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REVIEW ARTICLE

Energy Internet—Decentralized systems contributing to reduction of greenhouse gas emissions

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ABSTRACT

As the world's industrialisation and population increase, the amount of fossil fuels consumed also increases. This brings with it environmental pollution, greenhouse gas (GHG) emissions and the depletion of these non-renewable resources. With the significant industrialisation and increasing consumerism of societies, an important issue is the growing demand for energy. Energy production using fossil fuels contributes to climate change and environmental pollution. To meet these changes, the energy industry is undergoing a transformation towards green energy. Increasing the use of renewable energy sources and substituting fossil fuels to reduce CO_2 emissions and slow the greenhouse effect is a key objective for countries around the world. To achieve these ambitious goals, new technologies such as the Internet of Things (IoT) are coming to the rescue. Ubiquitous digitisation is supporting the transformation of the energy sector and the emergence of the Internet of Energy. The use of new technologies, smart sensors, photovoltaic panels, IoT-based wind turbines, smart grids supports the rapid development of Energy Internet (EI) and the decentralization of energy systems. This paper provides some insight into the issues surrounding the reduction of greenhouse gas emissions through the increased use of renewable energy sources in energy production systems.

Keywords: Energy Internet; IoT; renewable energy sources; decentralized energy systems; greenhouse gas; electric vehicles; smart grid

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1. Introduction

Globalization and world's growing population lead to the increasing demand for commodities, energy, and many others. Growing global demand for goods and services requires fossil fuels, increases energy consumption generated not only by industries, but also by households themselves. Climate change contributes to more extensive use of air conditioning in warm periods of the year and heating systems in the cold months. The demand for energy in recent years has been met through diversification of energy sources. An increase in use of renewable energy sources (RENs) not only allows for increased energy supply, but also contributes to the use of green energy. Green energy is beneficial, because on one hand it is generated from renewable sources, thus, supports the decrease in fossil fuels combustion, and on the other hand is beneficial for the environment. Moreover, current geopolitical factors play key role in oil and gas security and transportation that also favours RENs[1]. Energy production from fossil fuels generates greenhouse gas (GHG) emissions that among other things are responsible for climate change[2]. Among primary sources of GHG are electricity and heating. According to Center for Climate Change and Energy Solutions the largest emitter of carbon dioxide (CO_2) which is one of GHGs are China, the United States, and the European Union. A rapid increase in CO_2 emissions has been noted since 1950. Energy production itself accounts for 72% of total GHG emissions[3,4]. Moreover, energy demand continues to grow as it is an important factor in economic development of developed and especially in developing countries. In the latter, economic growth is more important than environmental pollution, which is why these countries still rely heavily on non-renewable energy sources.

2. Energy production and climate change

Energy production accounts for almost ¾ of total GHG emissions. This leads to increasing global warming and consequently to climate change[5]. Current global policies on GHG emission levels are estimated to limit global warming to 2.6 °C over the XXI century. This is not even close to the Paris Agreement temperature goal set to 1.5 °C in 2100. This is why additional efforts need to be taken to slow down this process. 88 parties that cover around 79% of global GHG emissions have adopted net-zero targets. This includes 74 parties at COP 26 (Conference of Parties (COP 26) for the UN Climate Change Conference). Those targets are adopted either in law, policy documents or long-term strategies and vary in legal status, time frame and others. Transformation leading to net-zero target is most advanced in electricity supply sector due to increased use of RENs[6,7]. However, there are some obstacles that need to be handled like grid integration for effective use of renewable energy, fossil energy companies and supply chains. This needs to happen simultaneously around the globe at a similar scale so that the global warming is to be limited below 2.0 °C[4].

Moreover, the War in Ukraine had an impact on energy security due to energy supply shortages and rising costs of energy. This has showed how global energy system is vulnerable and dependent on fossil fuels coming from a small number of countries[8]. Energy supply sector is required to produce electricity only from RENs by 2050 and simultaneously phase out coal-based energy production. This is an enormous effort that needs to be taken as for example existing grid systems are not able to rely purely on renewables which requires adapting and rebuilding grid systems. In addition, storage systems and flexible decentralized grids must be developed to balance supply-demand of electricity considering specific characteristics of RENs. It's also worth mentioning that electricity demand is expected to grow as industries are to be more electrified to reach net-zero emission targets[4].

