Using Digitalisation in Emerging Markets and Developing Economies to Enable Demand Response in Buildings

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Abstract

Electricity demand in buildings is set to grow strongly in emerging and developing economies, driven by rising living standards, improved energy access and widespread ownership of electrical appliances. This growth will mean not only an increase in average power consumption, but also in peak loads. If left unmanaged, these new loads can have significant impacts on the grid, threatening the security of electricity supply.

Smart use of electrical appliances could trigger additional efficiency gains and lead to lower overall energy consumption. When connected, some electrical appliances can also provide flexibility to the system by enabling the use of demand response. Digitalisation can thus transform new electrical appliances from burdens on the system to flexible load sources that help improve energy security. However, despite the potential of digital technologies for energy systems in transition, there are still many barriers to their development in emerging and developing economies.

This report explores how digitalisation in buildings can bring value to the power system using demand response. Best practices, case studies and policy recommendations targeted to emerging markets and developing economies are presented to help policy makers, regulators and system operators unlock the multiple grid benefits of deploying digital technologies in buildings.

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Background

Rising living standards and decarbonisation policies boost electrification of buildings in EMDEs

Electricity demand in buildings is set to increase strongly in emerging markets and developing economies (EMDEs) owing to rising living standards, greater energy access and widespread ownership of electrical appliances. Furthermore, decarbonisation and clean-air policies promote the electrification of heating and the phase-out of traditional biomass for cooking.

The IEA estimates that under the Stated Policies Scenario (STEPS), energy demand for cooling in EMDEs will rise nearly fourfold between 2021 and 2050, while for electric heating it will more than double. Most of the growth in global cooling demand will come from EMDEs, where air conditioner (AC) ownership is significantly lower than in advanced economies (e.g. 7% across Africa versus close to 100% in the United States). In countries such as India, where residential buildings represent one-quarter of national electricity consumption, air conditioners are emerging as the largest single source of energy demand growth in buildings.

This growth will mean not only an increase in average power consumption, but also in peak loads. Residential AC units especially cause electricity demand surges in the evening when people are returning home, and the huge demand fluctuations caused by more frequent global warming-related extreme temperature events are likely to place further strain on power systems.

If left unmanaged, these new loads can have significant impacts on the grid during peak consumption times, threatening electricity security. In Southeast Asia, for instance, space cooling could make up close to 30% of peak demand in 2040, compared with 10% in 2018.

Smart flexible-load management in buildings could minimise impacts on the grid and support system resilience

Smart use of electrical appliances could trigger additional efficiency gains and lead to lower energy use overall. The associated potential for energy savings is particularly significant in buildings, where widespread adoption of digitalisation could reduce energy consumption by 30 to 40%. When connected, some electrical appliances (e.g. for heating, ventilation, air conditioning and water heating) can also provide flexibility to the system by enabling demand response utilisation. Depending on the power system's needs, their loads can be shifted, shed or modulated upward or downward, contributing to peak load reduction and frequency regulation. Flexibility is commonly harnessed through smart meters associated with price signals (such as time-of-use tariffs) or by paying consumers directly to participate in demand response programmes.

Digitalisation can thus transform new electrical devices from system burdens into flexible load sources that help improve energy security. However, despite the potential digital technologies offer for power systems in transition, the additional costs are deterring investment in EMDEs.

While digitalised demand response strategies are more often explored in jurisdictions with advanced power markets, they can also have an important role in EMDEs where buildings sector electrification and distributed variable renewable energy (VRE) deployment is advancing rapidly.

Higher VRE penetration entails the need for new sources of power system flexibility. Smart buildings and connected devices, which optimise the use of demand response in a grid-interactive and energy-efficient manner, are therefore emerging quickly because their potential to mitigate the impact of new electrical loads on the grid and to better integrate VRE sources are being increasingly recognised.

In the ASEAN region, for instance, the number of smart buildings could exceed 4 million by 2026, a threefold increase from the 1.3-million fleet of 2021. In this fast-growing environment, policy makers should elaborate targeted digitalisation strategies to ensure that the right technologies are being deployed and are offering benefits at every level of the power system value chain.

