household-connected virtual power plants to balance energy supply

Shizen Connect

Source: Shizen Connect

Shizen Connect is developing a virtual power plant (VPP) platform to balance supply and demand as renewable energy integration grows. Starting in 2024, the company will demonstrate remote VPP controls using distributed energy resources (DERs) like EVs and Daikin's EcoCute heat pumps. The household EVs charge during surplus energy and discharge when needed, while EcoCute shifts boiling times to peak renewable periods. The system achieves 90% accuracy in EV charging/discharging for economic demand response (DR) and balancing markets. This demonstration aims to assess technical, economic and CO_2 reduction effects, with plans to optimize efficiency through data analysis and next-day price forecasts.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Energy efficiency: thermochromic smart windows

i2cool

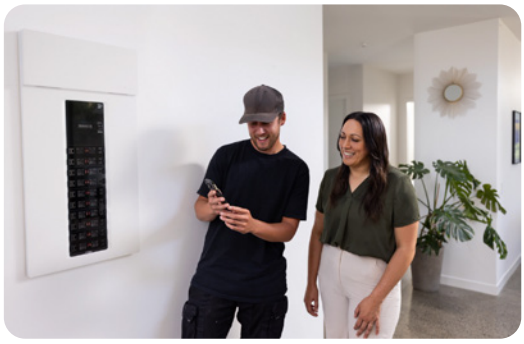
Source: Getty Images/babyrhino

These window add-ons are filled with a clear photochromatic microgel, meaning that they darken in color in response to incoming solar irradiance. They are easily installed onto existing windows, and the transition temperature can be customized within the range of 20°C to 32°C. As the ambient temperature increases above the transition threshold, the microgel particles transition from their hydrophilic swollen state into a hydrophobic shrunken state, where the window is darkened and opaque, passively regulating indoor temperatures. The difference in light transmittance between the blocking and transmitting states can reach up to 70%, resulting in a 54% decrease in solar intensity. A computer simulation where the windows were installed in a 12-floor office building in Hong Kong showed that the windows could reduce the entire building's energy consumption by 7% annually, in comparison with conventional double-glazed windows.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Hong Kong, China
- Availability: Hong Kong, China
- Contact: WIPO GREEN Database

Energy efficiency: next-generation electrical control panel

Basis



Source: Basis

The Smart Panel is a modern replacement for traditional household electrical switchboards, providing real-time insight and control over home energy use. Designed for quick installation, it can be set up in under an hour and processes over 2.3 million data points per second from its more than 120 built-in monitoring, control and safety devices. Users can manage electricity consumption via the Basis Home App, troubleshoot minor issues and integrate residential solar and battery systems to sell excess energy back to the grid. Unlike conventional breaker boxes, the Smart Panel's circuits can be reconfigured digitally without costly hardware upgrades, and the device continuously updates with new features over-the-air. It will be available in three versions of varying complexity, launching in 2025.

- Contracting type: For sale
- Technology maturity: Horizon
- Technology level: High
- Place of origin: New Zealand
- Availability: Australia, New Zealand
- Contact: WIPO GREEN Database

Green solutions for public spaces and transportation

Public spaces like streets, parks, roads and public buildings are essential to urban life. They rely on energy to power streetlights, buildings and transport systems, ensuring the seamless operation of cities. As cities grow, so does the demand for energy, especially in the Asia-Pacific region, where rapid population and economic expansion are driving a surge in passenger transport. Yet, public transportation remains largely reliant on fossil fuels. Without intervention, 75% of transport-related energy will still come from oil, driving a 47% increase in CO_2 emissions in the region by 2050 compared to 2015 levels (ESCAP, 2023). To change course, cities must embrace innovative and proven technologies that integrate renewable energy, making the transport sector a key player in the journey to net-zero emissions. This chapter explores how urban planning and technological advancements can accelerate the energy transition in public spaces and transport.

Technological development and trends

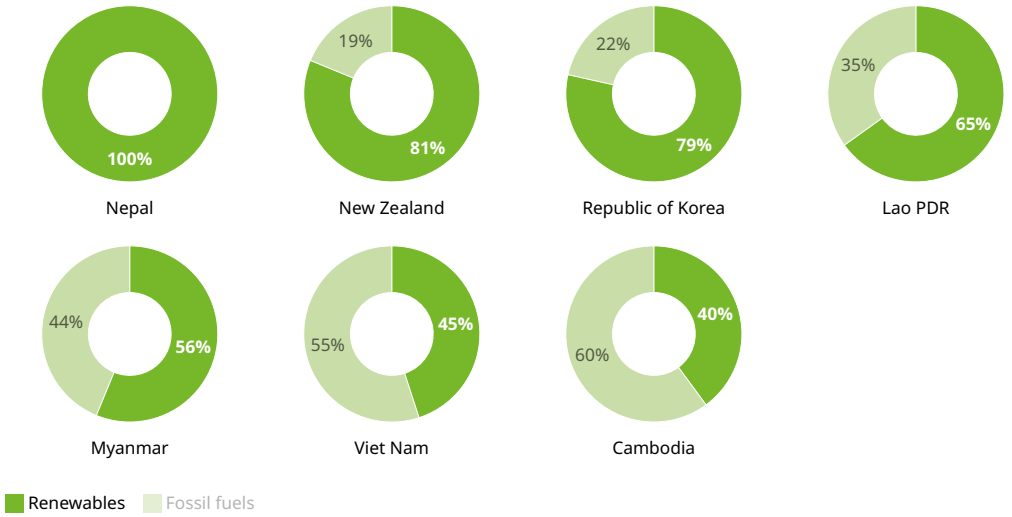
Energizing urban mobility with electric transit solutions

The integration of EVs into public transport systems presents a significant opportunity to reduce reliance on fossil fuel and accelerate emissions reductions. However, EVs are not cleaner than the electricity feeding them. Luckily, and to a large degree thanks to significant hydropower potentials, several countries in Asia and the Pacific have a notable share of renewables in their energy mix and hence a low-carbon electricity grid which provides an opportunity to accelerate a relatively low-carbon EV adoption. Figure 2.5 shows the renewable percent share of electricity production in Asia-Pacific countries. Nepal generates 100% of its electricity from hydropower, while countries like Myanmar, New Zealand and the Republic of Korea obtain a significant share of their electricity from renewable energy sources. Although countries like China and India currently have high CO_2 emissions in electricity generation, their emission intensities are projected to decline from 2024 levels by 2027, from 729 to 659 gCO_2/kWh in India and from 563 to 478 gCO_2/kWh in China, driven by rapid growth in solar, wind and hydropower renewables (IEA, 2025).

> Without intervention, 75% of transport-related energy will still come from oil, driving a 47% increase in CO_2 emissions in the region by 2050

Battery electric vehicle (BEV) and fuel cell vehicle (FCV) buses powered by low-carbon electricity or hydrogen can significantly reduce GHG emissions compared to diesel buses (IPCC, 2022). However, their benefits are limited when electricity or hydrogen is produced from fossil fuels. Still, due to their higher efficiency, EVs generally emit less than conventional vehicles even in fossil fuel-dominated grids, while also improving urban air quality. For instance, in Mongolia – despite low renewable energy use – EV buses achieved a 30% GHG reduction compared to compressed natural gas (CNG) buses (ESCAP, 2023).

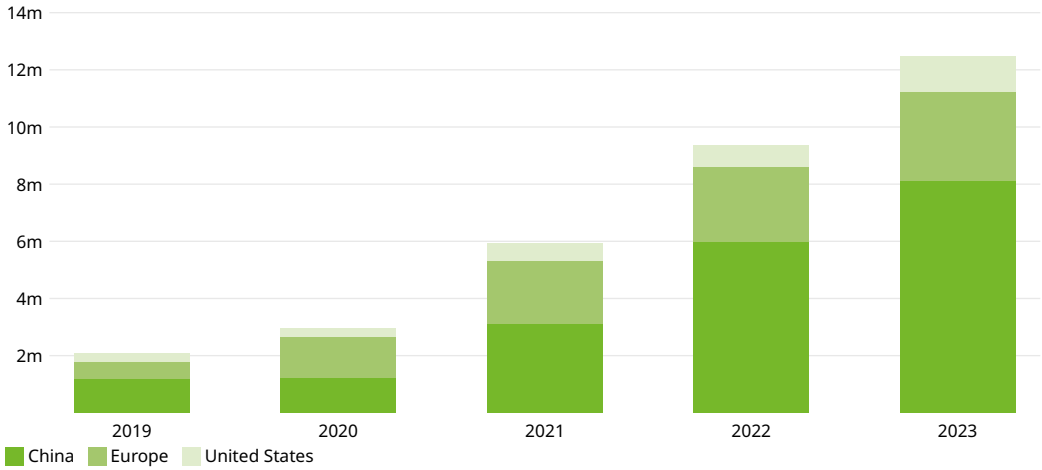
Figure 2.5 Renewable % share in electricity production in selected economies in the Asia-Pacific region



Source: Adapted from ESCAP (2019).

China is at the forefront of the global EV market (figure 2.6). The country is home to over 8 million electric buses, with thousands operating in big cities like Beijing, Guangzhou and Hangzhou. Already in 2018, Shenzhen became the world's first city to have an all-electric public bus fleet. By 2035, the country aims to electrify all public vehicles nationwide, targeting 600,000 units, including buses, taxis, sanitation trucks and postal vans (Mengnan, 2023).

Figure 2.6 Global passenger EV sales by market



Source: Adapted from BloombergNEF (2024).

EV sales are rising quickly elsewhere in Asia too. In India, the National Electric Bus Program (NEBP) is aiming to introduce 50,000 electric buses nationwide by 2030 (Sustainable Bus, 2024). In Thailand, CNG buses still dominate the public bus fleet (SLOCAT, 2023), but also here it is changing. In 2023, the public transport company Thai Smile Bus had 2,100 electric buses in Bangkok and its surrounding provinces (Chelvan, 2024). Nepal, as well, with its clean hydropower generation, sees electric mobility as a key solution to lowering emissions. It has introduced 3,500 electric mini- and microbuses (EMBs) for public transportation, which offers significant saving over diesel buses (GIZ, 2025).

Other than public bus systems, electric ferries (E-ferries) for mass rapid transport have recently been launched in Bangkok, Thailand. The project will operate 27 e-ferries along the Chao Phraya River in Bangkok carrying 250 passengers each and potentially saving 18,900 tons of CO_2 equivalent per year (ADB, 2022a). Countries like Japan, Malaysia, Singapore and Thailand

have urban electric rail systems. Japan's Shinkansen (bullet train) network is entirely electric, connecting major cities with a high-speed and efficient service.

Different battery technologies

When it comes to electric public transport system, batteries play a pivotal role. Zero-emission vehicles include BEVs and FCVs as they do not burn any fuel during operation. The most widely used batteries are based on lithium-ion (Li-ion) technology (Box 2.3).

Box 2.3 Different battery technologies

Lithium-based batteries are currently the dominating energy storage technology in electric vehicles. There are three types dominating: lithium manganese cobalt oxide (NMC), Li-Titanate (LTO), lithium iron phosphate (LFP) and lithium nickel-cobalt-aluminum oxide (NCA) batteries.

A vehicle's range per charge depends on battery size and chemistry. Li-ion batteries combine high specific power (300 Wh/kg) and energy density (90 Wh/kg to140 Wh/kg). High specific power refers to the ability to deliver a large amount of power quickly, which is important for applications where quick bursts of energy are needed, like in acceleration for electric vehicles. High energy density means a system can store a lot of energy in a small space or mass, which is essential for long-range applications. Among different types of Li-ion batteries, NMC and NCA batteries are more expensive than LFP batteries, but they weigh less and can provide longer travel range due to higher energy density.

In addition to Li-ion batteries, emerging technologies for buses include solid-state batteries, which replace liquid electrolytes with solid ones for higher energy density, though at a higher cost. Sodium (Na-ion) batteries are more cost-effective but have lower energy density and are still in the early stages of commercialization. Both are safer than Li-ion batteries.

Source: SAARC (2018); US EIA (2024).

Powering public transport with charging technologies and battery swapping

One of the main concerns for potential EV users is an insufficient public charging infrastructure and high upfront cost. Cold weather also makes a battery's charging time longer and its range shorter. The reason China has not achieved 100% electrification for its buses is its northern regions, which have harsh winters (You, 2023). The alternatives emerging to tackle such challenges are hybrid electric vehicles (HEV) and plug-in hybrid vehicles (PHEV). Both use an internal combustion engine and a battery-powered electric motor. Regular HEVs primarily use conventional fuel with the electric motor assisting the engine reducing the fuel consumption. The battery is not charged by the grid but through the engine itself supplemented with regenerative braking[1], which captures energy from braking and therefore contributes to lower emissions. On the other hand, a plug-in hybrid vehicle has a larger battery than HEVs, that allows the vehicle to operate solely on electric power for a longer distance, providing a "zero-emission capability." The battery can be charged by plugging the vehicle into an external power source such as a public charging station.

There are various charging methods for electric buses, each with its own advantages. In China and India, conductive charging is widely used where buses are connected directly to the power grid either via pantographs[2] or plug-in connectors. Pantograph charging is automated and suited for large fleets, while plug-in charging requires manual connection. Though

1 Regenerative braking system captures the kinetic energy from braking and converts it into electrical power to recharge the vehicle's high-voltage battery.
2 This is a mechanical arm mounted on either the bus roof (**top-down pantograph**) or at a charging station (**bottom-up pantograph**). The pantograph connects to overhead power lines or charging points to quickly transfer electricity to the bus's battery.

dedicated charging facilities for heavy duty vehicles are still in early stages, ultra-fast charging technologies like the ChaoJi-2 megawatt charging system (MCS) are being introduced in China and Japan, offering up to 1.2 MW (EV Update Media, 2023).

However, high-powered charging poses challenges for electricity grids, leading to potential supply-demand imbalances (IEA, 2024f). Here V2G (vehicle-to-grid) or "bidirectional charging" is getting more attention. This technology allows EVs to not only charge from the electrical grid but also discharge electricity back into the grid, which reduces grid strain and offers potential cost savings for consumers. For instance, school buses can charge during low-demand periods and provide energy back to the grid during peak times, making it an ideal solution for public transport systems operating around the clock.

> A notable share of renewables in the energy mix provides an opportunity to accelerate a relatively low-carbon EV adoption

Limited space in dense Asian cities hinders the adoption of electric heavy duty vehicles (HDV) and electric buses, particularly due to the lack of room for large charging depots and overnight parking. Innovations like battery swapping and wireless charging roads offer space-efficient alternatives. China leads in battery swapping, enabling quick exchange of depleted batteries for fully charged ones, and thus extending battery life, and easing grid demand (ESCAP, 2023). It is cost efficient compared to the cost of electricity to charge them separately (Hanley, 2024). However, high initial costs and a lack of charging infrastructure present barriers to scaling. For more of such technologies see the energy edition of the *Green Technology Book.*

Wireless charging is another evolving technology, being tested and trialed in a few cities. For instance, in the Republic of Korea, wireless charging is developed by KAIST and operates on routes between campuses and city centers. Wireless or inductive charging uses special lanes equipped with charging coils which generate electromagnetic fields, allowing buses to charge without physical contact, even while in motion. This reduces downtime for stationary charging, allowing vehicles to operate longer without interruptions, ultimately optimizing energy use throughout the day.

Hydrogen as a fuel for public transport

Fuel cells function like batteries, but they need a continuous supply of fuel (e.g. hydrogen) and oxygen (air) to produce electricity through an electro-chemical process which is often twice as efficient as internal combustion engines and turbines. Fuel cell vehicles are refueled like conventional vehicles, with hydrogen stations supplying pressurized hydrogen.

Fuel cell buses are expected to grow in China, Japan and the Republic of Korea over the next 20 years, with China and the Republic of Korea leading the push to develop a new industrial value chain (Sustainable Bus, 2025). Several Chinese companies have made notable progress in this area. For instance, Citybus has launched the first hydrogen-powered double-decker bus in Hong Kong, China and also committed to creating a zero-emission bus fleet by 2045, with a 70% hydrogen and 30% electric bus ratio (ITDP, 2024). Also, Japan has for years supported hydrogen technology, and Tokyo currently has 85 hydrogen-powered buses, with plans to increase this number to over 300 by 2030 (Ahmad, 2022).

However, hydrogen-based technology is not inherently green, as most hydrogen today is produced from fossil fuels, limiting its climate benefits. Although advancements in green hydrogen are progressing, its production remains costly. Furthermore, the lack of filling stations is another critical issue. Even in countries like Japan and the Republic of Korea, H_2 filling stations are less than 0.5% of electric chargers. Such challenges are hindering the widespread adoption and progress of hydrogen technology.

Harnessing solar energy for urban public transport systems

Cities like Hong Kong China, Singapore and Tokyo are integrating solar buses into their transit systems, using third-generation ultra-thin film solar cells on bus roofs. These panels generate electricity to help regulate cabin temperature and power onboard electronics, reducing fuel consumption. On average, each solar-equipped bus saves 3 to 4% in fuel daily, cutting around 6 tons of carbon emissions per year (KMB, 2023). Bus stations also use photovoltaic technology to create self-sustaining power systems. In Tianjin, China, a solar bus shelter outside a library integrates 28 thin-film solar cells providing functions such as news browsing, e-book borrowing, and city WiFi hotspot coverage (WSL Solar, 2018). Solar rooftops can serve several other purposes such as powering lights, collecting rainwater and charging appliances. In Singapore, solar panels are to be installed on the rooftops of more than 10 Mass Rapid Transit (MRT) stations, train depots and bus depots, which have the capacity to meet the annual charging needs of up to 113 single-deck electric buses (Shan, 2024).

Two- and three-wheelers as key segment of electrified road transport in developing countries

China is the global leader in the electric share of two- and three-wheelers, with over one third of all such vehicles being electric (IEA, 2023b). In smaller and mid-sized Chinese cities app-based services for bike-sharing, e-bikes and car-sharing present energy-saving alternatives to privately owned cars. However, managing millions of shared bikes has created issues like indiscriminate parking, safety concerns and accidents, which led the government to introduce regulations on its usage. Over 10 major cities in China, including Beijing, Guangzhou, Shanghai and Shenzhen, have restricted or outright banned e-bike usage (Shepard, 2016). But still by the end of 2022, there were an estimated 350 million electric bikes in China, with Shanghai leading the nation with over 10.5 million registered electric bicycles (Jian, 2024).

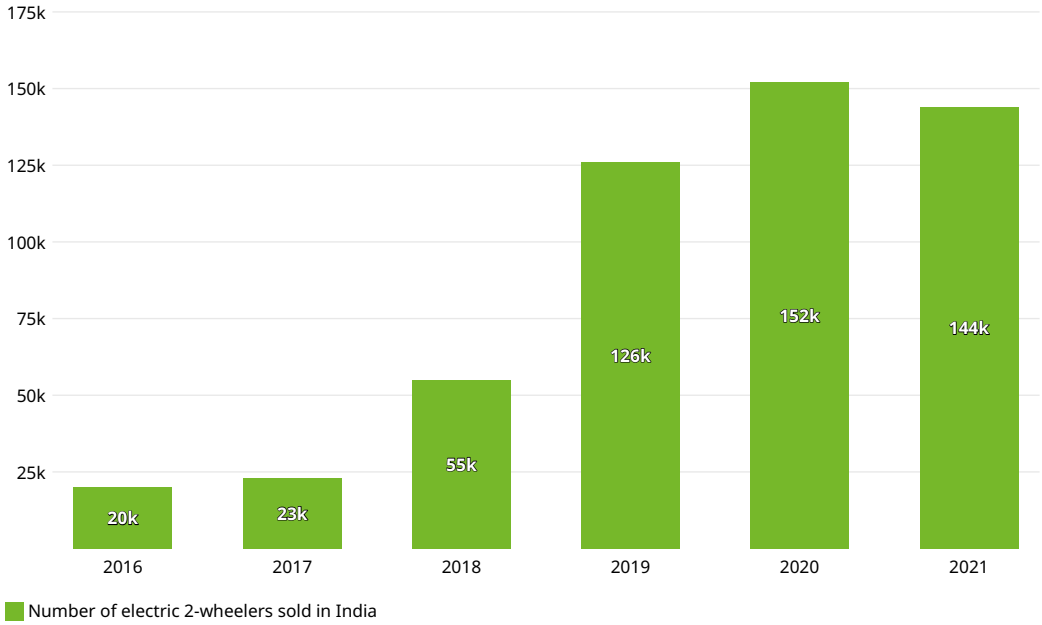
Nevertheless, in developing countries, e-bikes and e-scooters have significant potential to reduce urban air pollution by replacing gasoline-powered scooters and motorcycles. Therefore, efforts are underway to make e-bikes safer and more energy efficient. This includes the development of self-charging batteries that store energy during pedaling. Further advancement in bicycles is solar-powered batteries (figure 2.7). Solar power could potentially reduce the need for recharging stations. Additionally, many e-bikes feature removable batteries that can also be charged overnight at home, providing a practical hybrid approach.

Figure 2.7 The BEM® Savitré™ solar bicycle, retrofitted over a Stryder® Zeeta Plus™

Source: Baroda Electric Meters (BEM) Ltd.

In many Southeast Asian cities, two-wheelers are widely used for both private and public transport. For example, Viet Nam had registered 1.35 million electric two-wheelers by June 2020.The stock and sales of two-wheelers continue to rise in India and ASEAN countries (IEA, 2024f), with growing interest in battery-swapping technologies (figure 2.8). The region is also seeing a rise in start-ups and companies offering electric bicycles, motorcycles and scooters on e-commerce platforms. For example, in Cambodia and Thailand, smart three-wheelers such as e-tuktuks offer features like remote battery monitoring and PAYG (pay-as-you-go) leasing, providing drivers with extended battery life, cost savings and higher mileage.

Figure 2.8 Electric 2W sales in India



Source: Adapted from Kumar (2021).

Traffic flow optimization and smart transport: a key to energy efficiency in dense cities

Optimizing traffic flow in Asian cities is essential for enhancing mobility, reducing energy consumption and improving air quality. Cities like Bangkok, Beijing, Jakarta and Tokyo face significant traffic congestion due to high population density and rapid urbanization. Besides improved mass transport systems such as bus systems and sky-trains, intelligent Transport Systems (ITS) can play a key role in addressing such challenges. It is an evolving, data-driven and adaptive approach to public transport planning, operations management and customer service applications to improve the safety, efficiency and sustainability of public transport networks (World Bank, 2024).

> The region is seeing a rise in start-ups and companies offering electric bicycles, motorcycles and scooters on e-commerce platforms

The system includes technologies such as adaptive traffic signal control and traffic management centers that use real-time data and AI algorithms to optimize traffic light timings, reducing vehicle idle times and the associated fuel consumption. Meanwhile, centralized traffic centers continuously monitor traffic conditions and reroute vehicles away from congested areas, improving traffic flow across cities. For example, it can be used to prioritize public transport in traffic, allowing buses and trams to have a quicker route by adjusting traffic signals for them (e.g., bus priority lanes). It also offers real-time updates to commuters (e.g. bus arrival times, delays, monitoring parking spaces at parking lots and guiding drivers to available spots etc.) thereby minimizing congestion and vehicle idle times, which is a crucial factor in energy efficiency. A study on vehicle idling at intersections in Delhi found that daily fuel losses due to idling could be 9,036 liters of petrol, diesel and LPG, along with 5,461 kg of CNG, leading to approximately 37 tonnes of CO_2-equivalent emissions per day in the city (Sharma *et al.*, 2019).

Limited space in dense Asian cities hinders the adoption of electric heavy duty vehicles and electric buses

Other ITS components include sensor-based communication technologies like Vehicle-to-Infrastructure (V2I) and Vehicle-to-Everything (V2X). These systems allow vehicles to communicate with traffic signals and road signs, receiving optimal speed recommendations and alternate routes to reduce stop-and-go driving, which further improves safety and energy efficiency. However, real-world application faces challenges such as signal degradation, interference from buildings and complex driving scenarios. Cellular V2X (C-V2X) with 5G offers better performance in such cases, especially in non-line-of-sight conditions.

Smart traffic lights with geomagnetic sensors further improve efficiency by adjusting signal timing based on vehicle flow, cutting congestion and reducing unnecessary fuel use. The AI-driven "City Brain" platform, used in China and Malaysia, analyzes traffic patterns in real time, optimizing signal timings and reducing travel delays. In Shanghai, the City Brain is extensively used for public safety and community services, where it has lowered congestion by 15% and cut average travel time by 8% (Zhang *et al.*, 2019).

Electronic Road Pricing (ERP) is another element in ITS. In many Asian cities including Bangkok and Singapore, ERP is used to reduce car use and encourage public transit on highways by charging higher fees during peak hours. Using smart card in-vehicle units, it enables automatic, contactless payments, easing congestion. Advanced satellite-based ERP even eliminates the need for toll booths, using GPS to track vehicles and adjust tolls based on road usage and real-time traffic conditions.

The growth of autonomous public transport in Asia

Autonomous public transport technology is rapidly advancing in Asia and the Pacific, with several countries leading the way in deploying driverless vehicles to enhance urban mobility. However, the effect of autonomous vehicles on transportation energy consumption is highly uncertain (Chase *et al.*, 2018). Autonomous driving (AD) can save up to 60% energy by accelerating smoothly on urban roads. However, frequent stops, intersections and mixed traffic flow demand more precise control with sensitive sensors and robust computations to maximize energy efficiency. In addition, frequent human disengagement may increase energy consumption by 8% to 40% due to factors like inconsistent driving patterns, less smooth acceleration and braking etc. (Tu *et al.*, 2024). Such trade-offs raise challenges about the environmental benefits of autonomous vehicles in real-world conditions. China is at the forefront of developing AD technology, where cities like Shenzhen are using AI and 5G technologies to optimize routes and enhance passenger safety with autonomous electric buses, and plan to deploy 20 driverless buses in 2024 (Deng, 2024). To have a closer look at autonomous public transport technologies see also the energy and mitigation editions of the *Green Technology Book*.

Asia's drive for energy-saving LED traffic lights and streetlights

Each year, over 4 million traffic lights consume about 3 billion kilowatt-hours of electricity globally, with red lights accounting for 85% of this usage, as they are on 60% of the time and often have higher wattage (FAMA Traffic, 2020). Replacing a 150-watt red incandescent bulb with a 10-watt LED can significantly reduce energy consumption. Technologies like Siemens' one-watt digital LED driver modules have improved traffic light energy efficiency by over 85%, eliminating the need for energy-draining load resistors and switching elements (Siemens, 2016).

LED traffic lights have replaced incandescent bulbs due to lower energy use and maintenance costs. Integrated signal lights, combining light and pole, offer additional functions such as clocks, billboards and LED displays for real-time information sharing, traffic safety improvement etc. In semi-urban areas, solar-powered traffic lights offer a cost-effective alternative by adding a solar panel and battery to conventional signals, However, the performance of solar

traffic lights relies on sunlight intensity. To optimize system efficiency, it's crucial to use a solar radiation map to identify suitable areas for the technology's application (Ha *et al.*, 2022). Despite their potential as a low-carbon investment, solar traffic lights remain uncommon in developing countries.

> Recent advances have upgraded solar and wind-powered LED lights and smart streetlights with cameras and sensors

Other than traffic lights, street lighting can also represent up to 40% of a municipality's electricity bills (C2E2, 2024). However, LED streetlights provide cities with energy and cost savings and enhanced safety. Compared with traditional streetlights, LED streetlights can save up to 50% of streetlights' energy consumption (Yang, 2019). Recent advances have upgraded solar and wind-powered LED lights and smart streetlights with cameras and sensors for dynamic lighting and dimming. These lights can communicate with one another, adjusting brightness based on movement, and are IoT-integrated for remote monitoring and maintenance alerts.

Cities like Jakarta included the upgrade of 90,000 streetlights to energy-efficient LEDs as part of their smart city transformation (Signify, 2018). The second phase expands this to 150,000 streetlights, all centrally controlled and managed by interactive city lighting software, making it Southeast Asia's largest smart street lighting project. The data enables city officials to efficiently monitor the city's lighting infrastructure and remotely manage illumination levels according to varying needs by district, and thus helps reduce energy cost by up to 70% (C2E2, 2016).

Harnessing nature-based urban solutions for cooler cities

Nature-based cooling solutions offer an energy-efficient and sustainable approach to managing rising temperatures in cities and communities. By integrating green spaces, wind flows and greenery on buildings, these solutions can lower air temperatures. For example, covering 50% of a city's surfaces with green roofs can reduce temperatures by up to 0.8°C (Estrada *et al.*, 2017). However, many cities still rely heavily on air conditioning, and nature-based strategies are underutilized (Wang and Wu, 2023).

> Vertical gardening is evolving in public buildings, utilizing wall spaces for plant growth

Cities like Guangzhou, China and Melbourne, Australia, are increasingly adopting these solutions. Guangzhou, for instance, has leveraged wind flow to create a "natural air conditioning system" by preserving six major ventilation corridors along mountains, water systems and open spaces (World Bank, 2022c). It has also planned cooling interventions around natural cooling sources like forests, lakes and rivers while incorporating plants on walls and rooftop to lower building temperatures.

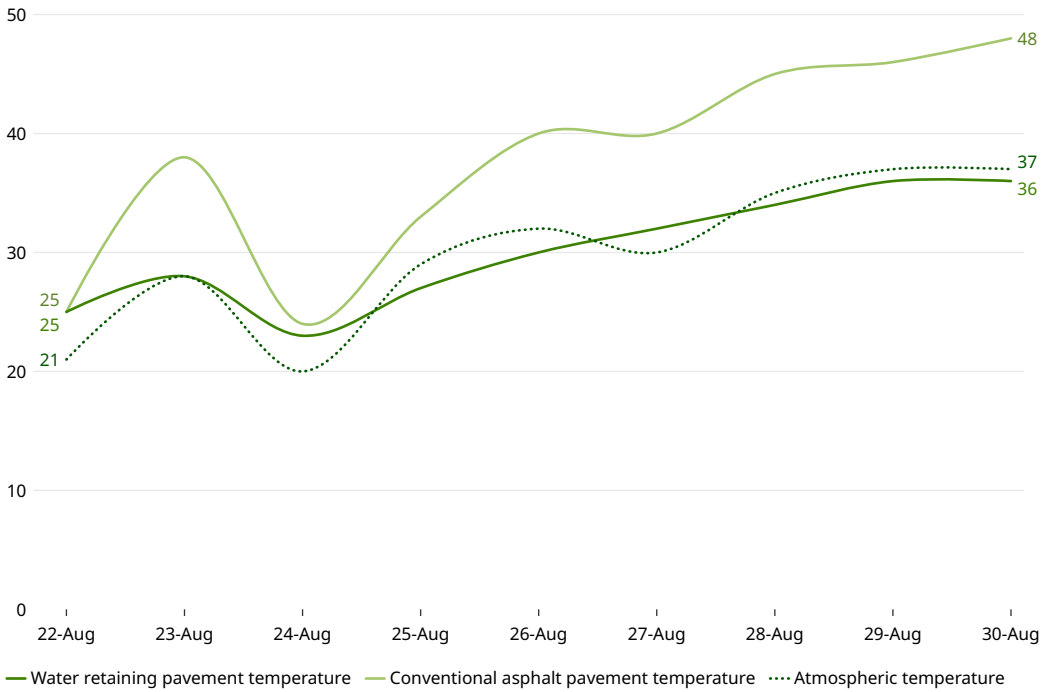
Singapore has also implemented an intensive greening policy, with green rooftops, sky gardens, pocket parks and pedestrian park connectors. This has raised the city's green cover from 36% to 47%, lowering temperatures by up to 5°C. This helps the city adapt to climate change while also lowering GHGs, since a 1°C decrease in air temperature can reduce peak electricity demand by up to 4%, leading to reduced energy consumption and emission (World Bank, 2022b). The reduction in electricity demand is mainly due to the decrease in the need for air conditioning, which is a major energy consumer in urban areas.

Vertical gardening is evolving in public buildings, utilizing wall spaces for plant growth. Modular panel systems, popular for their flexibility and easy installation, use pre-vegetated panels mounted on a support structure, enhancing thermal and sound insulation. For more nature based urban solutions see energy and mitigation editions of the *Green Technology Book.*

Water-retaining pavements and district cooling to lower temperatures

Water-retaining pavements are made of porous asphalt filled with water absorbing materials such as special cement milk that can store a large amount of rainwater. As the water gradually evaporates, it absorbs heat from the surrounding environment, helping to lower the road surface temperatures by 8 to 10°C compared to the conventional pavements (figure 2.9). However, they cost about 30% more than conventional paving (Sankei, 2024). The Tokyo Metropolitan Government has installed around 190 kilometers of water-retaining cool pavements in public squares and small parks to mitigate the heat island effect.

Figure 2.9 Comparison of road surface temperature on summer days in Japan (°C)



Source: Adapted from JRCA (2014).

Large-scale district cooling systems can also significantly lower energy consumption as seen in cities like Dubai and Singapore. They can deploy more energy-efficient technologies such as chilled water storage and heat recovery which reduce overall energy consumption. The cooled water is distributed through underground pipes to multiple buildings thus eliminating the need for individual air-conditioning units and saving energy. It also avoids heat release from aircon units and thereby lowers the urban heat island effect. Overall energy savings of up to 50% have been observed (Bjerregaard and Junge, 2024). In Hong Kong, China the integration of seawater for cooling further enhances system efficiency.

However, there are still some barriers to the widespread adoption of this technology. Proper urban planning and regulations, like Singapore's District Cooling Act, can help facilitate its rollout. Singapore's Marina Bay district operates one of the world's largest underground district cooling networks, saving enough energy to power 24,000 residential units (Ruefenacht and Acero, 2017).

Integrating renewable energy into public spaces and buildings

Creative governance models, policies and laws are often instrumental in expanding the use of renewable energy sources. Municipality-led renewable energy communities are also spearheading solar and wind power in public spaces and buildings. Several Asian cities are adopting such tools (Box 2.4).

Box 2.4 How different governance strategies can help renewable energy integration in public buildings

Seoul is expanding its solar capacity by leasing unused municipal land to private power generators and cooperatives for large-scale solar panels. Solar PV installation is now mandatory for public buildings under the city's environmental standards. The city collaborates with various divisions to install solar systems on available sites, offering low-interest loans and feed-in tariffs to promote community-scale projects. Currently, 14 cooperatives run 29 solar plants, generating 1.3 MW of electricity (C40 Knowledge, 2019).

In China, rooftop solar panels are set to roll out in public buildings. In 2021, China's National Energy Bureau mandated solar installations on 40% of public buildings such as schools and hospitals (Ye, 2023). Also, in Indonesia, APT Pranoto airport will become the country's first solar-powered airport, generating 755 MWh annually from a 600 kWp system, covering 20% of its energy needs.

Beyond rooftops and parking space, floating PV on lakes or ponds and building-integrated PV (BIPV) are gaining momentum. Floating solar farms can produce more electricity than rooftop or ground-based installations while also helping to regulate the temperature and evaporation of lakes and reservoirs (WEF, 2021). Singapore is utilizing floating solar farms to increase its clean energy supplies due to space limitation. Singapore's Tengeh Reservoir floating solar project spreads over an area of 45 hectares generating 77,300 MWh of clean electricity (Power Technology, 2021).

The latest innovative solar solution includes BIPV such as patterned vertical panels on building façades that blend aesthetics with functionality. However vertical panels may have 5 to 25% lower efficiency compared to that of the conventional tilted position, new materials and designs aim to address this (YS and Ng, 2022). In recent years, retrofitting buildings with micro wind turbines has been developing. An example of this is Bahrain's World Trade Center, where integrated wind turbines generate 11% to 15% of the building's electricity needs (Kwok and Hu, 2023).

Innovation examples

Hong Kong, China's first-of-its-kind district cooling system using seawater

Source: Veolia Water Technologies

Veolia, a leader in environmental solutions in Hong Kong, China designed, built and operates the Kai Tak District Cooling System (DCS). This facility uses seawater as a cooling medium to produce chilled water, replacing traditional decentralized air-conditioning systems in consumer buildings across the Kai Tak District. The chilled water is then distributed through an underground water distribution network, providing green cooling to over 1.7 million m^2 of non-domestic air-conditioned spaces, including offices, schools, Mass Transit Railway (MTR) stations, a shopping mall, a hospital and the cruise terminal. With a cooling capacity of 284 MW, the DCS helps the community to save up to 85 million kWh of electricity annually upon its full operation while optimizing energy efficiency and reducing space requirements (Veolia, 2025).

Tallest vertical garden in Sri Lanka

Source: Getty Images/Veit Störmer

Recognized as the tallest vertical garden in the world, ClearPoint residences is a collaborative project by Milroy Perera Associates and Maga Engineering. This residential apartment tower exemplifies holistic green building practices, featuring 171 apartments across 47 floors. Its special feature is the array of planted terraces that wrap around the building. These terraces are nourished by a specially designed automated drip irrigation system that utilizes recycled water. In addition, the building incorporates several self-sustainable elements, including solar panels, rainwater harvesting, water recycling and solid waste management systems. The planted terraces not only enhance the building's unique aesthetic but also offer other benefits. The greenery acts as a natural cooling system which reduces energy consumption for air conditioning. Additionally, this lush cover provides sound insulation, shade and a buffer against radiant heat.

Technology solutions

Proven technologies

Energy efficiency: smart streetlight

Delta

Source: Getty Images/Lari Bat

The Smart Street Light Delta offers a comprehensive solution for sustainable cities by integrating the DeltaGrid communication platform. This system collects data from connected, high-efficiency LED streetlights and transmits it to cloud servers via 3G/GPRS. It allows for real-time control, including on/off switching, dimming, and reporting on status and failures, optimizing energy savings and maintenance efficiency. This proven technology has been successfully implemented in large-scale projects in New Taipei City and Taoyuan City, Taiwan, Province of China managing over 10,000 smart LED streetlights.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Taiwan Province of China
- Availability: India, Oceania, Southeast Asia
- Contact: WIPO GREEN Database

Alternative energy vehicles: Electric bus for countries with extreme high temperatures

Yutong

Source: Getty Images/onurdongel

Yutong introduced battery electric buses to the Saudi Arabian market, E11PRO and D8E to address the “Extremely Hot Challenge.” The buses are able to operate effectively in high temperatures and extreme desert conditions. In the Middle East, the company has been operating for two decades selling over 10,000 buses across 12 countries including Qatar and Saudi Arabia, of which 950 buses are battery electric. The model E11PRO has demonstrated exceptional durability, with over 110,000 kilometers traveled in nearly two years of service, while the D8E is versatile for various urban transport needs. It is fitted with an independent liquid cooling system for the battery and an electric A/C with high cooling capacity, sufficient to increase the vehicular safety and provide a cool and comfortable experience to the driver and rider. In addition, the motor is equipped with a unique mudguard to prevent foreign matter from being blown into the motor and causing failure. The special anti-collision beam structure of the battery pack is added to ensure a safe and smooth operation. Yutong’s buses are particularly convenient due to their long driving range and ability to operate continuously in the intense heat, ensuring smooth transportation for large numbers of passengers.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Asia
- Contact: WIPO GREEN Database

Energy efficiency: end-to-end mobility sharing platform

Gogoro

Source: Getty Images/franz12

GoShare is an app created by Gogoro that provides renting and riding Gogoro Smartscooters. Available 24/7, the app lets users quickly access high-performance electric scooters with smart features and wireless connectivity for daily travel. With GoShare, riders can swap batteries at any time using the Gogoro Network, allowing them to extend their ride without worrying about running out of power. The app uses advanced technology like AI and real-time management to help users easily sign up, find and reserve a scooter for riding in a few minutes. This solution facilitates the shift to electric urban vehicles which, depending on the source of the electricity, can contribute to climate change mitigation.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Taiwan Province of China
- Availability: Asia, Colombia
- Contact: WIPO GREEN Database

Passive cooling: vertical garden grates and frames

Latham Australia

Source: Getty Images/KjellBrynildsen

Latham's grates and frames provide a sturdy structure for attaching planters, pots and greenery without affecting the overall look. These grates, made from aluminum and brass, are typically used in safety flooring systems but can also be custom-made to fit the specific size requirements of a vertical garden. When installed upright, they create a reliable surface for supporting plants while serving the aesthetic purpose of the design.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Australia
- Availability: Middle East, Oceania, Southeast Asia
- Contact: WIPO GREEN Database

Passive cooling: hanging vertical garden system

Ecogreen Landscape Technologies (ELT)

Source: Getty Images/Mystockimages

Living Globe Strings is an ultramodern, non-modular system designed for hanging vertical gardens, covered spaces and indoor settings. Instead of using a back frame, it features hanging pots, or "Living Globes," suspended on stainless steel wire ropes, allowing for continuous greenery without obstructing light. The globes, made from hydrophilic foam composite, require minimal maintenance and are available in 4", 7" and 11" diameters, capable of holding 15, 25 and 45 plants, respectively. The system is modular, customizable and includes integrated drip irrigation. This innovative solution supports dense planting while efficiently utilizing limited space.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Low
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Energy efficiency: wireless intelligent solar traffic signal controller

FAMA Traffic

Source: FAMA Traffic

A wireless intelligent traffic signal controller is the core component of the city's traffic signal control system, responsible for managing traffic signals, gathering traffic data, enabling communication and monitoring intersections. It is suitable for various intersection types, including T-junctions, multi-forks and ramps. The controller operates multiple control modes, with the ability to intelligently switch between them. Key features include solar power capability, a built-in central control system for reliability, outdoor protection against lighting and power fluctuations, and a modular design for easy maintenance and upgrades. It supports 2x24 work periods for workday and holiday settings, 32 adjustable work menus, emergency yellow flashing mode and customizable steps for each menu.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Alternative energy vehicles: smart electric three-wheeler charging with PAYG technology

SOLshare

Source: SOLshare

SOLmobility services replace traditional lead-acid batteries with lithium-ion batteries in electric three-wheelers, offering faster charging, better charge retention and increased power capacity. These batteries are integrated with PAYG technology, providing extended battery life, cost savings and improved mileage. Garage owners can lease batteries, reducing upfront costs and enabling remote monitoring for better management. Additionally, these lithium-ion batteries can be repurposed for rural energy storage, such as solar grids. SOLmobility is part of SOLshare's Rickshaw virtual power plant, utilizing bidirectional chargers and rooftop solar power to integrate more renewables into Bangladesh's grid, stabilize peak loads and enhance revenue for electric three-wheeler drivers.

- Contracting type: For sale/service
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Bangladesh
- Availability: Bangladesh
- Contact: WIPO GREEN Database

Space heating and cooling: district cooling

SP Group

Source: Getty Images/windcatcher

As Singapore's largest district cooling operator, SP Group designs, constructs and manages district cooling systems for clients across the region. District cooling and heating distribute chilled or hot water to provide air conditioning across multiple buildings, offering a reliable and energy-efficient alternative to individual cooling systems. By consolidating chiller and heating capacities, this system leverages economies of scale, managed by an expert operations team, making it comparable to public electricity supply in terms of energy and cost efficiency.

- Contracting type: For sale/contract
- Technology maturity: Proven
- Technology level: High
- Place of origin: Singapore
- Availability: Australia, China, Singapore, Thailand, Viet Nam
- Contact: WIPO GREEN Database

Passive cooling: water-retentive pavement COOL POLYSEAL

Nippo

Source: Getty Images/hellojulie

Water-retentive pavement is a pavement created by injecting and filling the voids of open-grained asphalt with a special cement mix called Cool Grout, which has excellent water absorption and retention properties. This design utilizes evaporative cooling to reduce road surface temperatures, helping mitigate the heat island effect in urban areas. It provides improved comfort by cooling the road environment during summer and is suitable for all types of roads, from high-traffic streets to sidewalks. By retaining water and releasing it through evaporation, the pavement effectively lowers surface temperatures and also enhances the overall walking experience in hot conditions.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Japan
- Availability: China, Japan, Tanzania, Thailand, Viet Nam
- Contact: WIPO GREEN Database

Alternative energy vehicles: regenerative solar electric vehicle for developing countries

Advanced Dynamics

Source: Getty Images/Andrey Grigoriev

Advanced Dynamics offers the BEAN technology, a comprehensive electrification solution that includes electric vehicle motors, batteries, control systems, solar body components and other essential parts. Their innovative solar electrification technology enables the conversion of fossil-fuel vehicles into regenerative solar electric vehicles. This technology is adaptable for various vehicle types, from compact cars to large commercial trucks, allowing immediate contributions to reducing carbon emissions and promoting sustainability.

