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Advancing Sustainable Construction Through Renewable Energy Integration: A Review

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Abstract*—The global construction industry faces increasing pressure to reduce greenhouse gas emissions and transition toward sustainable practices as part of broader climate change mitigation efforts. This review examines the role of renewable energy integration in advancing sustainable construction, with particular emphasis on the United States while drawing comparisons with international leaders such as the European Union. The paper synthesizes recent literature on the adoption of renewable energy technologies, including solar, wind, geothermal, hydroelectric, and hybrid systems—across the construction lifecycle, from energy-intensive material production to building operation and infrastructure development. Key technological challenges are analyzed, including grid compatibility, transformer design, energy storage limitations, and intermittency issues associated with variable renewable energy sources. Economic considerations are also explored, highlighting trends that indicate improving financial performance and profitability of renewable energy producers relative to fossil fuel-based counterparts. Additionally, the review discusses policy mechanisms such as feed-in tariffs, energy efficiency standards, and decarbonization strategies that have proven effective in accelerating renewable energy adoption, particularly within the European Union. Socioeconomic implications, including workforce transitions, energy equity, and the gradual phasing out of fossil fuels, are identified as critical factors influencing the pace of change. The findings suggest that while significant barriers remain, coordinated efforts across technological innovation, economic investment, and policy reform can substantially accelerate the integration of renewable energy into construction practices. Ultimately, this review concludes that renewable energy integration is not only a viable pathway but a necessary foundation for achieving a resilient, low-carbon, and sustainable built environment for future generations.

***Keywords*—Renewable Energy Usage; Sustainable Construction; Fossil Fuels Usage; Construction Equipment**

I. INTRODUCTION

The global construction industry stands at a critical juncture, facing mounting pressure to decarbonize amidst accelerating climate change and ambitious international sustainability targets. As one of the world's largest consumers of energy and contributors to greenhouse gas emissions, the sector's traditional reliance on fossil fuels throughout the lifecycle of buildings—from material manufacturing to operational energy use—has become increasingly untenable. In response, the integration of renewable energy technologies into construction practices has emerged not merely as an alternative but as a fundamental imperative for achieving net-zero emissions and fostering long-term environmental resilience [1, 2].

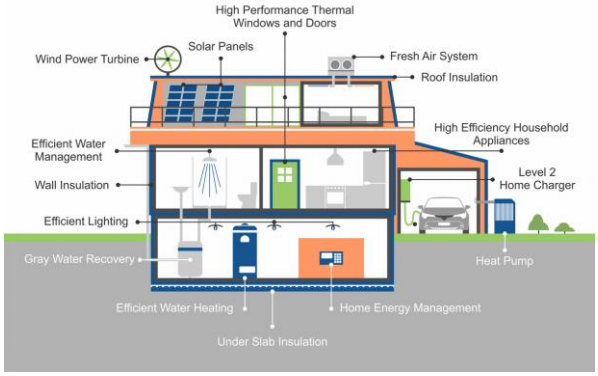

Fig. 1 Schematics of Net-Zero Building System Architecture (Diwakar, 2023)

Net zero buildings are structures that produce as much energy as they consume over a year. These buildings can generate energy through renewable sources, such as solar panels or wind turbines, and use energy-efficient systems and appliances to minimize energy

consumption. Ref Fig. 1, where schematics of net zero building system are conceptualized (Diwakar, 2023).

This review firstly examines the multifaceted role of renewable energy in advancing sustainable construction, with a particular focus on the challenges and opportunities shaping the transition in the United States and other developed economies. The paper synthesizes recent literature to explore key themes, including the technological, economic, and policy dimensions of renewable energy adoption. It critically evaluates the progress made in integrating solar, wind, geothermal, and hybrid systems into building design and construction processes, while also addressing persistent barriers such as grid infrastructure limitations, energy storage constraints, and the socioeconomic implications of phasing out fossil fuels. Furthermore, this review situates the U.S. transition within a broader global context, drawing comparisons with the European Union's renewable energy advancements and highlighting lessons that can inform more effective policy frameworks.