Value of digitalisation

Consumers are taking a more active role in energy management

Applying digitalisation to flexible loads is a keyway to enhance future power systems, with the value for users and the system overall covering multiple dimensions.

The first dimension is **scalability** to any level of aggregation. Digital technologies and advanced data analytics enable the pooling of millions of distributed loads with diverse technical characteristics, allowing the system operator to use them as aggregated energy resources.

Various demand response programmes all over the world involve large pools of households equipped with smart meters, giving consumers the opportunity to reduce their power bills by lowering electricity consumption during specific hours/days. In the United Kingdom, more than 1 million households took part in the National Grid's demand response programme between November 2022 and March 2023, reducing power consumption by more than 2.9 GWh during grid-strain episodes in exchange for financial incentives.

Easy-to-handle consumer-facing applications or websites often accompany these programmes to enable participants to track their energy and cost savings. In France, the Ecowatt app acts as an electricity "weather" forecast and sends alerts to users to voluntarily reduce consumption on days of grid tension. Presenting a simple educational interface, the app has been downloaded more than 2.5 million times, with a sharp increase during the winter of 2022/23 when the power system was at risk. While no alert was issued during that period, RTE estimates that the signal would have helped reduce evening peak demand by up to 5 GW.

Introducing automated alert-sending systems could also be considered in EMDEs to help avoid or shorten power outages. Consumers would receive mobile phone notifications asking them to curtail consumption when power loads spike.

Digital technologies can unlock a wider range of grid services

Another dimension of the value offered by digitalisation is **controllability** of connected devices, which allows consumers to manage their electricity consumption when it would otherwise be largely outside of their control. System-wide, the ability to remotely control flexible loads helps ensure distribution grid reliability.

Furthermore, the new flexibility services offered by controllability can be monetised, creating additional revenue streams for grids and energy utilities. It is necessary, however, to have conditions in place to aggregate end-user flexibility. For instance, virtual power plants operated by service providers are an increasingly widespread digital solution to aggregate distributed generation, storage and demand response to function as a single resource from the grid's perspective.

In Australia, a pilot virtual power plant project involving 1 000 households reduced peak demand by as much as 27% and led to 30% savings on participants' energy bills. Virtual power plants thus have considerable potential to emerge in countries where distributed generation is being deployed rapidly (e.g. India and the People's Republic of China [hereafter "China"], where many projects are being demonstrated).

Automated demand response, wherein utilities directly control loads on the consumer side, is also an option. In developing countries where voltage fluctuations are a common issue, smart meters can help improve power quality by automatically cutting off electricity supplies during excessive fluctuations, extending the lifetime of electrical appliances.

Digitalisation makes data on behind-the-meter resources accessible

Digitalisation also offers users and operators greater **visibility** over the system. Technologies such as smart meters and distributed energy resource management systems enable close monitoring of the energy demand of behind-the-meter resources.

Data collected by smart meters can provide more visibility over low-voltage networks, revealing end users' load patterns and increasing consumers' awareness of their own consumption. For instance, India's eMARC initiative was designed to inform policy makers and distribution companies on residential household electricity consumption, with corresponding data made available through online dashboards.

Going one step further, learning algorithms can leverage data to predict consumer behaviour, using lifestyle factors to develop tailored load control strategies to avoid unnecessary energy use.

Using digitalisation in buildings

Smart HVAC systems provide considerable demand-side flexibility in buildings

Heating, ventilation and air conditioning (HVAC) systems are the most promising source of demand response in commercial and residential buildings. While they claim a significant share of the electricity consumed in buildings and of peak electricity demand, they can be thermostatically controlled without significantly affecting occupant comfort, provided that the building is sufficiently insulated or thermal storage solutions are in place.

Devices that introduce cyclical loads into a power system (e.g. heat pumps and air conditioners) can be curtailed or adjusted to lower or higher temperatures for short periods (from several minutes to a few hours) to provide loadshedding and fast frequency response, operating reserves, and other services to the grid. Pre-heating and pre-cooling strategies enable load-shifting by leveraging a building's thermal inertia.

