# SUSTAINABLE ENERGY MANAGEMENT IN SMART HOMES: A REVIEW OF CURRENT TECHNOLOGIES AND PRACTICES

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## ABSTRACT

In this paper, the present status of the green technology, which gained great popularity a few years ago, but has been designed more with specialized applications characterized as "sustainable energy management in intelligent homes", and the main technology, implementations and challenges for providing both decreased energy consumption and reduced environmental impact are reviewed. Given that the demand of energy services is rising in the world and so does the urgency of various forms of sustainability at this very moment, intelligent homes provide innovative solutions through the integration of energy efficient technology, intelligent automation and renewable energy sources. Instead, the review is concerned with technologies like smart meters; Home Energy Management Systems (HEMS); energy efficient appliances; and uses of Renewable Energy solutions for instance harnessing the wind turbine or solar panels. Furthermore, artificial intelligence (AI)'s and machine learning (ML)'s role in the prediction and real time adjustment of energy use is elaborated upon. However, as much as yours and our hopes, there are a few obstacles to the broad adoption of intelligent homes. However, these include high initial costs, potential interoperability challenges, data privacy issues, supportive regulatory frameworks, and so on. It offers us a forward look of what lies ahead at the horizon; what will be the future trends on 5G access networks, block chains for energy transactions, vehicle to grid (V2G), and how energy storage technologies will turn out to become a mean for integrating various power grids. Instead, a final end result that seems unnecessary is what one should be able to derive from a complete summary of research frontiers and challenges associated with these trends.

## INTRODUCTION

Due to energy consumption and energy use efficiency problem and also climate change, lately, a large amount of attention has been devoted to achievement of sustainable energy management in smart homes. It optimizes the deal with high technology, for example, automation framework and energy effective massive appliances which gives comfortable living uses and less power utilization with it. Secondly, these houses are convenient to the homeowners and additionally, they have resulted in reduced environmental impact and increased energy efficiency of residential buildings.

Smart homes incorporation are based on principles of sustainable energy management through reduced waste, low cost and improving the environment sustainability. The rising dependence on renewable energy and progressing world towards decarbonization has made smart home an important player into achieving the energy goals. Smart meters, sensors and energy management systems that enable the real time monitoring of how much energy is being used and how to better control electricity use including being able to integrate with renewable energy such as solar panels or wind turbines (EDEM report 20114). Furthermore, energy storage systems and demand response programs are also involved to optimize the energy management ability (Zhao et al., 2020; Muntean et al., 2021).

In recent years, many advancements have been brought upon by the use of Artificial Intelligence (AI) and Machine Learning (ML) algorithms that have improved the decision making of the smart homes and therefore they are capable of doing predictive energy management. These technologies can be used to for forecasting energy needs by analysing historic data, which has the potential to optimally assist in utilising appliances and HVAC systems for optimum efficiency (Zhao et al., 2020). Besides, these systems are able to work based on the user behavior pattern and learn user habits of living and work in accordance with it without going to the sacrifice of its comfort (Gungor et al., 2018).

That aside, it is clear that smart homes will become more important towards achieving the sustainability targets as governments and regulatory bodies put into place policies to push for energy efficiency. Integrating renewable energy sources, energy storage solutions and smart grid technologies in smart homes in the background, can help pave the road to a more sustainable and more resilient end (Chien et al., 2021). I would like to study the latest technologies and procedures of the sustainable energy management in smart home in terms of the energy efficiency, renewable integration, etc. in this review.

**Problem Statement:**

Energy management practices have reached the climax of advancements with the quick rise of smart home technologies together with the increasing demand for sustainable solutions of energy infusions. To date, the smart home has become to be so popular on a large scale but energy efficiency, renewable energy and realtime monitoring systems of energy management for the home are not integrated in a complete way. Additionally, much of the present studies target the isolated facets of energy management, without regard to the overall matter of the integration of AI, IoT and user's behavior in decreasing an energy use. In order to fill in the research gaps, the paper calls an integrated review of the possibilities of technologies, practices and the trends of implementation of sustainable energy management in the smart homes, which would be focused at the feasibility of implementation, energy consumption reduction and the reduction of negative environmental impact.