3. Sustainable development goals and green production

The urge for sustainability is observed internationally and one of its goals is energy efficiency. Development of smart devices pushes the energy demand and relying only on fossil fuel combustion is no longer the answer. Countries like the US, China and the EU seek solutions for clean energy production and efficient supply-demand management. Feng and Liao[1] described China's power demand-side management aiming among other things at energy saving. They also mentioned that in the Nineteenth National Congress report promoting an energy production and consumption revolution as well as development of a clean, efficient, low-carbon sustainable energy system is necessary. The European Union has set a 55% emissions reduction target by 2030 compared to 1990 and aims to be the first climate-neutral continent by 2050[9]. France as one of its member states has also increased its targets and focuses on priorities like reducing energy consumption (especially from fossil fuels), developing renewable energy sources and clean mobility. France aims to reduce greenhouse gas emissions by 75% by 2050 and increase the final energy consumption from RENs to 32% by 2030[7].

More and more research is being done on the use of RENs in order to meet the electricity demand and decrease CO_2 emissions. Most of them take into account photovoltaic panel (PV) and wind turbines as they are cost effective and can generate substantial amounts of electricity. Yadav et al.[5] evaluated a hybrid energy system comprising of PV-Wind-Diesel generator. The obtained results showed that at the proposed site in Maharashtra, India this hybrid system was cost-effective with levelized cost of energy of 0.2424 $/kWh. Moreover, solar radiation at the studied site was calculated at 5.34 kWh/m^2/day. Agarwal et al.[8] studied the techno-economic feasibility of a PV plant at Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, India, to minimize the electricity grid dependence. Their studies showed that the best location for the plant was library building allowing for a 42 kWp plant that would meet its daily electricity requirements. Furthermore, such plant would reduce the CO_2 emission by 1199 tons. Albadi et al.[2] proposed a rooftop photovoltaic system designed at 50 kW in Oman, however calculations showed that it's not feasible to design such a system on a given rooftop area. Despite this it was presented that such a system can be designed but requires different settings. In a period of approximately 25 years the net GHG emissions reduction would be 1842 tons CO_2. Kazem and Khatib[10] conducted techno-economical study on a grid connected PV system in Sohar, Oman. The daily global radiation for that area is 6.182 kWh/m^2/day and annual yield factor is 1696 kWh/kWp. Khalid and Junaidi[11] studied the feasibility of a PV based power plant in Quetta, Pakistan. Their emissions calculations showed that a 10 MW PV plant could avoid CO_2 emissions by 17,938 tons/year. Quetta has the average daily global radiation on a horizontal surface estimated to 5.54 kWh/m^2/day. This makes it a suitable site for such a PV plant in Pakistan. Although, the design of such plant is not feasible economically at present, when several price factors are met its feasibility will increase. Shakeel et al. pointed out that Pakistan suffers from blackouts and energy production relies mainly on fossil fuels combustion[12]. Moreover, deficiency in electricity in Pakistan has led to growing prices of final products and services due to increasing electricity prices. Rafique et al.[13] studied an off-grid PV system that was to build a zero-energy community in five cities in Pakistan (Islamabad, Lahore, Karachi, Peshawar, and Quetta). Their daily solar irradiations were calculated at 4.0, 4.7, 5.3, 5.2, and 5.5 kWh/m^2/day for Islamabad, Lahore, Karachi, Peshawar, and Quetta, respectively. The scope of the study was a zero-energy community that fulfils its electricity demand through a PV system and battery energy storage. The average total daily load demand was estimated at 789.78 kWh with a total of 50,780 Ah set of storage batteries to provide continuous supply of electricity to the community. Zaghba et al.[14] investigated a 2.25 kWp PV power station located in Ghardaia, Algeria. The aim of the study was to determine the best power plant system for a desert environment and analysis of harsh conditions on the long-term operation of PVs (e.g., temperature, dust, sandstorms, and degradation). The pilot installation was estimated to reduce CO_2 emissions on an average of 14.17 tons in five years period. Ruan et al.[6] evaluated the potential of rooftop PV system in Hammar by district of Stockholm, Sweden. Depending on the analysed scenarios the system had a power potential ranging from 9000 to 10,000 MWh. However, it was economically feasible regarding current energy prices in Sweden, the system had a huge gap between electricity production and loads, especially when considering irradiation changes during the year. These factors made it difficult to rely entirely on PV generated electricity that relies on weather conditions. The external grid was still required to balance supply-demand throughout the year. Moreover, the system in both scenarios showed line overloading that was even twice higher than the threshold. This is observed in summer months (May–July) in countries located at high latitudes. Arowolo and Perez[7] investigated different scenarios of hybrid grid consisting of PVs and electric vehicles (EV) with and without feed-in-tariff located in Paris, Marseille, and Lyon. When 'PV only in 2019 without a feed-in tariff' scenario was considered could reduce CO_2 emissions by 15,800, 39,600 and 51,200 tons in Lyon, Paris, and Marseille, respectively. When 'PV only with 2030 projected pricing' without a feed-in tariff scenario was analysed CO_2 emissions reduction was estimated at 9300, 23,400, and 30,300 tons in Lyon, Paris, and Marseille, respectively. The study showed that the most sustainable scenario was hybrid rooftop solar photovoltaics and batteries to power electric buses. It is a feasible approach that can lead to reduction of carbon emissions and tackle air pollution in high-density cities. Adam and Apaydin[15] studied the potential of PVs connected to the grid in CO_2 emissions reduction. The analysed location was Gaziantep, Turkey with average irradiation of around 4.83 kWh/m^2/day. They studied a 500 kWp PV system that was expected to generate 881.475 MWh/year of electricity thus reducing GHG emissions by 933.2, 686.9 and 331.4