Establishing flexible HVAC system operations can be done either statically under pre-set operational patterns, or more dynamically through digital technologies within a building's energy management system. Sensors, thermostats and microcontrollers on heating and cooling devices connected to the energy management system permit both electricity consumption and user comfort to be maximised according to many parameters (room occupancy, preferred temperature and solar panel output, when applicable). Meanwhile, smart meters allow HVAC systems to react automatically to external signals (prices and weather data).

Smart AC systems are particularly relevant for countries subject to prolonged high temperatures. In China, for instance, the IEA estimates that, compared with only AC efficiency and building design improvements, deploying connected and responsive AC units could help reduce energy consumption an additional 15% on a summer weekday in 2030. In fact, real-life examples of connected AC equipment being operated under demand response programmes have demonstrated their ability to reduce stress on the grid during heat waves without noticeably affecting consumer comfort.

Digitalisation can also help mobilise flexibility from heat pumps. Through the decarbonisation of heating, the growing share of heat pumps in buildings could be a significant flexibility resource, and numerous pilot projects using connected devices are already being deployed across various countries.

Among them, the ViFlex project in Germany demonstrates how the flexibility of heat pumps can be aggregated within a virtual power plant to manage grid congestion. In addition, air-to-water heat pumps that optimise their operation according to weather data and anticipated distributed PV production are becoming commercially available.

In countries where market-based price mechanisms are not (fully) in place, the system operator can still use connected devices to implement direct load control strategies for HVAC systems. In this case, activation is triggered by a system's technical constraints, for instance when demand reaches a certain threshold or when grid congestion occurs.

For regions where cooling demand usually leads to peak loads during the summer, using a simple communicating thermostat can provide economic and environmental benefits while minimising user discomfort. This was demonstrated in a case study of direct load control of residential AC units in the Indian state of Karnataka.

Other electrical loads in buildings can also be flexibly operated using digital technologies

Buildings also house various deferrable-load appliances such as electric resistance water heaters and white appliances (washing machines, dryers, dishwashers and fridges) for which energy consumption can be shifted to a different time of day.

Load control of water heaters subject to a time-of-use tariff is now widely used in some countries. In France, for instance, over 80% of water heaters automatically shift their charging to off-peak hours without impacting consumers. While most of the flexibility potential of water heaters can be harnessed using a simple static signal, dynamically controlling their recharge with smart meters is promising in systems with high VRE penetration and for solar panel-equipped dwellings seeking to optimise their output.

Moreover, as smart meters allow water heater charging to be controlled remotely in case of stress on the electricity network, the French distribution system operator was granted exceptional authorisation to temporarily suspend charging for customers subscribed to time-of-use tariffs during the winter of 2022/23. Water heaters can also be controlled to provide ancillary services such as fast frequency response.

Plus, smart meters offer new options to defer the power load of washing appliances by a few hours. For white appliances, demand response often involves consumers under a time-of-use tariff scheduling appliance operations through a manual relay. However, with smart-enabled equipment, the user can define a maximum time at which the washing/drying cycle must begin, which then presents a flexibility window to optimise the appliance's start time to minimise energy costs. Provided that flexible-load schemes and technologies are not too complex and fit user lifestyles, households do tend to shift consumption to more grid-friendly hours.

Communication devices and smart metering can also be used to control commercial and residential refrigerator power loads, thus providing ancillary services to the grid. In this configuration, a thermostat maintains interior temperature within a certain range to guarantee food safety, and triggers overcooling cycles when it receives low-price signals to reduce consumption at peak hours. These strategies are still at the exploratory stage but have potential for certain commercial buildings such as supermarkets.

Various strategies also exist for on-demand consumption such as for lighting, cooking and IT devices within a building's energy management system: modulating lighting according to time of day and a user's preferences; switching cooking appliances to function during off-peak periods; and turning off idle electronic devices when left unused. However, deployment of these solutions is highly subject to consumer acceptance.