- Contracting type: For service
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Bangladesh
- Availability: Asia
- Contact: WIPO GREEN Database

Frontier technologies

Alternative energy vehicles: hydrogen fuel cell city bus

Higer

Source: Getty Images/Acumen86

The Higer KLQ6106 hydrogen fuel cell city bus can accommodate up to 80 passengers, offering a spacious interior with a special ramp and designated area for wheelchairs. It features sixth-generation hydrogen fuel cell technology, which extends the fuel cell's life expectancy to 15,000 hours. The bus can operate smoothly even in extreme conditions at temperatures as low as -30°C and automatically shutting down to preserve itself at -40°C.Powered by a 92 kW hydrogen fuel cell, the bus achieves high energy efficiency, consuming just 5 kg of hydrogen per 100 km. With a 25 kg onboard hydrogen storage capacity, it can travel over 400 km on a single fill, and refueling takes less than 20 minutes. Higer hydrogen buses successfully completed transportation tasks during both the 2008 and the 2022 Beijing Olympics.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Alternative energy vehicles: wireless chargers for autonomous bus

WiTricity

Source: Getty Images/Chesky_W

WiTricity Halo™ chargers streamline the charging process by eliminating the need to plug in, which is especially beneficial in transit applications. Traditional cords and cables are often heavy and awkward, potentially leading to slips and falls, a common cause of workers' compensation claims for commercial drivers. WiTricity Halo increases trip efficiency and removes the need for drivers to manage heavy cables – crucial for autonomous buses that have no drivers. WiTricity has partnered with Yutong Bus, China's largest bus manufacturer, to wirelessly charge their autonomous electric buses.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: United States of America
- Availability: Worldwide
- Contact: WIPO GREEN Database

Alternative energy vehicles: Smartuk – a modular, all-electric tuk tuk

ARVenture studio & E-Tuk Factory

Source: Getty Images/Itsanan Sampuntarat

The SmarTuk concept, designed by Vincent Chan and Andy Lee, aims to provide a cost-effective, modular electric vehicle solution for street vendors in Cambodia. Built for individuals selling food and goods, the SmarTuk leverages IoT and big data to enhance the lives of low-income individuals while promoting an eco-friendly environment. Its fully electric design, combined with energy-efficient infrastructure, ensures both sustainability and affordability. A key feature of the SmarTuk is its tracking device, which connects with a mobile app to help locate nearby street vendors, supporting both convenience for consumers and regulation of unofficial vendors. Additionally, its water-resistant design considers Cambodia's frequent flooding. The modular design also allows vendors to adapt the SmarTuk to their specific needs simply by changing the rear half. Its uses are many and range from a mobile cafe to a grocery cart, or just as a vehicle used for the transportation of goods. This flexibility, paired with its electric power, makes the SmarTuk efficient and low maintenance.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Netherlands
- Availability: Cambodia, Netherlands
- Contact: WIPO GREEN Database

Smart energy: Roadside Unit 2X communication

Yunex Traffic

Source: Yunex Traffic

The Yunex Traffic RSU2X serves as a central hub for wireless communication between roadside infrastructure and Onboard Units (OBUs). It enables real-time, two-way data exchange, facilitating the transmission of critical traffic information (such as speed limits) and the reception of OBU messages. This technology provides key data for a more precise picture of the current traffic situation, enabling more efficient traffic control, reduces accidents and helps cut emissions. The RSU2X is powered via Power-over-Ethernet, with integrated antennas providing up to 2,500 meters of radio coverage. It features a quad-core processor and powerful radio modules, handling high data loads with up to 4,000 message verifications and 130 message signatures per second. It also includes multiple connectivity options such as Ethernet, LTE, Wi-Fi and Bluetooth, housed in a weatherproof design for harsh environments. It has a high security level with tamper response and secure key storage.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Alternative energy vehicles: flash-charging system for e-bus

Hitachi Energy

Source: Hitachi Energy

Hitachi Energy's Grid-eMotion® charging infrastructure eliminates the need to take electric buses out of service for extended recharging or keep backup vehicles on hand, optimizing operational cost and availability for fleet operators. The ultra-fast charging starts within seconds, delivering over 600 kW of power after connecting the 24-meter-long metro to a feeding station. By using the Grid-eMotion® charging system, rather than carrying large batteries onboard, more seating can be allocated, providing a more sustainable and efficient solution that enhances both passengers' and drivers' experience with less noise and zero tailpipe emissions.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Alternative energy vehicles: hydrogen-powered Autonomous Rail Rapid Transit (ART) 2.0

CRRC

Source: Getty Images/elifilm

Combining green technology with oriental aesthetics, the ART is designed for medium-to-low passenger volumes. It merges the advantages of trams and road-based vehicles to meet the evolving demands of urban transportation. It operates on rubber wheels and uses virtual tracks, eliminating the need for traditional tracks and catenary systems, which reduces construction and maintenance costs. The ART 2.0 model is adaptable to various power sources, including fast charging lithium batteries, supercapacitors, hydrogen energy and overhead catenary systems, making it flexible for different operational environments. The hydrogen-powered ART 2.0 can travel up to 500 kilometers on a single charge, with the ability to add 20 kilometers of range in just five minutes of rapid charging. It also showcases advanced intelligence and safety features, including fully autonomous driving capabilities. The system achieves the highest functional safety level (SIL4), ensuring a safe and reliable passenger experience.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy storage: super charge blade battery with increased safety

BYD Auto Co, Ltd.

Source: Getty Images/SweetBunFactory

BYD's next-generation Lithium Iron Phosphate Blade Battery, integrated into the chassis structure, delivers enhanced safety, durability and efficiency. It has proven to withstand extreme conditions, such as nail penetration and high temperatures, without emitting smoke or fire. The Blade Battery features Silicon Carbide (SiC) technology in its 6-in-1 controller for efficient operation and quick roadside maintenance. With BYD's Cell to Pack (CTP) technology, space utilization is improved by 50%, enabling a longer range. The battery offers a maximum capacity of 500 kWh, allowing electric buses to travel up to 600 km on a single charge, reducing downtime and increasing overall energy efficiency.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Smart energy: heavy duty charging station with V2G application

Nuvve

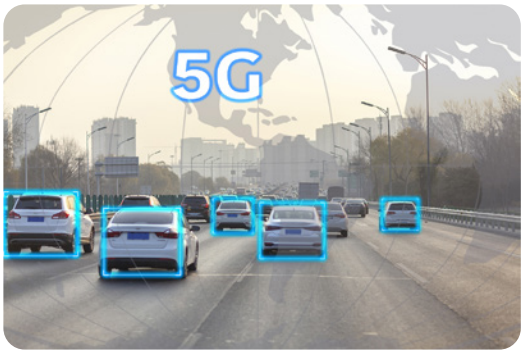
Source: Nuvve

The Nuvve DC Heavy-Duty Charging Station (RES-HD60-V2G) and DC Rapid HD Charging Station (RES-HD125-V2G) are specifically designed for vehicle-to-grid (V2G) applications, making them ideal for the fast, smart charging of heavy duty fleet vehicles like electric school buses. These stations are fully integrated with Nuvve's fleet management app and the V2G platform (GIVe™), supporting both unidirectional charging for any vehicle and full bidirectional V2G and vehicle-to-building (V2B) services when connected to a V2G-compatible vehicle.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: United States of America
- Availability: Worldwide
- Contact: WIPO GREEN Database

Smart energy: fully integrated 5G-V2X

Autotalks



Source: Getty Images/Tony Studio

TEKTON3 is a V2X sensor that helps vehicles share real-time information, improving road awareness and safety. It enables cooperative perception, meaning one vehicle can "see" what another vehicle detects, reducing blind spots and improving reaction times in complex traffic situations. It is designed to support automatic braking and meets ISO 26262 ASIL B functional safety standards. It works with all V2X communication technologies, including DSRC, LTE-V2X (C-V2X Rel. 14/15) and 5G-V2X (NR-V2X) (C-V2X Rel. 16/17/18). The sensor operates with two radios, each equipped with dual antennas for stable and reliable communication.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Israel
- Availability: China, Israel, Japan, the Republic of Korea
- Contact: WIPO GREEN Database

Energy storage: e-bus waterproof battery with long lifespan

Contemporary Amperex Technology Co Ltd (CATL)

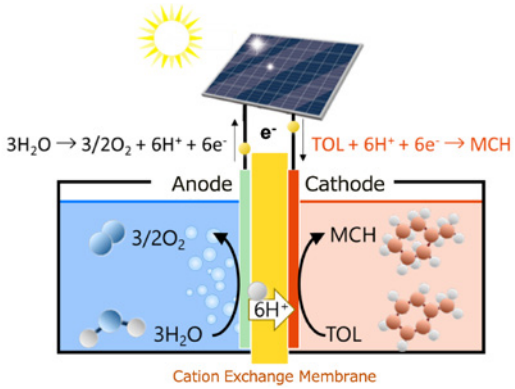
Source: Getty Images/zssp

Contemporary Amperex Technology (CATL) has introduced the Tianxing-B (Tectrans B) battery, designed specifically for electric buses. It has an energy density of 175 Wh/kg, which is the highest energy density in the industry as per the company. The battery is expected to last 15 years or 1.5 million kilometers (930,000 miles), while its warranty covers 10 years or 1 million kilometers (620,000 miles). With an IP69 waterproof rating, the battery can withstand submersion for up to 72 hours. The Tianxing-B has already partnered with 13 clients and will be used in over 80 different bus models. CATL has powered over 385,000 buses globally. The battery is also referred to as the Tianxing Bus Edition or B-series. CATL's Tianxing product allows commercial vehicle users to experience super-fast charging, enabling 60% charge in just 12 minutes.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Alternative energy vehicles: green hydrogen carrier for efficient supply chains

ENEOS



Source: ENEOS

The energy-demanding process of hydrogen electrolysis involves the splitting of water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2), producing hydrogen gas that can be used as fuel in vehicles with only water as a by-product. Areas abundant in renewable energy are thus attractive sites for hydrogen "harvesting" plants, but their uneven distribution poses a problem for the scaling of global hydrogen supply chains. ENEOS is working on a process called the Direct MCH® process, in which hydrogen molecules are added to toluene, generating hydrogen-carrying methylcyclohexane (MCH). This substance is compatible with existing petroleum infrastructures and, when compared in the same volume, it can be used to transport 500 times more hydrogen than hydrogen gas. MCH generated at a solar-powered Direct MCH® electrolyzer demonstration plant in Australia has successfully been transported and used to power a fuel cell bus in Japan.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Australia, Japan
- Contact: WIPO GREEN Database

Energy storage: next-generation lithium-ion battery using NTO technology

Toshiba

Source: Toshiba

Toshiba Corporation, Sojitz Corporation and Brazil's CBMM have developed a next-generation lithium-ion battery that uses niobium titanium oxide (NTO) in the anode. This new battery, which features an ultra-fast charge time of around 10 minutes and high energy density, has been demonstrated in an electric bus prototype unveiled at CBMM's industrial plant in Araxá, Brazil. This marks the first operation of a prototype e-vehicle powered by a lithium-ion battery with NTO anodes. The niobium oxide anode enhances safety and efficiency due to its stable voltage and ability to fully recharge in under 10 minutes without damaging the battery. This also results in a longer lifespan compared to traditional batteries. The companies plan to commercialize the NTO-based battery globally by Spring 2025.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy supply: aesthetic modular wind turbine

Airiva renewables Inc.

Source: Airiva renewables Inc.

Airiva is a modular, scalable and smart wind energy system consisting of an array of vertical wind turbines within a contemporary frame. It is designed to integrate within the architecture and infrastructure of urban and suburban landscapes. Complementing and supplementing other energy technologies, the electricity generated can be used directly on-site, stored or fed into the grid. The modular design can be scaled to suit site-specific needs, making it suitable for a broad diversity of applications, including commercial buildings and campuses, highway, rail and air transport networks, marinas and harbors. Airiva is currently a patented prototype and has a manufacturing target to use a minimum of 80% recycled and post-consumer materials compared with the frequent high use of virgin materials seen across the renewable energy category.

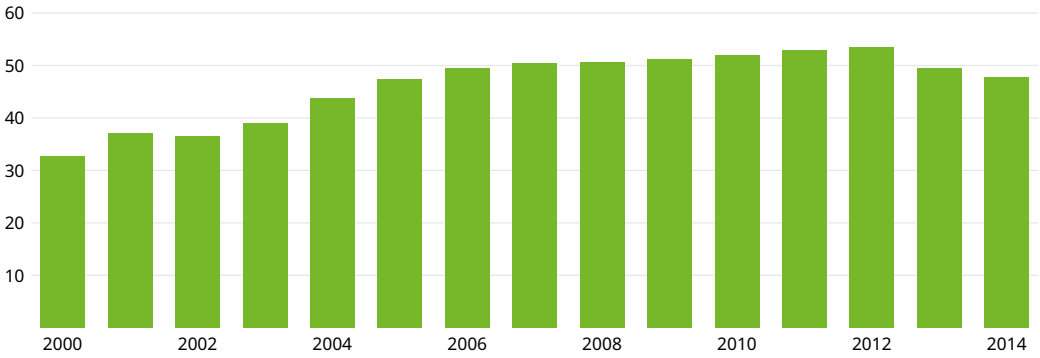
- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: United States of America
- Availability: N/A
- Contact: WIPO GREEN Database

Energy efficiency for water utilities

Energy production is a significant water consumer. The global energy sector accounted for approximately 10% of total global freshwater withdrawals in 2021, equating to around 370 billion cubic meters (IEA, 2023a). This significant water use spans all phases of energy production and conversion, from fossil fuel extraction and processing to electricity generation to biofuel cultivation. Nearly 90% of global electricity generation relies on water, mainly for cooling thermal power plants and for hydropower (ETH, 2025). As a result, reliable power generation is highly dependent on consistent access to freshwater, making it vulnerable to water scarcity. On the other hand, the extensive demand for water also relies on energy and requires electricity for every step of the water cycle, from extracting water from lakes or rivers to delivering clean drinking water and treating wastewater. This interlinkage and mutual dependence between water and energy systems is known as the water-energy nexus. It is anticipated to grow in importance as increasing demand and mounting pressures on both resources are driven by economic development, population growth and the impacts of climate change (IEA, 2024a).

The Asia-Pacific region is predominantly water-stressed (ESCAP, 2013). As population growth and urbanization continue to rise, cities experience significant resource demands. For instance, China's power sector has traditionally depended on thermal power generation[3] which requires large amounts of freshwater for cooling. Figure 2.10 shows that in 2014 around 48 billion cubic meters (bcm) of freshwater was used for power generation in China, representing about 8% of the nation's total freshwater. Similarly in India, the total water consumption for electricity generation is projected to increase by up to 4 billion cubic meters by 2030 and expected to account for nearly 9% of national water consumption by 2050 (IRENA and WRI, 2018).

Figure 2.10 Water withdrawal for thermal power generation in China (billion cubic meter), 2000–2014



Source: Adapted from ADB (2017).

Asia is also home to more than a third of the world's total hydropower generation, led by China, India and Japan. Unlike thermal plants, hydropower plants do not directly consume water. They are dependent on reliable water flow and are therefore highly vulnerable to changes therein, for example from climate change and competing uses of water.

Given this context, the energy sector is projected to use an increasing share of available water resources in the region, while competing demands for freshwater continue to rise due to growing population, urbanization and water-intensive agriculture. More than 75% of Asia experiences water insecurity, with climate change further exacerbating the situation (FAO, 2023). Extreme weather events – such as intense rainfall, floods, droughts and sea level rise – are disrupting water availability and, in turn, directly impacting energy production (IRENA, 2024b). Measures to mitigate and adapt to climate change can further impact surface and groundwater availability and their users (EU, 2021). At the same time, as water becomes harder to access, more energy is needed to pump it from deeper underground or distant sources, or for treating water extracted from alternative sources (e.g. seawater or brackish water). Singapore is a key example in Asia, using significant energy to tackle its water scarcity, with daily water demand reaching 1.73 million m^3 (ESCAP, 2013).

3 Thermal power generation burns fuel to heat water, creating steam that drives turbines to generate electricity.

Utilizing the most energy-efficient equipment in water supply systems is essential for conserving both water and energy, as water extraction and distribution can account for up to 65% of the total energy used in the urban water cycle (UNEPCCC, 2023). Advanced IoT technologies can help reduce leakages and other water losses (non-revenue water) in the region, improving the efficiency of the water supply systems. Renewable energy can further strengthen the water-energy nexus in Asia, for example, solar PV and wind do not require water in the electricity generation process. These renewable sources can also be integrated into existing thermal plants to meet part of the energy needs, reducing reliance on water-intensive cooling systems typically powered by fossil fuels.

Utilizing the most energy-efficient equipment in water supply systems is essential for conserving both water and energy

Water innovation is crucial in the Pacific region as well where limited access to piped water and high costs make affordability a major challenge. In Papua New Guinea, only 9% and in the Marshall Islands, 3% have access to piped drinking water (UNESCO, 2024). With such challenges in ensuring reliable freshwater, seawater desalination has become a vital solution in some areas. Such technologies are explored in more detail in the following sections.

Technological development and trends

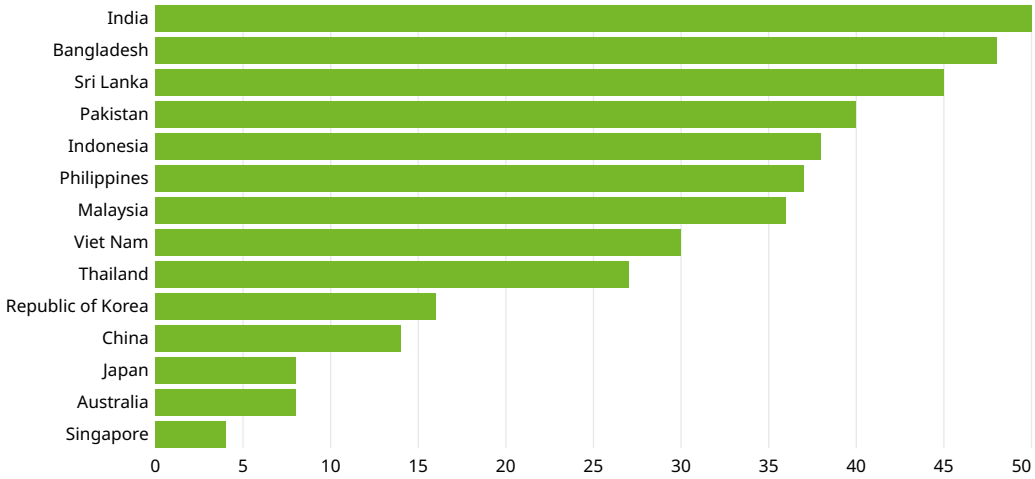
Saving water and energy by reducing non-revenue water in urban supply systems

Moving water requires a lot of energy because it is heavy and cannot be compressed like gas. Water utilities primarily use energy to power pumps to transport water through pipes, lift it to higher elevations and force it through treatment systems to supply consumers with clean water. However many cities in Southeast Asia lack good infrastructure for water supply and distribution systems (Edwards, 2024). This leads to increased energy consumption, as old pipes cause water losses that demand more pumping and treatment to compensate. Across Asia, water utilities lose between 5% and 50% of their daily production (ADB, 2016) (figure 2.11). This persistent challenge, known as non-revenue water (NRW), affects the financial viability and efficiency of water systems, making it a major concern for water utilities in the region. Therefore, reducing NRW is key to attaining energy efficiency in urban water supply.

Advanced technologies for managing water pressure and detecting leaks include smart pressure-reducing valves (PRVs) and smart water meters equipped with IoT technology such as digital sensors, real-time data analytics, remote communication and automation to optimize water management. They provide real-time alerts when abnormal water flow occurs, signaling potential leaks, and can be remotely monitored and controlled to reduce water loss and improve efficiency. Additionally, ultrasonic flow meters detect sudden changes in water flow using sound waves, while transient pressure[4] monitors identify pipes under stress, highlighting areas at risk of leakage.

4 Transient pressure is the rapid, short-term changes in the pressure within a pipeline or fluid system, which can be much higher than the normal operating pressure of the piping system and can cause damage to pipes, fittings or other infrastructure.

Figure 2.11 Non-revenue water (%) in selected economies in Asia and the Pacific



Source: Adapted from ADB (2016).

Aging infrastructure and rising water leakage are also major issues in Pacific regions like Australia and New Zealand, where much of the infrastructure is over 50 years old. With prolonged droughts stressing municipal water supplies, cities like Sydney lose billions of liters annually due to NRW, while in Wellington, over half of the pipes need replacement (Trelleborg, 2021). Trenchless pipe rehabilitation offers a non-invasive, cost-effective solution to repair or replace underground pipes with minimal environmental impact. It involves a cured-in-place pipe (CIPP) lining method where a resin-coated liner is inserted into the existing pipe, which hardens to form a new pipe inside the old one. There is also the slip lining method that inserts a smaller pipe into the existing one, reducing its diameter but restoring functionality without extensive digging.

Apart from the leakages, greater challenges of NRW lie in illegal connections, water theft, metering inaccuracies and inefficient billing systems, which make up 50% to 65% of NRW in Asia (ADB, 2007). For example, in Ho Chi Minh City, the utility reduced NRW from 42% to 31% in under a year by only updating its customer database to identify thieves and adjusting water pressure to minimize leaks, resulting in annual savings of $1.4 million. Reducing NRW in Asia requires strong governance, utility autonomy to allow the service providers to adopt new technologies, and accountability to regulators and the public. Furthermore, economic incentives for water utilities through benchmarking NRW can enhance water management (UNEPCCC, 2023).

Apart from the leakages, greater challenges of NRW lie in illegal connections, water theft, metering inaccuracies and inefficient billing systems

Low service coverage often goes hand in hand with high NRW (ADB, 2014). In the Philippines, where NRW is high due to illegal connections, a temporary low-cost solution known as "Temfacil" (temporary facility) is implemented. This approach involves laying galvanized iron pipes above ground, often embedded in cement, replacing old pipelines prone to unauthorized taps. Such a facility also extends water access to low-income and flood-prone areas where permanent pipelines are not feasible. In parallel, community-run cooperatives help reduce illegal connections and water theft by providing affordable and reliable potable water. More solutions for reducing NRW are covered in the *Green Technology Book* energy solutions and climate change adaptation editions.

Energy-efficient motors, pumps and aerators for water supply and treatment

Advanced motor technology with higher torque and power density can reduce energy losses by nearly half compared to traditional motors (WIPO, 2024c). Energy efficiency improvements can be achieved by upgrading traditional motor-pump sets to smart systems with the addition of digital sensors that can monitor and optimize their performance autonomously. Smart multi-pump systems can further control and manage multiple pumps at once. Based on real-time data derived from sensors (such as pressure, flow rate or demand), this interconnected system can start, stop or adjust the speed of individual pumps to maintain optimal performance, which saves energy. Further energy efficiency can be achieved by installing variable speed drives (VSD) that adjust the speed of a pump or motor according to the required water flow, with on-off functioning rather than operating at full speed constantly. Box 2.5 provides more information on motor technologies.

Simpler ways to manage water flow while saving energy involve replacing old suction and discharge pipes. This reduces resistance, allowing for smoother water flow and making pumps work less, which saves energy. Retrofitting pumping stations with gravity-fed systems can also minimize energy use by letting water flow downhill with little need for pumps. Additionally, optimizing operations – like shifting pumping to off-peak hours and upgrading facilities with energy-saving measures (efficient lighting, ventilation, insulation) – improves energy efficiency in urban water supply systems.

Box 2.5 Maximizing energy efficiency through advanced motor technologies

Electric motors are highly durable, with a typical lifespan of 12 to 20 years, depending on their power range (from small 1–7.5 kW to large 75–375 kW motors). This longevity, along with the tendency to stock reserve motors, has slowed the adoption of modern, energy-efficient technologies. The International Electrotechnical Commission (IEC) standards classify motor efficiency from IE1 (Standard) to IE5 (Ultra-Premium). High-efficiency motors, such as IE4 and IE5, include standard induction motors, permanent magnet synchronous motors and synchronous reluctance motors. Additional measures, such as avoiding motor oversizing, utilizing advanced controls (like torque control and VSDs), integrating digitalization and optimizing system components (e.g., pumps, fans, compressors), can boost efficiency. VSDs and high-efficiency motors can reduce energy consumption by 25% to 30% in clean water, desalination and wastewater processes, while digital solutions can save 10% to 20% in wastewater treatment. UNEP's "United for Efficiency" guidelines help governments develop frameworks to improve motor system efficiency, including incentive programs and energy performance standard.

Source: UNEPCCC (2023).

Energy-efficient aeration is crucial for effective wastewater treatment

In traditional wastewater treatment plants (WWTPs), the aeration process accounts for nearly 60% of the facility's total energy consumption (Wang *et al.*, 2023). The aeration process enhances the dissolution of oxygen in water, promoting the growth of aerobic microorganisms that break down organic pollutants. Surface aeration is the oldest and most common method which uses electric motors to drive mechanical devices like paddle wheels or floating aerators. More energy-efficient aeration technologies include bubble diffusers which produce fine bubbles with a greater surface area-to-volume ratio than traditional diffusers, allowing for more oxygen to dissolve in water while consuming less energy. Further, coupled with automated control systems that adjust airflow based on real-time conditions, the treatment process can ensure that energy is only used when necessary.

In China and Japan, membrane bioreactors (MBRs) are being increasingly adopted in urban environments to improve wastewater management and water recycling. Membrane Aerated Biofilm Reactors (MABRs) offer an energy-efficient solution by delivering oxygen directly to

bacteria through a gas-permeable membrane, which allows for more efficient oxygen usage in biological processes. See also *Green Technology Book* adaptation and energy editions for more details. Additionally, anaerobic membrane bioreactors (AnMBR) work without aeration, which reduces energy use; they also produce biogas as a potential energy source. Advanced technologies like high-speed blowers further optimize energy usage in water treatment systems by improving the efficiency of the aeration process. Countries like China and Japan are already adopting this technology. More details are in the technology solutions section.

Advancing desalination technologies in Asia to tackle water scarcity

By 2050, over half of the world's population are projected to live in water-scarce regions, with Asia accounting for 73% of those affected (Infrastructure, 2022). More frequent droughts and floods due to climate change are making water management more challenging, while sea level rise, combined with groundwater extraction, is giving rise to saltwater intrusion, threatening the supply of freshwater. For instance, more than 75% of provinces in the Mekong River delta in Viet Nam are affected by seawater intrusion (Cong, 2018). The growing demand for freshwater has driven greater reliance on desalination, a technology that separates saline water (seawater or brackish water) into freshwater and concentrated salt (brine) (IEA, 2024b). However, desalination is an expensive and energy-intensive process that contributes significantly to GHG emissions due to the energy required to power the process, particularly in countries with carbon-intensive electricity grids (Eyl-Mazzega and Élise Cassignol, 2022). Energy costs alone account for 33% to 50% of the total cost of desalination operation (Shtelman, 2019).

> Desalination is an expensive and energy-intensive process that contributes significantly to GHG emissions due to the energy required to power the process

Asia already accounts for a significant share of global desalination capacity (AIIB, 2019). While Singapore leads the way, with 25% of its water supplied through desalination, countries such as China, India, the Republic of Korea and Thailand are also increasingly adopting this technology (Tempest, 2019). Asian governments are investing in seawater desalination to build reliable and resilient urban water supply systems. Desalination plants can also be used for treating brackish water with lower salt concentrations.

Desalination energy demand varies by technology (Table 2.1). Reverse osmosis (RO), currently the most energy-efficient desalination technology, consumes 1 kWh to 8.5 kWh of electricity per cubic meter of treated water. It uses a high-pressure pump to force the water through a semi-permeable membrane at a pressure greater than the natural osmotic pressure, allowing only water molecules to pass while blocking most salts and impurities. In contrast, thermal desalination uses 70 MJ to 280 MJ of thermal energy (mainly from fossil fuels) and 1 kWh to 5 kWh of electricity per cubic meter of treated water, to evaporate seawater and run other components like pumps, fans etc.

Countries like China, India and Singapore are at the forefront of advancing RO membrane technologies, which is the primary option for the new desalination plants (ESCWA, 2017; Herber, 2024). Also, major Australian coastal cities are using RO desalination. For instance, in Victoria, the Millennium Drought led to the development of an RO desalination plant to address critical water shortages. The plant now produces 150 billion m^3 of purified water annually, showcasing how communities can adapt to extreme climate conditions by diversifying water sources with advanced desalination technology (DEECA, 2023).

Table 2.1 Energy requirement of different desalination technologies

Technology		Electrical energy (kWh/m3)	Thermal Energy (MJ/m3)
Thermal	Multistage flash distillation	2.5-5	70-280
Thermal	Multieffect distillation	1.0-3.0	32-72
Membrane	Reverse Osmosis (seawater)	2.2-8.5	Not required
Membrane	Reverse Osmosis (brackish water)	1.0-2.5	Not required

Source: ADB (2017).

Advancement in pump efficiency, the adoption of energy recovery devices (ERDs) and improved membranes have made the RO desalination process further efficient, with ERDs cutting energy consumption by two or three times in both small- and large-scale systems. (Alghoul *et al.*, 2009); (Prante *et al.*, 2014). The Jurong Island desalination plant in Singapore, equipped with advanced water treatment and membrane technologies like dissolved air flotation, ultrafiltration and RO, is about 5% more energy efficient than other existing plants in the country (Infrastructure, 2022).

More advanced technology includes hybrid desalination which combines thermal desalination and RO. In this method, saline feedwater is partially desalinated with RO before thermal distillation, which lowers the salinity of the water entering the thermal process, reducing the energy needed for evaporation. Forward osmosis (FO) is also gaining attention as an energy-efficient solution in hybrid desalination. It works by using a semi-permeable membrane to separate water from dissolved solutes through an osmotic pressure gradient. Unlike reverse osmosis, it operates with low or no hydraulic pressure, lowering energy demands. Pilot projects in Southeast Asia are testing its use in desalination and industrial wastewater treatment.

Box 2.6 Electro-deionization (EDI) technology for desalination

The technology combines ion-exchange resin (IER) with electrodialysis (ED) to continuously remove dissolved ions from water without the need for chemical regeneration. In an EDI system, water flows through compartments filled with ion-exchange resin, which captures unwanted ions. An applied electrical current then drives these ions through selective membranes into separate waste streams, effectively removing them from the purified water. Water splitting within these compartments generates H^+ and OH^- ions, which regenerate the resin, eliminating the need for any chemical treatment for resin regeneration. By improving ion mobility and current efficiency using resins, EDI provides an energy-efficient and environmentally friendly alternative for producing ultra-pure water.

Source: Khan *et al.*, 2023; Lee and Choi, 2012.

CO_2 emissions from desalination can be reduced by integrating renewable energy, with solar and wind-powered RO being the most common methods. However, their intermittent nature can affect RO performance, potentially shortening the lifespan of membranes and pumps (Alawad *et al.*, 2023). Energy storage is crucial for continuous operation. Currently, renewable energy-powered desalination plants account for only 1% of global capacity (Jongkwan Park, 2022). In the Republic of Korea, renewable energy desalination facilities have been set up for energy self-sufficient island projects, including a small RO plant with solar PV and energy storage on Juk-do Island for 70 residents (Jongkwan Park, 2022). Recent innovations like plug-and-play RO systems with digital monitoring enable better membrane management and remote access for efficient operations (Asian Water, 2022). For more desalination technologies see *Green Technology Book* on climate change adaptation and energy solutions.

Advanced water purification technologies

In addition to RO, Singapore is exploring other technologies, such as electro-deionization (removing salts through the adsorption of dissolved ions) and biomimicry (mimicking nature's filtration process, like plants or fishes), to enhance desalination efficiency and reduce energy consumption. Box 2.6 provides details on electro-deionization. Various types of desalination batteries, such as rocking chair, redox flow and metal-air batteries, have been developed to improve desalination capacity. They use electro-chemical reactions to selectively capture and release salt ions from water.

Harnessing digital technologies for water management in Asia

By 2025, half of the utilities in major cities in the Global South are expected to integrate digital water supply solutions like advanced metering infrastructure (Amankwaa *et al.*, 2021). In Southeast Asia, advanced technologies like Supervisory Control and Data Acquisition (SCADA), Geographic Information Systems (GIS), Enterprise Resource Planning (ERP) and sensors are being implemented to enable smart water grid systems which optimize the management of water distribution networks. GIS maps and analyzes networks for better planning, while ERP systems integrate functions like optimized resource allocation, billing and maintenance. SCADA systems allow remote management of processes and equipment, using sensor data to monitor key parameters (pressure, water purity, flow rates etc.) and automate real-time plant operations, improving efficiency and addressing issues like leaks system failures.

> By 2025, half of the utilities in major cities in the Global South are expected to integrate digital water supply solutions

The Changi Water Reclamation Plant in Singapore hosts one of the world's largest SCADA systems, with around 500,000 input-output points and a significant integration of programmable logic controllers, networked data communications and graphical interfaces, while in Phnom Penh, Cambodia, digital monitoring system reduced non-revenue water to less than 6% of the total water supplied (Infrastructure, 2019). Similarly, Malaysia's largest water utility in Air Selangor has used intelligent leak detection tools to reduce NRW and identified near 295 leaks so far through the deployment of more than 160 sensors (Lu, 2023).

Wastewater to energy

Wastewater from households can be properly treated to remove solids, nutrients or harmful compounds, and reused as "reclaimed water." This is increasingly seen as an alternative resource for fit-for-purpose applications, offering significant reductions in energy use, costs and environmental impact (Liao *et al.*, 2021). However, despite the potential, wastewater treatment and reclaimed water use remain underdeveloped across much of Asia, with 80% of wastewater in the region being discharged untreated (ADB, 2011; Liao *et al.*, 2021). This is mainly due to weak capacity, huge capital costs and lack of awareness (ADB, 2011). Only 9% of wastewater is treated in India, 14% in Indonesia, 10% in the Philippines and 4% in Viet Nam (ADB, 2012). Nevertheless, some countries have successfully integrated reclaimed water into their water resource management system, such as China, Japan and the Republic of Korea. Singapore, in particular, stands out as a global leader in water management with their advanced wastewater infrastructure.

Wastewater could play a significant role in climate solutions including generating biogas, heat and electricity, yielding up to five times the energy needed for treatment – enough to power around half a billion people annually (UNEP, 2023). For example, anaerobic wastewater treatment (AnWT) breaks down organic material using anaerobic microorganisms, producing biogas that offsets facility energy use and supports local power supplies, particularly in energy-scarce regions (Arthur *et al.*, 2022). This process reduces GHG emissions by lowering energy consumption, substituting fossil fuels and recovering methane biogas (EBA, 2021). In Ullalu, Bangalore, a decentralized wastewater treatment project has successfully provided hot water and lighting for toilet complexes (Nes, 2006).

Emerging technologies of microbial fuel cells (MFCs)

A recent innovation in wastewater treatment is the microbial fuel cell (MFC), which enables water treatment facilities to generate electricity for immediate use while simultaneously treating and recycling wastewater, all without disrupting the atmospheric CO_2 balance. The CO_2 produced as a by-product of MFC operation can be safely discharged without the need for additional treatment (Kurniawan *et al.*, 2022). This technology uses specialized microbes that break down organic matter as wastewater flows through the system. As the microbes decompose the organic material, they release electrons, which are transferred to an electrode to generate electricity. This device shows great promise as a practical solution because it produces more energy than it consumes, is cost-effective and requires minimal maintenance.

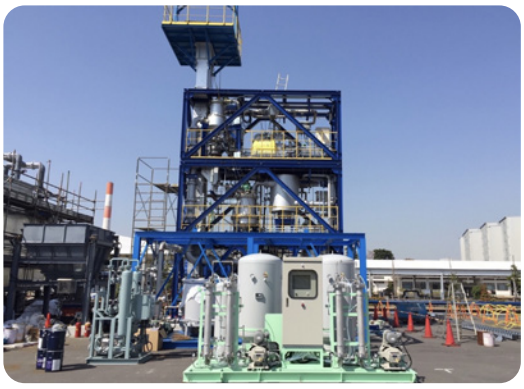
Innovation examples

Singapore's solution to water scarcity

Source: Singapore's National Water Agency (PUB)

NEWater is Singapore's high-grade recycled water, produced by further purifying treated, used water through a three-step process of ultrafiltration or microfiltration, reverse osmosis and ultraviolet disinfection. This advanced treatment makes it ultra-clean and safe for consumption. By continuously recycling water, NEWater enables Singapore to close the water loop, strengthening the country's water security and resilience to climate change. Compared to desalination, it is more energy- and cost-efficient due to the lower salt content in treated used water. NEWater is mainly supplied to wafer fabrication plants, industrial estates, and commercial buildings for industrial and air-con cooling purposes. During dry periods, NEWater is also added to reservoirs to blend with raw water before being collectively treated at the water treatment plants for potable use. Currently meeting 40% of Singapore's water demand, NEWater's capacity is set to expand to 55% by 2060 (Fi Group, 2025).

Sludge-to-hydrogen plant in Tokyo is producing hydrogen to fuel vehicles and generate power



Source: Japan Blue Energy Co., Ltd.

Japan Blue Energy Co., Ltd., a renewable hydrogen systems manufacturer, has completed a facility in Tokyo that converts sewage sludge into renewable hydrogen fuel for fuel cell vehicles and power generation. Located at the Sunamachi Water Reclamation Center near Tokyo Bay, the facility processes 1 ton of dried sewage sludge daily, producing 40 to 50 kilograms of hydrogen – enough to fuel 10 passenger cars or 25 fuel-cell e-bikes. It can also process plastic, paper, municipal waste, and other refuse. Waste is heated to high temperatures to form a gas from which hydrogen is extracted. The facility is carbon-neutral and operates on a closed-loop system, generating its own energy. Developed with the Tokyo Metropolitan Government, TODA Corporation, TOKYU Construction, CHIYODA Kenko, and Tokyo University of Science researchers, the facility supports Japan's growing demand for renewable hydrogen and offers an innovative solution for sustainable waste disposal (Japan Blue Energy Co., 2021).

Tackling non-revenue water (NRW) in Malaysia through digital monitoring and community engagement

Source: Xylem

Air Selangor, a major water utility in Malaysia, has partnered with Xylem to implement a long-term, state-wide monitoring program in Selangor. Xylem's Water Loss Management solution uses real-time digital monitoring through a sensing platform that integrates leak, burst and surge detection to prevent early asset failures. By analyzing pressure transients and hydrophone data, the system quickly identifies pipe bursts and slow leaks, localizing issues within minutes. The automated 24/7 platform streamlines data analysis and visualization, helping repair teams prioritize responses. Xylem's non-invasive surge detection provides early warnings by pinpointing pressure surges and identifying pipes at high risk, reducing premature failures and extending asset life. Launched in 2018 with 500 sensors, the program identified 65 major leaks in its first year. By January 2021, 1,600 sensors were active, detecting about two leaks weekly, totaling 295. Continuous monitoring helped reduce NRW from 33.3% in 2017 to 27.75% in 2023 (Xylem, 2022). Air Selangor also launched a "Leak Reporting Campaign" via its app, encouraging the public to report leaks, bursts and illegal tapping incidents. As of December 2023, over 15,000 verified cases were reported through this campaign, contributing significantly to NRW reduction.

Technology solutions

Proven technologies

Water/energy efficiency: Ice Pigging™ cleaning of pipes to increase pumping efficiency

Suez Asia

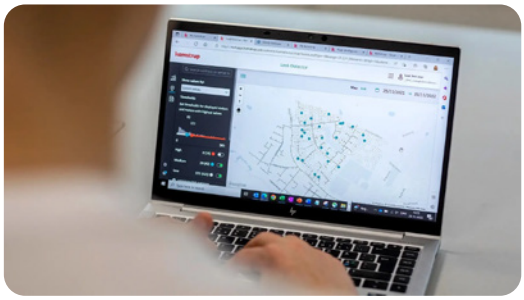
Source: Getty Images/Mumemories

Ice Pigging™ is an efficient pipeline cleaning process, commonly used by water supply and sewage companies as well as a wide range of industries. It improves performance of the pipe network and saves energy costs as pumps and filtration plants work more efficiently. It utilizes a slurry of ice crystals that forms a semi-solid plug, called the Ice Pig™, which moves through pipes under pressure, detaching contaminants and carrying them out. This method cleans several kilometers of pipe in hours or smaller pipes in minutes, requiring minimal water (typically 1.5 pipe volumes) and no chemical use. Ice Pigging™ works with existing fittings, fitting various pipe sizes from 8mm to 600mm, and handles complex pipe geometries, including diameter changes and valves. It flows like a liquid and can melt and flush out if it gets stuck, making it safer than traditional pigging. The method reduces energy use, minimizes downtime and offers higher-quality cleaning than air scouring, without damaging pipes. It is a cost-effective solution as well, as it uses up to 50% less water compared to a typical swabbing operation.

- Contracting type: For service
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: China
- Availability: Southeast Asia
- Contact: WIPO GREEN Database

Water/energy efficiency: smart water metering for water utilities

Kamstrup



Source: Kamstrup

A smart water meter uses ultrasonic technology to measure water usage and includes remote reading capabilities, advanced pressure monitoring, leak detection and data analytics for better water management. It not only tracks consumption accurately but also enhances customer relations, optimizes operations and safeguards revenue. With tools like the READy Manager, utilities can visualize individual water usage, detect leaks early and analyze water waste continuously, reducing costly field visits and water loss. The system monitors pressure surges, allowing operators to prevent leaks and bursts by identifying issues early. For high-priority areas, meters can be set to a five-minute reading interval, offering detailed network insights for optimizing operations and lowering energy costs. Pressure sensors strategically placed across the network provide data to adjust pressure, saving on operational and energy expenses while decreasing non-revenue water.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Denmark
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy-efficient pumps/motors: water pump with pressure boosting system

Davey

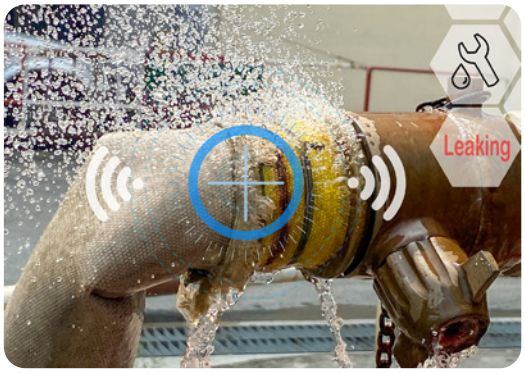
Source: Getty Images/RonFullHD

The Davey BT Booster Pressure System combines a durable centrifugal pump with the intelligent Torrium2 pressure controller to deliver consistent, energy-efficient water pressure for homes and light commercial applications. Designed with large water pathways for reduced head loss, the system enhances hydraulic performance while minimizing energy waste. It is particularly suitable for boosting low municipal supply or transferring water from underground sources. It ensures constant flow operation even with varying demand or intermittent supply. The totally enclosed fan cooled (TEFC) motor, rated for high ambient temperatures and voltage fluctuations, along with its IP55 protection, provides dependable performance even in the hottest climates.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Australia
- Availability: Australia, New Zealand
- Contact: WIPO GREEN Database

Water/energy efficiency: all-in-one toolkit for cloud-based leak detection

Ovarro



Source: Getty Images/Toa55

EnigmaREACH is an advanced, cloud-based solution for large-scale leak detection using multi-correlating acoustic loggers. Designed for rapid, mass deployment, it covers extensive pipe networks with high accuracy and minimal hardware, leveraging automated correlation data to pinpoint leaks precisely. Equipped with either 32 or 64 Enigma loggers, a tablet, a dedicated app and access to the digital analytics platform, it streamlines logger deployment, data retrieval and follow-up. Automated processes quickly identify and assign points of interest (POIs), allowing field technicians to address issues faster, reducing water loss and operational costs. EnigmaREACH automates key tasks, including sound file analysis, POI assignment and efficient data management. It provides 24/7 data access and is ruggedly built for all-weather use. With a user-friendly interface, it reduces leak detection time by 75% and lowers operational costs by automating analytics and optimizing field tasks, delivering a reliable, end-to-end solution for leak detection and proactive water management.

