Dean&Francis
ISSN 2959-6157

Effect of electricity use in residential building on the climate change: analysis, mitigation and recommendation

Pinrui Wu

Guanghua Cambridge International School, Shanghai, China

chemwu6769@gmail.com

Abstract:

The consumption of electricity has witnessed a remarkable surge in the past decade, driven by the growing demand for power across various sectors, including residential, commercial, and industrial. This escalating reliance on electricity has consequently led to an increased strain on the power generation sector, necessitating a significant expansion and modernization of existing infrastructure. Currently, a substantial portion of the world's electricity is generated by fossil fuel-intensive power plants, which rely heavily on coal, oil, and natural gas. These conventional power generation methods not only deplete the earth's finite resources but also contribute significantly to air pollution and greenhouse gas emissions, exacerbating the challenges of climate change. There is a growing global consensus on the urgent need for clean and sustainable energy solutions. One such solution is the process of decarbonization, which involves the systematic reduction of carbon emissions across the economy, particularly within the energy sector. The integration of smart grid technologies and energy storage solutions, such as batteries, is crucial for managing the intermittent nature of renewable energy sources and ensuring a stable and reliable electricity supply. In this paper, the status of electricity use in residential building is analyzed and some recommendation for mitigation to climate change is provided.

Keywords: Decarbonization; renewable energy; hydrogen fuel; PV panel; green roof.

1. Introduction

Nowadays, global warming has become an increasingly important issue, which is also known as greenhouse effect. This phenomenon is mainly caused by emission of greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases from fossil fuel (coal, natural gas and oil) in the anthropogenic activities such as generating electricity for powering and heating the buildings. The

ISSN 2959-6157

continuous increase in household demand for electricity may put a burden on power electric sector and the global environmental. This makes the use of renewable energy (RE) in electric sector and thus reduction on emission of CO_2 to nearly zero a very hot topic. More and more recent studies have focused on the way to solve this problem, such as decarbonization which is a feasible but challenging method, and modification on the building, the main electricity user, itself.

Decarbonization, as its name suggests, needs a shift of electric sector from a fossil fuel intensive one to a decarbonized one. Any sustainable development should take into consideration of three categories such as society, ecology and economy, and decarbonization is no exception. However, to decarbonize needs to reduce the investment on new coal-fired and oil-fired, which contradicts the economic goal in most countries where they prioritize the exploitation of natural resources rather than investing in the use of low-carbon resources which is long-term and may lead some regulatory risks due to uncertainties caused by inconsistent and not elaborated local climate policies [1]. Also, the security of electricity cannot be ensured since the use of RE resources is intermittent, making it difficult to meet the increasing demand on energy compared to fossil fuel-based plants, which are more flexible and can easily adapt to demand [1].

To reach net zero carbon emission, or reduce the use of carbon-containing resources (i.e. fossil fuel), both source and sink need to change, that is, power plant and where the electricity goes to, such as residential and official buildings, need modification. To electrify the residential building poses some challenges. One is the difficulty to gradually phase out the synthetic refrigerants used in the vapour-compression heating, ventilation and air-conditioning (HVAC) system, which is the main electricity consumer in residential buildings [2]. Others are the relatively low share of RE resources or carbon-neutral resources that are used in electricity generation in the electrification process and increased electricity consumption and demand caused by electrification, combined with more frequent extreme weathers, resulting in more brownouts due to demand and supply disparities [2].

There are also many researches digging into other aspects of mitigation of global warming due to use of electricity, generally for the purpose of making more use of RE resources to generate electricity and for sustainable purpose. Photovoltaic panel, or PV panel, is a well-known way to utilize solar energy to generate electricity. Although PV panel has proved to be an effective way of converting solar energy to electric energy, improvement in efficiency of such method is also suggested in many papers. Operating temperature is one of the key factors in the conversion efficiency of PV panel, since under high temperature, the output power cannot reach its maximum. So, there is a need to find a way to decrease the operating temperature of photovoltaic panel, such as using the air-cooled heat sink [3], or realizing a ventilated channel behind it to create a photovoltaic/thermal system to produce electricity and heat [3,4].

Other solutions like green roof will also be discussed as an effective way for sustainable development. In this article, the solutions to mitigating the global warming caused by use of electricity, both in the power sector and residential and official buildings are discussed. And the challenges facing the scientists recently and the feasibility of each solution in the future are analyzed and some recommendations are given.

2. Decarbonization in power sectors

Some present ways to decarbonization, such as using renewable energy, have both advantages and disadvantages. One of the most obvious drawbacks of RE resources is that the RE resources are intermittent and are difficult to meet long-term energy demand. To improve the efficiency of using RE resources, it is necessary to integrate the use of renewable and non-renewable energy sources instead of a single power source, which necessitate the use of hybrid energy systems (HESs) [6].