Case study: India

Digitalisation in buildings improves flexible energy demand management

In 2022, AC use during a historic heat wave caused an unprecedented spike in electricity demand in India, and further electrification and urbanisation could exacerbate power demand surges in the future. In fact, the IEA estimates that the buildings sector's share in India's electricity consumption will rise from one-quarter today to roughly half by 2040 in the STEPS scenario, mainly owing to an increase in the number of cooling appliances. The need for more efficient and smarter equipment is therefore urgent.

Digitalisation can enable Indian consumers to use flexible loads more cost-effectively and in a more grid-friendly manner, taking market and weather conditions into account. With digital technologies, the operational patterns of flexible loads can be optimised to avoid summer peaks. For instance, heat pump water heaters managed by a smart controller can preheat water to shift evening power demand to off-peak periods. Our case study thus assesses the benefits of digitalisation in India's buildings sector.

To illustrate the impacts of flexible resources in India's future power system, we modelled several different cases in the context of the *World Energy Outlook*'s Announced Pledges Scenario (APS) for 2030 using the IEA's India Regional Power System Model. The APS includes all recent major national announcements as of September 2022 for 2030 targets as well as longer-term net zero and other pledges. We consider space heating, space cooling, water heating and other home appliances in the buildings sector as flexible loads.

Three cases are presented for 2030:

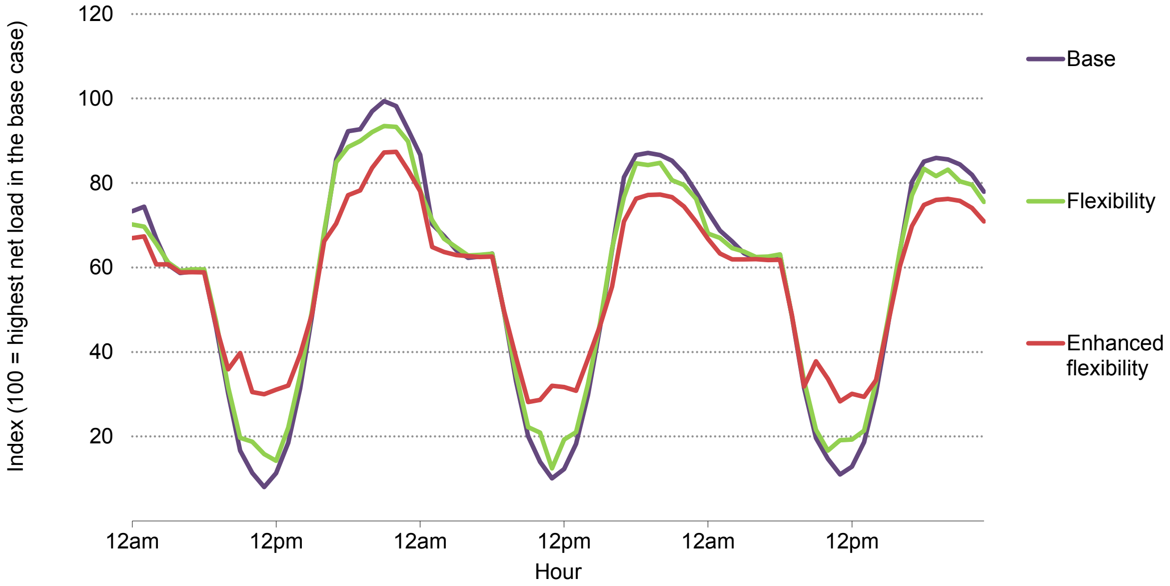
- a "base case," in which electrical appliances operate under a fixed operation pattern.
- a "flexibility case," in which digital technologies determine the operational patterns of electrical appliances, considering market conditions. We assume one-hour flexibility for heating and cooling.
- an "enhanced flexibility case," in which digital technologies enable electrical appliances to have more extended and larger-scale demand shifting than in the flexibility case (e.g. pre-cooling and pre-heating). We assume five-hour flexibility for heating and cooling.