- Contracting type: For sale/service
- Technology maturity: Proven
- Technology level: High
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water treatment: portable solar suitcase water purifier

NEWater

Source: AI Generated using ChatGPT 5.0

The solar suitcase water purifier is a compact, lightweight and modular unit designed for easy operation and portability. Equipped with foldable solar panels, it uses sunlight to continuously charge its battery, while an intelligent power management system ensures battery safety. This purifier provides safe water, and electricity for essential devices like mobile phones. The system is ready for immediate use with water inlet and outlet connections and supports various power sources, including AC, DC and solar. It features a built-in DC24V lithium battery for stable water production lasting 4–6 hours in emergencies, and the durable ABS casing has an IP65 waterproof rating with a secure waterproof seal. Integrated monitoring of total dissolved solids (TDS) allows real-time tracking of inlet and outlet water quality, while the space-saving design offers a compact, sturdy build for long-lasting performance. Meeting diverse purification needs, it produces both drinking and household water for multiple scenarios. It can be used for emergency and outdoor scenarios, such as disaster relief or post-earthquake recovery.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: China
- Availability: Africa, Asia, Eastern Europe
- Contact: WIPO GREEN Database

Energy efficiency: energy-saving turbo blower for aeration in wastewater treatment

Robuschi

Source: Robuschi

Turbo blowers improve energy efficiency in wastewater treatment plants, lowering environmental and financial impacts. With high nominal efficiency, they can save up to 40% on energy. A wide turndown ratio adapts air output precisely to process demands, using centrifugal and positive displacement technologies like rotary lobe and screw blowers. Their compact design minimizes the space needed in compressor rooms, and oil-free air foil bearings enhance safety by eliminating contamination risk. The plug-and-play inverter simplifies installation, while a high-speed, direct-coupled permanent magnet motor reduces maintenance by omitting gears and belts, ensuring low vibration, quiet operation and lower total cost of ownership.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Italy
- Availability: Australia, China, Europe, India, Indonesia, Israel, Japan, Malaysia, Saudi Arabia, the Republic of Korea, Singapore, United Arab Emirates
- Contact: WIPO GREEN Database

Water treatment: gravity-fed wastewater treatment system

ECOSTP Technologies

Source: ECOSTP Technologies

ECOSTP Technologies has developed a low-maintenance and energy-free sewage treatment system applicable to urban residential wastewater management. Inspired by the cow's anaerobic digestion process, the system uses a three-stage Rumen Digester Filter and tertiary treatment via planted gravel filters to clean wastewater without electricity, chemicals or any moving parts. The process begins with anaerobic digestion in chambers that mimic the rumen, reticulum and omasum, where custom-seeded anaerobic bacteria break down organic matter through hydrolysis, acidogenesis, acetogenesis and methanogenesis. This is followed by tertiary treatment using planted gravel filters, where microbial biofilms on plant roots and substrate remove pathogens, nutrients and residual contaminants. The resulting water meets reuse quality standards and is suitable for flushing, cleaning and gardening.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Energy-efficient pumps/motors: energy-efficient pump control with variable frequency drives (VFDs)

Franklin Electric

Source: Getty Images/yanik88

The DrivE-Tech Variable Frequency Drives enhance energy efficiency in pumping systems by adjusting motor speed to match demand, significantly reducing power consumption and operating costs. Compatible with vertical multistage, centrifugal and submersible pumps, it can be used for domestic, irrigation, commercial and HVAC applications in both new installations and retrofits. Its compact, die-cast aluminum IP55-rated enclosure is suitable for operation even in humid and dusty environments. It features integrated soft start and stop functions to extend system life and reduce peak variation, real-time monitoring and motor protection, and the ability to control a second or third pump at constant speed (DOL), ensuring long-term performance and flexibility.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: United States of America
- Availability: Asia-Pacific, North America, South America
- Contact: WIPO GREEN Database

Water treatment: electodeionization technology for water treatment and purification

Memiontec

Source: Getty Images/PongsakornJun

Memiontec-MIT's MIT-EDI™ system is an advanced continuous electro-deionization (EDI) technology that combines electric dialysis and ion exchange to effectively remove all types of cations and anions from water or wastewater to produce pure and ultra-pure water. It works without chemicals, offering a more energy-efficient alternative to traditional methods. Its modular, compact design supports continuous operation with automatic controls, eliminating the need for regeneration cycles, chemical transport and wastewater handling. MIT-EDI™ delivers a low-footprint, cost-effective and environmentally responsible solution for high-purity water applications.

- Contracting type: For sale/service
- Technology maturity: Proven
- Technology level: High
- Place of origin: Singapore
- Availability: China, Indonesia, Singapore
- Contact: WIPO GREEN Database

Water treatment: smart desalination with plug-and-play reverse osmosis (RO) technology

Veolia Water Technologies

Source: Veolia Water Technologies

The Barrel is a modular, plug-and-play RO or nanofiltration (NF) pressure vessel designed to deliver desalinated water that meets municipal and industrial standards. This scalable solution supports a range of capacities from 400 to 50,000 cubic meters per day per unit, making it suitable for wastewater reuse and low-pressure RO applications. Compact and ideal for outdoor installations, the Barrel reduces the required footprint by up to 25% and operates without a controlled environment, minimizing setup constraints. Additionally, it enhances energy efficiency by reducing electrical consumption to as low as 0.05 kWh per cubic meter of fresh water produced. The Barrel's modular design allows it to replace existing RO membranes and NF skids, offering a sustainable, economically viable alternative. Integrated with a digital system and smart connectors, it provides real-time membrane performance updates, allowing for automated monitoring, remote access and informed operational decisions regarding membrane maintenance.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water management: Water-as-a-Service (WaaS) for efficient water management

Ekopak

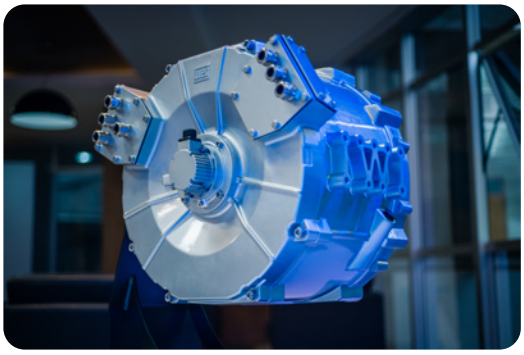
Source: Ekopak

WaaS is an innovative solution that helps companies manage their water needs, including production, treatment and recycling. This service by Ekopak takes over water management, ensuring a constant water supply without needing the company to hire its own staff. Ekopak designs, builds and maintains the water system sustainably, offering a leasing model where companies only pay for the recycled water they use. With this setup, customers can disconnect from the main water grid and switch to a circular water system. Ekopak's container-based treatment units can purify off-grid sources like rainwater, surface water or wastewater for reuse in industrial processes, optimizing water consumption.

- Contracting type: For service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Belgium
- Availability: Belgium, France, Netherlands, Philippines, , Singapore, Thailand, United States of America
- Contact: WIPO GREEN Database

Energy-efficient pumps/motors: high-efficiency hybrid motor for water utilities

WEG



Source: WEG

The W23 Sync+ is a high-efficiency hybrid motor that combines permanent magnet (PM), ferrite or neodymium magnets and synchronous reluctance (SynRM) technologies, offering IE5 ultra-premium efficiency across all speeds. This permanent magnet synchronous reluctance motor (PMSynRM) operates over a wide speed range, eliminating the need for forced ventilation or external blowers. Therefore, it can be adopted in the applications requiring adjustable speeds and constant torque. The W23 Sync+ delivers up to 30% energy savings, maintaining efficiency even with variable loads, unlike conventional induction motors which lose over 20% efficiency at reduced speeds. The magnets generate their own magnetic field without requiring induction of currents. Therefore, they reduce the total motor losses. It's ideal for compressors, pumps, fans, blowers and conveyors, providing higher efficiency, a better power factor and lower total cost of ownership. Available in frame sizes from IEC 80 to 450, the W23 Sync+ supports speeds from 750 to 6,000 rpm and outputs from 0.75 to 1,250 kW, with voltage compatibility across 220/380V, 230/400V, 240/415V and 400/690V. It is also compact, fitting in the same frame as IE3 motors, enabling easy replacement in existing systems.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Australia/Brazil
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy-efficient pumps/motors: smart and energy-efficient motor with multi-pump control

Delta

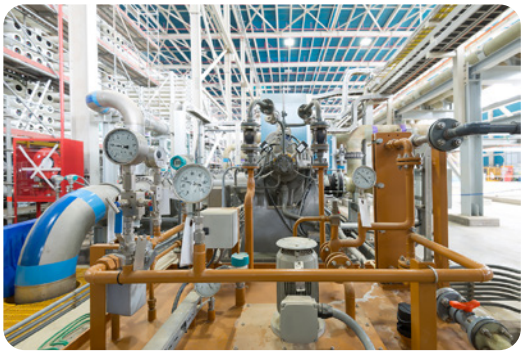
Source: Getty Images/Super Mario

The Delta Motor Mounted Pump Drive (MPD) is a high-efficiency IE5 motor solution with smart multi-pump controls for residential and industrial water supply. It reduces energy consumption by up to 10% compared to traditional induction motor pumps and has flange dimensions compliant with IEC standards for seamless installation to existing systems. Built-in multi-pump control functions eliminate the need for additional programmable logic controllers (PLCs), cutting installation costs and saving wiring space, while one master pump can manage up to seven others based on demand. The Delta MPD's auto load-sharing function saves up to 10% in energy, ensuring efficient performance. It also supports remote monitoring and commissioning via mobile devices, maintaining uninterrupted operations with multi-pump redundancy.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Taiwan Province of China
- Availability: India, Oceania, Southeast Asia
- Contact: WIPO GREEN Database

Water treatment: chemical-free seawater desalination

IDE



Source: Getty Images/tifonimages

IDE PROGREEN™ is an innovative, chemical-free seawater desalination technology that uses IDE's patented Direct Osmosis Cleaning (DOC) technology and natural pre-treatment to produce high-quality water for municipalities, resorts and industries. Instead of traditional chemicals, the pre-treatment process relies on natural bio-flocculation, where certain bacteria and algae release a sticky substance called EPS. This EPS acts as a natural glue, binding fine suspended solids in seawater, which are then efficiently removed through media filtration (MF). The DOC system uses the natural principle of direct osmosis to keep membranes constantly clean. Therefore, it enhances membrane performance and extends their lifespan, and reduces long-term energy consumption.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Israel
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water treatment: energy recovery device for reverse osmosis desalination plants

DMW Corporation

Source: DMW Corporation

DeROs® is an eco-friendly, isobaric energy recovery device designed for seawater reverse osmosis (SWRO) plants. It features high-efficiency, low pulsation, minimal noise and a low mixing rate. With a wide and adjustable flow range, it can adapt to varying freshwater demands. The device operates using multiple cylinders arranged in parallel, where low-pressure seawater and high-pressure brine are alternately fed into the system. When high-pressure brine is discharged from the RO membrane unit, it pressurizes the low-pressure seawater inside the device while simultaneously receiving freshwater and expelling low-pressure brine after energy recovery. This fluid-to-fluid energy transfer system enables DeROs® to achieve an energy recovery efficiency of up to 98%, cutting power use by 50%. Freshwater production can continue even when some RO units are being cleaned.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water treatment: ceramic flat-sheet membranes for bioreactor systems

Meidensha Corporation

Source: Meidensha Corporation

Meidensha has developed a durable ceramic flat-sheet membrane for water treatment systems. This technology is particularly effective for treating water and wastewater containing oil, solvents and inorganic substances, including hard solids. The membrane offers high chemical and thermal resistance, reducing the need for frequent maintenance, and allowing for long-term filtration performance and easier cleaning. The system's sheet-form arrangement and air dispersal method enhance air scrubbing efficiency, reducing overall energy consumption and lowering operational costs. The ceramic flat-sheet membrane has been applied in water, industrial wastewater and public sewage treatment plants.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Japan
- Availability: Asia
- Contact: WIPO GREEN Database

Water/energy efficiency: AI for pipeline infrastructure inspection

Fluid Analytics Inc.

Source: Getty Images/coffeekai

This AI-driven platform empowers cities to monitor water and wastewater systems effectively, ensuring infrastructure health, waterway quality and early detection of waterborne diseases on a large scale. A fleet of robots navigate the underground equipped with sensors to scan pipe networks, collect data and gather water samples. The AI analyses the real-time data and water sample, identifying points where untreated wastewater enters the environment and locating sewage discharge sources. This information helps cities divert wastewater for proper treatment and reuse, preventing pollution and protecting drinking water supplies. By leveraging proprietary global datasets, advanced mathematical models and machine learning, the platform has monitored over 1.5 billion liters of urban wastewater spills and enabled the treatment and reuse of over 800 million liters daily.

- Contracting type: For service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: India
- Availability: Asia, North America, South America
- Contact: WIPO GREEN Database

Water treatment: microbial fuel cell for wastewater treatment

Watasumi

Source: Watasumi

Building on microbial fuel cell technology developed at the Okinawa Institute of Science and Technology, the KAPPA is a modular wastewater treatment system capable of generating its own electricity. The system is designed for on-site wastewater treatment at small and medium-sized food and beverage companies, with a single unit capable of processing between 50 and 100 L/day depending on wastewater characteristics. It works with anaerobic bacteria and patented internal electrodes, which work to enhance the metabolic process of direct interspecies electron transfer. The bacteria break down and eliminate up to 95% of the organic content of the wastewater while harvesting and releasing electrons. Other bacteria partially use these to generate biogas, but the remainder make up harvestable electricity. This way, the system converts up to 80% of the energy in the wastewater into electricity, leaving maximally 5% sludge behind.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: India, Japan
- Contact: WIPO GREEN Database

Horizon technologies

Water treatment: solar water desalination and e-mobility delivery systems for crisis areas

Beam Global

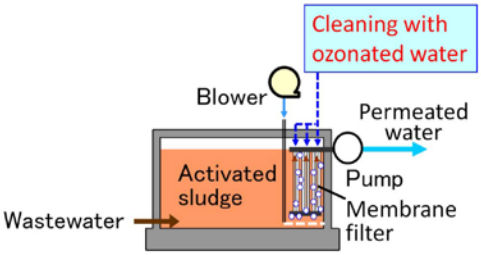
Source: Beam Global

The BeamWell™ system provides clean water, electricity and transport solutions for areas in crisis, such as war zones and disaster sites where only salt, brackish or dirty water is available because a reliable clean water supply is not available or has been interrupted. Built on the EV ARC™ technology, BeamWell™ is a self-sustained, mobile unit that uses solar technology to purify seawater into drinking water, stores it in a 3,000-liter tank replenished daily, and generates solar power for vital devices, such as medical, communication, cooking and lighting. It charges four integrated electric mopeds to distribute essential supplies like food, water and medicines. Designed for quick setup, it fits in a shipping container, requires no construction or extra infrastructure, and can be easily moved as water needs change. Beam Global aims to deploy BeamWell™ systems in the Middle East and Gaza, where many residents face severe water shortages, through global aid partnerships.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: United States of America
- Availability: Europe, Middle East
- Contact: WIPO GREEN Database

Water treatment: energy-saving membrane bioreactor

Mitsubishi



Source: Mitsubishi Electric Corporation

The Ozone Backwashing Energy-Saving Membrane Bioreactor (EcoMBR) represents an innovative approach to low-energy wastewater treatment and water recycling. It can achieve a high flux rate of 1.6 $m^3/m^2/$ day – more than twice that of conventional membrane bioreactors (MBRs). This technology employs regular backwashing with highly concentrated ozonated water to effectively remove organic foulants, enhancing membrane permeability. Additionally, the EcoMBR reduces energy consumption by utilizing a lower air flow rate from the blower, which cleans the membrane surfaces with bubbles, thus minimizing the required number of membranes and allowing for a smaller plant footprint.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: Medium
- Place of origin: Japan
- Availability: N/A
- Contact: WIPO GREEN Database

Water treatment: state-of-the-art I-TECH Packaged STP (Sewage Treatment Plant)

Manila Water Infratech Solutions (MWIS)

Source: Manila Water Infratech Solutions (MWIS)

Manila Water Infratech Solutions (MWIS), a subsidiary of Manila Water, is currently piloting the I-TECH Packaged Sewage Treatment Plant, a new technology for efficient wastewater treatment in small to medium settings. This compact system incorporates advanced membrane bioreactor (MBR) technology, which filters contaminants, including nitrates and phosphates, to meet stringent water quality standards set by the Department of Environment and Natural Resources. The treated wastewater is also suitable for water reuse, helping reduce environmental impact and improving sustainability. With a daily processing capacity of 10 cubic meters, this can accommodate wastewater requirements for small to medium-sized communities, industrial facilities or remote locations. Since it is compact, it requires low maintenance and only allows easy plug-and-play installation especially designed for confined spaces.

- Contracting type: For service
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Philippines
- Availability: Philippines
- Contact: WIPO GREEN Database

Energy efficiency: efficient biogas purification in wastewater treatment plants

Asahi Kasei

Source: Asahi Kasei

Besides methane, biogas derived from sewage sludge consists of around 40% CO_2 and around 60% methane. CO_2 gas is removed in Asahi Kasei's system (the System), generating high-purity methane gas for energy applications, and CO_2-rich excess gas. The System separates CO_2 and methane from biogas using the optimal combination of a special zeolite as adsorbent that selectively adsorbs CO_2 and a special pressure vacuum swing adsorption (PVSA) process technology. The System has the potential capability to produce high-purity methane of gas-grid-injection specifications with high recovery rates and lower costs. It is, as of 2025, being trialed at the Kojima Sewage Treatment Plant in Kurashiki City, Japan, and would be carbon negative if combined with carbon capture and utilization or storage technology, according to Asahi Kasei. Commercialization is expected around the year 2027.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

3. Green rural energy solutions in the Asia-Pacific region

Photos: Getty Images, Unsplash/Milin John

Climate solutions for rural households and communities

Rural and low-income households across the Asia-Pacific region increasingly benefit from off-grid renewable energy solutions, such as micro hydropower, solar home systems (SHS), wind power. These scalable, sustainable options are often more cost-effective than extending grid infrastructure in remote areas and can be tailored to local needs, empowering communities with reliable electricity and greater self-sufficiency (IRENA, 2019). In Pakistan, for instance, where power outages can last up to 10 hours in rural areas, solar power now supplies reliable electricity to over 12,000 public schools, benefiting 1.4 million students (ADB, 2022c). In addition, clean cooking technologies are advancing alongside electrification efforts, helping reduce indoor air pollution and reliance on traditional biomass fuels. Waste-to-energy systems are also emerging as a solution to both energy access and waste management challenges, for example, small-scale biogas plants are used to convert agricultural and livestock waste into clean cooking fuel and electricity for rural households. Rapid reductions in technology costs have further promoted off-grid solutions as a competitive choice for electrifying underserved regions.

Technological development and trends

Off-grid solutions: a vital boon for rural households and communities in the Asia-Pacific region

Solar home systems

Solar home systems (SHS) are an increasingly common off-grid solution. A typical SHS includes a solar PV module, battery, charge controller and often an inverter – especially in hybrid or grid-tied setups. These systems come in various sizes. Small and medium SHS models support essentials like lighting, phone charging and small fans, while larger systems can also power televisions, radios and other larger household appliances. Most SHSs in rural areas function as either off-grid or hybrid systems that combine solar power with grid electricity. In hybrid setups, generated electricity can be used immediately or stored in batteries for later use, such as at night-time or when grid tariffs are high. The excess solar power can also be fed back into the grid. Solar home systems are getting increasingly popular for electrification across South Asia. Bangladesh leads the region in adoption of SHSs, with around 20 million people accessing electricity through this technology (Ojong, 2021).

> Solar home systems are getting increasingly popular for electrification across South Asia

Recent advancements include third-generation solar home systems (3G-SHS). Such systems integrate advanced controls that monitor and manage the performance of the solar panels, rechargeable lithium-ion batteries, LED lamps, USB ports for charging devices and easy plug-and-play installation. With high-efficiency components and compact, lightweight designs with smaller PV modules, 3G-SHS units are ideal for remote areas, requiring fewer resources for transport and installation. While the upfront cost may be higher, the use of LED lighting and other energy-efficient devices significantly reduces overall energy demand. This, in turn, allows for smaller solar panels and batteries, making the system more cost-effective over time.

Small and micro hydropower

Small and micro hydropower is a simple and reliable form of renewable energy for households with access to flowing water, generating from a few kilowatts up to 10 megawatts (MW) of electricity. These systems are typically classified as pico hydro (below 5 kW), micro hydro (5–100 kW), and small hydro (100 kW–10 MW). Pico hydro is suitable for powering single homes or small off-grid communities, supporting basic needs like lighting, a television or a radio. Micro and small hydro systems, on the other hand, are often used by homeowners, farmers and small business owners to power larger homes, small resorts or hobby farms – even in remote

areas without access to central power grids. Beyond electricity, these systems can also produce mechanical energy for tasks such as milling, grinding, carpentry and irrigation pumping.

The systems typically consist of a turbine or waterwheel connected to a generator that produces electrical energy. Unlike large hydropower systems with big reservoirs, they use simple designs with natural river intakes, minimal damming and flooding, and low-voltage distribution, eliminating the need for long-distance power lines for easier installation and maintenance. Key factors for the power output include the head (the vertical drop of water) and flow (the volume of water). Impulse turbines (powered by high-speed water jets) are the most commonly used: these are effective in high-head situations and are resistant to debris in the water. In many cases, turbines and generators are sold together as a package or as a single unit. Most micro hydropower systems also include inverters that convert direct current (DC) into alternating current (AC).

Only 37% of Asia's small hydropower potential is currently developed

However, small hydro power (SHP) systems are not without challenges. Their performance can be affected by seasonal variations in water flow, and they are vulnerable to blockages caused by debris, which can damage turbines and reduce efficiency. Proper site selection, maintenance and debris management are therefore crucial for reliable operation.

Asia has significant small hydropower resources, with a total installed capacity of 51,069 MW out of an estimated potential of 138,226 MW, meaning only 37% of its SHP potential is currently developed (UNIDO and ICSHP, 2019). China leads SHP development both in Asia and globally, holding 54% of global installed capacity. This technology is ideal for mountainous regions and dispersed populations where large power grids are costly, or solar systems are impractical due to climatic condition (Azimov and Avezova, 2022).

Solar fans

Fans consume a considerable amount of energy in South Asia, making energy efficiency crucial. However rural areas show lower fan penetration compared to urban areas, which reflects broader disparities in energy access and living standards (CLASP, 2019a). Solar fans work independently of the grid by harnessing solar energy through photovoltaic cells. They have emerged as a vital and affordable solution, particularly during hot months, for low-income communities in countries like Bangladesh, India and Pakistan, where traditional air conditioning is unattainable due to cost and limited electricity access.

The electric motor is the main element and energy consumer in a fan, but brushless DC motors (BLDC - permanent magnet motors using electronic control instead of brushes) are able to increase energy efficiency by up to 50% (CLASP, 2019b). Additional efficiency improvements are achieved through innovative blade designs, such as twisted and tapered configurations, which can boost airflow without increasing speed, yielding up to a 15% increase in efficiency. However, some of these technological advancements come with higher production costs; for example, a Pakistani fan manufacturer reported a 32% price increase when integrating a BLDC motor (Efficiency for Access Coalition, 2024).

Off-grid refrigeration

Off-grid (OGR) and weak-grid (WGR) refrigeration systems are crucial for food preservation and other critical needs in developing countries. One common type of refrigerant used in these systems is R600a (isobutane), which is highly efficient at low energy levels and has a low global warming potential (GWP). However, the lack of standardization in off-grid refrigeration systems leads to inconsistent performance and efficiency, as products vary widely in design, quality and energy use without common benchmarks. To address this, the International Electrotechnical Commission (IEC) is developing standards for performance and energy efficiency for domestic and light commercial use (IEC, 2022).

Solar-powered DC refrigerators can operate efficiently using small photovoltaic (PV) setups – often requiring solar panels up to nine times smaller than those needed to power a conventional AC refrigerator (CLASP, 2019b). They typically include batteries, charge controllers and wiring, and are commonly integrated into off-grid SHSs (CLASP, 2019b). The integration of smart solar controllers can further optimize battery use, ensuring that the refrigerator operates efficiently even during periods of inconsistent sunlight.

> The lack of standardization in off-grid refrigeration systems leads to inconsistent performance and efficiency

While solar-powered refrigerators have made significant strides, some challenges remain. Battery failure is a common issue, as improper design, misuse and lack of maintenance can cause batteries to fail prematurely (UNICEF, 2020). As a result, newer solar direct drive (SDD) refrigeration systems have been developed. Instead of using an expensive lithium-ion battery to store energy, the fridge utilizes alternative technologies like phase-change materials (PCM), ice-lined refrigerators (ILR) and ice banks, often referred as "ice batteries," which store cooling energy when the fridge pulls power from a solar panel (or from the grid when power is available), and maintain a constant temperature in the compartment even after the solar power supply is cut off. The single compartment of the fridge can also switch between operating as a fridge or a freezer, depending on the need.

Solar water heater

A solar water heater uses flat-plate or evacuated tube collectors, usually mounted on the roof, to capture sunlight and directly heat water flowing through pipes inside the collectors. These collectors heat circulating fluid to ideal temperatures of 30–70°C, while evacuated tube collectors can reach 50–180°C with energy conversion efficiencies up to 90% (IIEC, 2011). The heated water is stored in an insulated tank and used for household needs. Some systems use pumps, while others rely on natural convection for water circulation where heated water rises and moves to the storage tanks, and cooler, denser water flows down into the collector, creating a continuous circulation loop without electricity or the need for PV panels. These technologies are efficient in the sunny climates of South and Southeast Asia and are commonly used for domestic hot water heating. Both flat-plate and evacuated tube systems require minimal maintenance, have relatively low upfront costs and are expected to play a major role in the solar hot water market by 2030, with further potential through the integration of automated controls, real-time monitoring and energy systems (IEA-SHC, 2023).

Solar pump

Solar water pumps offer a valuable alternative to traditional grid-connected or diesel-powered pumps, supplying water to remote areas beyond power lines for crop irrigation, livestock watering and drinking water. PV panels power the pump which typically draws water from a well or stream and stores it in an elevated tank, allowing gravity-fed distribution. This eliminates the need for a distribution pump which could require battery energy storage (CTCN, 2024b). In India, 55 million people have gained improved access to energy for water pumping through solar water pumps, saving $54 billion in fuel costs and reducing CO_2 emissions by 213 million metric tonnes (CLASP, 2023; 2025). Still, they make up only 1% of the total installed water pumps in India used for irrigation. However, the expanded use of solar water pumps must be carefully managed with effective water policies to prevent groundwater depletion. In India and Nepal, increased access to mechanized water pumping has led to unsustainable practices with lower water tables and raised energy demands as water is drawn from greater depths. Therefore establishing sustainable water management practices is essential to protect these water sources from overuse (CLASP, 2023).

Wind home systems (WHSs) are gaining momentum as a sustainable energy solution

While solar panels are widely regarded as the primary renewable power source for homes, wind turbines are gaining traction in residential applications. However, effective wind home systems depend on local factors such as elevation, topography, climate and property orientation, as these impact the turbine's efficiency and electricity output (Koons, 2022). In 2023, global installed wind capacity reached 1,017 GW, nearly half of which is in Asia (IRENA, 2024c). Despite the growth, wind and bioenergy require stronger policy support and investment, especially in emerging markets like China and India.

Wind home systems (WHSs) generally include a rotor, a generator, a tower and a control system (such as controllers, inverters and/or batteries). Most turbines generate AC power, which can either be used directly (in grid-connected systems) or converted to DC for battery storage in off-grid setups. Off-grid WHSs are typically standalone or roof-mounted and rely on batteries, while grid-connected systems may or may not include storage and require power converters to synchronize with the grid. Residential turbines typically range from 400 watts to 100 kW depending on the electricity need, while micro turbines range from 20 to 500 watts used for applications like charging batteries, lighting, appliances, vehicle charging etc. (WINDExchange, 2024).

> Micro wind turbines have primarily been deployed in remote rural areas, offshore islands and villages, where the cost of installation is often more economical

Micro wind turbines have primarily been deployed in remote rural areas, offshore islands and villages, where the cost of installation is often more economical than extending the power grid or building a power plant, for example, in inner Mongolia, around 250,000 micro wind turbines have been installed, with an annual manufacturing capacity of 40,000 units (CTCN, 2024a). Research shows that in windy coastal areas like the Kutubdia and St Martin's islands off the coast of Bangladesh, wind home systems (WHSs) are more cost-effective than solar home systems (Khadem, 2006). However, their exposure to storms and strong winds can pose a serious risk, especially in cyclone-prone regions like the Philippines. Newer models have improved in design, with foldable or flexible towers and reinforced blades, but site selection and storm preparedness remain critical for sustainable deployment.

Clean cooking access in Asia: a key to energy access, health and livelihoods

Around 60% of the global population lacking access to clean cooking solutions resides in Asia and the Pacific, where approximately 1.1 billion people still rely on open fires or basic stoves for cooking (ESCAP, 2024). Access to clean cooking is essential not only for universal energy access but also for protecting livelihoods, as traditional fuels like charcoal, firewood and kerosene harm human health, the environment and the climate (IRENA, 2024a). Annually around 3.2 million people die due to indoor air pollution caused by incomplete combustion of solid fuels and kerosene used for cooking (WHO, 2024). In addition, clean cooking is heavily intertwined with gender, as women and children are typically responsible for cooking and fuel collection, and therefore face health risks from air pollution (Farabi-Asl H *et al.*, 2019).

Asia has seen the most progress in clean cooking in recent years, with China, India and Indonesia all halving their populations without clean cooking access

Asia has seen the most progress in clean cooking in recent years, with China, India and Indonesia all halving their populations without clean cooking access (IEA, 2023c). These efforts have primarily focused on distributing free and improved cookstoves and subsidizing liquefied petroleum gas (LPG) that offers a cleaner alternative to solid fuels, providing energy savings, decreased deforestation and faster cooking with high-energy content fuels. Despite these gains, in countries like India, two-thirds of households still rely on solid fuels like firewood, crop residue, cow dung etc. Challenges such as limited financing, government policies and the need for awareness in rural, low-income areas hinder the transition to cleaner cooking fuels (Box 3.1). Moreover, unreliable electricity access limits the adoption of cleaner technologies like electric cookstoves or induction cooktops.

To address this, off-grid solutions like solar home systems and mini-grids are being introduced, providing electricity to power clean cooking options. Cooking appliances with integrated battery systems have also emerged but they remain too expensive for many rural households. Improved cookstoves (ICS) play a vital role, offering a more efficient and cleaner alternative to traditional stoves while still using solid fuels. These stoves reduce fuel consumption by 20% to 75% compared to traditional stoves, while also lowering smoke emissions and health risks (IEA, 2023c). They efficiently use available biomass fuels such as wood, charcoal, pellets, briquettes and ethanol, making them a practical solution in areas with limited electricity access.

In rural areas with abundant sunlight, solar cookers are beneficial. They generally fall into two types: concentrated sunlight cookers, which use mirrors or lenses – such as in parabolic or dish designs – to focus sunlight directly onto a cooking pot; and solar panel-powered cookers, which convert sunlight into electricity to power heating elements. Both perform best under strong sunlight, but only panel-powered systems with battery storage can function reliably during low-light periods. Biogas digesters and stoves also offer a clean cooking solution. Although both of these technologies have high initial installation costs, they are the most cost-effective option in the long run, with annual operating costs significantly lower than LPG stoves (less than one-fourth) or traditional charcoal stoves (less than one-fifth) (CEET, 2023). Furthermore, using biogas for domestic cooking presents an immediate solution to reducing global black carbon (a component of fine particulate matter (PM2.5) produced by incomplete combustion of fossil fuels and biomass) emissions by 50% (CEET, 2023).For more details on such technologies, see also the *Green Technology Book*, energy edition.

Box 3.1 Cross-cutting challenges and opportunities for clean cooking technologies in Asia

Access to finance is a key challenge for clean cooking solution providers, as financiers consider the sector risky due to its newness and uncertain returns. For instance, in the Lao People's Democratic Republic, despite widespread renewable electricity access, clean cooking remains the lowest in the region, presenting a major opportunity for expansion through climate finance.

Promotion of LPG implies the risk of import dependence amid population growth and price volatility. Therefore, new programs are necessary to provide incentives and subsidies to adopt clean technologies. For instance, in Indonesia a Results-Based Financing (RBF) fund is used to promote private investment and incentives to encourage innovation in the clean cooking sector. Additionally, PAYGO models enable payment for stoves and fuels like bioethanol via mobile money.

Various initiatives support clean cooking adoption. In 2022, the Clean Cooking Alliance (CCA) and World Resources Institute (WRI) launched the Clean Cooking Explorer in Nepal, providing

affordable electric cookstoves with data-tracking technology to 5,000 households. This technology tracks stove usage and helps carbon project developers measure emissions reductions and sell them as carbon offsets, reducing stove prices to as low as USD 15.

Cooking is deeply influenced by tradition and local customs, making the shift to cleaner fuels and technologies challenging. For instance, many people prefer firewood over solar cookers to preserve the traditional taste of food. Successful adoption requires addressing behavior change and aligning policies with local preferences such as stove design compatibility with local cooking practices.

Sources: IRENA, 2024a; Farabi-Asl H *et al.*, 2019; ESCAP, 2024; CCA, 2023; World Bank, 2018.

Waste-to-energy is a dual solution for waste management and electricity generation

Biogas from waste is a mature renewable energy technology that can be implemented at both household and community scales. Biogas produced through the anaerobic digestion of organic materials such as food scraps, household organic waste, and agricultural or animal waste, typically contains 50% to 75% methane, 25% to 50% CO_2, and trace amounts of other gases, with composition varying based on feedstocks and technology used (Li *et al.*, 2019). A small biogas system generally includes a digester tank with an inlet for organic material, a gas tank for collection, a pipeline connecting to a stove and a biogas stove.

After 30 to 60 days, the digester yields biogas that can be used for cooking, heating, lighting and power generation. The process also generates digestate (solid or liquid substances) as by-products that can be used as fertilizers or even to create bio-based construction materials. Additionally, the low heat produced during biogas production can support water purification through a heat recovery system, which transfers the heat to water, eliminating harmful pathogens and improving water quality. Thus, biogas deployment offers a sustainable approach to waste management, increasing energy efficiency and supporting rural economies through a circular economic model (CEET, 2023).

> Biogas deployment offers a sustainable approach to waste management through a circular economic model

Transporting surplus biogas is also affordable and feasible, using options like gasbags. Standard gasbags available on the market can store around two cubic meters of biogas, enough to power four hours of cooking (IRENA, 2017). This solution expands the geographic reach of small-scale biogas systems, facilitating the creation of local biogas markets. China leads globally in the number of small-scale biogas digesters, followed by India. In rural Bangladesh, an integrated biogas approach has been piloted to address electricity, cooking and clean water needs for 30 households, which used animal manure to power a biogas digester (CEET, 2023).

Another solution is a biomass gasifier, which primarily consists of a reactor or container where waste feedstock, such as wood and agricultural residues, is processed with a limited supply of air. The heat required for gasification is produced through the partial combustion of the feed material, generating producer gas which can be used to generate electricity or heat, covering some of the community's energy needs. In Mentawai village, Indonesia, a 700 kWp (kilowatt peak, maximum output power under optimal condition) biomass gasifier-based mini-grid project has provided electricity to 1,250 households using woody biomass as feedstock (Alliance for Rural Electrification, 2019). Furthermore, the by-products, such as biochar, are produced at the bottom of the gasifier, which can be used as fertilizers in home gardens or farms.

Mini-grids and micro-grids are key to electrification and resilience in Southeast Asia

By 2050, Southeast Asia's energy consumption will surpass that of the European Union, accounting for 25% of the increase in global energy demand up to 2035 (IEA, 2024d). However, electrification remains a challenge, particularly in rural and mountainous areas and islands, where extending the main grid is often not economically feasible. In such areas, technologies like mini-grids and micro-grids can play a critical role by providing independent electricity access to even the most remote communities. These systems also enhance energy resilience by supplying local power using batteries to maintain critical loads during outages, especially in disaster-prone regions like Indonesia, the Philippines and Thailand. Micro-grids, typically ranging from 20 to 500 kW, have traditionally relied on diesel or gasoline-powered generators but are increasingly transitioning to renewable energy sources such as solar panels or mini-hydro power (GEF, 2017; IEA, 2024d). The battery storage solutions capture excess energy produced during peak generation and release it when production is low.

Micro-grids typically serve small residential consumers, while mini-grids are larger systems capable of powering entire communities, including schools, factories and islands (IEC, 2024).

Mini-grids supply electricity to around 18 million people in Asia, with South Asia leading in planned capacity at 0.87 GW. The region including South Asia, East Asia and the Pacific, has 16,819 installed and 19,824 planned mini-grids, yet these would serve less than 1% of Asia's population (World Bank, 2022a). More information on mini-grids and micro-grids can also be found in the *Green Technology Book*, energy edition.

Countries that have adopted a comprehensive approach to electrification, combining main grid extensions, mini-grids and solar home systems, have seen the quickest progress in expanding electricity access, for example, Bangladesh, Cambodia, India, Myanmar and Nepal (World Bank, 2023). However, while solar PV and battery costs have decreased, the high upfront costs of renewable technologies remain a barrier (IEA, 2024d). A key challenge lies in the availability of cheaper diesel generators in local markets, which are familiar, easy to repair and supported by established supply chains. Despite their lower initial cost, diesel generators have higher operational costs due to fuel expenses, which can fluctuate and are often unpredictable.

> Mini-grids and micro-grids can provide independent electricity access to even the most remote communities

This is why technologies alone are not sufficient for rural electrification, especially in the least developed countries (LDCs) where the public sector often struggles to finance or implement these projects due to competing priorities (GEF, 2017). While alternative financing models like leasing, affordable loans and savings schemes can address financial barriers, a supportive institutional framework is essential for scaling up these solutions and ensuring they reach underserved communities. Additionally, the region's diverse geography and climate require tailored micro-grid solutions, with island systems needing to withstand typhoons and high humidity. Local innovation for these unique challenges can be a powerful driver of adaptation, allowing communities to co-develop solutions tailored to their specific needs. South–South technology transfer can further enhance this process, enabling knowledge and expertise exchange between regions with similar contexts and challenges.

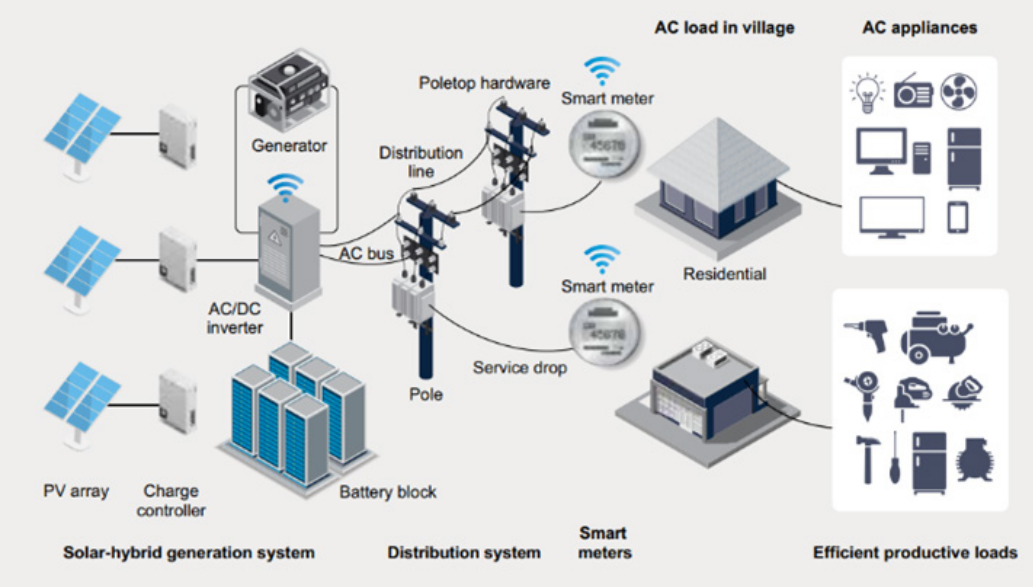
Third-generation mini-grids are gaining traction in South Asia

A new wave of third-generation mini-grids (figure 3.1) is emerging, integrating advanced technologies like smart meters, mobile payment systems and remote monitoring powered by cellular data for increased efficiency and reliability. In countries like Bangladesh, India and Myanmar, solar-hybrid mini-grids (combining solar power with battery storage and backup generators) are leading this shift (World Bank, 2022a). These systems enable pay-as-you-go

billing and real-time insights into energy consumption and performance, enabling operators to quickly address technical issues, thus improving reliability and customer service.

Many developers of third-generation mini-grids actively encourage customers to adopt energy-efficient household appliances, which can reduce the required installed capacity of a mini-grid by over 60% (ESMAP, 2019).They also facilitate financing options to help customers overcome the upfront cost barriers of these technologies. Additionally, these mini-grids can be designed for interconnection with the main grid, allowing the users to sell excess electricity and improve overall energy reliability. However, effective integration requires national strategies to support coordination between utilities, mini-grid developers and off-grid providers.

Figure 3.1 Features of a third-generation mini-grid system



Source: ESMAP (2019).

Excess energy can be accessible with hydrogen micro-grids

Hydrogen-based micro-grids have been proposed as an alternative for long-duration energy storage, particularly in scenarios where battery performance falls short or degrades over time. While traditional micro-grids often lose up to 30% of generated solar energy due to limited storage capacity, hydrogen systems address this by using surplus solar power to run an electrolyzer, which splits water into hydrogen and oxygen through water electrolysis. The hydrogen is then stored, usually under pressure, and later reconverted into electricity via fuel cells. In theory, this could extend storage capacity beyond what batteries currently offer, especially in off-grid or space-constrained areas (Chrometzka *et al.*, 2020).

Integrating hydrogen infrastructure could potentially be a viable option for a scalable and smoother transition to clean energy solutions (Dasgupta P., 2024). However, this approach remains highly debated. The process requires a full suite of additional infrastructure: electrolyzers, compressors or pressurization systems, high-grade storage tanks and fuel cells. Each transformation, from electricity to hydrogen and back, introduces energy losses, raising questions about overall efficiency. Moreover, while hydrogen may offer lower operational costs over time, the initial capital investment is significant.

Hydrogen micro-grids are thus not yet a proven solution for most rural or cost-sensitive contexts. However, they may hold potential in very specific use cases – such as in regions where land is limited, long-term storage is critical or where green hydrogen production is already subsidized or integrated. For instance, in Thailand's Nongnooch Tropical Botanical Gardens and Phi Suea House, hydrogen has been adopted as a long-duration energy storage solution, enabling the micro-grid to supply power for up to 35 hours. This provides a cleaner alternative to conventional systems that typically depend on batteries for short-term storage and diesel generators for backup.

Innovation examples

‘Rent-to-own’ solar home systems in Myanmar

Source: Getty Images/MyImages_Micha

In Myanmar, unreliable grid power forces families and businesses to rely on costly, polluting fuel for generators. SolarHome company offers a cleaner, more affordable alternative by integrating solar energy and appliance units at off-grid households, primarily for women-led or farming families in rural areas. Using a “pay-as-you-go” model, customers pay $5–$24 per month via mobile tokens. It is also a “rent-to-own” model, meaning users ultimately own their solar systems after a certain period of usage. So far, SolarHome has equipped 60,000 households in Myanmar, replacing open fires with solar lights. The initiative has benefited 300,000 people, saved 9.3 million kg of CO_2 emissions, and enabled 147,000 women to operate small shops and stalls for extended business hours with solar-powered lighting (Aung, 2022).

Solar micro-grid powering a village in the Philippines

Source: Getty Images/andresr

Solar Para Sa Bayan (SPSB) is a Filipino social enterprise that provides affordable, reliable, 24/7 electricity to communities. In 2018, SPSB completed Southeast Asia’s largest solar-battery micro-grid in Paluan, a town previously denied a grid connection due to limited supply. The system combines 2 MW solar panels, a 1.8 MW/1.5 MWh Tesla storage system and three diesel back-up generators, offering round-the-clock electricity at 50% below the local electric cooperative’s costs. The battery storage system includes two inverters, each with five sets of power stages and 12 batteries in each, having a total of 120 batteries connected in parallel at 1,800 kW capacity. The solar PV system powers Paluan during the day, while simultaneously charging the Tesla batteries. As the sun sets, the batteries begin powering the town. During peak demand between 8pm and 9pm, diesel generators activate to support the batteries. The generators shut down once the demand decreases, and the batteries supply power until 5am. Prior to this, locals in Paluan had just 3–8 hours of unreliable electricity a day. This initiative has significantly reduced electricity costs for both residential and commercial users, including schools. The micro-grid now serves nearly 3,000 customers, improving access to electricity and opening new opportunities for residents (Solar Para Sa Bayan, 2018).

Off-grid solar desalination: providing water for an indigenous school in Western Australia

Source: Moerk Water Solutions

Moerk Water Solutions company has delivered a solar-powered water purification system for an indigenous vocational training school in southwestern Western Australia. The school, which provides vocational skills to around 70 year-11 and year-12 students from remote communities each year, required a reliable water source due to its off-grid location. Moerk Water designed and installed a custom solar-powered reverse osmosis (RO) system using membrane filtration to treat local groundwater. It supports the school's drinking water needs as well as crop irrigation in the community. The system produces 12,000–15,000 liters of clean water daily, reaching up to 30,000 liters. It operates in automatic or manual modes, and features remote monitoring to minimize service requirements.