tons compared to same energy generation by means of coal, oil, and gas. respectively. The calculations made considered the feed-in-tariff in Turkey and the obtained results showed that the development of the 500 kWp PV system in Gaziantep is economically viable. Yang et al.[16] studied the CO_2 emission reduction in Yanqing district of Beijing, China using Energy Internet (EI). As Energy Internet incorporates renewable energy sources and through smart meters can provide real-time data on energy production and consumption it can support sustainable energy management. From the conducted research it was shown that the CO_2 emissions reduction increased year by year and was estimated at 13,383.80 tons in 2030.

Either in developed or developing countries energy especially electricity demand is constantly growing. Traditional fossil fuel combustion energy production generates pollution that affects the environment, human health and leads to climate change. The transition towards renewable energy sources is not only a necessity but can be a great opportunity for developing countries to meet their energy demands and contribute to GDP growth.

4. Decentralized energy system (DES)

In recent years a rapid digitalization has been observed. This is due to the 4th Industrial Revolution. It brought the development of the Internet of Things (IoT) that transforms the world into a digital, modern, and smart world. IoT mainly consists of Machine-To-Machine (M2M) networks, where intelligent devices are able to communicate with each other and make independent decisions. With growing digitalization of different industrial sectors, their specific characteristics and requirements emerged the Industrial Internet of Things (IIoT), Medical Internet (MIoT), Agricultural IoT and among others Energy Internet. Energy Internet (also named Internet of Energy) was first introduced in 2011 by Jeremy Rifkin in his book “The third industrial revolution”[17,18].

The biggest consumer of IoT is predicted to be Energy Internet as the energy sector is undergoing a transformation from a centralized to a decentralized system[19,20]. IoT requires a lot of energy as devices linked to the Internet like sensors, actuators, and smart devices run on electricity or batteries. This is a challenge for the energy sector that must integrate operational and information technologies to meet the energy demand as well as legal requirements (net zero emissions target by 2050). The pressure on the industry to use more RENs in energy production is enormous. However, renewable energy sources are abundant and produce clean energy, their incorporation into the existing power grids is not an easy task. It requires huge investment costs so as to make energy costs from RENs lower than those from fossil fuels. The European Union plans to invest a minimum of 200 billion euro and the US 2 trillion USD by 2030 to transform energy systems to more sustainable and climate neutral[21]. Energy Internet has the potential to support to a great extend achieving the goal of carbon neutrality. The main form of energy for the EI is electricity. Its prices have direct impact on energy savings, energy efficiency and power demand[22,23]. “EI can reduce energy loss, improve efficiency, optimize the allocation of energy demand, and realize the application of large-scale renewable energy”[16]. Moreover, it plays an important role in emission reduction and sustainable energy production. EI is a prosumer-centric concept[24] as traditional energy consumers with rooftop PVs and/or electric vehicles (EVs) can send their surplus energy to the grid and become prosumers.