Our model shows that by using digitalisation and flexible-load strategies for buildings, the net load (total load minus solar and wind generation) would have smaller peaks, reducing the effect of events such as those recorded in 2022.

India's net load curve for 2030 shows a peak during summer evenings due to rising cooling demand in the buildings sector, while at the same time massive solar PV deployment creates a deep net-load trough in the middle of the day. As the table below illustrates, using digitalisation enables the shifting of flexible loads to off-peak hours when solar energy production is abundant.

The enhanced flexibility case indicates an approximately 13% reduction in highest net load and a raising of lowest net load compared to the base case. Flexible operation also decreases VRE curtailment, which in turn helps curb fossil fuel use and cuts operating costs by around 4%. Thus, more flexible demand management through digitalisation in buildings helps limit the steepness of net load ramping and reduces power system operational costs.

India net load curve of sample days in summer in the Announced Pledges Scenario, 2030



Note: Net load refers to total load minus wind and solar PV generation.

India indexed net load values, variable renewable energy curtailment and operational cost reductions by flexible-load operational pattern in the Announced Pledges Scenario, 2030

	Highest net load	Lowest net load	VRE curtailment reduction	Operational cost reduction
Base case	100%	1.3%	-	-
Flexibility case	95%	3.4%	54%	2.2%
Enhanced flexibility case	87%	16%	78%	3.8%

Notes: Highest net load and lowest net load are indexed to the highest net load in the base case. This analysis does not consider additional energy consumption increases incurred by the demand shift and it does not take additional costs associated with the deployment of digital technologies into account. Operational costs include fuel costs, startup and shutdown costs and other operations and maintenance costs.

Policy

Although the potential benefits of digitalising flexible-load management are enormous, many barriers to development still exist in EMDEs. The obstacles are technical (lack of access to smart devices, the Internet, or even grid connection); regulatory (unfavourable market conditions and retail tariffs); financial (high cost of capital, indebtedness of utilities); and human (lack of qualified staff). EMDEs should therefore develop policies that leverage the experiences of advanced electricity markets while taking into account their own development challenges to encourage cost-effective digital technology uptake.

Infrastructure-side interventions

The precarious financial state of energy utilities, along with inadequate network planning and a high cost of capital (generally higher in EMDEs than in advanced economies) mainly explain the lack of investment in digital infrastructure. Furthermore, the structure of utilities (unbundled, regulated single buyer with private generator fully integrated) and the role granted to the private sector often condition investment flows towards distribution grid modernisation.

For instance, national utilities struggling with cost recovery in many sub-Saharan African countries lack the incentive to invest in capital-intensive smart-grid projects, as policies promoting competition and economies of scale in the distribution sector are insufficient. Moreover, because of cross-subsidisation, fears of income loss and off-grid defection can make energy utilities reluctant to promote demand response programmes to their high-paying consumers (industrial or commercial) and to expand distributed energy generation resources.

In particular, the lack of large-scale smart metering hinders the implementation of effective demand-side management schemes. The IEA estimated that EMDE investments in smart meters totalled less than USD 2 billion per year over the past five years, when advanced economies were spending over USD 10 billion annually. While several countries have well-established plans to deploy smart grid infrastructure and have initiated large smart meter rollout programmes, upfront investment costs are still a major barrier for many EMDEs.

Large smart meter rollout initiatives in several developing economies

China	India	Brazil	Malaysia	Brunei Darussalam
Completed deployment of 500 million first-generation smart meters in 2017	Plans to replace 250 million conventional meters with smart meters by 2025 under the Smart Meter National Programme	Started deploying 300 000 smart meters in São Paulo	Plans to install 9.1 million smart meters in Peninsular Malaysia by 2026	Plans to install smart meters in 200 000 homes and commercial buildings by 2026

Sources: IEA (2021), Energy Efficiency 2021; IEA (2022), Energy Efficiency 2022.