Proven technologies

Solar appliance: solar freezer

Rockwell

Source: Rockwell

The company's solar freezers cover cooling and freezing needs in off-grid locations. They provide flexible temperature settings ranging from -18°C to +8°C to meet user requirements. Designed to run exclusively on DC power, they operate entirely on solar energy without the need for AC connections. These freezers are also available with battery systems that can provide up to three days of autonomy without sunlight. They come in various sizes, require minimal maintenance and are built with durable, high-quality materials for long-lasting performance.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: India
- Availability: Asia, Australia, Belgium, United Kingdom, United States of America
- Contact: WIPO GREEN Database

Wind energy: small home wind turbine

A-WING

Source: A-WING

A-WING small wind turbines are designed for optimal performance even in low wind speed regions often found in Japan. They feature advanced blades, generators and controllers for maximum efficiency, generating eco-friendly power without CO_2 emissions. Using proprietary technology, the range includes compact 300W to 1 kW turbines. The coreless generator allows smooth operation, starting at wind speeds as low as 1 m/s, with battery charging from 1.5 m/s. These micro turbines deliver stable, efficient energy and are cost-effective. Paired with a wind and PV hybrid controller, they are ideal for remote homes, parking lots, signage, backup power or areas lacking access to commercial electricity.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Japan
- Availability: Indonesia, Japan, Mongolia, the Philippines, the Republic of Korea, Thailand,
- Contact: WIPO GREEN Database

Clean cooking: improved cookstove

5 Star Stoves

Source: 5 Star Stoves

5 Star Stoves Bangladesh Ltd offers an affordable, energy-efficient cooking solution using micro gasification stoves and improved non-toxic biomass pellets as fuel. These stoves achieve 99% combustion efficiency, reducing health risks, saving fuel and cutting 2–3 tonnes of carbon emissions per stove annually. The stoves are self-contained units and are powerful enough to cook large traditional dishes. Small-scale farmers supply agricultural waste to local 5 Star Stoves franchises, where it is processed into pellets. These are sold by "5 Star Ladies," creating income opportunities while combating deforestation – 1 kg of waste biomass pellets replaces 4 kg of firewood. In addition, the biochar by-product serves as a natural fertilizer for gardens or farms. This initiative targets urban slums, industrial zones and peri-urban areas reliant on wood and charcoal.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Bangladesh
- Availability: South Asia
- Contact: WIPO GREEN Database

Waste to energy: farm waste to clean biogas with portable biodigester

ATEC Biodigesters

Source: ATEC Biodigesters

ATEC portable biodigesters offer a resilient alternative to the traditional brick-based biogas plants that face challenges in flood-prone areas like Bangladesh and Cambodia, especially during rainy seasons. These biodigesters are made of highly durable plastic called linear low-density polyethylene, that can withstand adverse weather, and can be installed in a variety of locations. It can have a gas production of 1350–1800 L per day. It is a commercially scalable, plug-and-play solution. It takes animal manure, green waste and kitchen waste and converts it into renewable gas for cooking and organic fertilizer for farming. It also comes with smart financing with ATEC's patented PAYGO monthly payment method.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Australia
- Availability: Bangladesh, Cambodia
- Contact: WIPO GREEN Database

Renewable energy: off-grid wind and solar hybrid energy system

PVMars Solar

Source: Getty Images/rozaivn

Energy-storage hybrid wind-solar systems are customized based on power needs, usage patterns and local wind and sunlight conditions. These systems use wind and solar controllers for charging. Wind turbines above 3 kW require a three-phase alternator, necessitating a separate controller to convert power to direct current. The battery pack serves as the common point for both power sources, making battery selection crucial. PVMARS offers gel and lithium battery options. For complete off-grid solutions, a recommended 3:1 ratio, such as a 3-kW hybrid system with a 1-kW wind turbine and 2-kW solar panel, optimizes cost efficiency. A 1-kW wind turbine produces 1 kWh of energy per hour under optimal conditions, storing energy alongside solar power in a battery bank. This ensures a consistent power supply for household devices like TVs, computers, lights, water heaters, refrigerators and air conditioners.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: China
- Availability: Africa, Asia and the Pacific, Latin America
- Contact: WIPO GREEN Database

Solar energy: hybrid solar inverter for small homes

ANERN

Source: Getty Images/moisseyev

The ANERN patent solar hybrid inverter (AN-SCIO2-Azure series) can improve the utilization efficiency of solar energy, and is especially suitable for situations where the power grid is unstable, or the cost of the power grid is high. This hybrid inverter features a compact power range of 1.5–2.4 kW, suitable for small households. The 2 kW hybrid inverter combines the functions of a solar power inverter and a battery inverter, converting DC electricity from solar panels into AC electricity, storing excess energy in batteries, and supplying power as needed. It efficiently manages battery charging and discharging, making it suitable for off-grid and backup power applications. The 2.4 kVA solar inverter is optimized for converting solar energy into AC electricity for home use or grid export. Key features include Wi-Fi monitoring, efficient conversion, a smart display, a smart battery charger for optimized performance and configurable AC/solar charging priority via an LCD interface.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: waterless bio-toilet system for house, community and village

Ecoflo-Wash

Source: Ecoflo-Wash

A bio-toilet system is a simple, hygienic, waterless toilet solution for homes, communities and villages. Ideal for rural and farming areas with limited access to water and electricity, they require no energy for water pumping, convert waste into compost and can be integrated with solar energy systems. The toilets use minimal energy to power a small fan in the vent pipe, are easy to install with basic tools and require little maintenance. Designed to support water-based hygiene practices common in many Asian and Muslim countries, they create a safe and eco-friendly sanitation solution and help protect local water sources like marshlands and rivers.

- Contracting type: For sale/service
- Technology maturity: Proven
- Technology level: High
- Place of origin: Australia
- Availability: Asia and the Pacific, Australia, Papua New Guinea, Timor-Leste
- Contact: WIPO GREEN Database

Lighting: semi-integrated solar streetlight

ZGSM

Source: Getty Images/Lazartivan

The PV7 series semi-integrated solar streetlights combine the benefits of fully integrated designs, easy installation, energy efficiency and environmental friendliness. Featuring a high-capacity battery, they are suitable for areas with prolonged rainy weather, providing 5–7 days of autonomous operation. Equipped with independent, high-efficiency LED lamp heads, the series offers customizable models to meet diverse project needs. The PV7 is versatile and suitable for various applications, including municipal roads, urban streets, commercial centers, squares and playgrounds. Key features include an intelligent controller with up to 96% charging efficiency and smart control options like motion/PIR sensors or timer dimming tailored to client requirements.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Renewable energy: durable off-grid power system

NTN Corporation

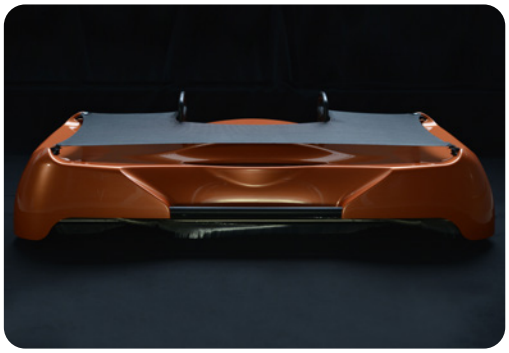
Source: NTN Corporation

The N3 N-CUBE is a containerized renewable power source for off-grid, emergency or back-up applications. The system, available in five sizes, is designed to withstand severe typhoons of up to 46 m/s, and seismic activity of the highest intensity. It features a vertical-axis wind turbine with a rated output of 0.5 kW, solar panels of between 1.5 kW and 3.7 kW, and storage batteries. In normal times, the container space can be furnished and used for many applications, such as an air-conditioned rest area, storage facility or bus stop. A version with a circulation-type flush toilet also exists, for deployment in parks and other public areas. In case of emergency, the freight container can be transported by truck, cargo ship or helicopter and quickly start generating electricity.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Solar energy: dry-cleaning robot for solar panels

MiraiKikai



Source: Mirai Kikai

The Type 1 robot from MiraiKikai has been developed for dry regions, where dust and sand can cause a loss of around 15% in solar power generation capacity per month. Designed for use in arid climates, it does not require water for cleaning panels. Instead, it employs a patented combination of a soft brush and fanning. The Type 1 robot comes with a rechargeable battery and weighs 28 kg, making it light enough for a person to carry. It navigates solar panel arrays using proprietary sensor technology and can move over gaps of up to 3 cm. If cleaning is required for multiple separate arrays, a person must carry the robot between them.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: India, Japan, Qatar, Saudi Arabia, United Arab Emirates
- Contact: WIPO GREEN Database

Renewable energy: solar PV + biomass hybrid system

Husk Power

Source: Getty Images/kontrast-fotodesign

Husk Power delivers reliable 24/7 electricity to households, businesses and institutions in rural areas by combining solar PV and biomass gasification technologies. Their cloud-based remote management platform enables real-time monitoring of site performance and customer energy usage. The rice husk char, a by-product of the gasification process, is repurposed to produce eco-friendly incense sticks, providing employment exclusively to women. Additionally, their integrated system includes smart prepaid metering, big data analytics and voice-enabled, easy-to-understand custom messages to enhance customer service.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: India
- Availability: India, Nigeria, United States of America
- Contact: WIPO GREEN Database

Hydropower: wave energy green power station

Eco Wave Power

Source: Eco Wave Power

Eco Wave Power has developed a patented cost-effective technology that converts ocean and sea waves into electricity, offering a potential solution for sustainable coastal electrification. The company owns and operates a wave energy array, which is connected to the grid in accordance with a Power Purchase Agreement (PPA).The system uses floaters that move with the waves to compress hydraulic pistons, transferring biodegradable hydraulic fluid to land located accumulators. This generates pressure that rotates a motor connected to a generator, producing electricity, which is then fed into the grid via an inverter. The system operates in a closed loop, with the fluid reused after decompression. It starts generating electricity with wave heights of 0.5 meters and is controlled by smart automation. When waves are too high, floaters rise above the water until the storm passes and return to operation mode once the storm has passed. Eco Wave Power has partnered with the company I-Ke for its first Asian onshore project, where I-Ke will locally produce the floaters, hydraulic cylinders and other components of the technology.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Sweden
- Availability: Worldwide
- Contact: WIPO GREEN Database

Clean cooking: biomass clean cooking stove

Gansu Hengxin Energy Saving Technology Co. Ltd.

Source: Getty Images/ablokhin

The high-efficiency biomass cooking stoves are designed to deliver strong firepower, smoke-free operation and rapid heating, making them both environmentally friendly and user-safe. The stoves heat up quickly, enhancing cooking efficiency and saving time for users. In addition, these stoves aim to reduce indoor air pollution, improve health outcomes and enhance cooking efficiency. The simple and reliable design offers a sustainable cooking solution for rural and urban households.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: China
- Availability: Asia and the Pacific
- Contact: WIPO GREEN Database

Energy storage: vanadium redox flow batteries for large-scale energy storage

Sumitomo Electric Industries

Source: Sumitomo Electric Industries

Sumitomo Electric's vanadium redox flow batteries (VRFBs) are designed to enhance grid stability and smooth out fluctuations in power generation. This long-duration energy storage technology is particularly beneficial for isolated or off-grid systems, where diesel-powered backup generators are often critical for maintaining a consistent power supply. Unlike conventional batteries, VRFBs store energy through reversible changes in the oxidation states of vanadium ions in the electrolyte, without phase changes. This results in stable batteries and minimal degradation. With a design life of over 20 years, the VRFBs use a non-flammable electrolyte that can be reused even after the battery is decommissioned.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Solar energy: floating solar power plants with trackers

Tonking New Energy

Source: Getty Images/zhongguo

Tonking New Energy's floating solar systems are available in fixed and single-axis tracking configurations. The tracking model uses independent buoys and GPS-based east–west orientation to optimize solar exposure throughout the day. Light transmittance of approximately 30% allows sunlight to reach the water surface, limiting impacts on aquatic life and supporting concurrent fish farming. The floats are made of fiberglass with built-in food-grade foam, and structural components are built with aluminum alloy and galvanized steel. A 1.6-MW installation at Jiangshan Xintangdi Reservoir in Zhejiang Province occupies approximately 15 to 16 acres per megawatt, with an expected operational lifespan of over 25 years.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Asia
- Contact: WIPO GREEN Database

Hydropower: micro hydro turbine generator

Suneco Hydro

Source: Getty Images/oopoontongoo

The micro hydro generator system includes a turbine, a generator and the appropriate controller for the size and output of the system. Hydro power systems are available from 5 kW to 10 kW. The service includes assistance in matching the right size generator to customer specific site and requirements according to the site's flow rate and head as well as wattage requirements.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: China
- Availability: Asia and the Pacific
- Contact: WIPO GREEN Database

Clean cooking: green char briquettes

Khmer green charcoal

Source: Getty Images/showcake

KGC has introduced green charcoal, a clean cooking fuel that offers a sustainable alternative to the environmentally harmful consumption of wood charcoal. It supplies the green charcoal to over 6,500 users across Cambodia. By integrating modern processing techniques with innovative technology, it produces high-quality, sustainable char briquettes from organic waste. Their Diamond Eco Char Briquettes, crafted entirely from coconut shells without any chemicals, provide a smokeless, spark-free burn lasting around five hours.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Cambodia
- Availability: Cambodia
- Contact: WIPO GREEN Database

Horizon technologies

Energy storage: gravity energy storage system

Energy Vault

Source: Energy Vault

Energy Vault's EVx™ gravity energy storage system (GESS) is an innovative mechanical energy storage technology that converts renewable energy such as wind and solar into gravitational potential energy by lifting blocks to store power, which later get released to generate electricity. Using AI algorithms, the GESS operates automatically, responding to grid or user demand. Its modular design supports scalability, stacking 10 MWh units to achieve GWh-level storage. Importantly, GESS is versatile, requiring no specific terrain or climate conditions, making it suitable for diverse environments, from mountainous regions to icy deserts. With round-trip efficiency exceeding 85%, it also enhances grid stability by providing inertia response to prevent frequency fluctuations.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Switzerland
- Availability: China, Italy, Switzerland, United States of America
- Contact: WIPO GREEN Database

Solar energy: micro solar domes

NB Institute for Rural Technology (NBIRT)

Source: NB Institute for Rural Technology (NBIRT)

The Micro Solar Dome (MSD), or Surya Jyoti, is an innovative lighting device for day and night-time use. During the day, it captures sunlight through a clear acrylic dome on the roof and channels it indoors via a reflective sun-tube, acting like a natural skylight. There is a shutter at the bottom of the lower dome which can be closed if light is not required in the daytime. Photovoltaic modules also charge a battery in the daytime, providing backup light for up to six hours after sunset. Designed for off-grid households, each dome provides illumination equivalent to a 60 W incandescent bulb. Widespread use in 10 million homes could save 1,750 million units of electricity and reduce CO_2 emissions by 12.5 million tonnes. A program providing training and licenses for startups and self-help groups to produce the domes has been initiated.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: Medium
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Hydropower: hybrid tidal and pumped storage power generation

Korea Institute of Ocean Science and Technology

Source: Getty Images/Breedfoto

The tidal and pumped storage hybrid power generation system uses the mechanical force of ocean tides to pump seawater into a storage tank on land. When the water is returned, its potential energy can be converted into hydroelectric power. A 2024 study successfully tested the fully passive pumping mechanism at an offshore site in the Republic of Korea, using a two-armed flapping-foil hydrokinetic turbine. The motion of the flapping arms, as activated by the tide, managed to fully passively drive the water pump. This pump transports seawater through a pipeline to an onshore tank several meters above sea level, which in future applications could be used for aquaculture. The trial achieved a pumping height of 9 meters at 1.8 m/s and delivered 3.3 kW of pumping power with 34% efficiency at a reduced frequency of 0.126. Viable for shallow or near-shore deployment, this developing technology offers rural or off-grid communities a sustainable option for seawater pumping and damless hydroelectric power.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Republic of Korea
- Availability: N/A
- Contact: WIPO GREEN Database

Renewable energy: grid-forming inverter (GFM) for inertia-free renewable energy generation

Fuji Electric

Source: Fuji Electric

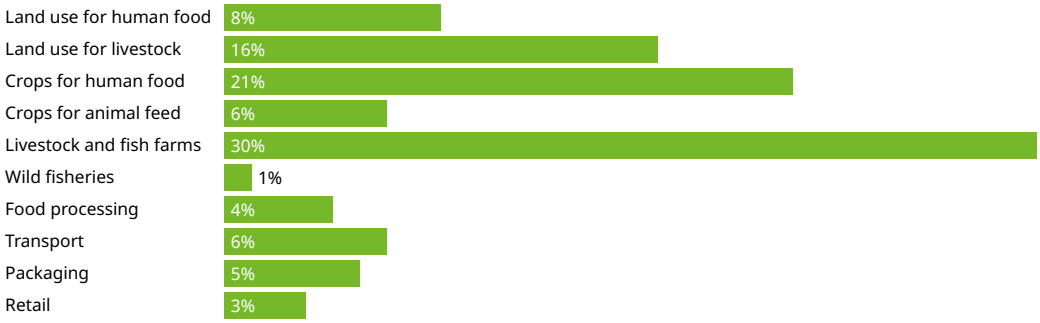
Fuji Electric is developing a new type of inverter called a grid-forming (GFM) inverter. This inverter uses special software to behave like a traditional generator, helping to keep the power grid stable. Unlike traditional generators, renewable energy sources don't have this stabilizing feature, which can lead to power problems. The GFM inverter is being tested to work with energy storage systems, such as batteries, to improve how renewable energy is used. Traditionally, large power plants use spinning generators to keep the grid steady, but renewable energy sources can't do this on their own. Fuji Electric is testing how the GFM inverter can work alongside other systems to make the grid more stable. One challenge is ensuring the inverter can safely keep working during power outages, as current rules require it to shut down when the grid fails. Fuji Electric is working on solutions for this issue.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: N/A
- Contact: WIPO GREEN Database

Clean energy solutions for agriculture on-farm

The relationship between agriculture and climate change is reciprocal: agriculture significantly contributes to climate change, and it is, in turn, highly affected by its impacts. Approximately one-quarter of global greenhouse gas emissions stem from food and agriculture. These emissions are driven not only by energy use, such as fossil fuel-powered machinery and the energy-intensive processing and distribution of food, but also by non-energy sources including methane from livestock and rice cultivation, nitrous oxide from fertilizer application, and carbon stock released through deforestation and land-use change (figure 3.2). Conversely, agriculture is highly susceptible to climate change, facing altered weather patterns and more frequent extreme events such as heat waves, droughts, storms and floods, which threaten crop yields and food security. Agriculture therefore requires climate strategies that integrate both adaptation and mitigation efforts, for example, shifting from fossil fuels to renewable energy sources while ensuring that farmers' adaptive capacity is not compromised (IWMI, 2023a).

Figure 3.2 Share of GHG emissions by stage within the food production sector (%)



Note: Values represent the percentage share of GHG emissions by stage within the food production sector, which accounts for approximately 26% of global GHG emissions.

Source: Adapted from Ritchie (2019).

Importantly, agriculture is unique among economic sectors in that it is both a consumer and a producer of energy. Beyond its energy demand, it also contributes to energy supply through bioenergy – such as crop residues, livestock waste and dedicated energy crops – which can support rural energy access and reduce dependence on fossil fuels.

Agriculture also holds the potential to mitigate climate change. Farmland crops, hedgerows and agroforestry capture carbon through photosynthesis and store it in soil and biomass. Well-managed soils and protected grasslands offer long-term carbon storage, contributing to climate mitigation (European Commission, 2025). In addition, practices such as precision farming and the use of renewable energy can lower emissions and bolster resilience to environmental changes, which are discussed later in this sub-chapter and also in the energy and mitigation edition of the *Green Technology Book*.

> Agriculture is unique among economic sectors in that it is both a consumer and a producer of energy

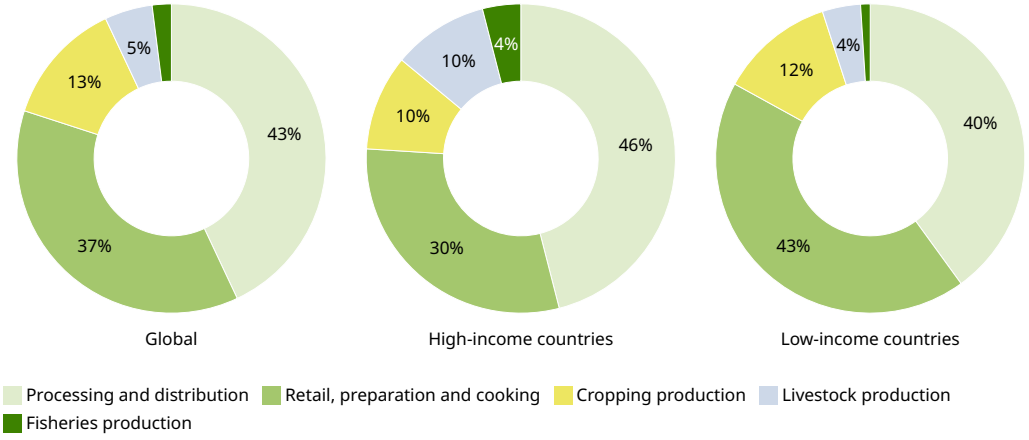
In Asia, rice cultivation is a major contributor to global greenhouse gas emissions, particularly methane, due to traditional flooded farming methods. As a staple for 3.5 billion people and accounting for 8% of global crop output by weight, rice is especially significant in countries like Bangladesh, China, India and Indonesia. It contributes 10% of global methane emissions, with Southeast Asia accounting for 25% to 33% of the region's total methane output (Umali-Deininger, 2022). Adopting more sustainable practices such as alternate wetting and drying (AWD), improved land leveling and better seed varieties can lower emissions while boosting yields and resilience. This chapter highlights an array of such technological innovations aimed at reducing emissions and energy usage in regional agricultural production.

Energy consumption in the food production stage

Agri-food chains contribute to approximately 30% of global energy consumption (IRENA and FAO, 2021). As shown in figure 3.3, most of the energy used is in the post-harvest stages of food processing, distribution, preparation and cooking, primarily in the form of fossil fuels. The post-harvest energy technologies and trends will be further explored in the next sub-chapter, while retail and cooking are discussed in the hospitality and rural chapters of this book as well as in the *Green Technology Book*, Energy edition.

Energy use during agricultural production involves the consumption of energy for various inputs, including the production of chemical fertilizers, pesticides and feed, as well as the operation of machinery such as irrigation pumps and tractors, heating or cooling animal stables, aerating fishponds and managing protected cropping systems like greenhouses (Magalhaes *et al.*, 2021; IRENA and FAO, 2021). Nitrogen fertilizer alone contributes roughly 2% of all global GHG emissions (CIEL, 2022).

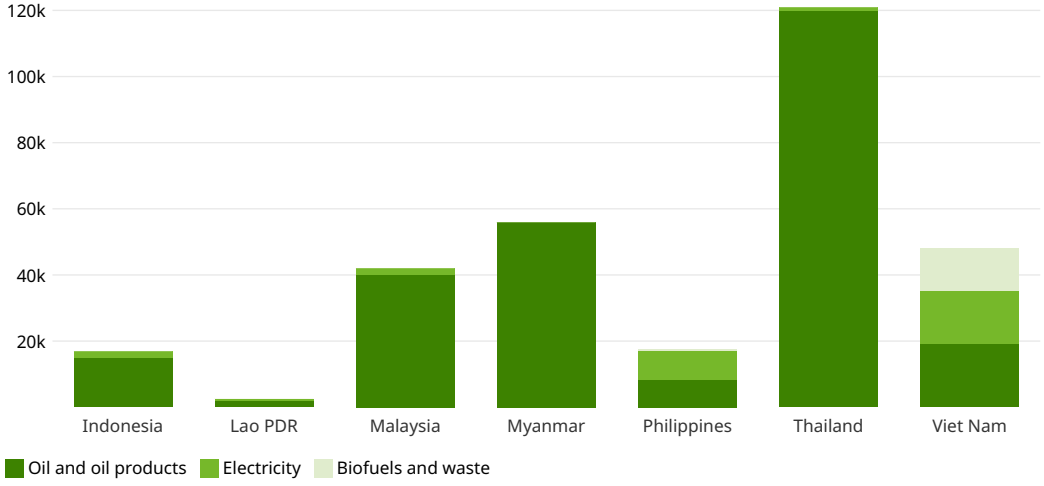
Figure 3.3 Share of total energy consumption globally and in high- and low-income countries in the agri-food chain



Source: Adapted from IRENA and FAO (2021).

Over the past two decades, energy consumption in Asia's agriculture sector has increased as farming has become more mechanized (IRENA and FAO, 2021). By 2050, South Asia's population is projected to reach 2.3 billion, with cereal demand expected to double (Neupane *et al.*, 2022). In addition, rapid urbanization and rising incomes are also driving a shift from starch-based to protein-rich diets, such as meat and dairy, which are more energy- and water-intensive. From 2009 to 2019, energy consumption in the agriculture sector grew by 35% in Asia, reaching over 8 million tonnes oil equivalent (MTOE), which accounted for about 2% of the region's total final energy consumption in 2019 (IRENA, 2022). Figure 3.4 shows that in Southeast Asia's major agriculture-intensive countries, a significant portion of this energy is derived from fossil fuels, including oil products and electricity (IRENA, 2022). These fuels primarily power on-farm equipment like pumps, tractors etc. However, rising fuel costs and unreliable electricity access are making it harder for smallholder farmers to adopt energy-dependent technologies, increasing production costs and widening rural inequalities. Optimizing land use, enhancing energy efficiency, reducing fossil fuel use and minimizing environmental impacts are all essential components of sustainable agriculture (Chandio *et al.*, 2024).

Figure 3.4 Energy consumption in agriculture, forestry and fishing, by country (in terajoules)



Source: Adapted from IRENA (2022).

Irrigation is the main on-farm energy consumer in Asia

Irrigation plays a pivotal role in ensuring global food security, contributing to 40% of global food production while utilizing only 22% of the planet's cultivated areas (Feng Qin *et al.*, 2024; Jingxiu Qin *et al.*, 2024). Combined with improved water harvesting and conservation measures, irrigation can also boost yields, reduce vulnerability to fluctuating rainfall patterns, and support multiple cropping practices (IRENA and FAO, 2021). However, it contributes significantly to environmental challenges, accounting for 216 million metric tonnes of CO_2 emissions and consuming 1,896 petajoules of energy annually, about 15% of global agricultural greenhouse gas emissions and energy use (Jingxiu Qin *et al.*, 2024).

> Over the past five decades, agriculture has grown increasingly energy-intensive, largely due to the expanding use of groundwater irrigation

Asia accounts for 72% of global irrigation, driven by its intensive agriculture practices to meet significant food demand and the long-standing tradition of irrigated rice cultivation across its tropical regions (Jingxiu Qin *et al.*, 2024; FAO, 2020b). Crops have specific water requirements, and these vary depending on local climatic conditions. Producing 1 kg of rice requires an average of 1,432 liters of water and 6.4 MJ of energy, with irrigation and fertilizer application being the primary energy inputs (Nayak *et al.*, 2023). In comparison, an average kilogram of wheat grain produced in Europe demands about 3.25 megajoules of nonrenewable, fossil energy (Achten and Acker, 2016). This highlights the higher resource intensity of rice cultivation, particularly in terms of energy consumption, compared to other staple crops like wheat. During the wet season rice is typically irrigated through rain- and gravity-fed systems where water flows naturally into the rice fields through a network of canals and ditches. However, in the dry season, many farmers depend on pumps, particularly in Southeast Asia. This region is home to 25–30 million agricultural pumps, the largest concentration globally (CGIAR, 2023a). As the pumps typically are powered by diesel or electricity, they significantly increase energy demand and carbon emissions. For instance, in India alone, replacing only 5 million diesel pumps with electric pumps has the potential to save almost 10 billion liters of diesel annually, resulting in significant emission reduction (Neupane *et al.*, 2022). However, it depends on the electricity being sourced from renewable or low-carbon energy sources.

Over the past five decades, agriculture has grown increasingly energy-intensive, largely due to the expanding use of groundwater irrigation. While surface water remains the primary source,

groundwater extraction has surged in countries like Bangladesh, India and Pakistan to support specific crops (FAO, 2020b). In Bangladesh, for instance, around 1.6 million pumps are used for groundwater irrigation, with 80% being diesel-powered and primarily supporting "boro" paddy cultivation, a dominant water-intensive post-monsoon crop in the region that relies heavily on groundwater (IWMI, 2023b).

The type of pump used varies based on the water source. Surface pumps, drawing water from rivers, lakes or shallow wells, generally consume less energy due to the lower lift required. Groundwater irrigation often depends on submersible pumps operating fully submerged and being efficient in extracting water from significant depths, but requiring more energy (CTCN, 2025).

As global warming and rising energy demands threaten food security, expanding more sustainable irrigation is crucial. Replacing fossil fuel-based pumps with solar irrigation pumps is a promising mitigation strategy, especially in rural areas with limited grid access and rising fuel costs (Senthil Kumar *et al.*, 2020; CGIAR, 2023). For example, in South Asia, where 60% of farmland is rainfed and depends on increasingly unpredictable weather patterns, solar pumps can boost crop yields by two- to three-fold by enabling affordable and reliable irrigation where diesel or grid electricity is too costly or unavailable, particularly for water-intensive crops like rice and maize (CLASP, 2023). Solar pumps use solar energy to power a motor for irrigation, often storing water in tanks for gravity-fed distribution. Both DC or AC based solar pumps can be used, with AC models incorporating a converter for grid-fed night-time irrigation. Brushless DC pumps provide a more energy-efficient, off-grid solution by adjusting motor speed based on solar power and water demand. Variable speed drives allow irrigation systems to operate at optimal efficiency by adjusting water flow based on soil moisture. These systems prevent over-irrigation and reduce unnecessary pump operation, leading to significant energy savings. Further details on various solar pump and motor technologies for energy-efficient irrigation are covered in-depth in the climate change mitigation, adaptation, and energy editions of the *Green Technology Book*.

> Replacing fossil fuel-based pumps with solar irrigation pumps is a promising mitigation strategy

Although solar water pumps are commercially available, it is yet to reach scale. In India, solar pumps make up only 1% of the total installed pumps (CLASP, 2023). The government aims to solarize 3.5 million irrigation pumps – 2 million with standalone solar pumps and 1.5 million by grid-connecting existing agriculture pumps (IWMI, 2023b). Grid-connected pumps can sell back surplus energy to the grid which encourages farmers to use energy and water efficiently to boost income. In Bangladesh, excess electricity from solar pumps is utilized for powering equipment like husking machines, threshing machines, cold storage and supporting aquaculture (IRENA and FAO, 2021). Solar pumps also offer major climate benefits, with life-cycle emissions (in CO_2 equivalent per kWh) 95% to 98% lower than the pumps powered by grid or diesel (IRENA and FAO, 2021). Beyond mitigation, solar pumps also support climate adaptation by enabling irrigation during erratic monsoon years and allowing farmers to diversify into dry-season cropping. However, the upfront cost of solar pumps remains a significant barrier for many smallholder farmers, despite growing subsidy schemes and financing options. Additionally, the availability of solar energy raises concerns over the potential for groundwater over-extraction, especially in regions with weak groundwater governance or limited monitoring.

Reducing energy consumption with different irrigation methods

Adopting highly efficient irrigation methods could potentially reduce global energy consumption for irrigation by half, and also could reduce associated CO_2 emissions by as much as 90%, based on country-specific feasibility of mitigation options (Jingxiu Qin *et al.*, 2024). While flood or surface irrigation is most common for rice cultivation, more efficient systems like drip and sprinkler irrigation are increasingly used for other crops to enhance water and

fertilizer efficiency. Drip irrigation, in particular, offers significant energy savings primarily by reducing the volume of water that needs to be pumped, as it uses water more efficiently compared to traditional flood or surface irrigation (Arouna *et al.*, 2023). For more details on these and other irrigation methods, please see the *Green Technology Book*, energy, mitigation and adaptation editions.

> Adopting highly efficient irrigation methods could reduce global energy consumption for irrigation by half, and could reduce associated CO_2 emissions by as much as 90%

In recent years, water-saving irrigation methods like alternate wetting and drying (AWD) and system of rice intensification (SRI) have emerged as promising technologies in Asia for rice cultivation, with growing adoption in Bangladesh, China and the Philippines (Johnson *et al.*, 2024; Zeng *et al.*, 2023). As an alternative to continuous flooding of rice fields, AWD saves water and hence energy by allowing fields to dry until the sub-surface water level reaches a set threshold and triggers re-flooding. This practice can reduce methane emission by up to 70% (with an average 48% reduction) and save up to 30% water (IRRI, 2019). Further efficiency can be achieved through IoT-based AWD, allowing farmers to optimize water-saving benefits with precise and real-time measurements of soil moisture, water levels and environmental conditions in real time using sensors, automated valves and control systems.

In China and several other countries, some farmers cultivate rice on raised beds of soil and flood only the furrows in-between the beds, thus reducing water use as well as methane emissions, reportedly by up to 80%. The furrows can remain flooded all year round, which further eases irrigation management requirements (Zhijiang, 2023).

Smart agricultural transformation in Asia

The Asia-Pacific region is among the fastest-growing markets for agritech, with smart agriculture offering significant potential for agricultural transformation in developing nations (APO, 2023). Smart farming, often referred to as precision agriculture (PA), is a farming approach that uses technologies such as GPS, sensors, data analytics and IoT devices to optimize crop production and improve resource efficiency by tailoring inputs like water, fertilizers and pesticides to specific field conditions. It integrates hardware (e.g. drones, irrigation controllers, satellite remote-sensing etc.), software (local or cloud-based) and services (e.g. farm management). PA is categorized into “soft” and “hard” types. “Soft” PA uses low-cost tools such as digital soil-testing kits, basic sensors and mobile app-based weather services to monitor crop and soil health for smallholder farmers, while “hard” PA involves advanced technologies that require big data skills, for example AI-powered drones, autonomous tractors etc.

However, not all countries in the region are equipped to implement such advanced agricultural innovations (APO, 2023). In developed countries like Japan, using robotics, AI and IoT in agriculture is now commonplace, while smallholder farmers in developing Asia mostly rely on soft PA, due to financial constraints, limited technical expertise, low internet connectivity and regulatory challenges (Terra Agri, 2024a; Chandran, 2023). In India, for example, only 20 million farmers use any form of PA technology – a small fraction of the nearly 500 million in the country. Moreover, most energy and emissions savings from precision agriculture tend to accrue to larger farms, which are better positioned to adopt advanced technologies at scale. Bridging this gap requires collaboration among governments, private companies and educational institutions to provide resources and support. Initiatives like FAO’s Digital Village Initiative (DVI) are working across the Asia-Pacific region, including Bangladesh, China, Fiji, Papua New Guinea, Thailand, Viet Nam, and many other countries, to integrate digital solutions into rural farming and agri-food systems (FAO, 2025).

Nevertheless, despite regulatory challenges and land fragmentation, the Asia-Pacific region is seeing the fastest growth in agricultural drones, driven by declining agricultural commodity prices and rising labor costs, particularly in China and Japan (APO, 2023). Drones are increasingly used for seed planting and precision spraying of pesticides and fertilizers, improving efficiency through real-time data collection for targeted interventions. By optimizing such inputs, drones help reduce indirect energy use – the energy required to produce and transport these inputs – while lowering GHG emissions. Agribusinesses in Indonesia and Malaysia, known for high-yielding crops, are adopting drones which can manage 50 to 100 hectares per day and reduce fertilizer and pesticide use by up to 30% (Terra Agri, 2024b).

> IoT-driven smart irrigation systems are transforming water and energy management in agriculture by integrating sensors, automation and remote monitoring

Japan is also promoting agricultural robots equipped with Global Positioning Systems (GPS) alongside satellite-enabled tractors, rice planters and harvesters (APO, 2023). These technologies map rice fields using GPS, allowing autonomous machines to plant seedlings along pre-calculated routes. This optimizes agricultural machinery operation, reducing energy consumption and resource waste (Yao *et al.*, 2024). AI-powered self-driving tractors further collect environmental data during operation, sharing insights with other on-site machines to enhance efficiency.

IoT-driven smart irrigation systems are transforming water and energy management in agriculture by integrating sensors, automation and remote monitoring (Zeng *et al.*, 2023). These systems help farmers monitor and control irrigation remotely through smartphones or on-farm management platforms, reducing energy consumption linked to pumping and distribution. A satellite-based irrigation advisory system (IAS) is being implemented in South Asia to help farmers manage water usage more efficiently by alerting them when they are overwatering their crops. In a demonstration project, SMS text message advisories have shown the potential to save up to 80 million cubic meters of groundwater per season for irrigation in India and 150 million cubic meters in Pakistan (Bose I *et al.*, 2021). Meanwhile, young innovators in Cambodia, China and Indonesia are advancing smart irrigation solutions, improving efficiency and sustainability across diverse farming landscapes (IFAD, 2024).

Agrivoltaics enhancing dual harvest of food and energy in Asia

Agrivoltaics combines agricultural practices – such as crop cultivation and livestock farming – with photovoltaic (solar) technology, addressing the dual challenges of energy generation and food security. It entails growing crops beneath solar panels, maximizing land for both food production and solar energy generation. The Asia-Pacific region, with its diverse agriculture, high solar incidence and growing energy needs, is particularly well-suited for agrivoltaics. The region is experiencing the growing adoption of such technology, which is expected to grow from $654.8 million in 2023 to $6 billion by 2033 (The Agri-Food Data, 2025).

Agrivoltaics installation capacity has grown rapidly – from just 5 MW in 2012 to over 14 GW by 2021 – with Asian countries such as China, Japan and the Republic of Korea leading the growth (Fraunhofer ISE, 2024). China holds the largest share, with 1,900 MW installed by the end of 2020 and over 500 agrivoltaics projects spanning crop cultivation, livestock grazing and aquaculture (Silan J *et al.*, 2024). Japan has deployed around 2,000 agrivoltaic systems producing 200 MW of electricity while supporting 120 crop varieties (Fraunhofer ISE, 2021). Countries such as China, India and Japan are advancing adoption through supportive policies and targeted incentives. In contrast, in developing countries like the Philippines, despite abundant solar resources and a large agricultural base, agrivoltaics remains largely untapped. Key barriers including

regulatory ambiguity, fragmented land ownership, limited access to farmer financing and a lack of technical capacity for dual-use system design and maintenance have stalled progress. As a result, the technology remains in its infancy, even though it could address critical energy and agricultural challenges in the region (AENZ, 2024).

> The Asia-Pacific region, with its diverse agriculture, high solar incidence and growing energy needs, is particularly well-suited for agrivoltaics

Agrivoltaics can be applied across various agricultural settings, including grasslands, horticulture, arable farming, indoor farming and pollinator habitats. Each setting presents unique opportunities for solar integration. In horticulture, translucent panels maintain optimal light for plant growth while generating energy. In arable farming (cultivation of crops like grains and vegetables on plowable land), fixed and tracking solar systems can be integrated into crop rotation to maximize both energy and agricultural yield. Fixed systems are stationary, ideal for areas with consistent sunlight, while single axis tracking systems follow the sun to enhance energy production. Bi-facial panels, capturing sunlight from both sides, further enhance efficiency.

Innovations in solar panel technology, such as transparent and movable panels, allow for optimal light penetration for crops while still generating electricity. These systems not only supply energy but also shield plants and animals from extreme heat and drought. Additionally, they help reduce water evaporation by up to 30%, improving crop yields in regions with intense sunlight and high temperatures. Furthermore, solar panels installed over vegetation maintain significantly lower surface temperatures compared to those mounted on bare ground. This cooling effect also reduces efficiency losses induced by solar panels reaching high temperatures.

Agrivoltaic systems contribute to decentralized energy generation, reducing reliance on centralized grids and enhancing energy access in rural areas. Additionally, energy storage technologies allow solar-generated energy to be stored and used when needed, providing reliable power for agricultural operations. This is an important factor in climate change adaptation where more prevalent extreme weather events can lead to frequent disruptions in transmission networks.

Aquaculture-photovoltaic integration, or aquavoltaics, is a type of agrivoltaics, which is covered in the next chapter on fisheries and aquaculture.

Energy-efficient livestock farming

Meat consumption in Asia has traditionally been lower than in Europe, with diets centered on fish and plant-based proteins. However, urbanization and rising incomes have fueled a shift toward protein-rich diets like meat and dairy products, driving intense commercialization in the livestock sector in Asia. This is especially evident in China, the Republic of Korea and Viet Nam, where pork consumption is growing, while chicken and pork dominate in Japan, the Philippines and Thailand (Wen Bo, 2022). In contrast, beef farming has long been a major industry in Australia. Over 63,000 farming businesses produce beef across 43% of Australia's landmass, making it the world's second-largest beef exporter (WWF, 2018).

Livestock farming involves raising animals such as cattle, poultry, pigs and sheep in pastures or barns. It is a major contributor to GHG emissions, releasing about 7.1 gigatonnes of CO_2 equivalent annually (FAO, 2021). As livestock value chains expand in developing countries, energy demand rises due to increased processing, mechanization and transportation. High energy consumption in feed and fertilizer production is particularly concerning. In addition, in many regions, it faces challenges such as a harsh climate, water scarcity and increasing

consumer demand for environmentally friendly, chemical-free meat, which calls for innovation in energy-saving practices and more sustainable production methods.

> Solar solution systems, used in both on-grid and off-grid farms, help lower energy expenses while improving water access for livestock and irrigation

Improving energy efficiency can involve adopting high-efficiency machinery and equipment on the farm and natural ventilation in barns and sheds instead of energy-intensive cooling systems (FAO, 2021). Sensor-controlled ventilation systems optimize air circulation automatically, while variable speed drives (VSDs) can reduce energy loss by adjusting motor speed to match demand. In heat-stressed regions like China and India, high-volume low-speed (HVLS) fans are being used in large dairy farms to enhance air circulation while reducing electricity consumption. Details on such technologies can be found in the energy edition of the *Green Technology Book*.

Insulation in buildings can reduce fossil fuel energy consumption while protecting livestock. Insulated barns using agricultural textiles or aerogels are emerging in China, providing more protection from extreme weather. An aerogel is a nano-porous insulation material with extremely low thermal conductivity, which is one of the most important parameters for increasing the energy efficiency of buildings (Kotov *et al.*, 2024). They can be used as insulation in barn walls and roofs, either as blankets, panels or sprayed-on insulation.

Farmers are increasingly adopting solar solutions for a variety of purposes beyond irrigation, such as powering electric fencing, controlling greenhouse climates and charging machinery. Portable solar units are especially beneficial for remote cattle stations, offering a reliable power source for water pumps and monitoring equipment without the need for costly grid connections. For instance, in Cambodia, large-scale pig farms that rely heavily on electricity for lighting and water pumping have introduced solar-powered solutions. These systems, used in both on-grid and off-grid farms, help lower energy expenses while improving water access for livestock and irrigation. Similarly, in Viet Nam, where poultry farming is expanding rapidly, high energy consumption for heating, incubation and ventilation presents a challenge. In response, smallholder farmers are adopting solar-powered incubators and other renewable energy systems to reduce grid dependance and support rural electrification (IRENA, 2022). Moreover, as battery storage becomes more affordable, these farms are moving closer to energy self-sufficiency.

Efficient water management is another crucial factor in reducing energy waste. Automated watering systems for cattle, pigs and poultry help regulate water flow, preventing spillage and overflow while optimizing energy use for pumping.

Adapting to climate variability with energy-efficient greenhouses

As climate variability impacts crop yields, energy-efficient greenhouses are becoming more popular. These greenhouses integrate similar technologies as mentioned earlier to optimize energy usage in heating, cooling, ventilation, insulation and lighting. In India, thermal screens help regulate greenhouse temperatures, reducing cooling energy demand. In China and the Republic of Korea, double-layered polyethylene and bubble wrap linings are used to retain heat without obstructing light transmission. Additionally, digital greenhouse systems enhance farm management while maximizing energy savings.

Leveraging on-farm waste for energy and advancing circular economy

Agriculture serves a dual role as both an energy consumer and a supplier of bioenergy (FAO, 2000). This provides significant opportunities for rural development and contributes to climate change mitigation by replacing fossil fuels with bioenergy. The region's highly productive

agriculture sector and large agro-industries produce significant volumes of underutilized residues (IRENA, 2022). In countries with high agricultural activity, agricultural residues like rice husks, animal manure and crop waste are used to produce biogas or electricity through anaerobic digestion and biomass combustion. Additionally, these residues can be converted into biochar, a stable form of carbon produced by heating organic material in a low-oxygen environment (pyrolysis). Biochar helps sequester carbon in soil for long periods, improving soil health, fertility and water retention, while helping to mitigate climate change. These technologies help reduce the environmental impact of waste while providing a reliable source of renewable energy for farm operations, both in the form of electricity and as biofuel. Such technologies are already detailed in the previous sub-chapter on *rural households and communities.*

Countries with high agricultural activity, agricultural residues like rice husks, animal manure and crop waste are used to produce biogas or electricity through anaerobic digestion and biomass combustion

In several countries, smallholder farmers are also adopting small-scale biogas units, which not only provide energy but also yield organic fertilizers as a by-product, promoting a circular agricultural economy. Such an approach addresses the dual challenges of waste disposal and energy access, particularly in rural areas with limited access to the electricity grid.

Indonesian farmers saving energy through solar-based irrigation

Source: Tanahair/Hartatik/2023

Due to more frequent droughts caused by climate change, Indonesian farmers are struggling to access water for their rice fields. Traditionally, they've relied on diesel-powered pumps during the dry season, but this method is costly – about 60% of their irrigation expenses go toward fuel alone. Now, farmers are starting to adopt solar-powered irrigation systems to save energy costs and provide a cleaner solution. In Krincing Village, a new off-grid system uses 64 solar panels of 100W each to power an electric pump that draws water from the Elo River into a reservoir. A 400-meter pipe distributes water to nearby rice fields. The system currently irrigates 15 hectares, with the potential to reach 70–80 hectares. Farmers benefit from zero fuel costs, low maintenance (just panel cleaning), and reduced CO_2 emissions. With a 10–15 year lifespan, the system offers a clean, cost-effective solution to climate-resilient farming (One earth, 2023).