**Objectives of the Review:**

1. You may also explore some of the other types of the energy management technology used by the smart home including smart meters, sensors, and energy efficient devices.

1. Examine the methods of utilizing renewable energy, for example, solar panel and wind turbine in the smart home system.

3.Enable energy users to participate in the process of identifying how artificial intelligence and machine learning can reduce energy consumption and make forecasts of energy consumption in smart homes.

1. Determine what energy efficiency trends are emerging and what that means to their ability to estimate the value of storage and demand response programs.

IV. Determine cost, technical and user awareness barriers impacting wide spread adoption of residential sustainable energy practices.

**Research Question(s):**

1. What are the current technologies and systems used for energy management in smart homes, and how effective are they in improving energy efficiency?

2. How can renewable energy sources be integrated into smart homes to optimize energy use and reduce reliance on conventional energy grids?

3. In what ways can artificial intelligence and machine learning contribute to better energy management and predictive maintenance in smart homes?
4. What are the challenges and limitations faced by smart home owners and energy managers in implementing sustainable energy practices, and how can these be overcome?
5. What are the emerging trends in smart home energy management, and how can they shape the future of residential energy consumption?

**Smart Homes and Sustainable Energy Management**

Smart home is one of the key elements of sustainable energy management, a home that is a combination of luxury, security and comfort for its residents and is equipped with the latest technology for use of low power consumption. When the IoT devices, the automation systems and the renewable energy sources are integrated, the reduction in the energy waste and promotion of energy use efficiency in residential sites depends on it. As the demand for energy efficiency is increasing, smart homes can give an answer, not only to meet the needs of the dwellers, but also the broader sustainability goals, in which the added carbon footprints being mitigated and support the integration of the renewable energy.

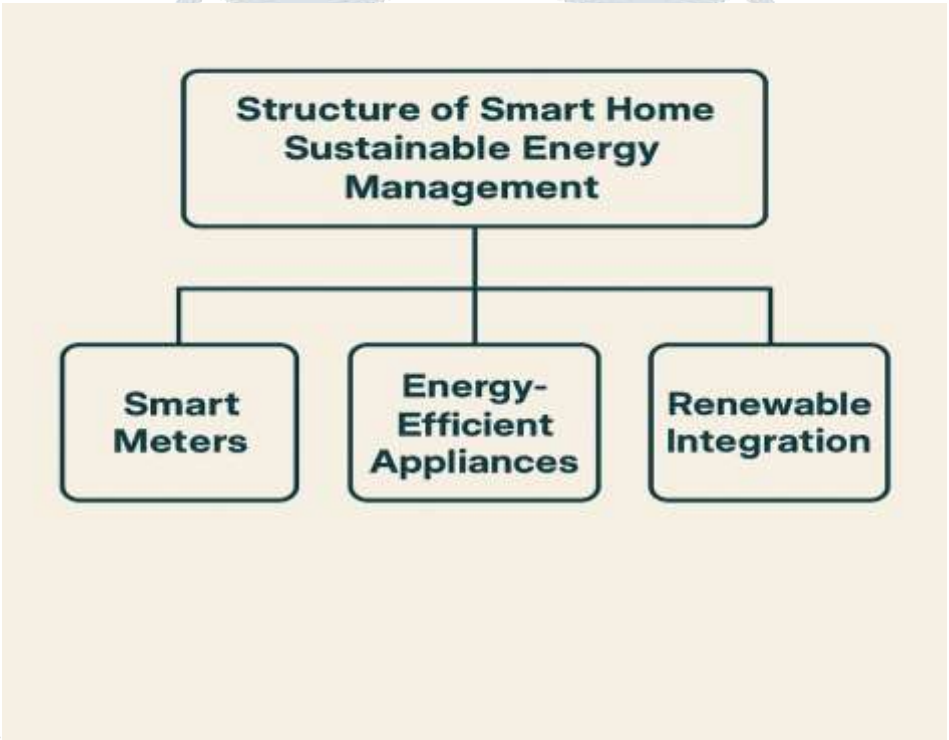
Using advanced energy monitoring and control systems is one of the important components for sustainable energy management in smart homes. There functions are able to collect and record the data as well as analyse the house hold energy consumption in real time, therefore, it is possible for the users to make decision regarding how they can use energy. The smart meters, energy management platforms and IoT sensors allow residents to check their energy consumption pattern and identify energy waste to adjust their settings to the limit wastage. Candanedo et al., (2016) and Liu et al., (2020) consider such technologies as crucial in order to bring about a dynamic building that can react to the shifting energy requirements as in real time and reduce dependency on the traditional energy grids.