2.1 Use of hybrid energy systems (HESs)

HESs are composed of a wind turbine, a PV panel, an alkaline fuel cell (AFC), a Stirling engine and an electrolyzer. Fig. 1 shows a small hybrid of solar and wind energy system, which is used as a reference to visualize the process [7].

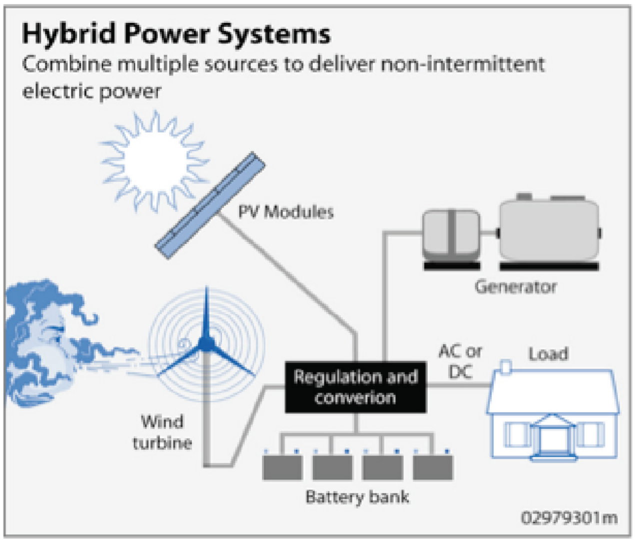

Fig. 1 Example of HESs [7]

In a more complex model, after the conversion of energy from solar and wind form to electricity, the generated electricity is used in the water electrolyzer where water is decomposed into oxygen and hydrogen gases. Then, the chemical energy stored in the hydrogen-hydrogen bond is converted to electricity and heat in AFC by chemical reactions [6].

The products of such a hybrid energy system are various, including electricity, heat, cooling and hydrogen fuel. Electricity is used in almost everywhere in human's daily life, while heat and cold are often used to meet heating and cooling demand in residential buildings [6].

2.2 Use of hydrogen fuel and hydrogen fuel cell

Hydrogen is regarded as the main solution to the climate change and the main alternative to fossil fuel due to its clean characteristics. It can effectively reduce the environmental impact caused by carbon emission [8]. Fig. 2 shows that H_2 has been widely used as a clean renewable energy in transportation and power sector, since it is very eco-friendly with no CO_2 emission and hydrogen as a fuel can improve the engine efficiency. However, there are also some concerns about the safety of hydrogen fuel in the storage and transportation process, which is now the focus of many research paper. Some methods, like bio-hydrogen treatment using cryogenic and absorptive method is discussed by some papers [9-11], as well as some physical and chemical methods.

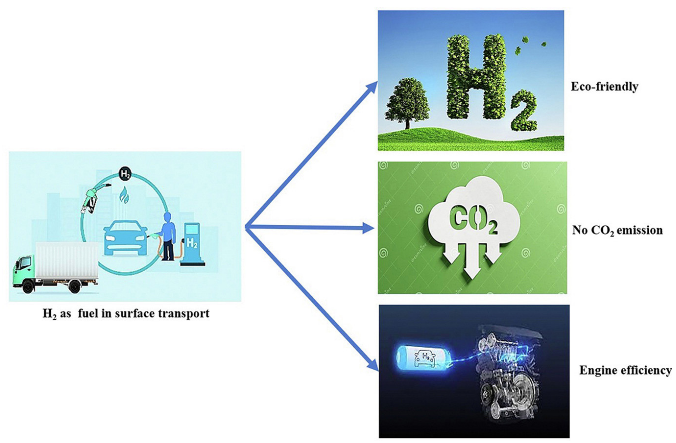

Fig. 2 Advantages of using hydrogen as fuel [11]