Robot helps Japan grow food and energy together

Source: Otani et al., 2023

In Japan, a collaboration between Waseda University, Shibaura Institute of Technology, Sustainergy and Sony CSL led to the development of SynRobo, a robot designed for Synecoculture farming. Synecoculture™ is a method that grows many types of crops together for ecosystem restoration and to boost biodiversity. Since traditional machines can't work in such complex, dense vegetation, this robot was built to handle sowing, pruning and harvesting – even under solar panels. It runs on a four-wheel system that can navigate rough terrain and uses cameras to help with tasks like weeding and harvesting. By combining food production with solar energy use, the robot supports efficient farming that saves energy and restores ecosystems (Otani *et al.*, 2023). Demonstration tests are being conducted with farmers in Japan to bring agricultural robots into practical use.

Technology solutions

Proven technologies

Water pump: Krishi Meter

Gham Power

Source: Gham Power

With Gham Power Krishi Meter, farmers get data-driven and real-time farm insights that help them optimize their farming methods and resources. The smart device leverages IoT technology to automate, monitor and control solar water pumps, improving water management. The sensors in the meter measure and analyze crucial agricultural parameters assisting farmers to make informed decisions regarding crop quality and yield. In addition, the system is designed to be user-friendly and accessible.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Nepal
- Availability: Worldwide
- Contact: WIPO GREEN Database

Precision agriculture: digital platform for resource optimization

SenzAgro Solutions

Source: SenzAgro Solutions

With solutions such as sensor-based monitoring, automatic irrigation and a digital platform for gaining agronomic advice in real-time, SenzAgro helps farmers optimize their resource use and efficiency. Their smart agriculture solution is claimed to decrease water and herbicide usage by 40%, while the automated operations can contribute to a 20% increase in yield and lowered operational costs and energy usage. The collected data on soil conductivity, ambient temperature and overall humidity can be viewed in the company's Farm Management App and informs the automated irrigation scheme. In addition, tasks such as fertilization and pest control can be assigned remotely based on the received data.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Sri Lanka
- Availability: Bangladesh, India, Malaysia, Sri Lanka, United Arab Emirates
- Contact: WIPO GREEN Database

Waste to energy: on-farm electricity generation from biogas

EGreen Technology

Source: Getty Images/unkas_photo

Many large and medium-sized commercial farms in Viet Nam use on-site anaerobic digesters to produce biogas for cooking. A common challenge is the flaring or release of excess biogas, as production often surpasses local demand. EGreen addresses this issue by providing an energy-as-a-service solution, converting diesel generators to operate on biogas for electricity generation. These generators are available for purchase or rental, with EGreen committing to lifetime maintenance in both cases. By adopting this solution, farmers can reduce their electricity costs by over 50%. By 2024, the company had deployed 80 biogas generators with a total capacity of 12 MW to farms across Viet Nam.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Viet Nam
- Availability: Viet Nam
- Contact: WIPO GREEN Database

Water pump: pump controller for areas with unstable energy supply

Intech Harness

Source: Getty Images/Natalia Kokhanova

The Jalaprayah pump controller is an IoT-enabled controller for electric irrigation pumps. It supplies water with respect to water availability and fluctuations in power supply, reacting to water scarcity or power outages by automatically shutting off and later completing the irrigation cycle. These features deter pumps from working under dry conditions, contributing to on-farm energy efficiency.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Water pump: solar water pump with digital platform

SOGE

Source: Getty Images/Ghulam Hussain

SOGE provides solar-powered water pumping solutions for both individual farmers and farming communities. Their solar panels use trackers to follow the sun throughout the day, maximizing efficiency. The pump system, designed for individual farmers, includes an inverter and pump motor and can be connected to the grid if needed. For farming communities, the irrigation station offers a pay-per-use pump system. Both solutions can be enhanced with the SOGE app, which enables remote control, irrigation scheduling, data tracking, monitoring and more.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Cambodia
- Availability: Cambodia
- Contact: WIPO GREEN Database

Livestock: high-volume low-speed (HVLS) ceiling fan for livestock farm

Fujian Diamond Electrical and Mechanical Equipment Co., Ltd.

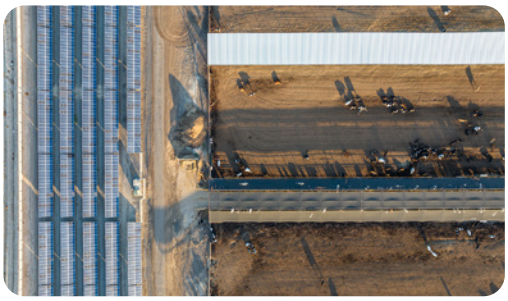
Source: Getty Images/isitsharp

This industrial ceiling fan features a high-efficiency IE5 permanent magnet synchronous motor (PMSM), enabling energy savings of over 30% compared to conventional systems. With diameters ranging from 3 to 7.3 meters and wind speeds of 1–5 m/s, it covers up to 1,700 m^2, offering effective ventilation and cooling for large spaces on livestock farms including cattle farms, feedlots, hatcheries, etc. The fan enhances air circulation by pushing a steady breeze downward to create a consistent airflow layer, improving indoor comfort and reducing reliance on energy-intensive cooling systems. Its intelligent control system further maximizes operational efficiency.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Renewable energy: energy as a service for cattle beef farms

REDEI



Source: Getty Images/JasonDoiy

Renewable Energy as a Service (REaaS), offered by REDEI provides beef cattle farms with reliable, cost-effective energy without upfront investment. The service delivers solar power systems integrated with energy storage and grid connectivity, which are tailored to the specific energy needs of each farm. REDEI designs, installs and maintains the infrastructure, ensuring efficient energy delivery through flexible, scalable solutions. This approach reduces reliance on the grid, mitigates the impact of rising electricity costs and enhances energy resilience. The REaaS model offers fixed-price green energy, lowering operational costs and supporting long-term sustainability while capping energy expenses with a single monthly bill.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Australia
- Availability: Australia
- Contact: WIPO GREEN Database

Livestock: solar poultry incubator

Lifeway Solar

Source: Lifeway Solar

Designed for rural areas with unreliable or no access to grid electricity, this semi-automatic solar poultry incubator supports hatching of up to 100 quail, 40 chicken or 25 goose eggs. It features a fiberglass, double-skinned cabinet with polyurethane foam insulation for thermal efficiency and stable internal temperatures – critical for high hatch rates. A 12-V/40-W solar photovoltaic panel, connected to a battery via a charge controller, ensures continuous 24-hour operation. The unit operates on solar, battery or grid power and consumes just 20–60 watts. Key features include automatic heat control via a proportional thermostat, fan-assisted ventilation and a manual humidity system. The design enables reliable, low-energy egg incubation for remote farming communities.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: India
- Availability: India, Nepal
- Contact: WIPO GREEN Database

Energy storage: battery solution for agricultural farms

Energy Renaissance

Source: Energy Renaissance

Energy Renaissance battery storage solutions, integrated with solar technology, enable farms to generate and store renewable energy, reducing dependence on grid power and diesel generators. The solution offers a reliable, eco-friendly alternative that lowers operating costs and minimizes the farm's carbon footprint. It ensures a stable energy supply, reducing disruptions and keeping farm operations running smoothly. The solution is completed with an energy management system controlling the charge–discharge cycles of batteries, providing streamlined monitoring and management of the energy-generating and energy-storing systems.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Australia
- Availability: Australia
- Contact: WIPO GREEN Database

Waste to energy: small-scale and mobile bioreactors

Takachar

Source: Getty Images/photovs

Crop residues are often burned in the absence of other handling methods, increasing the risk of wildfires and contributing to health-damaging issues of smog. In response, Takachar developed the Takavator, a mobile, small-scale and low-cost multi-chamber biomass reactor. The solution is meant to facilitate biomass upgrading in rural and off-grid communities and can latch onto the back of tractors and pick-up trucks. It can upgrade a wide variety of loose, wet and bulky crop residues directly on-site, generating dense and more manageable products such as solid biofuels and biochar-based soil amendments. For power, the reactor consumes about 10% of input biomass. The biofuel it generates is a solid, clean-burning type, which generates less smoke than traditional alternatives such as wood, peat and animal dung.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: United States of America
- Availability: India, Kenya, United States of America
- Contact: WIPO GREEN Database

Agrivoltaics: bi-facial solar modules with smart controls

Trinasolar

Source: Getty Images/Karl-Friedrich Hohl

Trinasolar provides agrivoltaic solutions suitable for both crop and livestock farming. The solution includes bi-facial solar modules mounted at least two meters above the ground and trackers that use algorithms or real-time meteorological data to maximize energy generation while considering both agricultural activities and the sun's position. For example, after excessive rain, the modules can be positioned vertically to help the field dry more quickly.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Irrigation: sensor-based system

Sense it Out Intelligent Solutions

Source: Getty Images/alacatr

The Sensor-based Intelligent Crop Centric Automation (SICCA) is a smart irrigation system for automatic or remote control of irrigation with respect to factors such as soil moisture, temperature and humidity. The solon-powered and battery-equipped sensor nodes record microclimatic and soil data and transmit it to the main pump controller. Here, irrigation either triggers automatically or via the My SICCA smartphone app, with the help of valve nodes on the field. The valve nodes, similar to the sensor nodes, are solar-powered and equipped with a rechargeable battery. The system components communicate wirelessly and require no changes to the existing pipeline structures to function, and valve nodes can be placed up to 2 km away from the main pump controller. Suitable for farms of 1 to 50 acres, SICCA can reduce irrigation water use by up to 80%, significantly cutting pump energy consumption.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Precision agriculture: spraying drone

TerraDrone

Source: TerraDrone

The E16 spraying drone is designed for high-efficiency, precise spraying of fertilizers or pesticides in plantations. It significantly reduces water and chemical waste while spraying up to 40 times faster than traditional methods, offering cost savings. Built to withstand harsh conditions, it features real-time kinematic navigation for centimeter-level accuracy and a contour-following sensor, allowing it to adapt to terrain and optimize spraying coverage efficiently.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Indonesia
- Availability: Indonesia, Malaysia
- Contact: WIPO GREEN Database

Farm input: biocompatible photosynthesis enhancer

Qarbotech

Source: Qarbotech

QarboGrow is a photosynthesis-enhancing foliar spray that uses tiny carbon particles known as carbon quantum dots. The spray works by penetrating leaves where it enhances light absorption and electron transfer in the organelles responsible for converting sunlight into energy. Therefore it increases photosynthetic efficiency by up to 100%, reducing fertilizer dependence, promoting healthy soils, and reducing water usage by up to 20% which saves energy. The solution also enables energy savings for indoor farms using artificial lighting. Past applications have resulted in a 40% increase in rice yields and a 20% reduction in crop cycle duration, and improved drought resilience.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Malaysia
- Availability: Indonesia, Malaysia
- Contact: WIPO GREEN Database

Precision agriculture: self-driving robot tractor for sustainable agriculture

Yanmar

Source: Yanmar

Yanmar's Robot Tractor has a tablet user interface which is fitted with a global navigation satellite system (GNSS) unit and inertial measurement unit (IMU), enabling precise autonomous navigation along pre-set paths for accurate and safe operation on farmland. It features obstacle detection, an intuitive tablet interface and centralized data management via Smart Assist. A portable base station allows use in remote areas without existing infrastructure. The system supports dual operation, where one operator can manage both an autonomous and manual tractor, improving efficiency.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Livestock: smart poultry farming

Chickin

Source: Chickin

SmartFarm solution uses IoT technology to enhance efficiency in poultry farming. Its CI-Touch hardware automatically monitors and adjusts cage temperature and humidity via sensors, optimizing fan speed. According to Chickin, this can reduce electricity consumption by up to 35% and lower feed costs by improving nutrient absorption. Real-time climate data is displayed on a dashboard, eliminating manual reporting. The company also claims mortality rates can decrease by up to 50% due to better environmental control. The system digitizes performance tracking, allowing farmers to analyze trends and adjust operations.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Indonesia
- Availability: Indonesia
- Contact: WIPO GREEN Database

Greenhouse: spectral monitoring for energy-efficient greenhouse lighting

nanoLambda

Source: Getty Images/PrathanChorruangsak

The XL-500 is a compact spectroradiometer designed for continuous, real-time light spectrum monitoring in greenhouse environments. It measures spectral power distribution, photosynthetically active radiation, photon flux density and illuminance, along with color characteristics such as color temperature, color rendering and chromaticity. In horticultural settings, this helps optimize the light spectrum delivered to plants, reducing unnecessary energy consumption while maintaining or improving crop yield and quality. Using Bluetooth Low Energy, users can set custom measurement intervals, with the device operating for several weeks on a single charge.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Republic of Korea
- Availability: Worldwide
- Contact: WIPO GREEN Database

Solar energy: mobile URJA – scalable solar power beyond silicon technology

KARMA

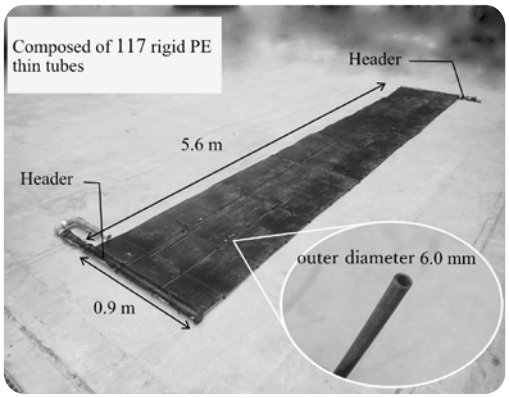
Source: Karma

Mobile URJA, developed by KARMA, a startup from the Indian Institute of Technology (IIT), in collaboration with MIT and Flissom, is an innovative energy solution addressing the challenges of rain-fed agriculture and diesel pump reliance. This mobile energy platform uses solar panels and power units that can be easily relocated and shared by multiple users, offering affordable energy access to marginal farmers, particularly for irrigation. Powered by Flissom's copper indium gallium selenide (CIGS) solar panels, the system can operate within five minutes of relocation and power pumps of up to 3 horsepower. It provides a scalable and flexible alternative to traditional, fixed solar systems.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Greenhouse: energy-saving low-carbon technology in greenhouse horticulture

National Agriculture and Food Research Organization



Source: National Agriculture and Food Research Organization

This technology reduces energy consumption and greenhouse gas emissions in agricultural greenhouses which traditionally rely on heavy fuel oil for heating. By extracting heat from nearby flowing water such as irrigation canals, the sheet-type heat exchanger can reach a heat exchange efficiency 15 times better than underground water and 2.5 times more than stagnant water. The solution also cuts construction costs since no boreholes are needed during the installation of the heat exchanger in irrigation canals, and protective materials can reduce damage from debris in the water.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Wastewater treatment: energy-efficient wastewater treatment for pig farms

Okinawa Institute of Science and Technology (OIST)

Source: Okinawa Institute of Science and Technology (OIST)

OIST researchers have developed a bio electrochemical system for energy-efficient wastewater treatment and nutrient recovery at pig farms. These farms are characterized by large volumes of organic waste. Conventional wastewater treatment with activated sludge requires aeration which can be an energy-intensive and costly operation. This two-tank configuration builds on the principle of having microbes breathe through electrodes, moving electrons from the organic content in raw wastewater and transferring them to nitrified substances in the other tank containing wastewater after aeration. The process allows denitrification without requirement for organic compounds. By cutting aeration needs and minimizing sludge production, it lowers energy consumption and operational costs by 20% to 50%. A 525-liter prototype is now set for joint development after successful pilot trials.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Precision agriculture: versatile platform robots for the future in agriculture

Kubota

Source: Getty Images/sarawuth702

These fully autonomous platform robots are designed to perform a wide range of tasks in agriculture and other fields without human intervention. Equipped with various implements, they enable data-driven precision farming, automate manual tasks and even support civil engineering work. The robots are highly adaptable, with adjustable height and width to accommodate different crop spacing and growth conditions, ensuring they are suited for specific tasks. Their ability to automatically swap implements allows a single unit to handle multiple operations. For example, in rice farming, these robots can perform tasks traditionally carried out by separate machines, such as tilling, intermediate management, pest control and harvesting, resulting in significant energy savings and greater operational efficiency.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Clean energy solutions for agriculture post-harvest

While much attention has been given to energy use in crop cultivation and irrigation, the energy demands of post-harvest activities – such as processing, cold storage and transport - are equally critical. These post-harvest stages are often where significant food loss occurs due to malfunctioning infrastructure and unreliable power. Approximately 14% of the world's food valued at USD 400 billion is lost each year between harvest and the point of sale (FAO, 2020a). The climate cost is significant with food loss and waste accounting for about 8% of annual global greenhouse gas emission, making it the third-largest emitter if treated as a country (WRI Indonesia, 2018). Every unit of food lost also represents wasted irrigation, fertilizer, diesel and energy embedded across the supply chain. Post-harvest technologies and innovations therefore represent a critical entry point for integrated climate and energy solutions.

> The deployment of decentralized renewable energy technologies is gaining momentum across the Asia-Pacific region in the form of solar-powered milling systems, biogas digesters and cold storage

The deployment of decentralized renewable energy technologies is gaining momentum across the Asia-Pacific region in the form of solar-powered milling systems, biogas digesters and cold storage based on CO_2 or ammonia technologies. Such innovations not only reduce emissions and operating costs but also enhance the resilience of rural communities to climate shocks. When integrated with energy efficiency measures, they play a crucial role in climate mitigation and advancing sustainable, inclusive agri-food systems – especially in the post-harvest phase where energy demand is significant (OECD, 2021).

Technological development and trends

Post-harvest processing

Post-harvest processing refers to all the steps that transform raw agricultural produce into storable, market-ready products. These include drying, cutting, threshing, milling, winnowing and additional processes like fermentation, sterilization, meat and dairy processing, and cold storage. Each stage relies on energy to maintain quality, extend shelf life and reduce losses.

Drying, which removes moisture from crops like grains, tea etc. to prevent spoilage and reduce transport weight, is a critical first step after harvest. It plays a vital role in minimizing storage losses and reducing the risk of mold and aflatoxin contamination (a family of toxins produced by certain fungi on agricultural crops), especially for crops like nuts and grains. While natural sun drying is common in developing countries, it is labor-intensive and weather dependent, and can also result in increased losses due to pest and rodent attacks. Mechanical dryers offer a more controlled alternative but require significant energy input and are often inaccessible to smallholders due to high upfront and maintenance costs, adequate size availability and lack of knowledge regarding their use (Kumar and Kalita, 2017). Active solar dryers use solar panels to power drying systems and may also support functions like lighting or phone charging. In developing countries, farmers value them not just for preserving food but also for benefits like improved hygiene and reduced labor.

Threshing separates grains from panicles – done manually, with animal power or via mechanical threshers. Winnowing and cleaning follow, removing broken grains, straw and sand through screening and sifting to prevent mold and insect infestation and improve taste and appearance.

In many places in the Asia-Pacific region, these processes are commonly done using manual or simple and often energy-inefficient tools.

Milling involves grinding or polishing grains like rice or maize, manually or with milling machines. However, yields from milling machines are dependent on the method, crop conditions and operator skills, and low maintenance and poor calibration can reduce yields significantly. Studies show that rice milling yields in small villages across several Asian countries can drop to 57%, well below the ideal of 71% to 73%, mainly due to poor maintenance, small-scale operations and improper machine calibration (Alavi *et al.*, 2012). Still, local milling facilities remain preferred by small farming communities for affordability, accessibility and often for preservation of traditional flavors in crops like rice. Addressing these inefficiencies through improved milling technologies not only boosts grain recovery but also can help smallholder farmers reduce losses, boost incomes and build local skills and enterprises, strengthening rural economic resilience (Urugo *et al.*, 2024).

Rising energy demands in grain drying drive diverse solutions

Grain drying is essential for preserving crop quality, especially in Asia, which produces 90% of the world's milled rice (Nguyen-Van-Hung *et al.*, 2019). In countries like Cambodia, Myanmar, the Philippines and Viet Nam, where rice and other grains are crucial to the local economy, efficient post-harvest drying is vital to prevent losses. While traditional sun drying is inexpensive, it depends on weather conditions and risks uneven drying and contamination. To address these challenges, modern energy-efficient drying technologies are vital to improve reliability and reduce food loss.

One such technology is the solar bubble dryer (SBD), which uses solar energy in a sealed, bubble-like structure to dry grains, cutting energy use and GHG emissions by over 50% compared to traditional methods (Nguyen-Van-Hung *et al.*, 2019). Such solutions are ideal for smallholders in off-grid areas although costs remain a barrier.

The flatbed dryer (FBD) is a common drying method in Southeast Asia. It works by blowing heated air through a perforated floor beneath a shallow bed of grain. While it is cost-effective and energy efficient, it requires a larger land area compared to other systems. In contrast, the recirculating columnar dryer (RCD) offers faster drying by continuously recirculating heated air within a vertical column, at a range of 40°C–80°C depending on moisture content (Champ *et al.*, 1996). It is a hybrid of batch and continuous-flow dryers, where a batch of grain is continuously moving and recirculated within the dryer during the entire process. Although the RCD method uses about 15% more energy than the FBD, it provides faster drying and better control of grain moisture, making it a popular choice for mid-to-large-scale drying operations (Champ *et al.*, 1996; Nguyen-Van-Hung *et al.*, 2019). Another option is the two-stage dryer system, which is ideal for large-scale operations (over 200 tons/day). It combines a high-temperature drying phase followed by a lower-temperature drying phase, or even ambient air drying, allowing for better moisture control and energy conservation.

> Efficient post-harvest drying is vital to prevent losses in Asia, where 90% of the world's milled rice is produced

These conventional dryers discussed above, although still in use, are gradually being replaced by more energy-efficient and smart systems. For example, smart dryers with cloud-based controls and real-time monitoring are increasing in high-income regions like Japan. These systems reduce energy consumption by up to 25% by improving drying precision (DataVagyanik, 2024). Meanwhile, biomass-based dryers are gaining momentum in India and Indonesia, where off-grid energy reliance is high. Biomass stoves, often fueled by rice husks or straw, provide a low-cost and sustainable heat source. Electric hot blast stoves use electricity to power heating elements and a blower, generating high-temperature air with precise control – ideal for drying sensitive grains like rice that require strict temperature regulation. Southeast Asia is also seeing

a rise in hybrid systems that combine electric heating with biomass combustion, enabling farmers to use both energy sources depending on availability and cost.

Renewable energy for agro-processing

Agro-processing systems powered by standalone renewable energy or mini-grids are emerging as cost-effective solutions that reduce emissions, support decentralized rural infrastructure and minimize labor-intensive processing. As part of this shift, solar-powered mills are increasingly preferred over diesel-powered alternatives due to ease of operation, lower maintenance costs and elimination of fuel expenses (Power for All, 2020). For example, in Vanuatu, where about 150,000 people live in off-grid villages, 180 solar agro-processing mills are used for processing different kinds of key crops like coconut, cassava and kava, as well as meat and other products (Village Infrastructure Angels, 2024). Solar mills have reached even remote islands in Indonesia, where they are used to process rice, maize and other major crops. Additionally, geothermal energy is being utilized to meet thermal and electricity needs for agro-processing, as demonstrated by the Mokai geothermal field in New Zealand, which supplies steam to a dairy factory processing over 250 million liters of milk annually (IRENA and FAO, 2021). However, scaling up the adoption of these technologies will require long-term concessional credit for smallholders, supported by grants, training and better market access (IRENA and FAO, 2021).

Sustainable bioenergy is a valuable renewable resource for electricity, heat and transport fuels in the agri-food sector. Biomass by-products like bagasse from sugarcane processing are used in India, the Philippines, Thailand, and Viet Nam to power sugar mills, enabling energy self-sufficiency and even producing exportable electricity (IRENA and FAO, 2021). In Thailand, both solid and liquid wastes from cassava processing are converted into biogas for power generation. In Myanmar, rice husks, a by-product of rice milling, are used to produce electricity and heat, improving energy access in rural areas and supporting value-added rice products. For more details on biogas, please see the chapter section on rural households, and also the energy edition of the *Green Technology Book*.

Keeping it cool with advanced refrigeration innovations

Refrigeration has transformed food consumption and storage patterns, enabling extended preservation, diversified diets and global food trade. However, it has also contributed to climate change through energy consumption and refrigerant emissions. The refrigeration sector, including air conditioning, contributes roughly 17% of global electricity consumption, even exceeding 40% of total national electricity demand in some countries (Coulomb, 2021).

> The refrigeration sector, including air conditioning, contributes roughly 17% of global electricity consumption

In Asia, refrigeration technologies have advanced significantly, focusing on energy efficiency and sustainability. Adaptive or inverter compressors, which adjust their speed based on cooling demand, are prevalent in the region. These compressors operate at variable speeds, reducing energy consumption and enhancing operational efficiency compared to traditional compressors. Vacuum insulation panels (VIPs) are utilized to improve insulation performance in refrigeration appliances. VIPs achieve super low thermal conductivity, significantly reducing heat transfer and enhancing energy efficiency. Some refrigerators now contain convertible freezer compartments, allowing users to switch between freezer and refrigerator modes based on their needs, optimizing energy usage and storage efficiency. Modern freezers often feature microprocessor-controlled temperature settings and defrost sensors, allowing for precise temperature regulation and efficient defrost cycles, which help save energy and extend the appliance's lifespan.

Blast freezing is a widely used but energy-intensive process where pallets of fresh produce are placed in large freezer rooms and subjected to rapidly circulated cold air to quickly preserve

quality for safe storage and transport. To address the high energy demands of this method, several innovative solutions are emerging across Asia. Cryogenic freezing using liquid nitrogen offers ultra-rapid temperature reduction with significantly lower energy use, making it ideal for delicate or high-value agricultural products. However, it is more costly than conventional freezing due to the price of liquid nitrogen and operational expenses, and is therefore used selectively – notably in Japan, where the market demand for premium product supports the adoption of such advanced methods.

To enhance energy efficiency in more cost-sensitive contexts, freezer spacers are commonly used for fruits and vegetables to enhance airflow between stacked items, enabling faster and more uniform freezing while reducing energy consumption. Additionally, auto pressurization systems (APS) in spiral freezers help minimize cold air loss and reduce defrost cycles by balancing internal pressure, further improving operational efficiency.

> As the Asia-Pacific region experiences rapid growth in food production, consumption and digital commerce, modernizing cold chain infrastructure has become essential

Chlorofluorocarbons (CFCs) and halons, once widely used as refrigerants and in industrial applications, were found to damage the ozone layer, leading to increased UV radiation exposure. While alternatives such as hydrochlorofluorocarbons (HCFCs), like R-22, have lower ozone-depleting potential, they still pose environmental risks. Hydrofluorocarbons (HFCs), including R-134a and R-404A, have high GWP, contributing to climate change. In response, new low-impact technologies are emerging. Air-based refrigeration systems, discussed in the horizon technology section below, use air instead of high-GWP gases to achieve temperatures as low as –100°C with over 50% improved energy efficiency (Refindustry, 2024). In China, researchers are developing thermogalvanic cooling, which generates cooling through reversible chemical reactions, potentially reducing electricity use and emissions. In Thailand, supermarkets using liquid pressure amplification (LPA) technology have achieved 15% to 25% energy savings in hot climates by eliminating flash gas (the portion of a refrigerant that evaporates when pressure is suddenly reduced) and optimizing compressor performance (HY-SAVE, 2024). Additionally, cold chain systems are increasingly adopting CO_2 (R-744) refrigeration, which has a very low GWP and offers high-efficiency, superior heat transfer and waste heat recovery for secondary uses like water or space heating (HR Asia, 2025).

Energy efficiency is paving the way of cold chain logistics, but progress is still needed

Cold chain logistics encompass the storage and transport of temperature-sensitive goods across the supply chain to preserve the quality and safety of perishable food products. It relies on specialized refrigeration, temperature control systems, monitoring devices and cold storage facilities to maintain optimal conditions. However, in many developing countries, producers still store food in basic rooms instead of modern warehouses or cold rooms, resulting in substantial post-harvest losses. Upgrading these facilities not only reduces spoilage and emissions but also leads to meaningful energy savings, which can lower operational costs and shorten payback periods – enabling producers to offer goods at more competitive prices while contributing to climate mitigation goals.

As the Asia-Pacific region experiences rapid growth in food production, consumption and digital commerce, modernizing cold chain infrastructure has become essential. Valued at USD 168.24 billion in 2025 and projected to reach USD 253.92 billion by 2030, the cold chain logistics market is being reshaped by innovations focused on energy efficiency and sustainability (Mordor intelligence, 2025). Storage dominates the sector, making up about 65% of the market, especially

in fast-growing economies like China, India and Viet Nam. The rise of e-commerce and quick-commerce platforms is intensifying demand for fast, temperature-controlled last-mile delivery of fresh produce, dairy and frozen goods. This has driven the need for decentralized cold storage, energy-efficient transport and real-time temperature tracking.

> Automation is a key energy-saving strategy, with the adoption of automated storage and retrieval systems becoming more widespread

To meet these challenges, energy-saving technologies are becoming essential – not only to maintain product integrity from farm to consumer, but also to reduce operational costs and environmental impact. Key innovations include solar-powered refrigeration for last-mile delivery using solar panels mounted on three wheelers or electric vehicles to cool produce during transit; phase-change materials (PCMs) that absorb and release heat to maintain stable temperatures without continuous cooling; and thermal energy storage systems, which freeze water or specialized materials during off-peak hours and release the stored cooling during peak periods, cutting energy use and easing pressure on the power grid.

Japan is at the forefront of technological innovation in the cold chain sector, with significant progress in automation and energy efficiency. In 2023, GLP (a leading global investment company based in Singapore) announced the construction of two fully refrigerated warehouses in Japan, totaling 55,000 square meters. They feature advanced cold storage technologies like variable temperature zones (-25°C to 10°C) that switch between freezing and refrigeration, allowing it to cater to a wide range of customers including food manufacturers, wholesalers etc. The multi-tenant facility offers flexible storage options, allowing customers to rent small lots based on their needs (GLP, 2023). Meanwhile, in Indonesia, DNR Corporation (a major supply chain solutions provider in Indonesia) introduced ultra-cold storage capable of reaching -80°C, setting a new standard in temperature-sensitive logistics (DNR Corporation, 2021).

Automation is a key energy-saving strategy, with the adoption of automated storage and retrieval systems (ASRS) becoming more widespread in large-scale cold chain operations. These computer-controlled systems significantly reduce energy usage by optimizing warehouse operations such as enabling automatic high-density storage, minimizing lighting and ventilation needs and limiting door openings to prevent heat ingress. For instance, Tee Yih Jia in Singapore (a leading frozen food manufacturing company) has introduced advanced ASRS-equipped cold storage hubs that drastically improve energy efficiency while maintaining consistent temperature standards. More details on this can be found in the technology examples.

Supporting these infrastructure upgrades are smart technologies that enhance visibility, traceability and temperature control across the supply chain. IoT-enabled sensors and GPS trackers are now standard for real-time cold chain monitoring, while blockchain offers the potential to provide a secure and decentralized transaction record to support the tracing of product origins and storage conditions. Predictive maintenance and demand forecasting, powered by AI and data analytics, further optimize both energy use and logistics. On the transport side, IoT-integrated refrigerated electric vehicles and route optimization software are helping maintain cold chain integrity while reducing fuel consumption and emissions.

Cutting energy costs in dairy farming with innovative processing solutions

Dairy farms consume more energy than most other types of agricultural operations (The Dairy Site, 2010). The energy demands of milk processing highlight the need for innovative technologies and practices to reduce both energy use and greenhouse gas emissions (Al-Tayawi *et al.*, 2025). Energy is primarily used in processes such as milking (e.g., vacuum and milk pumps), cooling and storing milk (e.g., refrigeration) and in cleaning, evaporation and pasteurization. Milk chilling and pasteurization are key areas of innovation in dairy processing.

Immediately after milking, milk must be cooled from approximately 37°C to 4°C to preserve quality and prevent spoilage – an energy-intensive step that can account for up to 30% of a dairy farm's total energy use (DairyNZ, 2023).

One effective energy-saving strategy is heat recovery. Plate heat exchangers (PHEs), for example, use thin stainless-steel plates to transfer heat from warm milk to cold water flowing on opposite sides. This pre-cools milk before it enters the bulk tank, reducing the refrigeration load. PHE systems are modular and adjustable in capacity, and when supplied with very cold water, they can lower milk temperatures from around 35°C to below 18°C, cutting refrigeration energy use by up to 60% (The Dairy Site, 2010). Additional energy savings of up to 20% can be achieved using vat wraps, which insulate milk storage tanks using materials like foam to maintain temperature during processing.

Milk chilling and pasteurization are key areas of innovation in dairy processing

New technologies are also emerging to replace conventional chilling methods, particularly in rural and off-grid areas. Thermal battery-based chillers use PCMs to store energy as ice when electricity is available, then release it to cool milk during power outages. Similarly, solar-powered bulk milk coolers are being deployed in India and Nepal, offering reliable milk preservation with minimal carbon footprint.

In processing plants, energy-efficient pasteurization systems with heat regeneration capabilities are being adopted to reduce fuel use. These systems reclaim heat from pasteurized milk to pre-warm incoming raw milk, thereby minimizing the total energy required. Equipment like homogenizers and separators equipped with variable frequency drives (VFDs) also reduce energy usage by allowing precise motor control during standardization and cream separation.

Further efficiency gains are being realized through membrane filtration technologies such as ultrafiltration and reverse osmosis. These methods allow for concentration of milk and whey with lower energy input than traditional thermal evaporation, while also improving yield and preserving nutrients. In powder production, modern spray dryers (evaporate the liquid in milk using a stream of hot air) with energy recovery and optimized airflow systems minimize thermal losses and increase drying efficiency. Additionally, robotic milking systems are being adopted to improve overall operational efficiency.

Brewing energy efficiency and technology in tea production across Asia

Tea is one of the most widely consumed beverages globally, with several Asian countries dominating its production. China leads the world in tea output, reaching nearly 2.4 million metric tons in 2024 while India and Sri Lanka closely follow. India, contributing over 23% of global production, holds the position of the second-largest tea producer (Mamchii, 2024).

The process of manufacturing tea comprises several stages – plucking, withering, rolling, maceration, fermentation, drying, grading and packing – all of which demand significant thermal and electrical energy. Specific energy consumption ranges between 4 and 10.4 kWh per kilogram of made tea (Kumar and Pou, 2016). The process is highly energy-intensive, with energy expenses accounting for approximately 30% of total production costs (Sharma *et al.*, 2019). In India alone, the tea industry contributes around 1,352,000 tons of CO_2 emissions annually due to fuel use (Sharma *et al.*, 2019).

Among all the processing steps, withering and drying consume the most energy. Together, these stages account for over 80% of the thermal energy used, primarily for moisture removal. Meanwhile, electrical energy supports various functions throughout the production cycle, such as operating motors, fans, humidifiers and lighting. Notably, the withering phase alone consumes approximately 40% to 45% of the factory's electricity usage (Ethical Tea Partnership, 2023).

Withering marks the beginning of the tea manufacturing process. It involves reducing the moisture content of freshly plucked leaves to about 70% making them pliable and ready for rolling and fermentation (Kirubakaran, 2024). This is achieved by circulating air through leaves spread over wire mesh troughs, facilitating the evaporation of surface moisture while retaining internal leaf hydration. Blowers, typically placed beneath the mesh, aid this airflow. To enhance efficiency, the systems utilize heated air – sourced from wood, coal or electrically powered heaters – to accelerate moisture loss.

> The withering phase in the tea manufacturing process consumes approximately 40% to 45% of the factory's electricity usage

Recent innovations include improved withering troughs equipped with automated air control systems, which adjust airflow and temperature for optimized drying and reduced energy use. Additionally, more sustainable heating sources, such as biomass-fired furnaces and gasifiers, are being introduced. These systems use agricultural residues, like tea prunings and wood chips, to generate cleaner heat compared to traditional firewood. Solar drying technologies, including hybrid solar-biomass systems, also help reduce energy consumption by harnessing solar power to assist in the drying process, particularly on cloudy days. Energy can also be saved with regular maintenance, like cleaning burner dust and replacing worn parts, improving combustion and efficiency.

The final drying stage in tea processing is highly energy-intensive, often involving rotary dryers that remove moisture with hot air. For certain varieties like gunpowder tea, ball tea machines are also used to roll leaves into small pellets. Upgrading these machines to higher capacities can reduce electricity use by minimizing the number of machines needed. Additionally, heat recovery systems in dryers can further cut energy consumption by capturing and reusing waste heat. Variable speed blowers, used in both withering and drying, adjust airflow based on real-time needs, reducing thermal losses and preserving tea quality.

Innovation examples

Zero energy "Subjee-Cooler" for vegetable and fruit storage in India

Source: RuKart

RuKart's Subjee-Cooler is a passive cooling solution that works without electricity or solar power. It uses evaporative cooling to lower temperature and maintain high humidity, where warm air is drawn through water-soaked pads. As the water evaporates, it absorbs heat and releases cooler, humid air into the storage space, keeping vegetables fresh for 5–7 days. The Subjee-Cooler is made up of seven layers of insulation walls, which lower the inside temperature by 5–21°C compared to the ambient temperature. It also maintains a high relative humidity of 85% to 90%, preventing moisture loss from stored produce. Each unit stores up to 100 kg of produce and uses just 15 liters of water daily. In trials at Sahaja Organics, five units reduced spoilage by over 50%, especially during hot months (Kanaujia *et al.*, 2024). This led to 414 kg CO_2-equivalent in greenhouse gas savings over six months. Compared to electric cold rooms, each Subjee-Cooler saves about 4,500 kg of CO_2 yearly, equal to the carbon captured by 16 trees (Wheels Global Foundation, 2024). Over 2,500 units have been installed across 19 Indian states, offering an affordable, energy-free solution for reducing food loss and emissions.

Bioenergy for tea drying in Viet Nam

Source: SWITCH-Asia

In Thai Nguyen, Viet Nam's key tea-producing region with over 23,000 hectares of cultivation and around 91,000 small-scale processors, traditional tea drying methods using wood and charcoal release significant smoke, toxins and CO_2, posing health and environmental risks. To address this, the SWITCH-Asia BEST project, led by international NGO Oxfam and the local NGO Center for Creativity and Sustainability (CCS), introduced continuous volumetric biomass gasification (CVBG) technology, which converts agricultural and forestry waste into clean-burning syngas. This innovation significantly reduces smoke, toxins, and CO_2 emissions, improves processed tea quality, reduces production costs, and produces biochar as a by-product for horticulture. The project targets 2,500 agro-processing MSEs in four provinces, aiming to benefit 1.2 million people and reduce 2 million tons of CO_2 by gasifying 1.4 million tons of biomass (switchasia, 2025).

Proven technologies

Solar appliance: portable solar cold storage box

Cold Storage Japan Inc.

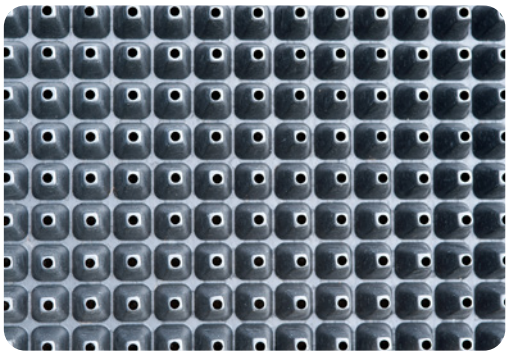
Source: Cold Storage Japan Inc.

This portable cold storage unit operates on standard utility power (100V–260V) and can function off-grid using integrated solar panels and batteries. It supports a wide temperature range (-25°C to 10°C) for both refrigeration and freezing needs. Compatible with various voltages and requiring no additional power infrastructure, it is well-suited for diverse locations – including rural and remote areas. The system also enables auxiliary power use, such as charging devices, making it a practical solution for extending cold chain access, reducing food loss and preserving local ingredients. By incorporating a remote monitoring module, users can track product temperature, humidity and location through their computer or smartphone.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Energy efficiency: freezer spacers boosting efficiency of blast freezers

Huaian East



Source: Getty Images/topten22photo

Freezer spacers, such as egg-crate-style plastic designs, are used in cold chain and food processing operations to improve airflow during blast freezing, cooling or tempering. Placed between layers on a pallet, these spacers enhance air circulation, speeding up freezing times and ensuring uniform temperature distribution. Their multi-directional airflow design reduces cold spots and supports product quality and freshness. Common in meat processing, cold storage and distribution centers, these reusable spacers perform efficiently in temperatures from -20°C to +45°C, with customization options down to -45°C for more extreme conditions.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Low
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Drying: intelligent tea withering, monitoring and control system (TWMAC)

Stesalit Automation

Source: Getty Images/Thiago Santos

TWMAC is an automated solution that improves the consistency and quality of tea withering while reducing energy use. The system monitors tea leaf weight every 30 minutes by switching off the fan for about 4 minutes, tracking moisture loss against a pre-set profile. Based on the weight loss trend, it automatically controls fan operation – activating it when drying is insufficient and keeping it off when over-drying is detected. Visual alerts signal when manual hot air input may be needed. By minimizing unnecessary fan use, the system reduces electricity consumption and may shorten the payback period to under 10 months based on energy savings alone.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Drying: solar bubble dryer

GrainPro

Source: GrainPro

The GrainPro® Bubble Dryer™ is a tunnel-type agricultural dryer that uses solar or electric power to reduce moisture content while shielding crops from unpredictable weather. It features a UV-resistant transparent cover and a black PVC floor, forming a sealed chamber where solar heat or electric energy evaporates moisture. The transparent top allows solar radiation to penetrate the chamber. As the temperature rises, the moisture within the produce evaporates. Built-in ventilators then help circulate the warm air, pushing the moisture-laden air out through a designated exhaust port. This controlled airflow ensures consistent drying. Designed for efficiency, it achieves an average drying rate of 0.5% moisture content per hour and can reduce moisture from 22% to 14% in 6–8 hours under optimal conditions.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: United States of America
- Availability: Worldwide
- Contact: WIPO GREEN Database

Drying: portable biomass-based batch grain dryer

Matharu

Source: Getty Images/AllaSaa

The MATHARU Bio-M6 is a portable batch grain dryer designed for flexibility in drying both small and large quantities of grains. It features an integrated biomass furnace that generates clean, ash-free hot air using fuels such as paddy husk, corn cobs, sawdust or wood chips. The system includes fully automatic temperature control and is designed for ease of use, reliability and quick installation in various settings. Suitable for crops such as maize, paddy, wheat, soybean, barley and rice, the Bio-M6 offers a lower operating cost compared to diesel or gas-powered dryers, supporting energy-efficient and cost-effective grain drying.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Waste-to-energy: modular biogas station

Enwise

Source: Enwise

This on-site biogas power station integrates biological digestion with advanced hardware and software to convert up to 80 tons of organic waste per day into renewable energy and high-quality fertilizer. Capable of producing up to 10,000 m^3 of biogas daily, it requires 70% less space and delivers up to 100% more energy output compared to conventional systems. Designed for energy efficiency, it operates without added water, uses 50% less heat and 60% less electricity, and fits seamlessly into existing workflows – reducing labor and transport needs. Real-time remote monitoring and adaptive controls optimize performance continuously without requiring an on-site team.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: China
- Contact: WIPO GREEN Database

Drying: rotary dryer for tea processing

Quanzhou Deli Agroforestrial Machinery

Source: Getty Images/voyata

This rotary dryer features two tray racks with 36 trays total, providing a 34 m^2 drying area and powered by a 36-kW electric heating system capable of reaching up to 180°C. Its rotary design ensures even heating and faster drying, while the patented air duct system allows the bottom of each sieve tray to enter the air, which quickly removes the moisture in the tea and improves the drying efficiency. Modular construction supports efficient production and maintenance. The double-door structure uses a container-style buckle for improved sealing and ease of use. Designed primarily for tea processing, it is also suitable for drying a variety of products including seafood, meat, fruits, vegetables, herbs and grains.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Drying: recirculating batch grain dryer

Agrosaw

Source: Agrosaw

This indirect-heating recirculating grain dryer is designed for efficient drying of various grains, cereals, pulses, oilseeds and fodder or grass seeds. Equipped with a dynamically balanced centrifugal or axial fan, it generates controlled hot air while venting exhaust gases separately through a chimney, preventing contamination of the drying chamber. The unit uses an elevator for both loading and recirculating materials to ensure uniform drying. Thermostatic controls manage the hot air temperature based on the specific crop, and an automatic light oil burner system supports consistent performance. The insulated structure minimizes heat loss, resulting in reduced fuel consumption and improved energy efficiency.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: India
- Availability: Kenya, Saudi Arabia, South Asia
- Contact: WIPO GREEN Database

Dairy processing: milk-chilling system with heat recovery

Coolsense

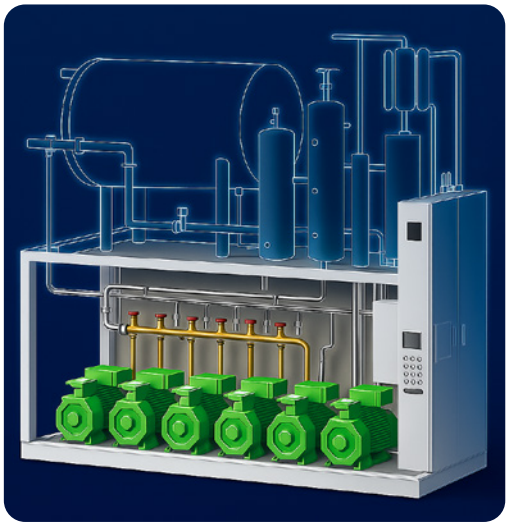
Source: Coolsense

The VariCOOL is a milk-chilling system capable of reducing shed power consumption by up to 30%. It uses a plate heat exchanger for snap chilling, cooling milk to 6°C at vat entry while generating free hot water for shed use. The milk is then further cooled through the base pad of the milk vat. The VariCOOL can chill multiple vats simultaneously and employs variable-speed compressors and fans for energy efficiency. Unlike conventional gas-based cooling, it relies on liquid glycol as the chilling medium, minimizing refrigerant gas requirements. According to the manufacturer, this reduces emissions by up to 90% compared to older HFC-based units.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: New Zealand
- Availability: New Zealand
- Contact: WIPO GREEN Database

Cold storage: CO_2 based cold chain refrigeration

Cold Chain Refrigeration Pte Ltd



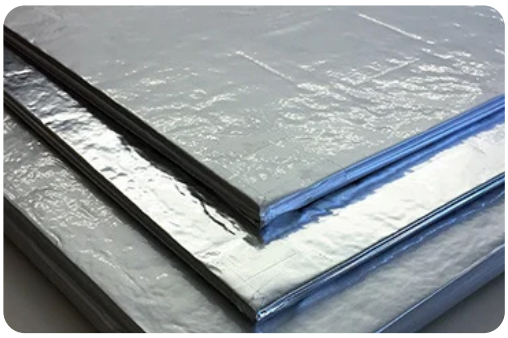
Source: Cold Chain Refrigeration Pte Ltd

Cold Chain Refrigeration offers energy-efficient cold room solutions using CO_2 (R-744) refrigeration technology, especially for food processing, storage and retail. With an ultra-low GWP of 1, CO_2 (R-744) is more environmentally friendly than conventional refrigerants such as HFCs and HCFCs. The system operates at higher pressures and offers superior heat transfer, leading to improved energy efficiency and reduced electricity consumption. A key advantage is their ability to recover and repurpose waste heat for water or space heating, further lowering overall energy demand. CO_2 is also non-toxic and non-flammable, making it a safe option for indoor use. In custom cold room installations, CO_2 systems provide precise temperature control, reliability and lower energy bills.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Singapore
- Availability: Singapore
- Contact: WIPO GREEN Database

Cold storage: vacuum insulation panels

Panasonic Holdings Corporation



Source: Panasonic Holdings Corporation

U-Vacua® vacuum insulation panels (VIPs) are designed to provide high thermal insulation with a low thermal conductivity of 0.002 W/mK. Using a vacuum core to limit heat transfer by conduction and convection, they offer compact insulation suitable for applications where space and energy efficiency are important. With a low GWP, U-Vacua® VIPs are used in sectors such as commercial refrigeration, cold chain storage and portable containers, and can support efforts to meet energy performance standards.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Cold storage: cryogenic tunnel freezer

Air products

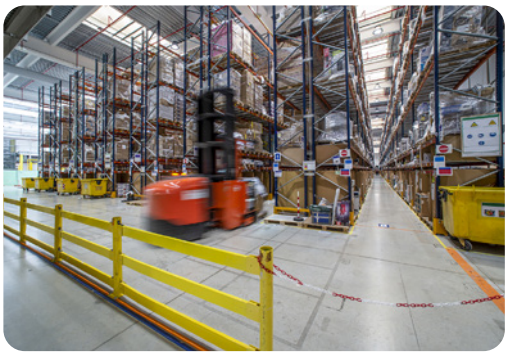
Source: Getty Images/Matveev_Aleksandr

The Freshline MP tunnel freezer is a modular cryogenic freezing system designed for rapid, energy-efficient food freezing using liquid nitrogen. Its design minimizes gas consumption, offers fast start-up and supports continuous operation for up to 20 hours per day. With freezing capacities ranging from 300 to 3,000 kg/hour, it suits various production scales. The system includes IoT capabilities for remote data monitoring and offers flexibility for standard freezing, crust freezing, individual quick freezing (IQF) and chilling. Its hygienic construction ensures quick cleaning and compliance with food safety standards, while rental options and low initial investment make it accessible for small and large producers alike.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: United States of America
- Availability: Worldwide
- Contact: WIPO GREEN Database

Cold storage: fully automated cold storage with ASRS technology

SSI SCHAEFER



Source: Getty Images/Gilas

SSI SCHAEFER provides warehouse automation technologies including rack-clad high-bay warehouses and automated storage and retrieval systems (ASRS) using SSI EXYZ cranes. Scalable and suitable for deep-freeze environments down to -30°C, the storage solutions support high-density configurations with direct access to each pallet position. The technologies are configured based on the specific operational needs of each facility and enable energy-efficient operations through optimal space utilization, reduced human activity in cold zones and minimized thermal losses through reduced door openings. Automated guided vehicles (AGVs) further enhance energy and workflow efficiency by streamlining internal logistics across storage, picking and dispatch areas, while also reducing manual handling.