These energy sources are not only sustainable but also when integrated in the smart home system, the spectrum of residential energy management is extended. Moreover, smart homes can be less reliant on non renewable energy sources, as well as positively contribute towards enhancing the status of the entire energy network, by generating their own self clean energy on the premises. They can also store energy produced by renewable sources that surpass the energy requirement of the smart homes and stores energy in the form of batteries for later use thereby reducing the energy consumption on an overall basis and less dependency in using electrical energy from grids during peak hrs (Fang et al., 2020).

The artificial intelligence (AI) and machine learning (ML) technologies are dramatically helping the optimal energy consumption in smart homes. On such technologies can be run predictive analytics that predict the household energy needs before time using historical data and user behavior, and weather patterns. Also, AI systems can intelligently adjust heating, ventilation, and air conditioning (HVAC) system to achieve comfort without any waste in energy

consumption. The application of AI or ML technologies further helps with the demand response programs (i.e., changed power usage as per the currently price by the utility) and controls the energy load to prevent grid overload (Zhou et al., 2020).

With such promising potential that smart homes possess, however, a few challenges still exist within sustainable energy management. Smart home systems and renewable energy solutions can be financially cost prohibitive for an average owner when factoring in installation costs. Additionally, issues need to be addressed related to the emergence of technical hurdles that prevent utilisation of various technologies, and guaranteeing privacy of data, and interworking of different devices. This study's learnings can also be applied in building public awareness and education on the advantages of smart home technologies and eco friendly energy practices due to their role towards increased adoption (Fong et al., 2019)

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Smart homes are an emerging concept which integrates energy efficient technologies, works for the renewable energy integration and also advanced automation for the energy saving in terms of sustainability and economic advantage. As with each advance in technology, slowly smart homes shall turn into an obstacle barrier within reaching and the potential for smart homes to be integral to the fight for the sustainable development goals of the world is surely big.

**Current Technologies in Sustainable Energy Management in Smart Homes**

Advanced technologies integration is key to the efficient use of energy in the smart homes, to energy efficiency and sustainability. Some key technologies used to promote sustainable energy management in smart homes are as follow:

**1. Smart Meters and Sensors**

Smart meters are the most prevalent form of energy management within smart homes as they allow real time readings of energy consumption. These are more accurate electricity measuring devices than traditional meters and have two way communication with utility grid. Smart meters collect data regarding the patterns of energy consumption and

allow consumers to monitor the amount of energy they are using, spot inefficiencies and choose the best practices of energy saving. Additionally, sensors in combination with smart meters allow the monitoring of different energy parameters like temperature, humidity and occupancy and thereby make it possible for the system to adjust and save energy (Xu et al., 2020).

**2. Home Energy Management Systems (HEMS)**

The development software is the Home Energy Management Systems (HEMS), a platform composed of software for the control, monitoring and optimization of energy consumption of a smart home. These systems tie together a plethora of smart devices including, lights, HVAC, and appliances, into a single network. Typically, HEMS obtain the data from smart meters and sensors in order to analyze the energy consumption patterns and make predictive or real time adjustments to enhance the energy efficiency. Also, some systems can be integrated into renewable energy sources, for example solar panels to manage the energy storage and distribution (Zhao et al. 2020).

**3. Energy-Efficient Appliances**

A home is energy efficient if it achieves the optimum degree of energy saving by using energy efficient appliances for kitchen facilities; refrigerators, washing machines and HVAC systems etc. This means these appliances are made with the intention to use less energy at the same level of performance. Many of these devices are IoT enabled thus providing capability to fetch data from HEMS for better management of energy. For example, smart thermostats can adjust the temperature of a room according to real time data of sensors and learn the preference of the occupants to optimize heating and cooling cycle (Taneja et al., 2020).