Recommendations

Keeping the world on a pathway to net zero emissions by 2050 would require a fourfold increase in smart meter investments in EMDEs by 2030 compared with 2020. There is a need for low-cost solutions designed specifically for developing countries where smart grids have yet to be deployed. However, prioritising limited advanced services could make it more difficult for countries to leapfrog to state-of-the-art technologies. In regions where Internet availability and quality is still an issue, communication between connected devices through the telephone network could be considered.

Governments should assist with the upfront costs of smart meters, and it is essential that regulators allow utilities to incorporate infrastructure modernisation and digitalisation costs into network tariffs. Furthermore, utilities and regulators should keep their financial outlay as low as possible by prioritising the digital technologies most relevant to their power system and promoting cost-effective deployment.

To encourage stakeholders to take a long-term view of smart meter development, rollout roadmaps need to be developed and minimum characteristics standardised. Roadmaps can also support tendering programmes for bulk procurement of smart grid infrastructure as part of a far-reaching vision for future electricity networks.

Rate design improvements

Harnessing the benefits associated with digitalising flexible-load management depends not only on the availability of infrastructure and smart devices, but also on regulatory and market conditions. However, with electricity prices and markets still regulated in most EMDEs, the economic value of such digital solutions is not fully obvious.

In many developing countries, inflexible rate structures shield consumers from price signals and therefore do not incentivise demand response. In India and China, while time-of-use prices exist for commercial and industrial sectors, residential consumers are subject to a tiered/block tariff (i.e. rates change depending on the amount of energy used), giving them no incentive to shift their consumption to non-peak hours.

In Brazil, while several time-of-use tariffs are in place (such as the white tariff since 2018 for low-voltage consumers), they have not yet been widely adopted and are not well matched to consumer load patterns, with on-peak periods often not corresponding to the system's actual maximum load. Moreover, smart meters must already be in place to enable consumers to opt into dynamic pricing schemes, leading to a chicken-and-egg situation.

Recommendations

Regulators should be encouraged to develop flexible rate designs that allow consumers to take advantage of demand response opportunities. Prioritising consumers subject to these tariffs (starting with the largest consumers ahead of households, for instance) will enable the gradual establishment of demand response programmes. As introducing more flexible tariffs would expose consumers to price signals, policy makers should aim to ensure affordability and protect the most vulnerable power users.

In addition, a market-based approach such as a local flexibility market provides appropriate incentives to enhance utilisation of demand response. Market operators should, however, take an economy's technical capacity into account when defining market products and technical requirements for demand response. A well-coordinated market and flexible rates will ensure appropriate remuneration for market participants.

Consumer-side interventions

While efforts are increasingly being made to improve the energy efficiency of appliances and buildings in EMDEs, the benefits of digitalisation have not yet been widely acknowledged. This explains the deficiency (or non-existence) of policy programmes to support the manipulation of flexible loads to implement demand response systems, and the lack of technical expertise in this area among skilled workers. On the consumer side, a lack of awareness inevitably leads to low acceptance and, hence, hesitance regarding the additional upfront costs associated with digital technologies.

Technology-wise, the lack of an effective data exchange system and of interoperability among distributed behind-the-meter resources have created a major bottleneck. Without the free flow of information and common technical standards all along the power system value chain, distributed resources have limited visibility, which prevents proper load management and cost-efficient decision-making.

Recommendations

Governments can subsidise the additional upfront costs associated with digital systems to encourage consumers to deploy advanced technologies, and they could also consider schemes to reward consumers for participating in demand response programmes in conjunction with power market deregulation. Additionally, awareness campaigns targeting commercial and residential consumers can help highlight the benefits associated with digitalisation and lead to wider acceptancy.

Regulators should work with transmission and distribution system operators to define standards and protocols to ensure the visibility and interoperability of flexible loads. To realise the full potential of digitalisation, common technical standards must be applied along with energy efficiency standards.

Ensuring the quality and uniformity of consumer equipment will guarantee system readiness for demand response while increasing energy efficiency. For instance, appliance replacement programmes such as the one implemented in Mexico ensure that newly installed appliances are more efficient and smart-enabled. Learning from past experiences in designing and implementing standards can be beneficial.

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