- Contracting type: For sale/service
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Milling: solar-powered flour mill

Shakti Pumps

Source: Getty Images/Fabricio Rosa

The solar-powered milling system is designed for off-grid and rural areas, operating independently of conventional electricity infrastructure. Powered entirely by solar panels, it reduces energy costs and supports sustainable agricultural practices. By enabling local grain processing, it minimizes travel, lowers emissions and offers a practical solution for areas with limited power access. The technology is patented and contributes to income generation and rural development goals.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: India
- Availability: Worldwide
- Contact: WIPO GREEN Database

Drying: smart grain dryers

Yamamoto

Source: Yamamoto

This grain dryer is designed to dry up to 30 tons of rice with higher milling recovery and lower energy consumption compared to conventional dryers. It features an automated control panel that adjusts hot air temperature and airflow based on load size, ambient conditions and moisture content. Compatible with biomass, diesel, LPG or steam as heat sources, the system maintains precise drying temperatures with a heat controller and suction blower that stabilizes hot air supply. Its multilayered drying chamber ensures even and efficient drying, while stainless steel screens provide durability. An integrated moisture sensor monitors grain moisture every 30 minutes and automatically stops the process upon reaching target levels.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Africa, Asia, the Americas
- Contact: WIPO GREEN Database

Dairy processing: spray dryer for milk powder processing

Tetra Pak

Source: Getty Images/Angelo Varela

The Tetra Pak® Spray Dryer Wide Body is a flexible drying system designed for producing various powders, including milk, whey and plant-based products. It features a single or multi-venturi air distributor that ensures uniform airflow with low pressure drop, reducing electricity use. Its modular design supports scalable capacity while maintaining consistent atomization. The chamber roof cooling system minimizes powder build-up and overheating. It supports both single- and multi-stage drying, including after-drying and cooling for delicate powders. Integrated nozzle assemblies and optional fines return improve efficiency and product quality, while the shaking motion enhances air-solid contact and thermal performance.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Sweden
- Availability: Worldwide
- Contact: WIPO GREEN Database

Dairy processing: rapid milk chiller

Promethean Power Systems

Source: Getty Images/vm

Promethean's Rapid Milk Chiller is a modular, energy-efficient system that chills 1,000 liters of milk per day from 35°C to 4°C without relying on diesel generators. The system operates on just four hours of intermittent grid power between milking shifts, making it ideal for rural areas with unreliable electricity. The system includes a thermal storage unit, chiller and milk heat exchanger. Thermal storage is charged when grid power is available and then used to chill milk even when there is no power. This reduces fuel costs and ensures better milk quality.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: India
- Availability: Bangladesh, India, Sri Lanka
- Contact: WIPO GREEN Database

Horizon technologies

Cold storage: eco-friendly air-based refrigeration

The Korea Institute of Energy Research (KIER)

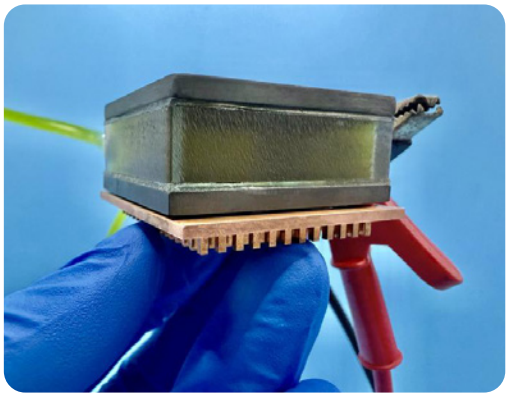
Source: Getty Images/Nordroden

The Korea Institute of Energy Research (KIER) has developed an air-based refrigeration system that offers a sustainable alternative to high-GWP refrigerants like Freon and HFCs. The system uses the reverse-Brayton cycle, a refrigeration process where compressed air is cooled, then expanded to absorb heat and provide cooling without using liquid refrigerants. Its integrated ultra-high-speed compander (combining a compressor and expander on a single shaft) achieves efficient, stable operation at ultra-low temperatures. Capable of reaching -100°C, the system has experimentally been able to show over 50% higher energy efficiency than conventional vapor compression technologies, with successful cooling below -60°C in under an hour.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Republic of Korea
- Availability: Republic of Korea
- Contact: WIPO GREEN Database

Cold storage: energy-saving thermogalvanic technology for cooling

Huazhong University of Science and Technology



Source: Huazhong University of Science and Technology

Researchers at Huazhong University of Science and Technology are exploring thermogalvanic technology as a low-energy, eco-friendly alternative to traditional vapor compression in refrigerators. Thermogalvanic cells use reversible chemical reactions to produce or absorb heat, and recent advancements have improved their cooling power by 70% through chemical optimization. With refrigerators and freezers accounting for nearly 4% of global electricity use in 2019, this technology holds the potential to significantly reduce energy consumption and carbon emissions. Researchers are now developing prototypes and seeking industry partnerships for commercialization.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: China
- Availability: N/A
- Contact: WIPO GREEN Database

Cold storage: smart solar-powered freezer truck

The Hong Kong Polytechnic University.

Source: The Hong Kong Polytechnic University

The smart solar-powered freezer truck features extensible solar photovoltaic (PV) panels mounted on the roof to enhance energy efficiency by increasing power output. It is equipped with an energy storage system that captures and stores solar energy for use by the truck's freezer system, while an onboard lithium-ion battery provides additional power and can be recharged using standard electric vehicle charging stations. The truck's refrigeration system, capable of maintaining temperatures as low as -45°C, can operate for up to four hours with a fully charged battery. Additionally, the vehicle supports energy sharing with other trucks and features a smart energy management system that optimizes energy use and freezer performance. This system is designed for flexible energy input and offers extended operation with options for battery expansion, making it a sustainable solution for last-mile delivery of perishable goods. The freezer truck is now ready for commercialization.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Hong Kong, China
- Availability: Hong Kong, China
- Contact: WIPO GREEN Database

Energy transition in fisheries and aquaculture

Aquaculture refers to the farming of fish, shellfish and other aquatic organisms under controlled conditions. In contrast, capture fisheries rely on harvesting wild populations from oceans, rivers and lakes. In 2022, Asia produced 167.1 million tonnes of fisheries and aquaculture products – accounting for 75% of global output – while Oceania's production stood at 1.8 million tonnes (FAO, 2024). That same year marked a milestone as global aquaculture production of aquatic animals surpassed capture fisheries for the first time.

> Global aquatic food needs are projected to grow by 15% by 2030

Both sectors are crucial to global food security and livelihoods, but they face different challenges. Capture fisheries are increasingly limited by overfishing and environmental degradation. Meanwhile, aquaculture is rapidly expanding to meet demand. Global aquatic food needs are projected to grow by 15% by 2030. Meeting this demand will require a 35–40% increase in aquaculture output (FAO, 2022b). Asia leads this growth, home to the world's top seven aquaculture-producing countries – Bangladesh, China, India, Indonesia, the Philippines, the Republic of Korea and Viet Nam.

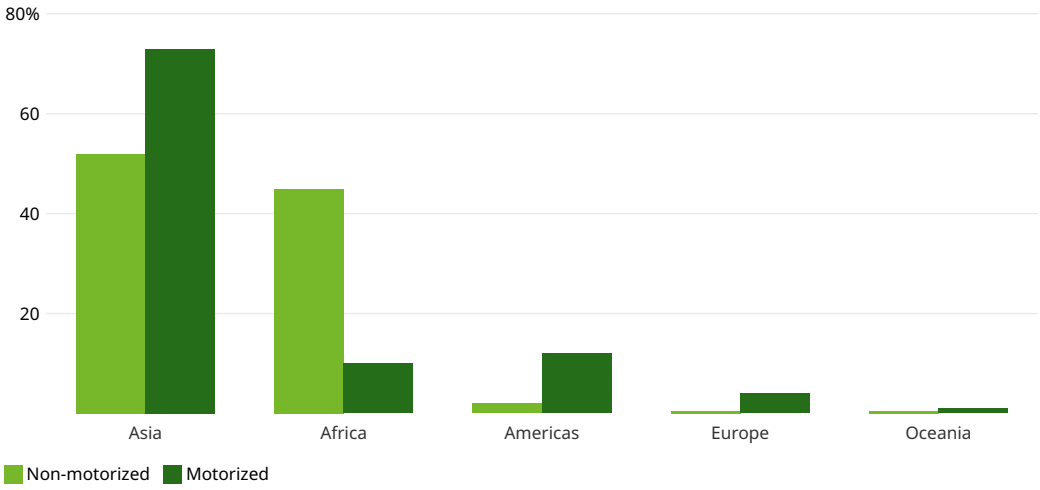
However, barriers remain. Small-scale farmers often lack access to quality feed, reliable inputs, knowledge, finance and insurance. The sector also faces energy challenges, as production and processing are energy intensive. This makes innovation and investment essential to build more efficient, inclusive and sustainable systems – particularly with a focus on energy use across the value chain.

Technological development and trends

Fuel-efficient fishing vessels

Motorized fishing vessels are the primary fuel consumers during fishing operations, powering engines, gears and onboard systems. However, significant energy use also occurs in post-harvest stages such as processing, refrigeration and transportation. Asia holds around 75% of the world's motorized fishing vessels, totaling approximately 1.9 million vessels in 2020 (figure 3.5). China alone accounted for 564,000 of these vessels. The commercial fishing industry's high fuel consumption is a major concern as it accounts for over 1% of global emissions (Eayrs *et al.*, 2017)

Figure 3.5 Percentage of global fishing vessels with and without engine by continent, 2020



Source: Adapted from FAO (2022a).

Fuel consumption in fishing vessels can be minimized by optimizing engine design and adjusting power and operational ranges. Energy-efficient technologies include modern, lightweight but powerful engines and improved rudder, propeller and hull designs. Small trawlers should limit engine size to 5 horsepower(hp)/ton displacement, operate at 3 hp/ton actual output and not exceed 80% revolutions per minute to conserve fuel (Chokesanguan, 2011). A higher reduction gear ratio further reduces fuel use by allowing the engine to run slower while maintaining the same boat speed and propeller thrust. However, this setup often requires a larger propeller, which might limit operation in shallow waters unless specialized designs are used.

Shifting tides: hybrid and renewable energy innovations for fishing boats

The transition from diesel to renewable energy in fishing boats is gaining momentum. Solar-electric boats using solar panels to power electric motors is becoming common in countries such as China, India and Indonesia. Makeshift solar charging stations are being used in Bali, Indonesia, to charge the batteries for those who cannot afford solar panels on the fishing boats. However, challenges remain due to the weight of batteries that can slow down the boat, increasing travel time (Gracia and Evan, 2022). Recent technological advancement includes hybrid fishing boats that combine a diesel engine and an electric motor, optimizing power usage for various operational modes like fishing or sailing. The electric mode is ideal for lower loads and slow speed operations like trawling and net setting. The diesel engine can be used for long-distance travel to the fishing spots, for hauling heavy loads or during rough seas when high, continuous power is required. They can function independently or alongside the electric motor, which also acts as a generator during diesel operation, charging the system. Although charging batteries with a diesel engine is less efficient and not environmentally ideal, it offers flexibility by keeping batteries charged when solar or shore-based power is unavailable.

Fuel consumption in fishing vessels can be minimized by optimizing engine design and adjusting power and operational ranges

In India, solar PV systems have been integrated into artisanal boats for lighting, communication and navigation. Solar electric lamps can replace traditional kerosene lamps for night fishing. Longer-term solutions include converting diesel engines to run on liquid biofuels like biodiesel or vegetable oils, which are already widely used in land transport (Puri *et al.*, 2023). Furthermore, studies have shown that Brown's Gas Electrolyzer (BG-E) technology can be effectively applied to small-scale fishing boats in Indonesia (Darma *et al.*, 2020). The system uses an electrolysis process of water to generate Brown's gas or oxyhydrogen (HHO), which is introduced into the boat engine to enhance combustion, potentially boosting efficiency by more than 25%. Also, hydrogen fuel cell powered workboats are piloted for bluefin tuna farming in remote islands of Japan. The hydrogen is generated by water electrolysis using offshore wind power (Fuel Cell Works, 2019).

Advanced hull and propeller technologies for energy efficiency

Innovations in hull design focus on reducing drag, thereby increasing fuel efficiency. Bulbous bow is a type of hull design feature that protrudes from the front of the ship underwater and can be retrofitted on old vessels. The technology creates a wave pattern around the hull that helps reduce the energy required to push the vessel through the water. Although the weight of the boat is increased by the prolonged length, the overall effect on the hull resistance is beneficial (Chokesanguan, 2011). Energy savings are also achieved through multihull vessel designs such as catamarans.

Objects or layers gradually building up on the hull increase friction and hence drag. This can be prevented by applying an anti-fouling coating below the water line. Friction can also be reduced by generating a layer of air bubbles along the hull bottom, a so-called air lubrication system.

The system uses air compressors to send compressed air through nozzles mounted along the hull bottom, forming a layer of microbubbles under the hull.

Highly detailed design options for fins and rudders can improve hydrodynamic efficiency

The propellers and other control surfaces have an important potential for energy efficiency. Examples include ductor propeller or nozzle, pre-swirl stator fin, rudder bulb and rudder fins. These are all highly detailed design options which can improve hydrodynamic efficiency by streamlining water flow around the propeller and hull, reducing drag and turbulence. This leads to better thrust and lower engine load, ultimately reducing fuel consumption. Small fishing vessels are incorporating sails for secondary propulsion, harnessing wind power to reduce fuel consumption, especially in coastal or offshore operations.

Optimizing energy use in fishing gear and techniques for commercial fishing

The energy consumption in commercial fishing relies on several factors including types of fishing gear and methods, distance to fishing grounds and target species and their migration routes (Basurko *et al.*, 2016). For most fishing methods, a significant portion of the total fuel consumption is used for traveling to and from fishing grounds. In addition, overfishing has led to declining fish populations, forcing boats to spend more time searching or deploying more gear over larger areas and depths and therefore consuming more energy. Advanced electronic tools for navigation, seabed mapping and fish detection are helping to optimize fishing operations. These tools are compact enough for use on almost any vessel and enable more efficient routes and precise fish location identification, ultimately reducing search time, improving catch accuracy and minimizing energy use. However, more efficient fishing also implies increased risk of overfishing. For example, Pacific Island states, contributing nearly half of the world's tuna catch, including Kiribati, Marshall Islands, Papua New Guinea, Solomon Islands and others, are implementing real-time tracking through technologies like electronic record-keeping, vessel monitoring systems (VMS) and cameras on boats to improve monitoring of fishing activities (Griffin P., 2024). Additionally, remote sensing from satellites and aerial surveillance enhances these efforts across the Pacific.

Acoustic gear surveillance technology allows crews to make on-the-fly adjustments for better efficiency

Fishing practices and gear types differ significantly in their environmental impact and fuel efficiency. Generally, passive fishing gear such as pots, traps, nets, hooks and lines are considered less harmful and more energy-efficient compared to towed gear like dredges and bottom trawls (Suuronen *et al.*, 2012; Basurko *et al.*, 2016). Bottom trawling, a fishing method where a large heavy net is dragged along the sea floor to capture fish, is often essential for species like certain shrimp and flatfish that live on or near the seabed. It can be made more energy-efficient by reducing gear drag and weight, since most of the fuel is spent pulling the trawl. This can be achieved with advanced net designs and hydrodynamic trawl doors that create less resistance while being pulled. Using the optimal warp length (the right length of cable connecting the net to the vessel) keeps the net at the best angle and depth, minimizing drag.

Acoustic gear surveillance technology, which uses underwater sensors to monitor the net's shape and position in real time, allows the crew to make on-the-fly adjustments for better efficiency. Service speed also plays a crucial role; studies have shown that reducing speed from 7 to 6 knots can lower total energy costs by approximately 30% (Gulbrandsen O., 2012).

Other types of gear like midwater trawls and purse seines (a type of net that hangs vertically with floats on top and weights at the bottom encircling fish) target dense fish schools, allowing large catches with minimal towing. However, an average tuna purse seiner operating in tropical waters consumes 381 tonnes of fuel, with 90% used for cruising (Blaha, 2021). Using strategies like fish aggregating devices (floating wooden structures with hanging nets to attract fish) or free school fishing (following tuna migration routes) helps reduce the time spent at sea and therefore saves energy. Moreover, in Asia, using artificial lights is common in fishing methods like purse seining and squid jigging, which can be energy intensive. For instance, small Japanese jigging boats may consume around 600 liters of fuel per operation just for lighting (Suuronen *et al.*, 2012). Switching to energy-efficient LEDs can save 20% to 30% on fuel, though concerns remain about the environmental impact of light pollution.

Energy-efficient aeration technologies in aquaculture

Land-based or near-shore aquaculture often involves ponds or pens, while offshore aquaculture takes place in deeper waters using floating cages or nets. Across these systems – especially in intensive land-based operations – aeration plays a critical role in maintaining water quality. Aeration, the process of adding oxygen to the water to maintain healthy conditions for aquatic organisms, is one of the most energy-intensive components in aquaculture, consuming 90% to 95% of the total energy (Nguyen *et al.*, 2024). In shrimp aquaculture, 50% of the carbon footprint comes from energy used for water pumping and aeration (Tansakul, 2024). Paddlewheel aerators are the most common and energy-efficient surface aerators which work by using rotating blades or paddles to agitate the water's surface, increasing the water's exposure to air (Boyd and McNevin, 2021). In Asian shrimp farming, long-arm aerators are also popular, which are basically paddlewheels mounted on floats and powered by an electric or diesel motor. While diesel-powered aerators offer better water circulation, they are more energy-consuming than electric aerators, which is why the latter are often preferred where an electricity source is available.

Aeration, the process of adding oxygen to the water to maintain healthy conditions for aquatic organisms, is one of the most energy-intensive components in aquaculture

A new low-cost and low-maintenance solar-thermal aeration technology has been piloted in Viet Nam which requires no electricity or fuel and is thus ideal for resource-constrained and off-grid settings (Mahmoud; *et al.*, 2015). The system uses a solar collector to heat water inside an insulated draft tube that extends from the pond surface to its deeper layers. As the water inside the tube warms and rises, it naturally draws cooler, oxygen-depleted water from the bottom upward. Simultaneously, oxygen-rich surface water flows downward outside the tube to replace it, creating a continuous convective circulation loop. This mixes oxygen naturally produced by phytoplankton from the surface throughout the pond, boosting overall oxygen levels while minimizing surface oxygen loss. Another renewable-powered aeration system uses a vertical axis wind turbine (VAWT) to directly convert wind energy into mechanical motion, driving an aeration device like a paddle wheel (figure 3.6). In a small-scale field trial in Bangladesh, this system demonstrated a 52% improvement in dissolved oxygen levels. Such technology is convenient and affordable for small-scale fish farmers to assemble using locally sourced materials like metal rods, wood or PVC and it can be easily maintained or upgraded.

Figure 3.6 Aerator powered by vertical axis wind turbine

Source: Cruz (2017).

Other types of aerators emerging are solar-powered diffused aerators, which push compressed air through pipelines to diffusers releasing fine bubbles, and venturi aerators, which use water flow to draw in air, forming coarse bubbles.

Harnessing renewable energy for sustainable fisheries and aquaculture operations

The fisheries and aquaculture sector relies heavily on energy across its value chain, with the post-harvest processes including fish smoking, cold storage, distribution and trade being particularly energy intensive (FAO, 2022b). In developing regions, limited or unreliable access to electricity and cold chain infrastructure leads to significant loss of aquatic products. To address this, expanding energy access is crucial, with renewable energy offering a sustainable solution, especially in off-grid or resource-limited areas. However, technologies are at different stages of maturity, and not all technologies are equally applicable and economically viable across countries and communities.

Renewable energy sources such as solar, wind and bioenergy offer environment friendly solutions to expand decentralized cold storage and processing capabilities. For instance, small-scale fish farmers can benefit from technologies like solar-powered cold rooms, portable chillers or refrigerators for short- and long-term storage. On fishing boats, ice containers remain the simplest preservation method. Electric ice-making machines, powered by solar PV systems, can produce flakes, cubes or blocks of ice, each with varying cooling efficiency. Flake ice cools fastest, while block ice, common in rural areas, is broken down for fish cooling. The machines can be either standalone or supplied with batteries.

Solar PV systems can also power aquaculture equipment such as energy-demanding feeders, pumps, ponds and security lighting, and solar-powered pumps can be used for intensive shrimp farming systems that require frequent water exchange. Around 30% of the carbon footprint in shrimp farming is attributed to feed production and feeding practices (Tansakul, 2024). Other systems like biomass-fueled feed processing systems utilizing rice husks or coconut shells for drying and pelletizing feeds, are popular in rural aquaculture setups in Bangladesh, India and Viet Nam.

> Renewable energy sources such as solar, wind and bioenergy offer environment friendly solutions to expand decentralized cold storage and processing capabilities

Solar energy can also be used for fish drying, which is traditionally performed via direct sun exposure. A simple technology is solar drying tunnels which use solar PV systems to power fans that facilitate air circulation inside the tunnel. Furthermore, cleaner fuels such as crop residue-based briquettes or pellets can replace traditional firewood or charcoal for fish smoking, when used in improved smoking kilns. Studies show that briquettes require around 55% less energy compared to firewood to smoke the same quantity of fish, while also improving food safety and nutritional quality (Banda *et al.*, 2023). Biofuels can power aquaculture equipment, vending carts and distribution of aquatic products. For instance, local biomass waste at a shrimp farm in the Mekong delta area is used to produce biogas, which is converted to electricity to power the operations of the shrimp culture (Box 3.2) (Shiratori Y. *et al.*, 2019).

In the Philippines, ultraviolet (UV) nets, which reduce sunlight penetration, are being installed in tilapia hatcheries to avoid rising water temperatures during hot weather (Cruz and Malvas, 2024). These nets minimize the need for energy-intensive cooling systems and can also be adjusted based on weather conditions to further optimize hatchery performance and save energy.

Box 3.2 Fish, farms and the future: Mekong at a crossroads

The Mekong is one of the longest rivers in the world. The Mekong delta is situated in southern Viet Nam, one of the most productive and intensively cultivated areas in Asia (Delta Alliance, 2024). The Mekong river is home to over 1,100 fish species, including the world's largest freshwater fish, and yields an annual catch of 2.3 million tonnes. In Cambodia and the Mekong delta in Viet Nam alone, nearly 7 million people depend on fisheries and aquaculture for their livelihoods (Mekong River Commission, 2024). However, the recent developments of large hydropower dams, particularly on the mainstream Mekong in Laos and upstream in China, are disrupting natural water flows and blocking key fish migration routes, threatening the region's rich aquatic biodiversity. These changes affect breeding and feeding cycles, leading to declining fish populations and impacting millions who depend on fisheries for food and income.

Aquavoltaics could be a win–win solution for a land-constrained region like Asia

In aquavoltaics, floating or elevated photovoltaic panels are installed over water bodies like fishponds or reservoirs, producing electricity for aquaculture operations and grid supply. The cooling effect of the water may also improve power generation efficiency of the panels. Furthermore, the panels may reduce evaporation and provide shade to regulate water temperature, creating an optimal environment for fish farming (Chen and Zhou, 2023). This innovative approach is gaining momentum, particularly in China, India, Japan and the Republic of Korea where increasing pressure on land and water resources drives interest in integrating energy and aquaculture systems for enhanced productivity (Chen *et al.*, 2024). For example, in China, 234 aquavoltaic projects are already constructed and connected to the grid, which has the potential to cut almost 1000 tons of CO_2 emissions per megawatt annually (Zhu *et al.*, 2024).

In Taiwan Province of China, where aquaculture has a long history, the government is promoting aquavoltaics policies which is facilitating species of high economic value that are normally more difficult to raise, for example white leg shrimps (Fairley P., 2024; Hsiao *et al.*, 2021). Shrimp farming is increasingly vulnerable to extreme weather and temperature anomalies, and aquavoltaics can help in creating controlled environments that enhance shrimp growth (Chen *et al.*, 2024). Viet Nam also hosts numerous pilot projects for breeding shrimp and pangasius fish under aquavoltaic systems (Ballagh and Weather, 2024). However, there are concerns about the potential impacts of such technology, like habitat conservation for aquatic birds and maintenance challenges.

Offshore aquaculture and renewable energy

Offshore aquaculture is expanding in Asia as countries like China, Japan, the Republic of Korea and Viet Nam seek to reduce pressure on near-shore ecosystems and boost sustainable seafood production. These systems, located in deeper and more dynamic waters, often require stronger infrastructure and higher energy inputs for anchoring, feeding and monitoring. To address this, several countries are integrating renewable energy and smart automation into their systems. China leads this trend with innovative projects like the "Mingyu-1," developed by Mingyang Energy, which combines a wind turbine capable of generating 45 million kWh annually with an offshore fish farming system (Global Times, 2023). This setup supports intelligent breeding, real-time monitoring and automated harvesting, aiming to rear over 150,000 fish and achieve an annual harvest of 75 tons. Additionally, the use of low-resistance cage designs and remote sensing technologies helps minimize the energy required for anchoring and daily operations.

Smart aquaculture

Smart aquaculture, also called digital aquaculture, deploys advanced technologies like sensors, AI and IoT to optimize aquaculture operations, including water quality, feeding, disease detection and farm management, and provide warning functions and faster response times. Key components include smart water quality sensors that track parameters like oxygen levels, temperature, salinity and pH, along with water levels and pressure sensors for feed silos, rearing tanks and transport vessels. By incorporating sensor data, operators can optimize the operation of pumps and aerators to match the actual oxygen demand of the aquatic life and thereby save energy through optimal equipment use. For instance, a rain sensor sends data to the control unit, which activates water pumps if rainfall is insufficient or turns them off to conserve pump energy when there is enough rainfall. In addition, they help optimize the heating and cooling system to maintain optimal water temperatures for aquatic species and to facilitate the processing operations by maintaining the required freezing temperature with minimum energy costs (Polavarapu M.K., 2024). Smart feeders use an IoT mobile-based solution with sensors and cameras to monitor the movement and feeding activity of fish and shrimp. This data helps detect their appetite, allowing the system to automatically feed them the optimal amount based on real-time data, reducing the waste and thereby energy use for water treatment and feed production.

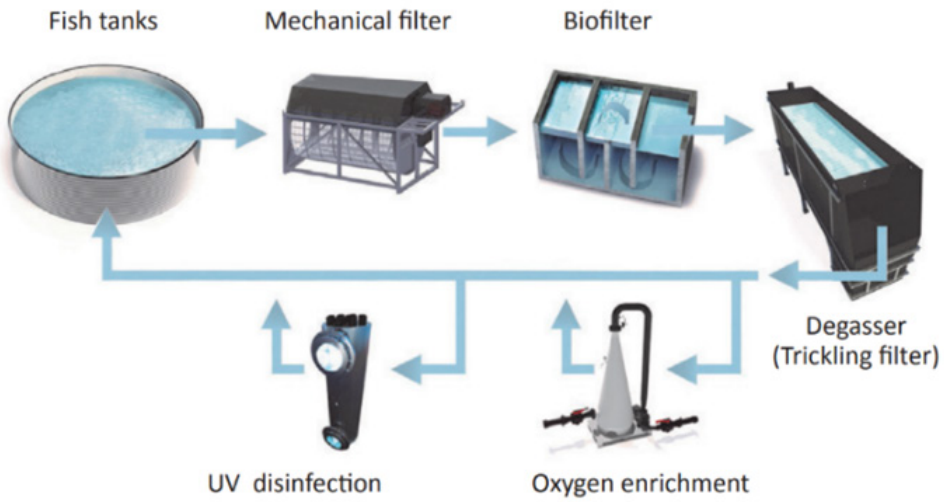
> In China, 234 aquavoltaic projects are already constructed and connected to the grid, which has the potential to cut almost 1000 tons of CO_2 emissions per megawatt annually

Advanced LPWAN (Low-Power Wide Area Network) technologies like narrowband internet of things (Nb-IoT) provide further improved coverage and energy efficiency. Data is processed through cloud-based platforms to identify trends and anomalies. The system's efficiency can be further enhanced with embedded logic that enables autonomous operation without constant reliance on central servers or cloud services, which is ideal for remote or critical applications with no network connectivity.

Shaping sustainable seafood: RAS technology for energy and water efficiency

Recirculating aquaculture system (RAS) is a technology which recycles and reuses water through filtration, reducing pumping energy requirements and enabling high-density fish farming with minimal land and water use. The basic principle is that water flows from the fish tanks to a mechanical filter and a biological filter before it is aerated and stripped of carbon dioxide and returned to the fish tanks (figure 3.7). Traditional fish farming requires 30,000 liters of water per kilogram of fish, while recirculating systems use just 300 liters, achieving a 100-fold water saving (Aytac *et al.*, 2024). Plus, the fish-excreted nutrients in the discharged water can be repurposed as agricultural fertilizer or for biogas production.

Figure 3.7 Recirculating aquaculture system



Source: Bregnballe (2015).

With global warming and climate change limiting water and energy resources in many regions, RAS can be considered as the most environmentally friendly method for commercial fish production (Aytac *et al.*, 2024; FAO, 2015). However, energy use in RAS is largely driven by the need to maintain optimal water temperatures for specific species (Engle, 2023). For example, raising tropical species like tilapia in northern climates requires more heating, while cold water species like salmon need more cooling in warmer regions. A heat pump can provide an energy-efficient solution in such cases, transferring energy between two circulation systems (FAO, 2015). The warm outlet water releases energy in a heat exchanger, heating the cold intake water, without mixing the two streams. Further energy savings are achieved through frequency controllers, which adjust the frequency and magnitude of constant grid voltage to match variable load voltage and help reduce pump electricity consumption. On average, this method can save about 20% of energy consumption (Badiola M., 2018).

RAS technology is rapidly growing in the Asia-Pacific region including China, Japan and Thailand, with Japan planning to build Asia's largest RAS salmon farm, which will occupy 70,000 m^2 of building space producing 10,000 tonnes of Atlantic salmon annually (RAStech, 2024). India is also advancing RAS technology nationwide, approving 11,995 RAS units across 31 states over the past four years, with government financial assistance supporting beneficiaries, including individuals, tribes, women and small-scale farmers (PIB Delhi, 2024).

IMTA: a sustainable, energy-efficient solution with minimal environmental impact

Integrated multi-trophic aquaculture (IMTA) involves farming multiple aquatic species from different trophic levels together in an integrated system. IMTA mimics natural ecosystems. By using the waste of one species as a resource for another, this approach minimizes reliance on external feeds and fertilizers, lowering energy usage and ecological footprint (Ngamsnae

P., 2024). Farmers can cultivate different species like tilapia, carp, prawns, snails and local edible micro-macroalgae or aquatic plants simultaneously. Species like shellfish, mollusks and seaweeds act as biofilters, improving water quality and reducing pollution. IMTA now accounts for over 50% of Chinese mariculture (farming of marine organisms in saltwater environments) production (Fletcher R., 2021a). Examples of a widely used IMTA in China include the production of shrimp, clams and the red *alga gracilaria* in pond systems (Fletcher R., 2021b). Pacific island countries, like Fiji, are also exploring innovative aquaculture solutions, including mangrove oyster farming, which could potentially benefit from practices like IMTA (Hewavitharane *et al.*, 2024). As filter feeders, mangrove oysters remove excess nutrients, reducing the need for energy intensive water treatment and circulation.

> Integrated aquaculture has been widely practiced by small households in freshwater environments in Asia, such as rice-fish farming

Integrated aquaculture has been widely practiced by small households in freshwater environments in Asia, such as rice-fish farming, showcasing the co-evolution of agriculture and aquaculture (FAO, 2009; Mai, 2020). This indigenous agricultural tradition is practiced in countries like Bangladesh, southern China, India, Thailand and in northern Viet Nam (Mai, 2020). Rice fields create a natural habitat for fish and other aquatic species, while fish help cycle nutrients by feeding on invertebrates and organic particles present in the flooded rice fields. Fish are typically raised during the flooded phase of the rice-growing cycle, before the fields are drained for harvesting.

Innovation examples

Aquavoltaics powers 550 MW solar farm in China

Source: Getty Images/Tsvetan Ivanov

Chinese power equipment manufacturer CHINT Group has completed a 550 MW solar plant deployed on a fishpond in Wenzhou, Zhejiang province, China. This solar installation, spanning approximately 4.93 million square meters in the Oufei Enclosed Area, integrates photovoltaic (PV) power generation with aquaculture (Bellini, 2022). The plant features around 1.4 million monocrystalline solar modules, each with a capacity of 450 W, enabling dual use of space for solar energy and fish farming designed to withstand Wenzhou's subtropical maritime climate – characterized by high humidity, salt, typhoons and summer rains – the system includes inverters with IP54 protection (a rating by International Electrotechnical Commission for protection against dust and water) anti-corrosion coating, and PID[1] recovery capability, making it well-suited for harsh offshore environments. Additionally, the facility is equipped with an energy storage interface, allowing for future upgrades to include battery storage.

Solar-powered freezers to support fishing community in the Solomon Islands

Source: Tessa Minter/WorldFish (2018)

The Women's Association of Rokotanikeni (WARA) in the Solomon Islands introduced solar-powered freezers to address the challenges faced by rural communities with limited access to electricity and cold storage facilities. In the Solomon Islands, centralized fish processing and distribution infrastructure remains out of reach for most, as 80% of the population lives in rural areas (Puri *et al.*, 2023). To tackle these issues, WARA provides solar freezers, renting services for cold storage of fish and other perishable foods to the rural community of Malaita, bringing refrigeration to the community for the first time. This innovation provided an off-grid solution with simple operational and maintenance technology. The introduction of this technology not only improved food security but also empowered women by creating a revenue stream and promoting renewable energy as a viable alternative for cold storage in remote areas. The income generated is sufficient to cover repair and operational costs, making the project self-sustaining.

1 Potential-induced degradation (PID) is a potential-induced performance degradation in crystalline photovoltaic modules which may cause power loss.

The world's first smart aquaculture vessel in the East China Sea

Source: Getty Images/MihailDechev

The world's first smart aquaculture vessel, *Guoxin-1*, a floating fish farm now operating in the East China Sea, achieves an annual production capacity of 3.3 million fish (CGTN, 2024). Measuring 249.9 meters in length and 45 meters in width, the ship accommodates 15 breeding cabins, with a total aquaculture water volume of 90,000 cubic meters for raising fish, setting a record for the largest aquaculture vessel, tanks and overall volume. *Guoxin-1* integrates the entire fish farming process – from breeding and feeding to harvesting and processing – delivering packaged fish to shore within six hours after catching. This integration minimizes the need for additional transportation and processing infrastructure, leading to energy savings. The vessel employs advanced water management, continuously pumping fresh seawater from 15 meters below the surface to maintain optimal conditions and water temperature, reducing the need for artificial temperature control. Equipped with underwater cameras, sensors and automated feeding systems, the ship represents an innovative approach to sustainable aquaculture.

Offshore renewable-aquaculture hybrid in China

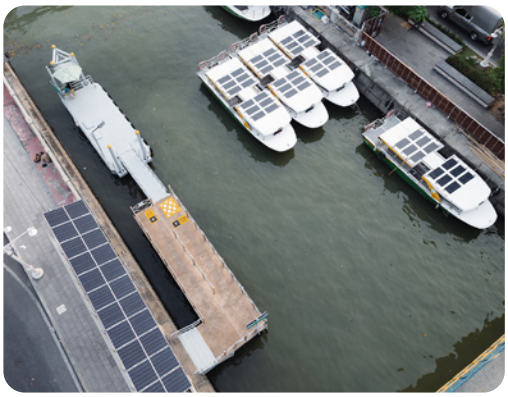
Source: Getty Images/Ian Dyball

Shanghai Electric and Longyuan Power Group have developed a hybrid offshore platform near Nanri Island, Fujian Province. This integrated system showcases offshore wind, solar and marine farming for sustainable energy and food production. It combines a 4-MW wind turbine, flexible solar panels and a central fish farming area. Located in a national marine ranching zone, the semi-submersible platform generates up to 96,000 kWh of electricity daily – enough to power 42,500 people – while supporting aquaculture in 35-meter-deep waters.

Proven technologies

Fishing vessel: eco-friendly boat with solar power

Cey-Nor Foundation Ltd.



Source: Getty Images/Thatphichai Yodsri

Cey-Nor has introduced eco-friendly technologies to its boats, successfully completing a 13-foot solar boat pilot project in 2020. This solar-powered boat is equipped with a 1.5 kW solar panel, achieving an average speed of 10–15 km/h for 4–6 hours during the day and 2–3 hours at night, offering a cost-effective and energy-saving solution, Looking ahead, electric motor boats are expected to enable fishermen engaged in small-scale fishing to travel 100 kilometers on battery power at a daily operating cost of just $1.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Sri Lanka
- Availability: Sri Lanka
- Contact: WIPO GREEN Database

Fishing vessel: hybrid fishing boat

AKA Energy Systems

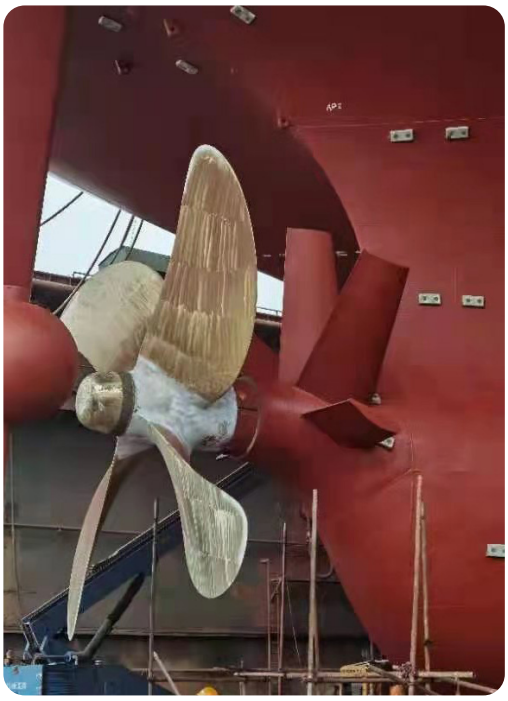
Source: Getty Images/homydesign

The hybrid fishing boat combines a diesel engine and an electric motor to power its propulsion system, offering flexible and efficient operation. The hybrid design allows the engine configuration to adapt to specific activities, such as fishing or sailing, optimizing performance at different load levels. In fishing mode, the boat operates on electric power, producing zero emissions. The electric motor acts as a generator to recharge the batteries during diesel operation. Additional charging options include shore power hookups and solar trickle charging. This innovative system reduces diesel engine running hours, lowering maintenance costs and extending engine life. The boat's hydraulic systems function in all modes, ensuring operational reliability.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: United States of America
- Availability: China, Singapore, United States of America
- Contact: WIPO GREEN Database

Fishing vessel: pre-swirl type energy-saving device

Fluid Techno Co. Ltd.



Source: Fluid Techno Co. Ltd.