**4. Renewable Energy Integration**

The sustainable energy management in smart home is the integration of the renewable energy source such as solar panels, wind turbine and geothermal systems. Using solar panels, smart homes can produce low carbon on site power and cut the greenhouse emissions and grid load. In addition, energy storage systems such as lithiumion batteries are capable of storing every surplus amount of energy generated from such renewable sources, for use at a later time. The storage capability alleviates the intermittent nature of the renewable energy as it is distributed power capable of providing reliable power supply. With smart homes, AI based algorithms can be used for optimization and consumption of renewable energy, directing stored energy to major devices during peak hours to avoid the need of pulling electricity from the grid (Fang et al., 2020).

**5. Demand Response and Dynamic Pricing Systems**

Electric utilities can use smart homes in DR systems, for example, to control the demand energy from such homes during peak periods. Utilities are also able to shift the demand to off peak hours by communicating real time pricing signals or control energy use remotely in order to prevent overload and ensure the stability of the grid. The operation of non-essential appliances can be delayed or reduced automatically in a smart home equipped with DR systems once energy price becomes high. It not only saves consumers' energy costs but also nurtures a balanced and sustainable energy grid (Ardakani et al., 2021).

**6. Artificial Intelligence (AI) and Machine Learning (ML)**

In the smart homes, they also utilize Artificial Intelligence and machine learning algorithms to predict the energy needs and also manage it optimally. Utilizing AI systems combined with historical data, weather forecast and user behavior historically, the parameters of the appliances, lights and HVAC systems can be fine tuned in real time, so as

to be in accordance with the behavioral profile of the house for optimal performance. In other words, specifically, they make homes 'smart', allow for the manipulation of energy consumption patterns without human interference, and consumption of energy below what is required to maintain comfort (Zhou et al., 2020).

**7. Smart Grids**

In addition, electricity has good distribution in smart grids in cases where digital communication technology used in it is enhanced in the field of monitoring and control. In smart homes combined with smart grids, the electricity can be flowed both from the home to the grid and vice versa which allows us to have best loads balance and improving the energy efficiency. A smart grid system is a system that is able to offer realtime energy usage data and dispatch energy more efficiently and to help incorporate more renewable energy sources into the system. Furthermore, the dynamic pricing models of smart homes are also easy to be enabled by the utility companies to allow the owners of smart homes use their energy usage flexibility in real time conditions.

**8. Energy Storage Systems**

The excess energy generated from renewable sources, or during the low cost and/or off peak, is utilized to power home battery units and other kinds energy storage devices. By guaranteeing that energy is available at the time it is needed most, in high demand hours or periods of low renewable generation, these systems offer opportunities for system operators to better integrate several types of energy sources. Solar energy, for example, of sunny days can be stored in a battery for the night time use. The smart home's energy management system is also stabilised with the aid of the energy storage systems to reduce reliance on the grid**.**

**HOME ENERGY MANAGEMENT SYSTEM**

A Home Energy Management System (HEMS) is a digital system that monitors and controls the production, storage and consumption of energy accompanied by a household. Typically, HEMS strives to optimize for objectives e.g. the reduction of cost, maximization of self sufficiency and reduction of emission. All these factors make HEMS increasingly popular as the potential saving increases with the growth in adoption of electric mobility and heating, residential PV, as well as with dynamic tariffs.

**Typical assets**

- **Photovoltaic (PV) -** PV system (or rooftop solar) is usually the starting point of the HEMS and enables households to be free from the grid (and the changing electricity price) and consume the locally generated electricity for the energy asset in their home. The main components employed are an inverter that turns the solar energy into usable energy for home appliances.

- **Battery -** With respect to solar energy, this can help in storing surplus power when the sun is shining and using it later when it is required.

- **Heat pump -** a heat pump is an electricity powered highly efficient heating device that extracts heat from an external source rather than producing it. And, because it is powered by local PV, it is becoming a popular element of HEMS.

- **Electric vehicle (EV) -** Another flexible energy-consuming asset is the EVs. Since they normally sit for a long amount of time, their charging can be delayed until time when either solar generation output is high or electricity prices are low. The HEMS must be linked with the car through a wallbox or any other smart EV charger.

- **Smart meter -** important element of HEMS is a smart meter which provide real time information about household consumption.
- **White goods** - lifestyle products for home such as washing machine and fridge can also be controlled intelligently to save up the electricity they use up.