Figure 1 presents a smart grid architecture in EI. It’s based on a traditional grid with traditional power plants (IN), renewable energy sources (PN), storage nodes (SN) (batteries, EVs), traditional consumers (CN) (individual, corporate, industrial) and the data storage and analysis centre[25,26]. At the core of Energy Internet is the power system, energy storage facilities support the increase in renewable energy generation and its distributed efficiency.

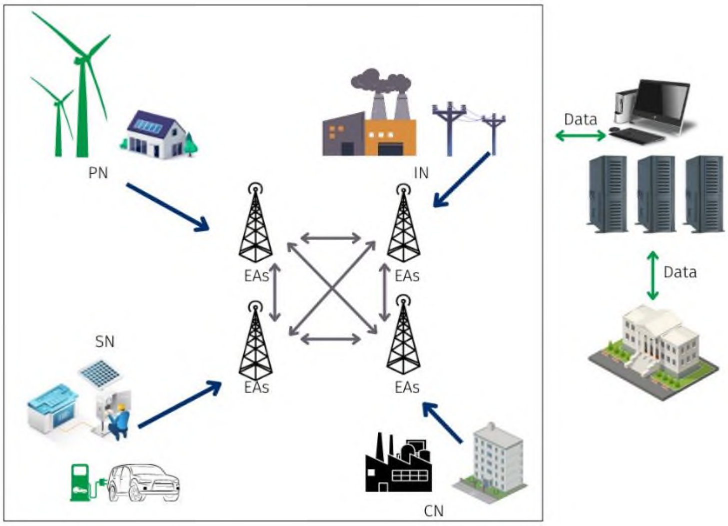

Figure 1. Smart grid architecture.

The cleaner energy is produced and utilized, the less energy is required from the traditional fossil fuel sources. This in turn leads to emissions reduction. EI requires high voltage transmission grids and interconnects smart grids providing better efficiency, network loss reduction and energy savings. EI distribution system comprises small energy network units—microgrids. A microgrid can connect numerous distributed devices like PVs, wind turbines, EVs, power banks and load and as an individual unit be self-controlled and managed. This provides an opportunity for energy transmission improvement[16]. However, it's still very difficult to rely entirely on RENs as for example photovoltaic and wind power generation are uncertain due to their nature and to meet energy demand traditional energy sources are still necessary. At the core of smart grids are renewable energy sources[27]. Most common ones are photovoltaic systems linked to the energy grid. In the grid-tied systems energy storage systems are not essential, as the surplus energy generated by PVs is sent to the grid. On the other hand, there are also off-grid power systems. These stand-alone systems are independent of the utility grid but require energy storage system to store the surplus energy to be used at night[2,5].

4.1. Photovoltaic systems

Photovoltaic systems use solar energy and convert it into electricity. They are a group of cells put in modules and connected in series for increased voltage or in parallel for increased current and which form panels. Several connected panels make an array[2,15,28]. PV systems can be divided into two categories: fixed or tracking systems. Tracked PV systems can be either one or two axis tracking. The tracing system is more effective than the fixed one as the panels can move constantly turning their face towards the sun, so they capture more solar energy during the day. Although, they are more effective, they are also more expensive and require more area, and part of the generated energy is used for sun tracking[5,11]. They are economically sound in regions with irradiation values exceeding 1800 kWh/m^2/year[11]. This factor makes fixed array tilt PV systems more commonly used. The fixed systems need to be placed in an optimal position to capture as much solar energy as possible. In the northern part of the globe, they are southward oriented and in the southern parts of the world northward. In general PVs have low maintenance requirements and operate quietly. Although PV systems are still expensive to install, although their costs have declined over the past years, many countries provide financial incentives to support their installation like feed-in-tariffs[6,7]. PVs are flexible in their design and can be a source of energy in remote places, rural areas where general grid facilities are limited[5]. Moreover, they can be installed on rooftops which reduces land use for renewable energy sources. Rooftop PV systems can provide power supply to consumers with minimal distribution loss and minimise the use of energy from the utility[7].