The “Eco-Stator” is a pre-swirl energy-saving device installed in front of a ship’s propeller. It features four or five stator fins arranged radially around the stern tube and above the propeller shaft. By rectifying water flow to the propeller, it improves thrust efficiency, so the propeller can push the ship better. This means the engine doesn’t need to work as hard, which saves fuel – about 3–4% less fuel is used at the same speed, or enabling higher speeds without increased fuel costs. Additionally, the rectified inflow reduces stern vibration. The main design features of the Eco-Stator include the span and chord length of the stator blades, their installation position and their angle settings. These are designed according to accumulated data base, tank test results and full-scale sea trial using the CFD (Computational Fluid Dynamics) tool.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Japan
- Availability: Asia
- Contact: WIPO GREEN Database

Aeration system: solar aerator with brushless direct current (DC) motor

Solair Group

Source: Getty Images/samael334

The TSG500B solar-powered aeration system uses solar energy to oxygenate fishponds, reducing electricity usage. Solar panels power an advanced brushless direct current (DC) motor. This latest motor technology features programmable gearing for optimal airflow at various depths and operates the compressor at a maximum pressure of 15 psi, enabling aeration at depths of up to 8 meters. Designed for continuous operation, the brushless motor requires minimal maintenance. The system also uses a specialized solar regulator that is designed to track the peak solar power from the panels, and efficiently distribute the power to the motor.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Australia
- Availability: Australia, China
- Contact: WIPO GREEN Database

Aquaculture: solar-powered automatic feeder

Fukushin

Source: Getty Images/v_zaitsev

The solar-powered automatic feeder includes a patent-pending feeding schedule configuration function (e.g., daily, every other day) and a timer adjustable in 15-minute increments. The solar panel charges a built-in battery, which then powers the feeder system, including the timer. A reverse-connection protection circuit safeguards the battery, while a durable stainless steel dispersal impeller enhances longevity. The feeder supports a maximum feed output of up to 150 kg/hour. It also features a digital touch panel for easy operation.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Japan
- Availability: Asia
- Contact: WIPO GREEN Database

Aquavoltaics: floating solar PV on fish pond

Ciel & Terre International

Source: Ciel & Terre International

The Hydrelio aiR Optim is a versatile floating solar system designed for building reliable power plants. An evolution of the original Hydrelio Classic, which was the first patented and industrialized floating solar solution introduced in 2010, the aiR Optim is engineered to withstand extreme conditions. It is capable of resisting winds of up to 210 km/h (130 mph) or a dynamic pressure of 1625 pascals and features UV-stabilized technology for up to 30 years. The system is customizable with anchoring and mooring solutions tailored to site-specific characteristics, making it suitable for harsh environmental conditions, including varying water levels, dry ponds and snow. It is also compatible with inshore and near-shore locations, handling waves of up to 1 meter depending on the wavelength. It can support PV modules up to 700 Wp.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: France
- Availability: Brazil, France, India, Japan, the Republic of Korea, Taiwan Province of China, United States of America
- Contact: WIPO GREEN Database

Aquaculture: ecological recirculating aquaculture system (RAS)

RecircInvest Biotech (RIB)

Source: Getty Images/Inzyx

The company has developed a patented RAS using exclusively Chinese-made parts and equipment to enhance cost competitiveness for high-value species farming compared to traditional low-cost pond-based systems. The system's main water circulation pump is energy-efficient, with daily water replenishment below 5% and a recycling speed of 200% per hour. The total system electricity requirement is just 40 kW/h. The fiberglass-reinforced plastic tanks support high-density feeding of multiple high-value fish species. The system employs biofilters and strong ultraviolet disinfection for water treatment. The RAS includes minimal water usage, green-labeled and local pellet feed.

- Contracting type: For service
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: China
- Contact: WIPO GREEN Database

Fishing equipment: LED fishing light

Delta

Source: Getty Images/chun jae yul

Utilizing patented active cooling fan technology, precise beam angles and energy-efficient LED, Delta's 1.2-kW fishing lights are 70% energy saving compared to traditional high intensity discharge lighting. The anti-vibration, corrosion-resistant and integral driver design enables the product to withstand harsh marine environments while reliably maintaining an efficiency of up to 104 lumens per watt. Additionally, the light source spectrum is tailored to attract specific species of fish, improving catch rates.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Taiwan Province of China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Aeration system: aeration tube and diffuser grid

AirOxi

Source: AirOxi

AirOxi™ is an advanced aeration technology specifically designed for commercial aquaculture. It is efficient in both freshwater and saltwater environments. AirOxi aeration tubes are made from durable elastomeric compounds, and these flexible and long-lasting tubes are perforated with tiny holes. When connected to a blower, they release fine bubbles, maximizing air-water contact and efficiently transferring oxygen into water. The AirOxi Diffuser Grid is a standalone aeration system that eliminates the need for expensive piping or external blowers. With a built-in blower, it requires only a single electrical connection, making it simple to operate: similar to turning on a paddle aerator but significantly more energy-efficient. This system consumes just 0.5 hp of power compared to the 2–3 hp needed by paddle aerators, offering substantial energy savings. The floating design ensures ease of maintenance, and users can choose between single-phase or three-phase blower options.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: India
- Availability: Africa, India, Israel
- Contact: WIPO GREEN Database

Aquaculture: solar and wind power water circulation system

Mirae E&I

Source: Getty Images/blanscape

This advanced water circulation system uses renewable energy sources, combining high-efficiency solar panels and wind turbines to drive water pumps for continuous movement and aeration of water bodies. By utilizing a dual-energy approach, it reduces the reliance on traditional energy sources and minimizes environmental impact. The system can operate 24/7 in varying weather conditions, providing a reliable and sustainable solution for aeration. It is specifically designed to prevent algal blooms by maintaining balanced water flow, disrupting algae growth conditions and improving water quality to support a healthy aquatic ecosystem. It is scalable for diverse applications, from small ponds to large lakes, and features remote control allowing operators to monitor and control the system from a distance without requiring on-site supervision.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Republic of Korea
- Availability: Asia-Pacific
- Contact: WIPO GREEN Database

Fishing vessel: plug and charge solar fishing boat with advanced fish-finding technology

Navalt Solar & Electric Boats Pvt. Ltd

Source: Navalt Solar & Electric Boats Pvt. Ltd

The SRAV solar electric fishing boat, developed by Navalt, is a cutting-edge solution designed to provide fishermen with a sustainable, cost-effective and environmentally friendly alternative to traditional fishing boats. It operates on solar power combined with battery storage with plug and charge system. The boat also features advanced navigation and fish-finding technology, and a reinforced hull for improved stability and maneuverability, making it a suitable vessel for both inshore and offshore fishing. It can navigate in rough seas with waves reaching up to 2 meters in height, and minimizes water drag, maximizing operational efficiency. SRAV's eco-friendly design is also applicable for ecotourism and research as it has silent, zero-emission propulsion, which helps protect marine ecosystems.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: India
- Availability: Canada, India, Israel, Maldives
- Contact: WIPO GREEN Database

Aquaculture: smart water quality analyzer

SenTec

Source: SenTec

The smart water quality online analyzer, also known as a water quality sensor, is suitable for industrialization aquaculture and other fields. The digital optical dissolved oxygen sensor is widely used in monitoring dissolved oxygen levels in aquaculture. The main features include 24 hours online monitoring, auto temperature compensation function and high accuracy and stability. It works independently without a controller or transmitter and supports an intelligent control aerator or feeder to save energy. It is directly connected to a computer, PLC or IoT system.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Aeration: energy-efficient and intelligent aeration

Sprintex

Source: Sprintex

The G15 jet blower is a compact and IoT-enabled solution claiming to deliver more than 50% in energy savings compared to conventional industry blowers. Trials in an aquaculture setting during 2024 showed that one G15 unit could replace up to three of the existing side channel blowers, enabling a projected 70% energy saving. Featuring a patented electric motor, the need for separate variable speed drives is eliminated. Energy consumption is further limited due to Sprintex's Smart Pulse Aeration (SPA™) Technology, which utilizes variable speed and flow control to deliver intermittent bursts of fine bubbles, enhancing possible oxygen transfer rates. Sensors for monitoring and managing factors such as flow, pressure, temperature and energy consumption are furthermore included, with possibilities to cloud-store captured data and receive automated alerts.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Australia
- Availability: Australia, India, Türkiye
- Contact: WIPO GREEN Database

NB-IoT wireless intelligent data collection controller in fishery

AKR

Source: Getty Images/seraficus

The Nb-IoT wireless intelligent data-collection system operates on LTE (long-term evolution) networks using licensed spectrum, offering low power consumption, low cost, extensive connectivity and enhanced indoor coverage. It supports a variety of power sources, including batteries, external AC power and solar energy, based on application needs. The system includes an intelligent data collection controller with features like power monitoring, a wireless smart temperature sensor and communication software. It allows on-site configuration via a mobile device, ensuring automatic data collection and preservation during communication outages. Once connectivity is restored, the system retransmits stored data and provides instant alerts for power failures or low battery levels.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Taiwan Province of China
- Availability: Asia
- Contact: WIPO GREEN Database

Fishing vessel: electric engine for small-scale fishermen

Azura Indonesia

Source: Azura Indonesia

In an effort to bridge the gap between new technology and the traditional livelihoods of small-scale fishermen in Indonesia and beyond, Azura Indonesia introduced the MantaOne, a fully electric engine for fishing boats. The engine is largely distributed through a community outreach program, and solar charging stations are provided. MantaOne is a 2-kW power engine that fully charges within 1.5 hours, giving it a 3.5-hour runtime at a maximum speed of 4–5 knots. Replacing traditional fuels and being low maintenance, the engine is claimed to lower monthly operating costs by up to 60% while avoiding up to 4 tons of greenhouse gas emissions annually. The MantaOne propulsion system is designed for smaller fishing boats of less than 3 gross tonnage.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Indonesia
- Availability: Fiji, Indonesia
- Contact: WIPO GREEN Database

Fishing vessel: boosting efficiency with fuel-saving bulbous bow technology

Cey-Nor Foundation Ltd.

Source: Getty Images/eugenesergeev

A prototype bulbous bow, designed to improve fuel efficiency in longline fisheries, was installed on a vessel in the Chilaw fisheries district of Sri Lanka. The design was developed by FAO, tested in a water tank at the Polytechnic University of Madrid in Spain, and constructed at the Cey-Nor Foundation shipyard in Colombo. Initial sea trials demonstrated fuel savings of 11% to 13%, with even greater efficiency at speeds between 7 and 8 knots. For an average longline fishing vessel in Sri Lanka, this innovation could result in annual savings of 1,150 liters of fuel per fishing trip.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: Medium
- Place of origin: Sri Lanka
- Availability: Sri Lanka
- Contact: WIPO GREEN Database

Aquaculture: next-generation AI-integrated RAS technology

AquaMaof

Source: Getty Images/Vladimir Zapletin

AquaMaof's integrated RAS technology prioritizes efficient power management, significantly reducing energy costs. Utilizing patented water-treatment and filtration techniques, it minimizes water consumption in fish production. Its low-maintenance design and advanced feeding management optimizes feeding. The system generates oxygen on-site, recovers waste heat and maximizes oxygen production with minimal energy. With 24/7 monitoring of critical components, it provides real-time alerts and automatically activates emergency backups, including power generation and oxygen supply. AquaMaof is advancing AI development through data mining and analytics, with systems for real-time monitoring, troubleshooting and inventory management. Future facilities will automate technical tasks like maintenance, harvesting, grading and counting, dissolved-gas control, temperature control and more, enhancing biosecurity and minimizing human error.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: Medium
- Place of origin: Israel
- Availability: Worldwide
- Contact: WIPO GREEN Database

Solar appliance: solar ice maker for small-scale fisheries

AIREF

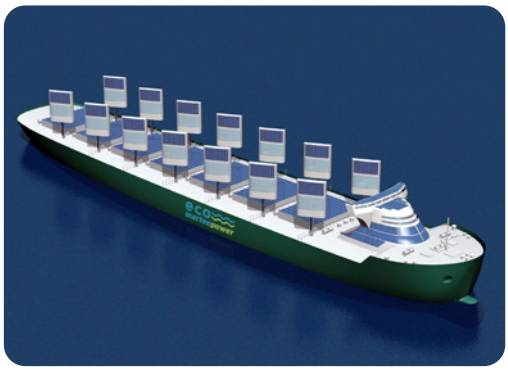
Source: AIREF

The solar ice maker dynamically and automatically adapts to available solar energy, operating completely carbon-free. Developed by AIREF with support from GIZ Indonesia and PT ASTB, the system uses thermal energy storage instead of batteries, producing up to one ton of ice per day entirely off-grid. It is powered by a 25-kWp solar photovoltaic system and delivers a cooling capacity of approximately 100 kWh per ton. Unlike conventional systems, it requires no grid electricity, propellants or costly large battery storage, enabling ice production even in remote areas. This ensures locally caught fish can be refrigerated, preserving freshness. The ice maker employs eco-friendly R290 refrigerant and is equipped with smart control systems. This scalable and replicable solution is well-suited for coastal regions facing similar logistical challenges.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Indonesia
- Availability: N/A
- Contact: WIPO GREEN Database

Fishing vessel: wind assisted propulsion system

Eco Marine Power



Source: Eco Marine Power

The EnergySail is a wind assisted propulsion system that can be integrated with onboard energy storage devices. These rigid sails can be fitted with flexible solar panels to offer a reliable and hybrid renewable source of supplementary or auxiliary propulsion. In larger ships, the sails have proved to enable fuel savings of more than 30%, and a variation suitable for fishing vessels is currently in development as of 2025. The sails can be used as a standalone device or as part of a sail array, with positioning automatically managed by a computer control system. When not in use, the sails can be lowered and stored, and at anchor or in port, the sails can remain up to continuously harness and store renewable energy.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

4. Green energy solutions for key service sectors in the Asia-Pacific region

Photos: Unsplash/Getty Images, Unsplash/Masaaki Komori

Low-carbon hotels

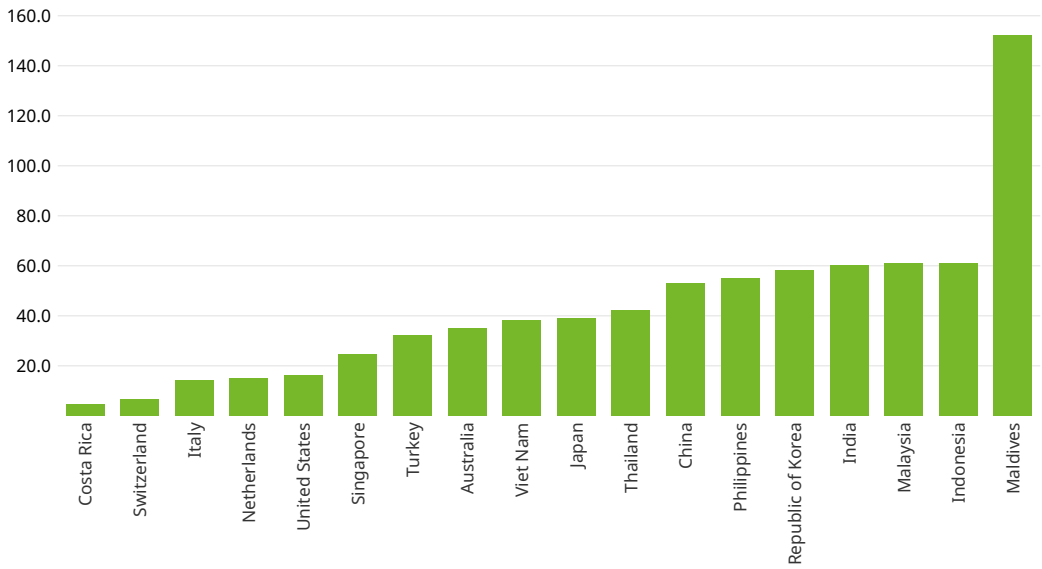
The hospitality industry in Asia has experienced significant growth over the past few decades, with destinations like China, India, Japan, Singapore and Thailand attracting millions of global tourists. The region's rich cultural heritage, scenic nature and history have caused this surge in tourism fueling economic growth. But this growth has also intensified environmental concerns since hotels are among the largest consumers of energy and water, with their constant need for heating and cooling, lighting, ventilation, hot water and running appliances round the clock.

In fact, globally the hotel industry alone accounts for approximately 1% of carbon dioxide emissions, with 60% of it coming from energy consumption (EHL, 2024a; Llanso, 2024). In 2021, hotels contributed around 363 million tons of CO_2 globally – equivalent to the annual energy use of 45.7 million homes.

> Globally the hotel industry alone accounts for approximately 1% of carbon dioxide emissions, with 60% of it coming from energy consumption

In Asia-Pacific, these emissions are even higher per occupied room (figure 4.1), primarily due to the region's hot climate and heavy reliance on air conditioning. Figure 4.1 shows that in 2022, the majority of countries with high carbon intensities per hotel stay were in Asia, with the Maldives having the highest impact at 152.2 kg CO_2e per hotel room per night (Circular ecology, 2023).

Figure 4.1 Hotel stays carbon impact in 2022 (kgCO_2^e per room per night)



Source: Adapted from Circular ecology (2023).

Given such an environmental footprint, sustainability has become a critical focus for the hotel industry. Simply encouraging guests to reuse towels is no longer enough. Today, energy-efficient technologies are essential and are increasingly in demand among travelers actively seeking eco-friendly accommodation (Banc, 2024). Hence, hotels across Asia are embracing innovations such as smart heating, ventilation and cooling (HVAC) systems, automated lighting controls, renewable energy integration to cut down on energy consumption while maintaining the luxury and comfort that guests expect. By investing in these solutions, hotels not only contribute to decarbonization but also enhance guest satisfaction and strengthen their competitive edge.

Technological development and trends

Heating and cooling are the leading energy consumers in hotels

Hotel energy consumption varies based on service levels, comfort needs and climate. One major energy-intensive area that hoteliers can target for efficiency improvements is the HVAC system, which accounts for 40 to 50% of a hotel's total energy consumption (Sensgreen, 2024). In hot, humid regions, cooling makes up 35% to 50% of the total consumption, while hot water energy usage ranges from 12% to 15% (Table 4.1).

Table 4.1 Shares of energy consumption of appliances in hotels in hot climates

Appliances	Share of energy consumption
Air-conditioner	35%-50%
Refrigerator	5%-6%
Water heater	12%-15%
Laundry (no heat)	1%-2%
Lighting	15%-22%
Pump and fan	10%-18%
Office equipment	4%-6%
Cooking	1%-2%

Source: IIEC (2015)

Heat pump units are increasingly prevalent in Asian hotels requiring year-round temperature control, especially in countries like China, Japan and Singapore. Heat pumps can be used for both heating and cooling spaces and for hot water, making them a more flexible and energy-efficient option than traditional air conditioners. Heat pumps can reduce a hotel's total electricity usage by 44% (Sintef, 2024). In summer, the system can also fully recover the waste heat from the air-cooling module to produce hot water for guest rooms. A heat pump can be three to four times more efficient than an electric water heater, reducing operating costs by up to 80% (IIEC, 2015). More details on air-to-air and air-to-water heat pump technology can be found in the previous sub-chapter of Urban households in this book, and also in the mitigation and energy editions of the *Green Technology Book.*

In the hotel industry, CO_2 heat pumps are an emerging technology. A Chinese hotel retrofit with CO_2 heat pumps achieved 50% energy savings (Koegelenberg, 2022). These heat pumps use a CO_2-based refrigerant instead of a chlorofluorocarbon (CFC) refrigerant, which has excellent energy savings and environmental performance. The technology is used to boil water with about a quarter of the electric energy of conventional electric water heaters.

> Heat pumps can reduce a hotel's total electricity usage by 44%

ACs are major energy consumers, but smart ACs are transforming the hotel industry by enhancing energy efficiency and guest comfort. With the help of advanced thermostat control and occupancy sensor, smart ACs automatically adjust room temperatures based on adaptive scheduling and temperature presets when guests are outside their rooms and turns them off when doors or balcony windows are left open. Centralized management allows remote monitoring and control of all units, while maintenance alerts and performance tracking further optimize efficiency. Additionally, inverter ACs can save 30% to 50% more energy compared to non-inverter models (IIEC, 2015). Inverter units adjust the compressor speed and refrigerant flow according to cooling demands, rather than operating at fixed speeds and cycling on and

off, making them more energy efficient. Dual inverter models, using twin rotary compressors, offer even higher efficiency. Heat recovery ventilation (HRV) systems further enhance energy saving by improving indoor air quality. They don't actively heat or cool air but recover heat from outgoing air in cold climates and remove heat from incoming air in warm climates, ensuring fresh air circulation while reducing the heating and cooling load on air conditioning systems.

Thermal storage systems coupled with chillers or heat pumps have been used in hotels in China, Japan and the Republic of Korea. The systems improve energy efficiency by storing excess cooling or heating during off-peak hours and using it when demand is high. When paired with chillers, they allow hotels to produce and store chilled water or ice during low-demand periods (typically at night) and use it for cooling during peak hours, reducing strain on the electrical grid and lowering energy costs. Similarly, when integrated with heat pumps, thermal storage can accumulate heat during times of lower energy demand and release it as needed.

> Thermal storage systems coupled with chillers or heat pumps have been used in hotels in China, Japan and the Republic of Korea

Many hotels in the Pacific are not designed for energy efficiency but there are opportunities for retrofitting (IIEC, 2015). These hotels now incorporate passive cooling designs to reduce reliance on mechanical air conditioning. For instance, applying white reflective paint on the roof to reflect solar heat radiation, adding shaded façades to the buildings with trees or awnings, and preventing air leakage from air-conditioned rooms by sealing gaps and installing double-glazed windows to improve insulation.

Optimizing hotel lighting for energy efficiency

Since hotels operate 24/7, lights in common areas remain on for extended periods. Replacing incandescent lamps with LED lighting in lobbies, elevator halls and hallways – where lights are always in use – can significantly improve energy efficiency and reduce electricity consumption (ECCJ, 2018). It is a simple yet highly effective way for hotels to cut energy consumption, as LEDs use up to 75% less energy and last significantly longer than traditional incandescent bulbs (Cosmina, 2025). Additionally, hotels integrate solar-powered lighting for outdoor spaces and pathways, reducing dependence on the grid.

Automated controls enable centralized building energy management systems (BEMS) to manage lighting across hotel properties, further optimizing energy use in real time. These systems use motion sensors, timers and Internet of Things (IoT) connectivity to monitor and adjust lighting based on occupancy, time of day and ambient light levels. For example, in guest rooms, lights automatically dim or turn off when no motion is detected, while in conference halls or banquet areas, scheduled lighting ensures energy is only used when needed.

> Automated controls enable centralized building energy management systems to manage lighting across hotel properties, further optimizing energy use in real time

Hotels can also integrate cloud-based lighting management systems, allowing facility managers to remotely control and monitor lighting across multiple locations. This reduces unnecessary energy consumption, enhances maintenance efficiency by detecting faults or

failures instantly and lowers electricity costs. Several systems including HVAC and electric appliances are integrated with energy management systems. These systems can also adapt to guest preferences – offering personalized comfort in terms of temperature or lighting – while maintaining overall energy efficiency.

By prioritizing energy efficiency, hotels can meet sustainability goals and improve guest satisfaction. In addition, predictive analytics is often embedded in energy management systems (EMS), which enables data-driven decision-making. By analyzing patterns in historical energy use, occupancy trends and equipment performance, hotels can forecast when equipment might need maintenance or when energy consumption might spike. This allows for proactive measures to optimize operational performance before problems arise.

Saving energy in hotel swimming pools

Swimming pools are a key feature in hotels. In recent years, there has been a growing focus on energy-efficient swimming pools. Eco-friendly pools integrate advanced energy-saving technologies like high-efficiency pool pumps, LED lighting, solar-powered heating systems etc.

Pumps are used for water circulation in many parts of the hotel, including swimming pools. They are typically oversized and operate at higher flow rates than needed, leading to excess energy consumption. Reducing pump flow rate and speed can significantly save energy; for instance, cutting the pump speed from 3,450 rpm to 2,400 rpm (a 30% reduction) can result in a 70% power reduction (IIEC, 2015). Variable speed drives (VSDs) are an efficient option for pump flow control, potentially reducing pump energy consumption by 50% to 70%. Operating pumps at optimal speeds also extends their lifespan, with various VSD types available to match specific pump requirements.

Using solar panels to naturally heat pool water reduces dependence on electricity or gas heaters and lowers energy consumption. Pool covers help further minimize heat loss and evaporation, helping maintain the water temperature and therefore cutting heating and water costs. Such covers also help to alleviate the load on the filtration system by keeping debris out of the pool. Efficient filtration systems help conserve water while maintaining its quality, supporting both energy and water saving. To further reduce energy usage, many hotels are switching to LED pool lighting.

> Variable speed drives are an efficient option for pump flow control, potentially reducing pump energy consumption by 50% to 70%.

Regular maintenance plays a key role in keeping equipment running smoothly, preventing unnecessary energy waste. In certain situations, such as swimming pools, significant energy savings can be achieved simply by turning off the pump when it's not needed. This can either be done manually by staff or through timers, with a backup battery to ensure functionality during power outages. Moreover, implementing automation systems allows for precise control and remote management over pool operations like filtration, heating and lighting, also contributing to optimizing energy use.

Integration of solar energy in hotels

Solar energy is not only relevant for heating pools. In Asia, an increasing number of hotels are installing solar panels on their rooftops to power lighting and water heating, for example. They provide hotels with a reliable and independent source of energy, protecting them from price hikes or shortages, and enhancing energy security during outages or emergencies. While battery systems are often needed to complement solar production, solar output typically peaks during the hottest hours when cooling demand is highest, making it especially effective

in hotel settings. For instance, Hotel Shangri-La in Bangkok has installed solar panels across a 938-square-meter rooftop to power a solar water heating system, which heats 25 million liters of water annually, providing sufficient hot water for the hotel's 802 guestrooms (Nicklin, 2011).

> In Asia, an increasing number of hotels are installing solar panels on their rooftops to power lighting and water heating

Other emerging solar energy technologies in the hotel industry include solar concentrators, solar windows and solar-powered charging stations. Solar windows is a new technology that use ultra-thin transparent photovoltaic coatings on rigid glass surfaces, such as windows or building façades, to generate electricity while still allowing natural light to pass through. Complementing this, solar concentrators use mirrors or lenses, to focus sunlight onto a smaller, more efficient solar cell or thermal collector, utilizing 70% to 80% of solar radiation to increase electricity generation and heat water (Oropeza, 2025).

Different government initiatives are also accelerating the transition to clean energy by reducing the upfront cost of installing solar energy systems. For example, the Indian government offers a range of incentives, subsidies, tax credits and grants to businesses investing in renewable energy sources like solar power. Plus, hotels that adopt these practices also align with the growing trend of responsible tourism, fostering a positive reputation and increasing brand loyalty among guests who value environmental sustainability.

Hotel guests can help reduce energy consumption

Hotels play a crucial role in influencing guest behavior to support energy conservation and sustainability goals. By incorporating behavioral strategies – such as nudges, incentives and clear communication – hotels can encourage guests to make more eco-friendly choices during their stay.

Simple measures like placing signs near light switches, thermostats or showers can prompt guests to reduce energy and water usage. Digital reminders sent via in-room systems or mobile apps also reinforce these habits throughout the guest's stay. Additionally, offering small rewards or recognition for participating in green initiatives has been shown to improve engagement. For instance, Singapore's ParkRoyal Collection Hotel's Go Green program plants a new plant in its gardens for every guest who opts for alternate-day housekeeping to help reduce water and energy consumption. This not only promotes sustainability but also gives guests a tangible sense of contribution. According to a study by Booking.com, 76% of travelers are more likely to book a hotel with a green certification, and 43% are willing to pay more for accommodations that prioritize sustainability (Booking.com, 2023). This highlights the growing importance of guest engagement in sustainable practices.

Turning hotel food waste into energy

At many hotels, vast amounts of food waste are discarded daily. To tackle this issue, hotels are increasingly adopting biodigesters, which convert food waste into renewable energy. The biodigesters are widely used in medium-sized and large hotels for on-site energy generation.

Food waste is fed into biodigesters, where anaerobic digestion breaks down organic matter, producing biogas which, when purified, becomes biomethane – a clean fuel for electricity and heat generation. Between 200 and 400 kilowatt-hours of electricity per ton of food waste can be produced, depending on the waste composition (NUS, 2018). Excess energy can be stored in batteries to charge devices like mobile phones and tablets. In addition, the biodigester also provides bio-water that can be used as liquid fertilizer for plants. These systems can also

be integrated with apps and digital platforms for real-time monitoring and management, enhancing efficiency. Besides replacing fossil fuels, the need for waste transport is also reduced.

> A biodigester can produce 200–400 kilowatt-hours of electricity per ton of food waste

Another advanced biodigester technology extracts filtered wastewater from food waste, recovering up to 267 gallons of water per ton (Hines, 2012). While non-potable, this water can be reused for irrigation and cleaning, reducing the energy needed for water treatment and transportation. This dual benefit of energy and water savings is helping hotels minimize environmental impact and improve operational sustainability in countries like the Philippines and Singapore, where food waste management is a challenge.

Energy-efficient appliances and smart technologies for hotel amenities

Several electric appliances can contribute to reducing energy consumption. The modern energy-saving key card system, which is commonly found in hotels, activates the room's lighting, air conditioning and other electronic devices as soon as the guest enters the room, and automatically turns them off when the room is unoccupied. Auto shutdown sockets prevent standby power waste (also known as "phantom load" or "vampire power") by cutting off electricity supply to connected devices such as televisions, chargers and desk lamps in guest rooms when not in use. Some advanced models can also be programmed to shut off appliances at specific times or integrate with hotel energy management systems for centralized control. Also, mini-bars and smart fridges can analyze guest usage patterns to activate cooling only when guests access them, thus optimizing energy consumption.

Smart windows, blinds and curtains are also used to automatically adjust based on sunlight and room temperature to optimize heating and cooling. For example, smart windows automatically lighten in winter to utilize natural heat and sunlight, while tint to their darkest shade to block heat in summer, saving up to 70% more energy than double-pane windows (Tara Energy, 2025). Although they require electricity for operation, 100 smart windows consume less energy than a 75-watt bulb (Tara Energy, 2025).

> Smart windows save up to 70% more energy than double-pane windows

Meanwhile, in the kitchen, induction cooktops, combi ovens (reduce cooking times and energy use by combining multiple cooking methods like steam and convection), etc. reduce energy usage in food preparation. Air-cooled ice machines use just 15–25 gallons of water per 100 pounds of ice and consume less electricity than traditional models by using air for cooling instead of water. Connectionless modern steamers further reduce energy use with their insulated, boiler-less design that retains heat, recycles condensed steam and requires just 14 gallons of water per day, significantly lowering energy demands for heating and operation (The Kitchen Spot, 2025).

Robots or AI are also being used in several hotels, such as Hilton Tokyo Bay and Fairmont Jakarta, to reduce food waste. AI predicts food consumption, adjusting portion sizes to prevent over-preparation, while robots sort and collect waste, which subsequently reduces the need for energy-intensive waste transportation and composting (Accor, 2023).

Saving energy through efficient water management technologies

Hotels in the Asia-Pacific region are increasingly adopting water-saving solutions – not only to conserve water but also to reduce the energy used in heating and pumping it. Hotels are among the biggest consumers of water in the tourism industry (Antonova et al., 2023). From guest rooms and amenities to laundries, kitchens, restaurants, gardens and swimming pools, water is needed everywhere.

On average, a hotel room consumes about 1,500 liters of water per day (EHL, 2024b). The most common strategies include installing water-efficient devices in guest rooms, such as low-flow showerheads and faucets, waterless urinals and low-flow or dual-flush toilets. For instance, low-flow showerheads cut water use to just 6–10 liters per minute, nearly half the amount of traditional models, yet maintain a strong pressure by aerating the water and increasing velocity through tiny apertures (Econation, 2025). This reduced water flow means less hot water is needed, directly cutting down on the energy used for water heating. Similarly, low-flow and dual-flush toilets minimize water use per flush, decreasing the volume of water that must be pumped, treated or heated. Smart technologies like motion sensors for taps and toilets further reduce unnecessary usage, contributing to both water and energy efficiency.

> Asian destinations are a priority for addressing water risks in tourism, as the region has the most water-stressed areas and the highest water intensity per occupied hotel room

Hotels are also adopting smart water management systems that use IoT-enabled smart meters to monitor water consumption, detect leaks in real time and optimize usage across hotel rooms and facilities. Hilton is an example of a hotel operator that has successfully reduced its water usage by 43% since 2008 through the implementation of a smart water management system (EHL, 2024b).

Asian destinations are a priority for addressing water risks in tourism, as the region has the most water-stressed areas and the highest water intensity per occupied hotel room (ITP, 2018). The destinations with highest water intensity per hotel room occupied include major tourist destinations in Asia such as Delhi, Hangzhou, Pattaya, Seoul, Singapore and Tokyo. This underscores the need for hotels operating in Asia to enhance their water management practices. For example, some hotels incorporate rainwater harvesting and greywater recycling from sinks, showers, laundry and kitchen for irrigation, cutting reliance on pumped water. Hotel Marina Bay Sands (Singapore) repurposes 77,000 liters of condensate water daily from air conditioning units for landscaping and plant irrigation throughout the property (Marina Bay Sands, 2025).

Hotel laundries are another major consumer of both water and energy, particularly due to water heating. Ozone laundry technology offers an energy-saving alternative by using ozone gas dissolved in cold water to clean and disinfect fabrics. This eliminates the need for hot water, reduces chemical use and shortens wash cycles – significantly cutting both energy and water consumption.

Innovation examples

Motion sensor lighting system reduces energy costs at Shangri-La Hotel, China

Source: Getty Images/Jakub Zerdzicki

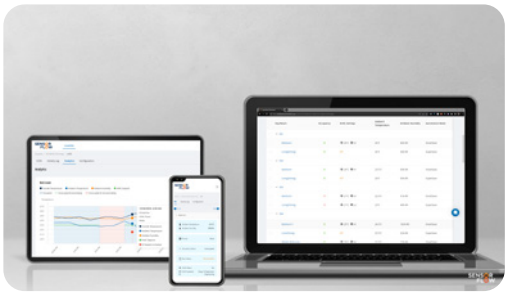
Shangri-La Hotel, Futian pioneered the use of motion sensor lighting across its 28 floors and guestroom corridors, optimizing energy efficiency without compromising guest experience. The system dims decorative lights by 25% when no movement is detected in the corridor, and instantly brightens them as guests enter the corridor from rooms or elevators. This innovation has led to annual savings of approximately 150,000 kWh of electricity, equivalent to US$21,405 (Shangri-La Asia Limited, 2010). Additionally, automated building management systems and timer controls regulate façade, garden and landscape lighting, ensuring they shut off at predetermined times.

Australian resort adopts solar energy

Source: Voyages Indigenous Tourism Australia

Ayers Rock Resort, nestled in the Australian outback, is a prime example of solar energy utilization. Its Tjintu Solar Field generates up to 30% of the resort's energy needs, reducing dependence on traditional energy sources. The resort's waste minimization program promotes efficient recycling and waste reduction to lessen its environmental impact. Additionally, a building management system is used to optimize energy consumption by controlling heating and cooling across the property. These initiatives not only enhance sustainability but also help preserve the region's natural environment.

Empowering guests to cut energy use with smart hotel systems in Hong Kong, China



Source: SensorFlow

A hotel group in Hong Kong, China has adopted Sensor Flow's intelligent hotel system actively to engage guests in energy conservation. Through the hotel's smart app, guests can access real-time energy data on their room's energy consumption and control the room's appliances accordingly. This enables them to manage their energy consumption more effectively. Moreover, such transparency empowers guests to make more sustainable choices, as they are charged only for the energy they use. Not only does this initiative promote eco-conscious behavior, but it also helps guests save on their hotel bills while reducing overall energy waste – a win-win for the hotel, their guests and the environment.

Proven technologies

Machines and appliances: heat recovery dishwasher

Champion

Source: Getty Images/Warut1

This energy-efficient dishwasher saves 66% more energy compared to traditional models, with an annual savings of 79,495 kWh based on 6 hours of operation per day. Its self-developed heat recovery system pre-heats the incoming water by reusing steam generated during the rinsing process inside the dishwasher, raising the water temperature from 25°C to 47–57°C. The dual thermostat technology ensures stable rinsing temperatures, optimizing both disinfection and energy savings. Additionally, the heat recovery system minimizes steam leakage, reducing inside temperature and further enhancing energy efficiency.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Australia, Southeast Asia
- Contact: WIPO GREEN Database

Energy supply: biogas cogeneration unit

Yanmar

Source: Yanmar

The Yanmar CP micro-cogeneration units utilize gas engine technology to generate electricity while reclaiming waste heat to produce hot water, maximizing energy efficiency. The units can run on biogas and provide a sustainable solution for hotels, restaurants and other facilities, reducing both energy costs and CO_2 emissions. By capturing heat from the engine, they efficiently heat water, eliminating the need for separate water heating systems. Multiple units can be integrated for higher output, and blackout-start models ensure reliable power during outages, making them a resilient energy solution.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy management: smart air conditioner and radiator control solution

Sensgreen

Source: Sensgreen

Sensgreen's Smart Air Conditioner (AC) and Radiator Control Solution is a wireless IoT-based system designed to optimize temperature regulation efficiently and cost-effectively. The solution integrates with existing AC units and radiators, eliminating the need for major modifications while providing precise temperature control. By leveraging real-time monitoring and AI-driven automation, it reduces energy consumption by up to 30%. Users can remotely monitor and control AC and radiator settings for convenient adjustments, troubleshooting and maintenance. It creates smart scenarios based on occupancy, window status and temperature thresholds to optimize energy efficiency and comfort, set temperature profiles for different time blocks and dynamically adjust settings using real-time weather data. It can also customize timetables for various zones, such as offices or meeting rooms, and adapt schedules seasonally to maintain ideal indoor conditions while minimizing energy consumption.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Turkey
- Availability: Asia, Australia, Canada, Europe
- Contact: WIPO GREEN Database

Energy efficiency: variable-speed pool pump

Maygo

Source: Getty Images/Evgeniya Sheydt

The variable-speed pool pumps feature a permanent magnet synchronous motor (PSMS) with IE5 efficiency, delivering up to 80% energy savings compared to standard single-speed pumps. The pump has a flexible speed adjustment and utilizes a mechanical seal to prevent leakage. The pump working temperature is 5°C to 50°C. It also includes an LCD screen for manual touch operation and offers installation connectivity through Wi-Fi or Bluetooth for convenient control via mobile devices.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: water and energy-saving showerhead

Smart & Blue SAS

Source: Getty Images/ben-bryant

The HYDRAO Aloe showerhead offers an efficient flow rate of 6.6L/min while maintaining a comfortable shower experience. Utilizing the nudge concept, the showerhead features LEDs that change color in stages to provide real-time feedback on water consumption, encouraging users to save water. With the accompanying HYDRAO app, one can track the shower history, visualize the progress, set personalized goals and adjust water-saving thresholds, transforming each shower into an opportunity for reducing water usage. It can be retrofitted to any conventional shower hose and doesn't need a battery, with everything powered by the flow of water through the shower.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: France
- Availability: France, Singapore
- Contact: WIPO GREEN Database

Machines and appliances: boiler-less combi oven for hotels

Electrolux Professional

Source: Electrolux Professional

The SkyLine Oven for professional kitchens features enhanced chamber insulation, a triple-glazed door and an optimized cavity design to minimize energy consumption. Its high-precision control system and 26 sensors work together to optimize energy use. The smart Lambda sensor controls humidity, generating steam only when needed and utilizing the moisture from the food itself, reducing water waste. With Plan-n-Save, energy consumption can be reduced by up to 20% by optimizing the cooking sequence for greater efficiency. Additionally, it offers effective cleaning and integrated boiler descaling.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Sweden
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: smart glass for windows and façades

Gauzy

Source: Gauzy

Gauzy's energy-efficient smart glass technologies, Polymer Dispersed Liquid Crystal (PDLC) and Suspended Particle Device (SPD), enable glass to transition between clear, tinted and opaque states, offering on-demand privacy and dynamic shading while blocking 99% of harmful UV rays. Operable in low-voltage and able to control solar heat gain and levels of natural light, smart glass reduces the need for air conditioning and artificial lighting, lowering a building's overall energy demand and carbon footprint. Replacing traditional blinds or shades, the system also minimizes material waste and maintenance over time. Integrated with smart building automation through Wi-Fi and remote-control capabilities, the solution enhances occupant comfort while supporting green building certifications.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: Medium
- Place of origin: Israel
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy supply: renewable energy microgrids and smart energy management

Canopy Power

Source: Canopy Power

Canopy Power designs and implements renewable microgrid systems, ensuring a consistent clean energy supply for remote businesses and communities. Their microgrids are made resilient by incorporating a diverse set of energy technologies tailored to the specific customer and location, such as solar panels, floating solar, wind turbines and battery storage. All microgrids are equipped with the company's smart energy management system (EMS), Hornbill™, allowing managers to analyze performance and monetize renewable energy attributes. Using blockchain technology, the EMS automatically generates tradeable Renewable Energy Certificates. Additionally, Canopy Power offers Operations & Maintenance services to ensure long-term system performance, including inspections, part replacements, lubrication and remote monitoring and management.

- Contracting type: For sale/service
- Technology maturity: Proven
- Technology level: High
- Place of origin: Singapore
- Availability: Asia-Pacific, Australia, the Caribbean
- Contact: WIPO GREEN Database

Energy efficiency: voltage optimization system

Co.Efficient Alpha

Source: Co.Efficient Alpha

Voltage optimization is a technique used to adjust voltage levels within electrical systems, helping to save energy and extend equipment lifespan by protecting against power surges. The transformer-based voltage optimization system from Co.Efficient Alpha ensures that loads draw only the necessary current, reducing power consumption by 8 to 12%. Compatible with both indoor and outdoor installations, the system is suitable for a wide range of settings, including commercial buildings and industrial facilities, where multiple energy-intensive appliances may be running simultaneously. The solution is scalable, supports real-time remote monitoring for smart energy management and has a virtually unlimited lifespan.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Singapore
- Availability: Worldwide
- Contact: WIPO GREEN Database

Machines and appliances: professional ozone laundry

BioSure

Source: BioSure

BioSure Professional's OWS Series utilizes a patented Indirect Electrolytic Ozone Generation (EOG) technology to produce ozone from water. This process generates pure ozone with no Nitrogen Oxides (NOx), making it a cleaner and more efficient solution for laundry applications. The dissolved ozone solution oxidizes linen soils, eliminates odor-causing elements and acts as a powerful disinfectant. Additionally, the oxygen from the ozone helps to open fabric fibers, which facilitates moisture release during drying, resulting in faster drying times and reduced energy consumption. Ozone also enhances the effectiveness of cleaning chemicals, reducing the need for multiple rinse steps and shorter wash cycles, which in turn decreases energy usage for water heating. Ozone also helps lower the overall chemical use.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Taiwan, Province of China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Machines and appliances: air-cooled ice machine

Ice-O-Matic

Source: Getty Images/kckate16

The Elevation Series ice machine offers up to 20% more energy efficiency with BPA-free parts. It uses less electricity by relying on fans to circulate air across the condenser coils and vent heat, rather than using water. In addition, its innovative design vents hot air from both the side and top, improving installation flexibility in tight spaces and reducing the risk of obstructed exhaust. The system features a plug-and-play design for easy installation, along with mission-critical indicators, a Smart Harness™ control board, universal components and digital diagnostics to simplify servicing.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: United States of America
- Availability: Worldwide
- Contact: WIPO GREEN Database

Space heating and cooling: CO_2 heat pump

ITOMIC

Source: ITOMIC

ITOMIC's heat pumps use natural CO_2 (R744) refrigerant. Unlike conventional CFC-based refrigerants, CO_2 has a global warming potential (GWP) of 1, and 0 ozone depletion potential (ODP). The largest model, CHP-80Y2 (65 kW), has a Y-shaped design for compact installations, making it suitable for industrial use or large facilities such as hotels. It operates at ambient temperatures from -20°C to +43°C, delivering hot water at 60°C to .