Hydrogen is not pure in its natural form, which means it needs to be produced using artificial method using hydrogen-containing compound [12]. There are recently many choices for the production of hydrogen, which are based on different sources utilized. The main source of raw materials of hydrogen production comes from conventional fossil fuel, which takes up approximately 96% of total hydrogen production due to its low cost. With fossil fuel, such as natural gas, oil and coal, the most prevalent pathway to hydrogen production attributes to steam methane reforming (SMR), which heat methane (CH_4) and steam (H_2O) under high temperature and pressure using a catalyst (usually nickel with additional noble and transition metals to increase catalytic reactivity) to produce hydrogen, carbon monoxide and carbon dioxide. Carbon monoxide will then undergo a reaction with steam, known as water-gas shift reaction, to produce more hydrogen and carbon dioxide. Other methods, such as partial oxidation, gasification, are also based on conventional fossil fuel to produce a mixture of hydrogen, carbon monoxide and carbon dioxide. Partial oxidation is an exothermic reaction, releasing heat, while SMR is an endothermic reaction, requiring a large amount of heat. As a result, these two methods can be combined in an autothermal reaction (ACT), where no external heat supply is needed and larger amount of hydrogen can be produced. Since they are all carbon-based ways to produce hydrogen, carbon emission is inevitable. Therefore, there are also some ways, such as biomass gasification and electrolysis, using biomass and electricity directly to produce hydrogen, which is clean due to its carbon-neutral characteristic [12].

Fuel cell is commonly used to generate electricity, converting chemical energy to electrical energy directly. Hydrogen fuel is the main source of fuel used in the fuel cell. A fuel cell device is generally composed of an anode, a cathode and a electrolyte membrane. Fuel cells are classified by their electrolyte membrane type. Electrolyte is either solid or liquid that allows the transport of ions from one electrode to another. There are mainly two fuel cells that can be used in the power generation, proton exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC). Fuel cell has several advantages, such as lower carbon emission, higher fuel flexibility and silent operation. Additionally, since the fuel cell is externally

ISSN 2959-6157

supplied with reactants and the constitute materials are not consumed, it can operate for an indefinite period as long as there are sufficient fuel and oxidants. Nevertheless, the high price and lack of hydrogen infrastructure has made it difficult for commercialization of fuel cell. There exist several solutions to that problem, such as establishing cost-efficient hydrogen supply and ensuring effective use of alternatives in the electrode. Generally, fuel cell is a very promising way to achieve zero carbon emission in the future to mitigate global warming.

3. Decarbonization in the residential buildings

It is also essential to decarbonize the residential buildings, such as use of low carbon-intensive energy fuel and more energy-efficient appliances, since residential buildings account for 27% total energy consumption around the world and 17% global carbon emission [13]. The following article will discuss the usage of PV panel and green roof.

3.1 Use of PV panel

Photovoltaic panel, or PV panel is widely used to mitigate global warming as green renewable energy due to its carbon-free nature [14]. PV panels consist of a set of solar cells which convert solar radiation directly to streams of electrons [16]. However, there are many environmental factors that affect the operating efficiency of PV panel, such as geographical location and environmental stresses. Environmental stresses include ultraviolet radiation, rain and snow. Additionally, hotspots will also reduce the PV panel performance efficiency, such as bird drops, shading and dust [14]. As a result, solutions are to be found to improve the performance efficiency of the PV panel. Some ways to achieve performance efficiency that are relatively easy include choosing a high-efficiency panel, ensuring a right tilt angle and proper operation conditions and clean the panel surface regularly [15].

Operating temperature will also affect the conversion efficiency of PV panel. As a result, it is essential to cool the PV panel in order to ensure operating efficiency. There is a suggestion that it is feasible to cool the PV panel using dual surface cooling [16]. Others such as passive cooling, cooling with phase change materials (PCMs) and cooling with PCMs with additive materials including nanoparticles or porous materials, are also suggested [17].

3.2 Use of green roof

Green roof has become increasingly popular among some countries around the world due to the benefits it brings to the ecological system and air quality and the reduction it brings to the general energy cost, which encourages many governments in different countries to provide funds for construction company for the construction of green roof [18].

Green roof is a type of roof covering with a layer of vegetation, substrate layer, filter layer and drainage layer. Green roof system must be applied over waterproof layer with a root barrier and insulation materials. Also, it must be applied over a slope with minimum tilt angle of 2^o to allow any rainwater to flow along the slope and to drain it [21].

Green roof can mitigation carbon dioxide emission (i.e decarbonization) in both direct and indirect ways, green roof can absorb CO_2 in the surroundings by its green coverings and stored in biomass and substrate directly, while reduce the total energy consumption in domestic settings through thermal regulation, which is an indirect way [19]. Among that, a recent paper has developed a particular framework, called GR carbon assessment framework (GRCAF), which introduces four pathways including embodied carbon, carbon sequestration, bioenergy supply and operational carbon [20].