Grid-tied PV systems can be divided into building integrated like rooftop PV systems, distribution generation PV systems developed only for energy production and transmission into the grid without supplying any local demand, and finally centralized PV plants. These are large systems connected to the utility transmission system[10]. The grid-tied systems can consist of PVs only or can incorporate another energy source like wind turbines, diesel generators and/or energy storage units as shown in **Figure 1**.

4.2. Storage systems

Integration of renewable energy sources in smart grids must consider their nature. Solar irradiation does not produce energy at night, it also is different in different seasons which is typical for high latitude areas. In some parts of the world, there are monthly periods when the sun doesn't shine at all. Also, wind power is always not available as it depends on wind speed, air density, and blade radius. Renewable energy sources are weather dependent which makes them uncertain and their performance throughout the year fluctuates[6]. This is the reason why there are peaks and valleys in the grid. Peaks occur when the amount of energy produced is higher than the load (including self-consumption) and must be sent to the grid. On the other hand, valleys are the opposite, these are situations when the demand for energy is higher than the RENs supply and the energy shortage must be covered from the utility grid. To minimize the dependence on external grid and increase the proportion of renewable energy storage systems should be implemented into the smart grid.

In PV systems, two main types of batteries are used such as lead-acid rechargeable batteries or deep cycle batteries. Most common are lead-acid ones as they provide cost effectiveness, can produce high currents[2,5]. Energy storage facilities can transfer power during off-peak hours and fill in the energy during peak hours which plays a positive role in reducing energy consumption of the power system (external grid).

Another type of energy storage units can be electric vehicles (EVs). EVs with a large battery capacity can store energy from the PV system and later discharge to meet household electricity demand through bidirectional charging. Bidirectional charging is an emerging technology, but it can also support transport decarbonization[7]. The concept of bidirectional charging not only gives incentive to EVs owners, but also promotes this kind of transport. What's more it can support balancing the supply-demand of the grid[16,29]. An EV owner can discharge at peak electricity price to obtain income, and charge at valley electricity price to obtain capacity reserves that can meet driving needs. EV owners can charge and discharge autonomously while meeting their own needs, which helps the power system reduce the peak-to-valley difference[22].

5. Financial incentives to increase RENs in smart grids

Some countries in order to promote utilization of renewable energy sources in power generation use subsidies. For example, in France there is a government's bonus for when buying an electric vehicle[7]. In Sweden there's a tax reduction or a subsidy for initial cost of PV system. The US and Australia provide feed-in tariffs to consumers[6]. This concept has also been adapted in Pakistan; it ensures guaranteed power purchase from renewable power producer at premium price. This higher price is paid evenly by consumers observed in a slight increase in electricity bills. However, consumers accept higher price of electricity if it is supplied uninterrupted and is obtained from renewable resources. Feed-in-tariff act as an incentive for starting and sustaining renewable energy projects in the country[11]. Feed-in tariffs can promote and support renewable energy systems incorporation into smart grids as long as the energy costs are higher than those obtained from fossil fuels.

Another policy is a time-of-use tariff that is closely combined with energy dispatch. It's based on different energy prices depending on whether it is a peak or valley period. Consumers will adjust their electricity consumption habits and electricity usage according to the price, that is, change the demand at a certain moment, so as to change the output of each unit. In the UK this "energy-saving method is to use heat storage in new buildings and heating floors when the electricity price is low, so as to keep buildings warm when the electricity price is high”[22]. This concept supports peak-shaving and valley-filling and can support the reduction of emissions through optimal scheduling.

6. Conclusions

The Energy Internet is a multi energy system that includes electric energy, thermal energy, and gas energy in a synergistic approach. It integrates small-scale renewable energy systems, electric loads, storage devices, and electric vehicles over the Internet. It’s a complex ecosystem integrating a wide range of emerging technologies. It supports decentralization of the energy system and utilization of renewable energy on a wider scale. In addition, it supports network infrastructure flexibility, efficient monitoring, fault diagnostics and meeting growing energy demand. Smart technologies in EI, smart homes, EVs, smart cities, etc. can improve energy efficiency and energy saving leading to emissions reduction. Distributed energy systems integrating renewable energy technologies are an attractive solution, however, designing such a system consisting of different energy sources is an uneasy task.

To achieve emission targets, carbon neutrality and clean energy development the growth and improvement of Energy Internet is inevitable.

Conflict of interest

The author declares no conflict of interest.

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