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Argentina, Asia, Oceania
- Contact: WIPO GREEN Database

Energy efficiency: smart room controller

Regin

Source: Regin

Regio RCX is a smart room controller with a sleek, modern design, ideal for design-sensitive environments. It features built-in sensors for temperature, humidity, CO_2, volatile organic compounds (VOC) and motion detection, along with an LED display that adjusts for visibility and night-time dimming. Designed for demand-based control, it optimizes comfort while reducing energy consumption. Its setup requires no programming, and detachable terminals simplify installation and maintenance. It integrates with building management systems supporting centralized control. Configuration can be managed through app (REGIN:GO) or Application tool.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Sweden
- Availability: Asia, Europe
- Contact: WIPO GREEN Database

Energy efficiency: AI-powered water filtration and refillable bottles

Boon

Source: Getty Images/jamesteohart

The water purifiers and dispensers from Boon leverage AI to optimize energy efficiency and minimize water wastage. When paired with Boon Refill, hotels also receive branded, refillable glass bottles. The purification system continuously monitors water quality in real time and adjusts the filtration process accordingly. It can be customized based on regional water conditions, using ultrafiltration in areas with good water quality to reduce the need for reverse osmosis (RO). In regions where RO is necessary, the AI adjusts pump speed and filter settings based on real-time water quality. Energy efficiency is further enhanced by using gravity-fed filtration systems, which reduce reliance on additional power.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: India
- Availability: India, Singapore
- Contact: WIPO GREEN Database

Water use efficiency: waterless urinals

Zerodor

Source: Zerodor

Zerodor Waterless Urinal is a plumbing kit designed to eliminate the need for water flushing and can be retrofitted to any conventional urinals. Featuring a patented mechanical one-way valve, it allows urine to flow into the drainage system while preventing odor-causing gases from escaping back into the restroom. This system operates without consumables, electricity or recurring costs, making it a low-maintenance and eco-friendly alternative to traditional urinals that typically require water to be pumped through plumbing systems, which requires energy. By eliminating the need for flushing, the waterless urinal saves around 150,000 liters of water per urinal per year and therefore reduces the amount of water being pumped, ultimately saving the energy used for this process. Its water-saving and odor-control capabilities make it suitable for high-traffic commercial restrooms.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Energy supply: thin-film solar cells

Hanergy

Source: Getty Images/Acumen86

Hanergy's thin-film solar technology offers advanced features such as flexibility, lightweight design, superior low-light performance and a variety of colors and shapes. Unlike traditional silicon-based panels, thin-film modules utilize materials like gallium arsenide (GaAs) and copper indium gallium selenide (CIGS), delivering higher efficiency in low-light conditions and improved adaptability to curved surfaces. These unique characteristics make it suitable for a wide range of applications, including Building Integrated Photovoltaics (BIPV), residential power, automotive power, electronics, consumer products and specialty applications. It can be integrated into flat and slanted rooftops, windows, façades, curtain walls and ceilings.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy management: cloud-based hotel management system

VDA-Telkonet

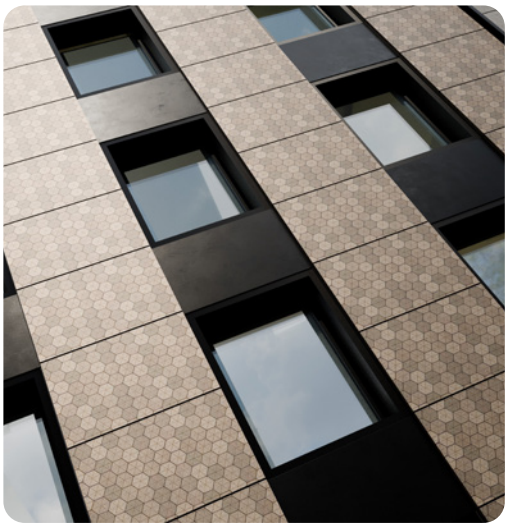
Source: VDA-Telkonet

Etheos is a smart automation system for hotels and multi-dwelling units, enabling hotel management to remotely control access, lighting and climate via a cloud-based platform from any device. With real-time monitoring, customized access and energy analytics, it optimizes resource usage, reduces costs and enhances guest experience. Seamlessly integrating with property management systems, Etheos enhances efficiency and supports strategic energy decisions.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy supply: solar cladding

ClearVuePV



Source: ClearVuePV

Photovoltaic cladding is a technology that transforms passive walls and non-transparent building areas into energy-generating surfaces. This flexible system mimics a variety of façade materials, including glass, marble, stone, masonry, brickwork, granite, wood and tessellation patterns, while maximizing energy generation across the building envelope. The cladding can produce up to 189 watts peak per m^2, depending on the selected texture and color. It is easy to implement, complies with relevant building codes and contributes to significant energy savings by offsetting traditional energy consumption. The energy generated can be integrated with the Building Management System (BMS), powering smart features or stored for peak demand usage.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Australia
- Availability: Australia, Netherlands, Qatar, Singapore, South Africa, United Kingdom, United States of America
- Contact: WIPO GREEN Database

Waste water: next-generation wastewater treatment

Hydroleap

Source: Hydroleap

Hydroleap's patented Electrooxidation (HL-EO) and Electrocoagulation (HL-EC) technologies provide chemical-free, energy-efficient water treatment by using electricity to remove contaminants from wastewater. HL-EO generates oxidizing agents to break down organic pollutants and pathogens, while HL-EC destabilizes suspended solids, metals and oils for easy filtration. These electrochemical processes enhance cleaning efficiency, reduce secondary waste and eliminate the need for energy-intensive chemical dosing. Designed as modular and high-performance solutions, Hydroleap's technology is now being introduced to the hospitality industry in collaboration with Biocare, Philippines.

- Contracting type: For sale
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Singapore
- Availability: Asia
- Contact: WIPO GREEN Database

Energy supply: electricity generating coating for windows and façades

SolarWindow Technologies

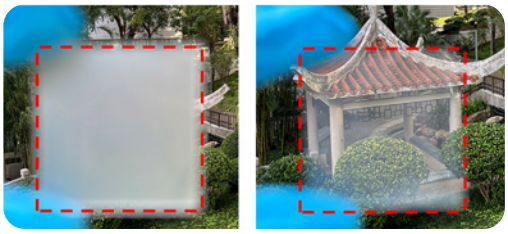
Source: Getty Images/nevodka

LiquidElectricity® is an organic photovoltaic (OPV) coating that enables glass, flexible plastics or films to generate electricity. Applied in ultra-thin layers, this technology allows windows and building fa□□ades to become transparent power generators without obstructing views or requiring additional space, unlike traditional rooftop solar panels. Designed to operate under both natural and artificial light, this offers enhanced energy generation potential across all building surfaces and indoor environments. The coatings are composed primarily of non-toxic, earth-abundant materials and are tailored for transparency and color based on application needs. The technology is currently in the pre-commercial phase, with ongoing efforts to establish manufacturing partnerships and scale up production.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: United States of America
- Availability: N/A
- Contact: WIPO GREEN Database

Energy supply: mask-inspired perovskite smart window

City University of Hong Kong



Source: City University of Hong Kong

Researchers from City University of Hong Kong developed a mask-inspired perovskite smart window that enhances energy efficiency and weather resistance. While thermochromic perovskite is a promising material for energy-saving smart windows, it struggles with weather resistance, water damage and high optical haze. The new structure, inspired by medical masks, reduces surface roughness, improves light clarity (cutting haze from 90% to 30%) and enhances waterproofing. The thermochromic perovskite material, which adjusts its properties based on temperature and light, allows for a reduction of up to 10% in building energy consumption by modulating heat and light entry. The windows use earth-abundant, non-toxic materials, and are applied directly to flexible PET films, reducing renovation costs while improving energy efficiency for green buildings.

- Contracting type: N/A
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Hong Kong, China
- Availability: N/A
- Contact: WIPO GREEN Database

Energy supply: glass-integrated perovskite solar cells

Panasonic Holdings Corporation

Source: Panasonic Holdings Corporation

Perovskite solar cells are a thin, lightweight and flexible alternative to conventional silicon-based cells. The material is printed onto a substrate surface, such as glass, making it suitable for building-integrated photovoltaics. Panasonic is developing such glass-integrated perovskite solar cell technology, and units of their energy-generating glass were as of 2025 demonstrated in a model home for more than a year. A key challenge for perovskite cells is their limited operational lifetime, as the material is sensitive to moisture. Panasonic addressed this issue by encapsulating the cells with a second sheet of glass, creating double-paned windows. In 2023, an 804 cm^2 unit of the company's cells achieved an energy conversion efficiency of 18.1%, comparable to that of traditional counterparts. Commercialization is expected within a few years, with the glass offering high customizability in size, transparency and design.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Energy-efficient shopping malls

In Asia, shopping malls are no longer just retail centers – they are evolving into vibrant destinations that offer dining, leisure, sports, cultural experiences and many more, making them an integral part of daily life for local communities. Particularly in Southeast Asia, cities like Bangkok, Jakarta, Kuala Lumpur and Singapore are home to numerous multi-story malls that serve as air-conditioned retreats from the region's hot and humid climate. People flock to these malls not just for shopping but also for socializing and entertainment, from food courts and cinemas to indoor theme parks and exhibitions. Experience-driven spaces are now shaping the future of malls, with immersive attractions designed to draw visitors. For example, ICONSIAM in Bangkok features stunning multimedia fountain shows, cultural exhibits and artisanal markets, redefining the mall experience. Various services and amenities are also offered such as wellness centers, coworking spaces, gyms etc. In a few cases it is even possible to go ice skating.

With so much going on, these malls are also big energy consumers. Air conditioning and lighting may use up to 85% of the electricity in some malls that are fully air-conditioned (RH1, 2024). The challenges lie in balancing the need for comfort and entertainment with more sustainable energy use. This chapter explores the technology options and trends in Asian shopping malls aimed at improving energy efficiency, including energy-efficient HVAC systems, advanced building management solutions, renewable energy integration and the installation of EV charging stations.

However, many technologies used in shopping malls are also commonly found in hotels and residential buildings, such as LED lighting, energy-efficient heating and cooling with heat pumps, smart devices/appliances, biogas generation from food waste and so on. Since these technologies are already covered in the sub-chapters of urban households and hotels of this book, they won't be discussed again here. For a deeper dive into these solutions, see also the energy and mitigation editions of the *Green Technology Book*.

Technological development and trends

Low-power technologies for billboards and large digital displays

Digital billboards, indoor digital signage and large screens dominate Asian shopping malls, often featuring touchscreens and QR codes for direct customer interaction. These dynamic displays serve multiple functions, including wayfinding, announcements, product launches and information sharing, making them an essential tool for communication, marketing and enhancing customer experiences.

By replacing traditional print materials, a digital signage not only reduces waste but also lowers overall carbon emissions (Praevar, 2025). The use of energy-efficient technologies for digital screens has therefore become a key component of sustainability efforts, including energy-saving displays like LCD (liquid crystal display), LED (light-emitting diode), or OLED (organic light-emitting diode).

> Replacing traditional print materials, a digital signage not only reduces waste but also lowers overall carbon emissions

LCD and LED are both widely used in digital signage, but they differ in technology and performance. LCD displays rely on CCFL (cold cathode fluorescent lamp) backlighting, which consumes more power than LED displays, which use individual light-emitting diodes for brighter, more vibrant visuals. LED displays are particularly effective in outdoor settings in direct sunlight, as opposed to LCD screens. The latest advancement in this field – Mini and Micro LEDs – further enhances energy efficiency by using smaller, more precise diodes that emit light more efficiently while generating less heat. These screens consume up to 40% less energy than conventional LED displays under similar conditions (Absen, 2024). Meanwhile, OLED displays

enhance efficiency by lighting each pixel independently, providing precise brightness control with individual pixels turning off completely to display true blacks. This results in a brighter display with energy savings, as power is used only by active pixels. However, OLED screens are generally more expensive than others.

Another trend is solar-powered LED displays. These screens use integrated photovoltaic (PV) panels to generate their own energy, which is then stored in batteries or capacitors to power the LEDs and other components of the display, such as controllers, sensors or speakers, making them self-sustaining and reducing dependence on the grid. These systems are particularly useful for outdoor signage, smart billboards and off-grid installations in remote or developing areas where reliable electricity access is limited.

The digital displays are further optimized with energy-efficient features such as dynamic brightness adjustment, which reduces power usage based on ambient light. Sleep mode enables the screen to enter a low-power mode during inactivity, reducing energy consumption during off-peak hours or at night. In addition, advanced remote energy management systems allow businesses to monitor and optimize screen settings in real-time to further improve energy savings.

Energy-efficient escalators and elevators

Most of the malls in Asia are high-rise buildings with escalators and elevators. These are energy intensive, but also there are means to reduce energy consumption. Many now feature variable-speed drives that automatically adjust escalator speed based on traffic, slowing down or entering low-power standby mode when not in use. Motion sensors enhance efficiency by activating escalators only when someone approaches, reducing energy consumption by up to 30% under typical usage condition, compared to continuous operation (Rony, 2024). Additionally, modern escalators use high-efficiency motors like permanent magnet synchronous motors (PMSMs) or gearless motors. This motor technology is described in detail in the rural household sub-chapter, and also in energy edition of the *Green Technology Book*.

Regenerative drive technology enhances elevator efficiency by recovering energy during braking – such as when the elevator descends with a heavy load or ascends with a light load. Instead of being lost as heat, this energy is converted into electricity and redirected back into the building's power system, helping to reduce overall energy consumption. Integrating batteries within the elevator further allows this recovered energy to be stored and reused during acceleration or peak demand or utilized as backup power during outages. Additionally, smart sensors and advanced destination control systems enable grouping passengers with the same destination into the same elevator. This reduces unnecessary stops and travel time, improving operational and energy efficiency. Modern elevators also use energy-saving LED lights, automatic shut-offs for non-essential features such as fans, lights, screens etc., and door motors that support variable door-open and -close times, contributing to significant energy savings over time.

> Smart sensors and advanced destination control systems enable grouping passengers withthe same destination into the same elevator

Another emerging type of elevator is the Machine Room-Less (MRL) elevator. In this design, the motor and other equipment are housed into the hoistway (the vertical space where the elevator operates) instead of a machine room. This innovation eliminates the need for extra energy to power a separate machine room. Additionally, the traction system features a smaller motor and optimized design, requiring less power to move the elevator car and generating less heat compared to traditional larger elevator systems.

Energy efficiency using innovative building materials and building initiatives

Innovative building materials can offer energy efficiency in shopping malls. For instance, ethylene tetrafluoroethylene (ETFE), a lightweight durable material, is commonly used for roofing and façades due to its excellent thermal insulation and high transparency. ETFE can transmit about 94% to 97% of natural light, reducing reliance on artificial lighting and promoting energy savings (Hu et al., 2017). In addition to its aesthetic appeal, it helps minimize heat gain, lowering the demand for air conditioning, making it ideal for malls in warmer climates. Prominent examples include Parqal Mall in the Philippines or World Sentosa in Singapore, where ETFE is used in the glass-like roofing system (Vector foiltec, 2024) (figure 4.2). Complementing such materials, transparent or colored solar cells are embedded on building façades (also known as photovoltaic cladding), which enables buildings to generate electricity while maintaining aesthetics and natural light, offering an integrated approach to energy-efficient design.

Figure 4.2 World Sentosa, Singapore

Source: Vector foiltec (2024).

Implementation of a multifunctional climate adaptive façade system, such as reflective coatings, movable shades or vents adjusting according to sunlight and wind, green façades (vegetation) providing natural insulation and cooling, can also save energy by reducing heating and cooling demand. Such technologies are discussed in detail in the *urban household* sub-chapter.

Green building certification schemes can motivate mall owners to implement energy-saving initiatives. For example, several malls in Malaysia have earned green certifications, including leadership in energy and environmental design (LEED), green building index (GBI), and green real estate (GRE). These certifications highlight the malls' commitment to sustainability through features like energy-efficient heating-cooling and lighting, water-saving fixtures, the inclusion of green spaces and so on (Arifin, 2023).

Advanced heating, ventilation, and cooling (HVAC) systems are emerging

Energy-efficient shopping malls require advanced HVAC technologies that can accommodate varying temperature, and ventilation demands based on occupancy, shop types and zone functions. For example, food courts and retail areas generate heat from appliances, lighting and crowds and therefore require more cooling and ventilation. Entrances and lobbies may be affected by cold drafts in winter, thus requiring heating. A variable refrigerant flow (VRF) system is an example of an advanced solution that provides simultaneous heating and cooling. The system efficiently adjusts refrigerant flow based on demand, from a single outdoor unit to multiple indoor units, and transfers excess heat between different mall zones using air or water. This optimizes energy use and prevents energy waste in unoccupied areas.

Air handling units (AHUs) combined with energy recovery ventilation (ERV) systems can further enhance HVAC energy efficiency. AHUs primarily manage ventilation by filtering, humidifying (or dehumidifying) and distributing fresh air throughout the building, while ERVs recover heat or coolness from exhaust air and transfer it to incoming fresh air. This pre-conditioning process reduces the load on heating and cooling systems, thereby lowering energy consumption, while also helping to maintain consistent indoor temperatures and improving air quality. Such ventilation units may also include built-in heat pumps or VRF technology, combining ventilation, energy recovery and climate control in a single system for more efficient air treatment (for details on heat pumps, see urban household sub-chapter in this book and mitigation edition of the *Green Technology Book*). They can be further enhanced for demand-controlled ventilation (DCV) by incorporating CO_2 sensors and variable-speed drives (VSDs). CO_2 sensors monitor the concentration of CO_2 in the air, which serves as an indicator of how many people are in a space, while VSD fans adjust airflow based on real-time occupancy. This minimizes energy waste when occupancy is low.

Another solution is underfloor air distribution (UFAD) systems that deliver conditioned air through floor-level diffusers, allowing the warm, stale air to rise to the ceiling for extraction. This bottom-up flow enhances cooling in high-traffic areas and requires lower fan pressures to distribute air, reducing energy consumption compared to traditional HVAC systems. It can also improve thermal comfort when used for heating, by delivering warm air directly to the occupied zone, providing more even temperatures. In Japan, UFAD is used in 58% of new commercial buildings (Bhatia A., 2022).

Chillers are widely used in large shopping malls across Asia. A chiller is an air conditioning unit that circulates chilled water through pipes located in walls, ceilings or floors resulting in cooler temperature. The efficiency of a water-cooled chiller can be up to twice as good as an air-cooled VRF or chiller (LG, 2022). However, in recent years, scroll air-cooled chillers are gaining attention for their compact design and improved efficiency. Unlike conventional air conditioners that deliver cool air directly, these systems use scroll compressors to cool a refrigerant, which then chills water in a heat exchanger. This chilled water is circulated through a building's air handling units to provide cooling. By using air-cooled condensers instead of cooling towers, these chillers simplify installation and reduce water consumption. But they are less effective in very hot and humid climates as air-cooled systems require more power to reject heat in high-temperature environments (H. Stars Group, 2024). Hybrid systems combining both chiller and VRF systems can meet a wide range of climate requirements while offering a more efficient and cost-effective solution.

The chillers can also be integrated with renewable energy sources like solar power to reduce carbon emissions and operational costs. In addition, integrating thermal storage systems that create and store ice or chilled water during off-peak hours, and using them to cool the building during peak demand, can also ease grid strain and reduce electricity costs. Such technologies are beneficial for regions where electricity supply is inconsistent and expensive.

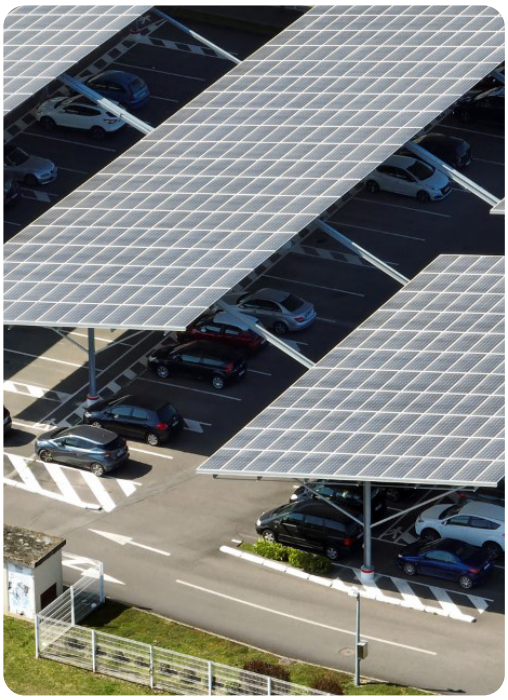
Renewable energy integration in shopping malls

There is a growing trend of solar panel installations in shopping malls across Malaysia, typically installed on rooftops, building façades, parking spaces or open walkways (The Edge Malaysia, 2024). In addition to clean energy production and reduced electricity bills, rooftop PV panels add a shading layer that lowers solar irradiation entering the building, reducing indoor temperatures and cutting cooling loads. Solar panels also serve as a symbol of a mall's commitment to sustainability, attracting eco-conscious consumers and boosting brand reputation. In Singapore, the largest solar panel installation project for shopping malls is expected to generate 920,000 kWh of electricity per year, saving $220,000 of annual energy cost while reducing 370 tonnes of carbon emissions (Tay, 2024).

However, if the building rooftop is used as a parking area for visitors and tenants, which is very common in high-rise shopping malls in Asia, installing solar panels on the roof may be understood as losing parking spaces. Nevertheless, in such cases, solar carports offer a practical solution (figure 4.3). These are standalone canopy structures installed over existing parking spaces, with solar panels mounted on their roofs. Widely adopted in Japan, they serve a dual purpose – providing shelter for vehicles without occupying building rooftops while

generating renewable electricity that can power shopping mall operations or be stored for later use (Sumitomo Corporation, 2024). They maximize energy output without impacting the natural environment while providing shade and rain protection to parked cars.

Figure 4.3 Solar carport



Source: Getty Images/Bilanol.

Though the installation costs of solar carports are higher than rooftop panels, expenses can be reduced by installing multiple units. Double-sided panels enhance further efficiency by capturing reflected light from parked cars to increase power generation using the backside of the panel.

Building energy management systems (BEMS)

Applying energy efficiency measures to many shopping malls and hotels requires effective building management and resource allocation. One way to reduce energy consumption is by implementing BEMS. BEMS is a network of sensors, controllers and software that monitors, controls and optimizes a building's energy use. It connects different building energy systems, like HVAC and lighting, into one integrated system to improve efficiency. This digitalization avenue is key to reducing operational costs of shopping malls, particularly when matched with some integrated battery energy storage system (BESS) and renewables. It allows certain flexibility in the electricity demand pattern, which allows the malls to benefit from dynamic electricity pricing (reducing consumption from the grid in peak price hours), which is a growing trend in many countries.

Modern BEMS use open communication protocols and web-based access, enabling remote monitoring of facility data. They provide real-time insights and future predictions for energy consumption across systems, and allow control of temperature, humidity, airflow, lighting levels and overall energy usage. By employing building automation and energy management systems, up to 60% of annual energy savings have been recorded which may allow for short investment payback periods of 2–10 years in commercial buildings (Wuppertal Institut - Gokarakonda et al., 2017).

EV charging stations in shopping malls

Shopping malls are increasingly integrating EV charging stations to support the rise in electric vehicle adoption while promoting sustainability and less reliance on fossil fuels. These chargers provide convenience for shoppers, allowing them to charge their vehicles while spending time

in the mall. In the Philippines, SM Supermalls has installed EV chargers across multiple locations, supporting the transition to low-emission transportation (SM Supermalls, 2022). Similarly, Malaysia's Johor Premium Outlets (JPO) aims to become Southeast Asia's largest EV fast-charging hub by installing 500 chargers, including a cutting-edge 1MW DC charger for public use, which can support ultra-fast charging of a high volume of EVs in the shopping mall (Wong, 2025).

However, installing large numbers of EV chargers could present challenges for distribution grid operators, since malls often require upgraded grid connections, cable infrastructure and additional electrical equipment beyond the chargers themselves. Integrating smart charging systems and linking them to BEMS can help mitigate these challenges. Smart chargers regulate electricity use by adjusting speeds based on peak and off-peak hours, reducing grid strain and energy costs while improving overall system efficiency. More details on different types of EV chargers can be found in the public transport and communities sub-chapter of this book and also in the energy edition of the *Green Technology Book*.

Supermarket refrigeration technologies

A dedicated chapter on energy technologies for supermarkets can be found in the energy edition of the *Green Technology Book*. Supermarkets and retail food stores, which are a significant component of many large shopping malls in Asia, are also major energy consumers. Refrigeration systems alone account for 35 to 50% of a supermarket's total energy consumption (Karampour et al., 2016). Simple retrofits, such as installing low-E glass doors on refrigerators, can reduce energy consumption by up to 40% (Saengsikhiao and Taweekun, 2021).

> Refrigeration systems alone account for 35 to 50% of a supermarket's total energy consumption

Common refrigeration setups in supermarkets include standalone plug-in cabinets, condensing units with "split systems" linked to remotely located condensers, and centralized systems using refrigerants with high global warming potential (GWP). However, there is a growing shift toward adopting low-GWP alternatives in response to environmental regulations and sustainability goals. A promising refrigeration technology that is being widely adopted in Japan is the transcritical CO_2 refrigeration system, which uses CO_2 as a refrigerant. As of December 2023, Japan had 8,385 stores, including 7,800 convenience stores and 585 supermarkets, utilizing transcritical CO_2 systems (IIR, 2023). This technology is recognized for its lower GWP and for achieving at least a 20% reduction in energy costs (CCAC, 2023). However, its adoption in most other parts of Asia remains limited, primarily due to the high upfront costs. Additionally, the region's diverse climate, regulations and technology preparedness highlight the need for locally adapted solutions to accelerate the widespread adoption of CO_2 systems (Hayes, 2024).

Heat recovery systems are becoming more popular, as they repurpose waste heat from refrigeration units for water or space heating, further enhancing energy efficiency. Managing humidity is another key efficiency strategy, utilizing technologies like advanced dehumidifiers, high-performance refrigeration designs, anti-sweat glass doors and humidity sensors.

Innovation examples

Japan's largest solar carport in AEON malls

Source: AEON MALL Co., Ltd.

AEON Mall and Sun Trinity are installing Japan's largest solar carport system, with a total capacity of 15 MW across 12 locations (Sumitomo Corporation, 2024). One site will feature over 2.4 MW, making it one of Japan's largest single-location solar carports. The project aims to expand to 50 AEON Malls by 2025, enhancing renewable energy use while providing shaded and weather-protected parking. These solar carports will generate approximately 18 million kWh of CO_2-free energy annually, equivalent to the power consumption of 4,300 households, maximizing space efficiency without impacting the natural environment.

Solar panels provide clean energy to SM City Fairview mall in the Philippines

Source: SM Prime

Property developer SM Prime has installed a 3.785 megawatts-peak (MWp) rooftop solar photovoltaic (PV) system at its SM City Fairview shopping mall in the Philippines. The system, consisting of over 6,800 PV panels, generates 5,960 MWh of clean electricity annually, reducing the mall's carbon footprint by approximately 4,130 metric tons of CO_2 each year (Clean Technica, 2025). SM Prime now operates 48 malls and properties with solar installations totaling 72 MWp capacity, with plans to add 20 more rooftop solar PV projects during 2025. The company also works to incorporate energy-efficient features across its developments, including LED lighting, sensor-activated escalators and skylights to maximize natural light (SM Prime, 2025).

Combined HVAC in the Starfield Hanam shopping center in the Republic of Korea

Source: LG Electronics

The Starfield Hanam shopping center in the Republic of Korea employs a combined HVAC approach, integrating both chiller and Variable Refrigerant Flow (VRF) systems, to optimize energy efficiency across its diverse spaces (LG, 2021).This shopping complex features various areas such as individual shops, department stores, atriums, food courts, and theaters, each with unique climate control requirements. By deploying LG's chiller systems and the Multi V VRF solution, the facility effectively addresses these varying demands. This strategic combination reduces energy consumption, providing a cost-effective and sustainable solution tailored to the complex's multifaceted environment.

Proven technologies

Energy efficiency: high-brightness, low-power digital signage

Praevar

Source: Praevar

High-brightness, low-power Liquid Crystal Module (LCM) digital advertising displays provide enhanced visibility while consuming 35% less power than traditional LCD displays. Models like the Podium 65" and 75" use advanced backlight technology, optical stacking and dynamic dimming to maximize luminance (nits) per watt, adjusting the brightness with the ambient light condition, reducing energy consumption. With 4K resolution and up to 4,000 nits of brightness, these displays can be used for outdoor and semi-outdoor signage in high-traffic areas like shopping malls or city centers, ensuring clear visibility in various lighting conditions. Their energy-efficient design enhances sustainability for high-impact digital advertising.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Canada
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy management: ECOWatch energy management solution

Advantech

Source: Getty Images/Maxiphoto

ECOWatch is an energy monitoring and management system designed for shopping complexes and other commercial buildings, centralizing real-time tracking of electricity, water, gas and heat consumption. By replacing manual meter readings, it reduces labor costs and improves data accuracy. The system enables administrators to analyze energy usage across different floors and retail units, identify abnormal consumption patterns and optimize operational efficiency. Built on Advantech's WISE-IoT industrial cloud platform, ECOWatch integrates with building power, water and HVAC systems, offering features such as real-time alarms, sub-metering, consumption analysis and detailed energy reporting, enhancing energy efficiency in shopping complexes.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Taiwan, Province of China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Machines and appliances: energy-efficient escalators and moving walks

Hyundai Elevator

Source: Hyundai Elevator

The S series escalators are made for hotels, shopping malls and office buildings, featuring a compact design and energy-saving mode with automatic operation. Radar sensors detect approaching passengers, restarting escalators as needed. The inverter with MSTVF control adjusts speeds based on traffic flow at different periods of time, optimizing motor efficiency and minimizing energy use. Long-lasting LED lights on handrails, combs, and under-step lighting consume 75% less power than traditional fluorescent lights, further enhancing energy savings.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Republic of Korea
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: solar-powered LED screen

VisionPI

Source: VisionPI

A solar-powered LED display that integrates a solar control unit, battery storage and an LED display module to ensure continuous operation using solar energy. The solar controller regulates battery charging and discharging, adjusts output voltage based on demand, and protects against overcharging, deep discharge, short circuits and overloads. Designed for efficiency, the system supports "charging and playing synchronization," allowing it to operate while charging. An integrated energy-saving module ensures up to 100 hours of display power in the absence of sunlight, making it suitable for locations with variable solar conditions.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: China
- Availability: Asia
- Contact: WIPO GREEN Database

Machines and appliances: energy-efficient machineroom-less elevator

Kone

Source: KONE

The KONE MonoSpace DX is a machineroom-less (MRL) elevator that minimizes energy consumption by eliminating the need for a machine room. Powered by the energy-efficient KONE EcoDisc® motor, it reduces the building's carbon footprint with eco-efficient hoisting, regenerative drive, energy-saving standby operation and long-lasting LED lighting. The next-generation EcoDisc motor is compact, highly durable and more energy-efficient than traditional elevator motors. Enhanced with connectivity, the elevator integrates with KONE's digital platform for smarter, more efficient operation and 24/7 AI-based monitoring, helping to identify potential issues and optimize maintenance.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Finland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Space heating and cooling: air handling unit

Daikin

Source: Daikin

Daikin's plug-and-play air handling unit (AHU) is an integrated solution for heating, cooling and ventilation in commercial buildings. Combining Daikin's heat pumps (Variable Refrigerant Volume technology or ERQ condensing units) with ventilation units, this system improves energy efficiency and indoor comfort while simplifying installation. The AHU incorporates heat recovery technology, using the heat from exhaust air to pre-condition incoming fresh air, reducing the energy required for additional heating or cooling. When heat recovery alone is insufficient, Daikin's heat pumps provide supplemental heating or cooling to maintain the desired indoor temperature. The system supports advanced air management features such as airflow and temperature control, integration with chilled water and direct expansion (DX) cooling, CO_2 monitoring, and Variable Air Volume (VAV) and Constant Air Volume (CAV) operation, ensuring optimal climate control across various applications.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Machines and appliances: modular gearless machines for mid-size elevator

Schindler

Source: Getty Images/Baloncici

Schindler's modular gearless technology can be retrofitted into existing mid-rise buildings, offering an energy-efficient upgrade for older elevator systems. By replacing traditional geared machines with gearless technology, it reduces power consumption and enhances ride quality with smoother, quieter operation. Integrated with regenerative drives, it captures and converts excess energy from the elevator's descent into reusable energy instead of dissipating it as heat, and feeds it back into the building's power grid, lowering overall electricity usage. The compact design, featuring a smaller sheave and suspension traction media (STM), allows for easier installation in existing machine rooms. This retrofit solution not only improves efficiency but may also qualify buildings for energy rebates and LEED certification points.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Space heating and cooling: air-cooled variable-speed drive screw chiller

Johnson Controls

Source: Getty Images/angeluisma

The YORK® YVAA Air-Cooled Chiller is an energy-efficient cooling solution designed to optimize performance and reliability. Featuring a patented liquid-cooled variable-speed drive, it delivers 15% to 25% annual energy savings. The chiller reduces energy consumption by minimizing refrigerant compression, leveraging a hybrid falling film evaporator and microchannel condenser coil for enhanced heat transfer. Its variable volume index (VI) technology further improves part-load efficiency, making it suitable for diverse operating conditions, including high ambient temperatures up to 55°C. With a focus on energy optimization, the YVAA offers a lower-maintenance, high-efficiency cooling solution for commercial and industrial applications.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: United States of America
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: ultra-slim EV chargers for smart charging

Charge+

Source: Getty Images/Scharfsinn86

The ultra-slim EV charger is a compact, energy-efficient charging solution designed to optimize space while delivering reliable performance. With only 10 cm width, its sleek design enables easy installation in tight spaces and seamless plug-and-play integration in all existing car parks, especially suitable for commercial applications. It comes with the smart charging software including energy management capabilities, real-time monitoring and remote control for optimized charging. Through the mobile app and cloud-based platform, it ensures efficient power distribution, minimizes energy waste and allows users to track charging performance and adjust settings.

- Contracting type: For sale
- Technology maturity: Proven
- Technology level: High
- Place of origin: Singapore
- Availability: Asia
- Contact: WIPO GREEN Database

Energy management: smart controller and tracking device for retail air conditioning units

BenKon

Source: BenKon

The BenKon SmartAir is a compact controller that functions like a fitness tracker for air conditioning units in the retail sector. It can turn any AC into a smart unit and transmits data to a cloud-based management platform. Through the BenKon App, managers can monitor the energy consumption of multiple air conditioners simultaneously, receive alerts and implement automated scheduling. The platform also leverages artificial intelligence to detect energy-wasting habits among personnel and recommend adjustments. According to the company, users in Viet Nam's retail sector have reduced energy consumption by up to 20%. Additional applications include schools and hospitality businesses.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Viet Nam
- Availability: Viet Nam
- Contact: WIPO GREEN Database

Energy efficiency: AI-integrated energy-efficient variable refrigerant flow solution

LG

Source: LG

The Multi V™i is an advanced energy-efficient variable refrigerant flow (VRF) system designed for mid- to high-rise buildings such as shopping malls, offices and hotels. Equipped with a highly evolved AI engine, it improves energy efficiency by up to 24.7% through smart features like AI Smart Care, which optimizes heating and cooling based on factors such as occupancy and ambient temperature. The system's AI energy management feature allows users to set energy consumption targets, reducing overall power usage. With a newly designed biomimetic fan and optimized air flow, it further cuts fan-motor power consumption. The system comes with auto tuning and remote upgrade. It is capable of operating in extreme temperatures, providing full cooling at up to 43°C and heating at as low as -10°C, ensuring energy savings and a comfortable indoor environment year-round.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Republic of Korea
- Availability: Worldwide
- Contact: WIPO GREEN Database

Space heating and cooling: air-cooled modular inverter chiller

Carrier Japan Corporation

Source: Carrier Japan Corporation

The Universal Smart X is an energy-efficient air-cooled chiller system designed for a wide range of applications, from air conditioning to industrial processes. Featuring a new DC twin rotary compressor, it improves motor performance and reduces pressure loss, achieving industry-leading energy efficiency. It performs well in different load conditions and across a wide temperature range. The compact design saves 58% in installation space compared to traditional systems, making it ideal for replacing cooling tower systems. It also includes harmonic current suppression, boosting power factor to 99%, and features advanced controllers and wireless LAN for optimized energy management and real-time monitoring.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Space heating and cooling: advanced AI for HVAC optimization

BrainBox AI

Source: BrainBox AI

BrainBox AI enhances HVAC efficiency by integrating with existing networked control systems or cloud-connected AI-enabled thermostats. It maps and normalizes data before applying predictive algorithms based on the building's unique thermal behavior. External information such as weather forecast, utility tariff structures, grid emission factors and occupant density is fed to the AI engine. By analyzing these factors, the AI engine autonomously adjusts HVAC operations every five minutes to optimize performance. The system continuously learns and adapts to changing conditions while implementing advanced controls like demand ventilation and humidity regulation. Such an AI-driven approach reduces HVAC energy consumption by up to 25% and lowers HVAC related carbon emissions by up to 40%, contributing to more sustainable building management.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Canada
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: micro-LED display

Absen

Source: Absen

The KLCOB V2 Series micro-LED display features a black polymer coating for enhanced contrast and visual depth. It utilizes flip-chip LED technology that has a smaller footprint and emits light from all five sides, resulting in improved brightness and 40% reduction in energy consumption compared to traditional face-up LED displays. It is versatile, offering installation options like stacking, wall-mounting and precise 90° splicing, providing a reliable and energy-efficient solution for various display environments.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Space heating and cooling: new generation oil-free centrifugal air-cooled chillers

Smardt

Source: Getty Images/tzahiV

The AeroPure AF Series is a new generation of air-cooled chillers featuring oil-free, magnetically suspended compressors, designed for energy-efficient comfort air conditioning. By using magnetic fields to suspend the compressor components, friction is significantly reduced, which minimizes energy loss and increases efficiency. This innovative design also reduces wear and tear, enhancing long-term performance. Available in 36 models with capacities from 211 to 1800 kW (60 to 510 TR), it offers configurable options for extreme temperatures, harmonic filtering and noise reduction. The Smardt Global Controls Platform enables real-time monitoring, intelligent optimization and seamless integration with building management systems, while its compact design suits space-constrained installations.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Australia
- Availability: Asia, Australia, Europe, North America
- Contact: WIPO GREEN Database

Space heating and cooling: ETFE roofing and façade technology

Vector Foiltec

Source: Vector Foiltec

The Texlon® ETFE system is a lightweight and transparent material used for roofs and façades adaptable to various architectural and environmental requirements. It helps save energy by letting in natural light, reducing the need for artificial lighting, and providing insulation to regulate indoor temperatures. With low environmental impact, it is applicable for both new construction and refurbishments. Additionally, its translucent design creates visual effects, especially when lit up at night, making it a popular option for modern shopping malls and other large, open spaces.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy efficiency: AI-assisted destination floor reservation system

Hitachi Building Systems

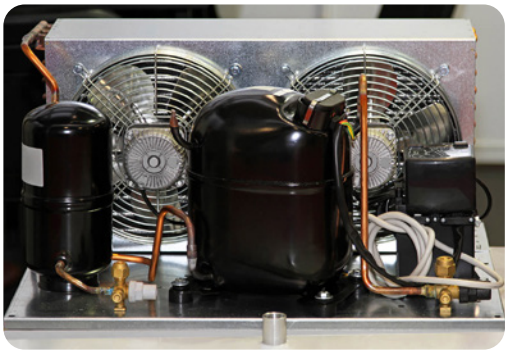
Source: Hitachi Building Systems

AI-assisted destination floor reservation systems enhance elevator efficiency by predicting traffic flow and assigning elevators based on demand, reducing waiting times and unnecessary stops. By optimizing dispatch and passenger distribution using AI algorithms, the system lowers energy consumption and minimizes the likelihood of fully loaded elevators traveling inefficiently. Additionally, regenerative braking technology recovers excess energy when elevators descend with heavy loads or ascend with light loads, feeding it back into the building's power grid. When integrated with energy-efficient gearless traction machines, these systems can save up to 50% of energy consumption, enhancing sustainability in high-traffic buildings like shopping malls.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Machines and appliances: high-performance refrigeration with monitoring solution

Emerson



Source: Getty Images/Baloncici

Emerson's Copeland™ scroll compressor rack system is designed for large-scale food refrigeration, offering improved performance and reduced power consumption. This system enhances refrigeration and freezing efficiency by 15%, while increasing cost-effectiveness over its lifecycle. The use of vapor injection technology reduces compressor power consumption, improving reliability and energy efficiency. The integrated monitoring system allows for store-level management, preventing malfunctions and ensuring stable operation. Equipped with electronic sensors and controllers, the system ensures precise temperature control, durability and enhanced efficiency. Additionally, the new R448A refrigerant cuts the GWP in half compared to traditional refrigerants.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: High
- Place of origin: United States of America
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy supply: solar waterproof carport

Kinsend

Source: Getty Images/Acumen86

The solar waterproof carport mounting system typically includes a series of brackets or rails that are fastened to the roof or surface using screws or bolts. The solar panels are then attached to the brackets or rails using special clamps or clips. These mounting systems are designed to withstand harsh weather conditions, including strong winds, rain, snow and extreme temperatures. This ensures that the solar panels are always positioned at the optimal angle for maximum energy production. It is suitable for open field areas, or supermall parking area.

- Contracting type: For sale
- Technology maturity: Frontier
- Technology level: Medium
- Place of origin: China
- Availability: China, Europe, Japan, Southeast Asia, the Republic of Korea
- Contact: WIPO GREEN Database

Energy supply: a friction power-generating mat

Toyo Aluminium Ekco Products Co. Ltd.

Source: Toyo Aluminium Ekco Products Co. Ltd.

Toyo Aluminium Ekco Products, in collaboration with Kansai University, Survey Research Center Co., Ltd., and Toyo Aluminium K.K., has developed a mat that generates electricity through friction when stepped on. The mat can produce several tens of milliwatts of power per step and is expected to serve as a carbon dioxide-free energy source. Unlike traditional ceramic-based piezoelectric elements, it is made from flexible materials, offering enhanced durability. The generated electricity can power electronic devices such as LEDs and signal transmitters, with potential applications including visitor or pedestrian counting systems, among others. Following a test marketing phase in 2024, product advancement is ongoing.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Energy supply: plug-and-play building-integrated photovoltaics

Power Facade

Source: Getty Images/ideeone

Power Facade, a spin-out from the Solar Energy Research Institute of Singapore (SERIS), is addressing the lack of plug-and-play BIPV solutions by developing a modular BIPV wall system, using light-gauge steel prefabrication technology. Each unit can operate independently or be installed in an interlocking design, allowing for quick installation and water tightness. The modules come pre-assembled and wired, enabling installation from inside a building without the need for scaffolding. Using SERIS-patented hybrid printing technologies, Power Facade offers a solution that can mimic the appearance of common building materials such as brick, concrete or marble. After receiving a startup grant in 2023, the company aims to refine its product in collaboration with SERIS throughout 2025.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Singapore
- Availability: Singapore
- Contact: WIPO GREEN Database

Space heating and cooling: energy-free cooling tiles inspired by fungi and elephants

Nanyang Technological University (NTU)

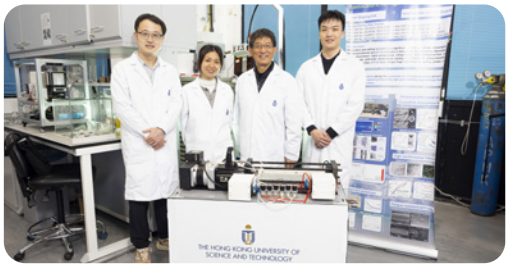
Source: Nanyang Technological University (NTU)

Researchers at Nanyang Technological University (NTU) Singapore, in collaboration with biomimicry design firm bioSEA, have developed an energy-efficient building tile made from fungi-based mycelium and bamboo shavings that passively cools structures without using electricity. Inspired by the textured skin of elephants, the "fungi tiles" feature a bumpy surface that enhances heat dissipation through increased surface area, mimicking natural thermoregulation. Lab tests show these biodegradable tiles outperform traditional insulation materials in thermal regulation, offering a zero-energy cooling alternative. With successful proof-of-concept results in the lab, the next phase of the project involves scaling up production and conducting real-world trials on building exteriors. If successful, these tiles could offer a sustainable solution to reduce building temperatures in hot climates, potentially lowering dependence on air conditioning and cutting energy costs while using the power of nature.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Singapore
- Availability: Singapore
- Contact: WIPO GREEN Database

Space heating and cooling: elastocaloric green cooling device

Hong Kong University of Science and Technology (HKUST)



Source: Hong Kong University of Science and Technology

Researchers at the Hong Kong University of Science and Technology (HKUST) have built a kilowatt-scale elastocaloric cooling device. It cools indoor air from 30–31°C to 21–22°C in just 15 minutes. This is the first elastocaloric system to reach power levels suitable for commercial air conditioning, exceeding the previous 260-watt limit. The device connects 10 small cooling units in series, using only 104.4 grams of nickel-titanium alloy. These tubes have a high surface area, which improves heat exchange. It also uses graphene nanofluid, which transfers heat 50% more efficiently than water. The system runs at a frequency of 3.5 Hz and a low pressure (<1.5) bar, achieving 1,284 watts of cooling power. Solid-state cooling technology based on the elastocaloric effect of shape memory alloys (SMAs) has zero greenhouse gas emissions and high energy efficiency potential. In tests, it successfully cooled a 2.7 m^3 model house in hot summer conditions, stabilizing indoor temperatures at 21–22°C. HKUST is working with industry partners to commercialize the technology.

- Contracting type: For collaboration
- Technology maturity: Horizon
- Technology level: High
- Place of origin: Hong Kong, China
- Availability: Hong Kong, China
- Contact: WIPO GREEN Database

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This Green Technology Book is a special edition developed for the EXPO25 in Japan.

With a focus on Asia and the Pacific, it showcases over 200 examples of significant energy technology innovations for climate change across key sectors of society, including households and communities in both urban and rural areas, public transport, hospitality and retail, agriculture, and fisheries.

A wide array of renewable energy and energy efficiency technologies are being developed, with many already available for use. These technologies are becoming increasingly crucial in an era of sharply rising energy demand, compounded by the growing impact of climate change on energy systems and infrastructure.

Adopting an end-user perspective, this edition focuses on practical energy solutions that can be implemented by cities, utilities, businesses, communities, and individuals in the Asia-Pacific region. It aims to bridge the gap between the critical need for energy technology solutions and their practical implementation in both developed and developing countries.

The Green Technology Book also serves as a matchmaking tool. Information about the featured technologies can be accessed through the WIPO GREEN Database of Needs and Green Technologies, where technology owners can be contacted directly and where needs and new technologies can be uploaded.