4. Conclusion

This paper discussed the current solutions to mitigation of climate change caused by use of electricity in domestic buildings, ranging from decarbonization in power sector to decarbonization in domestic settings. In the existing literature, there are many papers dipping into the application of using hybrid energy systems to reduce the impact of limitation of renewable energy on the general decarbonization goal, the improvement in the efficiency of manufacture, storage, transport of hydrogen fuel, the enhancement of the performance of PV panel by searching to lower the operating temperature and minimizing the effect of environmental stresses and the feasibility of green roof system, which is a new carbon-neutral renewable way to achieve sustainability of the urban areas, by choosing the most suitable material as vegetation layer through experiments. In the future, studies will focus on the improvement and advancement of currently existing technology and innovation of new technology to alleviate the global crisis, climate change.

References

[1] Elisa P., George T. Challenges in the decarbonization of the energy sector. Energy, 2020, 205: 118025.

[2] Srinivas G., Kristian L., David P., et al. Realistic pathways to decarbonization of building energy systems. Joule 2022: 956-971.

[3] Popovici, C. G., Hudisteanu S. V., Mateescu T. D., et al. Efficiency improvement of photovoltaic panels by using air cooled heat sinks. Energy Procedia, 2016, 85: 425-432.
[4] Tonui, J. K., Y. Tripanagnostopoulos. Improved PV/T solar collectors with heat extraction by forced or natural air circulation. Renewable energy, 2007, 32: 623-637.
[5] Huang W, Marefati M. Energy, exergy, environmental and economic comparison of various solar thermal systems using water and Thermia Oil B base fluids, and CuO and Al_2O_3 nanofluids. Energy Reports, 2020, 6: 2919-2947.
[6] Wang Z. L., Zhang X. Q., Ali R. Hydrogen fuel and electricity generation from a new hybrid energy system based on wind and solar energies and alkaline fuel cell. Energy Reports, 2021, 7: 2594-2604.
[7] Energy efficiency & renewable energy, U.S.A. Small Wind Guidebook. Retrieved on September 15, 2024, retrieved from https://windexchange.energy.gov/small-wind-guidebook#grid
[8] Singla M. K., Nijhawan P., Oberoi A. S. Hydrogen fuel and fuel cell technology for cleaner future: a review. Environmental Science and Pollution Research, 2021, 28: 15607-15626.
[9] Qiu Y. N., Yang H., Tong L. G., et al. Research progress of cryogenic materials for storage and transportation of liquid hydrogen. Metals, 2021, 11: 1101.
[10] Bosu S., Rajamohan N. Recent advancements in hydrogen storage-Comparative review on methods, operating conditions and challenges. International Journal of Hydrogen Energy, 2024, 52: 352-370.
[11] Roy A., Sabyasachi P. A review of the hydrogen fuel path to emission reduction in the surface transport industry. International Journal of Hydrogen Energy, 2024, 49: 792-821
[12] .Ahluwalia R. K., Peng J. K. Dynamics of cryogenic hydrogen storage in insulated pressure vessels for automotive applications. International journal of hydrogen energy, 2008, 33.
[13] Leibowicz B. D., Lahgam C. M., Brozynski M. T., et al. Optimal decarbonization pathways for urban residential building energy services. Applied energy, 2018, 230: 1311-1325.
[14] Ahmed W., Sheikh J. A., Farjana S. H., et al. Defects impact on PV system GHG mitigation potential and climate change. Sustainability, 2021, 13: 7793.
[15] Sistine Solar. 9 Ways to increase solar panel efficiency. Retrieved on September 15, 2024, retrieved from https://sistinesolar.com/how-to-increase-solar-panel-efficiency
[16] Agyekum E. B., PraveenKumar S., Alwan N. T., et al. Effect of dual surface cooling of solar photovoltaic panel on the efficiency of the module: experimental investigation. Heliyon, 2021, 7: e07920.
[17] Mohamed S., Mohamed S. Y., Ahmed S. H. Review of cooling techniques used to enhance the efficiency of photovoltaic power systems. Environmental science and pollution research, 2022, 29: 26131-26159.
[18] ShafiqueM., Reeho K., Muhammad R. Green roof benefits, opportunities and challenges-A review. Renewable and Sustainable Energy Reviews, 2018: 757-773.
[19] Tan T., Kong F., Yin H., et al. Carbon dioxide reduction from green roofs: A comprehensive review of processes, factors, and quantitative methods. Renewable and Sustainable Energy Reviews, 2023, 182: 113412.
[20] Dong X., He B. J. A standardized assessment framework for green roof decarbonization: A review of embodied carbon, carbon sequestration, bioenergy supply, and operational carbon scenarios. Renewable and Sustainable Energy Reviews, 2023, 182: 113376.
[21] Manso M, Teotonio I, Silva C. M., et al. Green roof and green wall benefits and costs: A review of the quantitative evidence. Renewable and Sustainable Energy Reviews, 2021, 135: 110111.