**Technical requirements**

To implement a HEMS, there are certain technical requirements that must be met, to ensure seamless and consistent functioning of different distributed energy resources (DERs);

- A stable and reliable internet connection securing proper communication between the energy management system (EMS),server and each energy device would be beneficial but a local network would suffice
- A local gateway typically in the form of a central control unit, like our gridBox, that optimizes energy flows on site. Cloud-based energy management is also possible without a local gateway, however, this is less prevalent and has increased latency.
- Software and applications compatible with the hardware to control, monitor and access the DERs in a household.

**Goals**

The goal of a home energy management system is to cover the energy demand of a household while minimizing costs and/or emissions. Typically, a HEMS reduces costs and emissions by maximizing the utilization of renewable energy as it aligns consumption with times when renewable energy is available.

**Use cases**

As every household is different, needs differ from household to household. The use cases and applications can hence vary according to the specific demand. The setup of Home Energy Management Systems can be simple and involve a couple of assets, but grow this list further in order to add more savings.

- **Monitoring** – obtaining real time data and visualization of the operational behavior, site specific details and status of all the connected assets.
- **Self-sufficiency optimization** – Minimizing costs and emissions through maximizing self generated power to power the remaining assets in a home.
- **Time-of-use tariffs (ToUT)** – allows shifting the electricity consumption of connected DERs, for example, heat pump, and electric vehicles to low price times.
- **Flexibility Marketing** – In situations where there is excessive power stored in the battery, match the flexibility of the asset and the flexibility of assets by feeding energy back into the grid given electricity price and grid capacity variations.
- **Larger use cases** - HEMS is the scaled down version of energy use cases that are larger now and their future i.e. in smart districts (energy is connected and optimised over a larger area), in virtual power plant (flexibility of multiple energy assets is put together and monetised by participating in wholesale market) or energy communities (energy is shared through peer to peer trading)..

## CHALLENGES AND BARRIERS TO IMPLEMENTATION

However, several challenges and barriers still stand in the way of the widespread implementation of the smart homes that have this potential of promoting sustainable energy management. The second significantly thorny difficulty is a too high initial installation cost. Smart home technologies such as energy efficient appliances, renewable energy systems and home energy management systems (HEMS) are types of smart home technologies that are often expensive (upfront) and prohibitive investments for many homeowners unless there are financial incentive and or subsidy available to them in their regions. But the cost barrier that exists is too high to allow for adoption, and in particular by middle income households.

The problem with creating a system of diverse technologies is one of complexity. The reality is that most smart homes are a combination of interconnected devices (smart meters, sensors, smart systems of renewable energy, storage et al). Interoperating all these devices, how they work together could be a technical challenge, as it's not guaranteed that they work with other devices or systems from different vendors. Due to the fact that there are no standardized

protocols, the integration can have some complications, and it may result in some inefficiencies or in a worst case it causes the malfunction of the energy management system.

Primary access is blocked by data privacy and security concerns as well. Since smart homes monitor energy use, status of appliances and even many household activities, it generates trove of data. In case this data is not properly secured, the data is used as a threat for cyber attacks and unauthorized access. Smart home technologies might be met with reluctance by homeowners if they think that their personal data is not safe but can potentially be misused. To strengthen the existing robust cybersecurity measures and transparently managing data on these technologies to ensure trust for these technologies.

The last component includes educational and public awareness aspects that are still critical challenges. The fact that there are many consumers who are still unknowledgeable with the benefits resulting from the functionalities of smart home systems has contributed to the misconception or unwilliness of consumers to invest in those technologies. Despite the lack of knowledge about the smart homes, their related energy efficient practices and the potential savings, the smart homes are not widely adopted. On the other hand, in areas where awareness is not present in general, the governments, power suppliers and the rest of the concern bodies are expected to teach the population about the future benefits of such integrations.

Second, technological change frequently outruns its regulatory and policy definition. There are many countries that have no codes, incentives or regulations which match with the standards for energy efficient integration of renewable energy. While the guidelines are lacking or the incentives are not provided for integrating renewable energy systems and energy storage in residential buildings, the adoption of these green technologies can be hindered. The combination of technological developers, policymakers, and consumers in designing an ecosystem that facilitates the inclusion of smart homes in the use of sustainable energy management practices is the best approach to solving the above challenges.

## CASE STUDIES AND APPLICATIONS

It has been proved in several case studies all over the world that smart homes have the resulting potentiality to stimulate energy management in a sustainable manner. The first is a series of real world applications that employ combination of these new technologies and strategies to optimize energy consumption, decrease costs and lessen environmental impact. Few noteworthy case studies and applications of how sustainable energy management could be used in smart homes are given below among other such examples.

### 1. The Energy Hub Project – United Kingdom

The Energy Hub is conceptually a visionary idea for smart homes within a circular, lower impact energy system in the United Kingdom. The aim of the project was to reduce the energy consumption of the buildings set in the various types of housing structures with the help of smart meters, home energy management systems, and renewable energy sources. Data was collected in real time from smart meters that were used in the project so that the homeowners can monitor their energy demand patterns and be able to optimize the use of their energy efficient appliances. Finally, components such as solar panels and battery storage systems were integrated to produce and store renewable energy on the homeowners' houses, in order to make them less dependent on the national grid. However, Energy Hub demonstrated that it is feasible to integrate IoT connected devices using renewable energy resources in order to achieve substantial energy savings and decrease the carbon footprint (Hargreaves et al., 2018).

**2. Masdar City – Abu Dhabi, UAE**

Masdar City in Abu Dhabi is a fine example of a sustainable urban development project which aspires to be one of the most exciting examples of such a project: a sustainable urban development project geared around renewable energy sources, smart technology and renewable energy management. The smart home systems of the city are up to date; it uses its home appliances such a manner that it allows the citizen to use his energy efficiently. Masdar City, is the first such development in the world and is comprised of smart homes, where energy management systems are installed to manage (in real time) lighting, heating and cooling systems. Secondly, the solar panels provide clean energy throughout the city, store it in the battery systems and distribute the energy to homes when required. The city also boasts a smart grid that smartly sends the energy in between the buildings in order to reduce peak demand throughout the entire grid. Masdar City (Fathy et al., 2020) is an outstanding example of integrating smart home technologies to achieve large scale goals of sustainability in an entirety of a community.

**3. The Smart Home Program – United States**

In the United States, utilities and energy companies promote the Smart Home Program for making their customers aware of energy-efficient home solutions by the use of smart home technologies. With favorable financial incentives, the program is urging the homeowners to install smart thermostats, smart lighting, or any other item which is energy efficient. One major application in the program involves the use of smart thermostats including Nest and EcoBee that enable homeowners to manage their home heating and cooling from afar as well as improving the usage of energy. Homes provided with solar panels and energy storage system (Tesla Powerwall) can also store excess energy production during day time for use at night. These systems are combined within the home energy management platforms which provide real time data to the users to help them cut off the energy usage and reduce the utility bills. According to Vassileva et al. (2019), the Smart Home Program has proven that even small and cheap smart technologies can result in considerable energy savings.

**4. The Zero Energy Home – California, USA**

The California Zero Energy Home (ZEH) initiative is a breakthrough of the idea of energy management for sustainable energy. The design of a ZEH home, the second generation of the earthship, produces as much energy annually as the home consumes. This is done by integrating high efficiency insulation, solar panels, energy efficient appliances and control of home energy management. As a result, The California Energy Commission has helped to support the ZEH initiatives by providing rebates and incentives to the homeowners for the installation of such energy efficient technologies. These homes are home to smart systems that will control energy consumption, heating and cooling and maximize use of renewable energy. The concept of Zero Energy Home has been widely known as a path to achieving net zero energy use in a residential building (California Energy Commission, 2020).

**5. Solar-Powered Smart Homes – Germany**

The 'Living Lab' project has seen the development of solar powered smart homes in Germany. The solar panels, home energy management system, and energy storage solutions are available in these homes. With the integration of those technologies, the homeowner now has the ability to generate and store some renewable energy, thereby reducing his dependence on the conventional energy sources. Smart meters in the homes measure the energy every day and give users feedback on how to maximise the energy used. The Living Lab project shows also how combining renewable energy with smart home technologies allows to have energy independent homes. Moreover, the supply from one home to another within the community illustrates the significance of community level integration whereby one house's

excess energy can be sold to another house thereby promoting sustainability and resilience in the energy ecosystem (Geiger et al., 2020).

## FUTURE TRENDS IN SMART HOME ENERGY MANAGEMENT

The future of smart home energy management starts to draw out a number of emerging trends that are soon to take its path and are having a far reaching effect on the level of convenience, sustainability and efficiency that the user enjoys. Integration of 5G technology is one of the biggest trends of modern age, because the 5G will make communication between smart devices faster and more reliable. Since 5G has a higher speed and lower latency, future smart homes utilizing 5G will have the ability to process a greater amount of data more quickly resulting in somewhat more precise energy optimization and the ability to respond to system oscillations faster. In addition to this, it shall help enhance the capability of home energy management systems (HEMS) and facilitate the connection with the external energy grids (Yang et al., 2021).

Another key trend would be advancement of artificial intelligence (AI) and machine learning (ML) that would not run out of the role in optimising energy consumption. As these technologies advance, it means that these AI powered systems can learn how owner's behave, act on volatile weather patterns, and can predict energy demand. These systems would automatically manage appliances, heating and cooling systems, and these systems would carry out real time adjustment of energy use balancing comfort and efficiency. In addition, AI can predict when it is most beneficial for the energy storage system to be charged or discharged using the predicted data from weather forecasts and energy pricing patterns (Zhou, Ji, Menéndez, & Villalba, 2020).

As mentioned earlier, Vehicle to grid (V2G) technology is another future trend which could change the way we manage smart home energy, as this new technology has come to the sophisticated minds of many for almost years now. In V2G, electric vehicles (EV) can exchange energy with the home's energy system and also with the grid in two directions. For example, the fully charged EV could store energy from additional rooftop solar panels on the house during the day and discharge when energy demand reaches peak. This is because besides unloading the energy loads, it allows homeowners to use their vehicles as energy storage asset further reducing their reliance on traditional sources of energy (Yang et al., 2020).

Also, the energy blockchain technology will come to stay in the future. Indeed, it is desirable to enable the energy transaction in Smart homes to be transparent and trusting in nature, which are possible by tracking and verifying this secure transaction through Blockchain. Thus, opportunities for local energy trade are opened by decentralized energy markets, in which homeowners could sell excess energy to their neighbors or the grid generated from solar panels or other renewable sources (Zhou, Liu, Lo, & Leung, 2021). It might make energy management less expensive and enhance the use of decentralized energy systems.

The grid independence will be a sublime goal for many smart homes; and with battery storage system becoming more accessible and efficient, it will continue to be. As renewable energy technology matures, more homes will be able to generate, store and manage their own energy, without using traditional power grids, and improve energy resilience. On the flip side, smart homes are able to be used as energy hubs that consume their own energy and better assist in demand side management and real time energy sharing with the stability and sustainability of the local or national grids (Fang et al., 2020).

The trend of next generation smart homes is to achieve environmental impact and even to be integrated with other energy system components to secure more sustainable and more resilient energy future.

## CONCLUSION

Finally, it is crucial that smart homes should be have the ability to manage sustainable energy in order to have the cleanest energy consumption possible and hence the way to be most environmentally sustainable. integrated with the latest technologies such as smart meters, home energy management system (HEMS), renewable energy sources and AI based best way optimization techniques and thus transforming the residential energy consumption. Beyond the consumer control on energy use, smart homes help integrate renewable energy and create less dependency on the traditional power grids.

However, the prices of such smart home technologies are still too high, the technology is still too complex, privacy of data is a worry, and there is no standardisation, which often leads to regulatory barriers. Overcoming these obstacles requires further innovating and that should be supported by the public and policy frameworks. The smart homes market remains alive and is continuously updating with smart homes market capable of growing further and even newer trends like AI integration, vehicle to grid system, blockchain etc. for smart homes market. The pathway to a more sustainable, more resilient and cheaper home living environment as the future of smart home energy management and a contribution for a more general goal; global energy sustainability and environmental preservation is promising.

Ultimately, this will have a positive effect on the home owners and on the energy efficiency targets that need to be achieved to meet the climate change challenges imposed on the EU. This is because technology and connectivity is moving so rapidly that there needs to be a chapter in the future as a sustainable community and that we are leading the way on the innovation required to utilize residential energy management to its maximum.

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