By consolidating findings from diverse studies on topics ranging from transformer harmonics and green synthetic fuels to the financial performance of renewable producers, this paper aims to provide a comprehensive overview of the current state of knowledge. Ultimately, it seeks to identify pathways for accelerating the integration of renewable energy into construction practices, thereby contributing to a more sustainable and resilient built environment.

II. The Evolution of Building-Integrated Renewable Energy

Renewable energy over non-renewable energy has been on the minds of the United States over the past few years. The United States includes finding new ways to transition from non-renewable energy to renewable energy to create a cleaner air quality without trying to cause any hiccups in the way people will receive the energy (Johnson, 2013). It will be necessary for everyone to provide a better future for the generations to come, even companies trying to find the right renewable energy for their organization as this has been proven since 2016, that renewable energy has been more effective compared to non-renewable energy with a new approach towards creating a greener society with natural resources (Conserve Energy Future, 2020). Both renewable and non-renewable energy will be needed until the United States can be dependably only with renewable energy, which it would be time to start a new revolution of the usage of renewable energy.

The growth of renewable energy has been around in multiple states. However, only hydroelectricity and geothermal electricity has been the most used throughout the United States even though we have proof that solar and wind can create other states a cleaner way for the states that cannot have hydro or geothermal electricity (Khare & Baredar, 2016), which is not easily attainable for these other states. As it has caused a change towards a new policy, the United States needs to create a more significant impact in the country to create a new way of living that will give the United States a cleaner way of living. In addition, there will be implications for how the electricity will be received from renewable energy that has to be redesigned to configure the amount of electricity transferred to the power grid.

The redesign of the transformers will have to be taken place during the first few months of the trial phases of the usage of renewable energy (2021). After they have a general idea that the transformer will provide, the engineers will have quality data to provide enough evidence to redesign the usage of the transformer. It will also make changes toward the future of the construction process of how they will improve the harmony of the use of renewable energy while increasing the use of other materials that can be used from the power grid or even updating how the power will be provided throughout the power grid it is designed. Overall, this will provide evidence that will continue to improve the usage of renewable energy for years to come.

A. Transitioning From Fossil Fuels to Renewable Energy

The primary question has been effectively transitioning from non-renewable energy to renewable energy without slowing down how people live. It starts with learning from the European Union and understanding where they come from to change the United States' usage of non-renewable energy. The United States has been slowly incorporating hydroelectricity and geothermal use but now needs to rely on newer advancements with wind and solar power that is easily accessible (Halkos & Gkampoura, 2020). First, however, hydroelectricity and geothermal need to be refined to make a more significant impact on creating a more sustainable resource for other countries.

As stated before, the United States has been transitioning to using renewable energy to eliminate fossil fuels. The European Union has provided it, the EU, which has been provided the resources of renewable energy to the world (Halkos & Gkampoura, 2020). The United States needs to understand that we have to get away from the industrial revolution and allow the modern technology to replace the fossil fuels that produce CO2. We must start realizing that the future that we thought we were going to have been currently in the present and is okay with the change that will benefit the future generations to see what we have seen over the years.

It has all started with the impact of the EU having renewable energy that the natural environment has provided. The industrial revolution was over two hundred years ago, and it is time to have a new revolution with renewable energies, such as solar, wind, hydro, geothermal, and biomass. It has been proven that the market around the world is starting to

invest more money into resources that will impact renewable energy usage (Halkos & Gkampoura, 2020). The construction and electrical industry must be understood to change the energy they use to build these projects with renewable resources, including solar, wind, or hydropower, to continue using the tools without using fossil fuels. Hydroelectric and geothermal have been most recently used to create electricity, but now they have included solar and wind as acceptable for providing a greener future with energy (Halkos & Gkampoura, 2020). However, hydroelectricity and geothermal electricity need to be updated to require a more sustainable energy source for countries with no tools or equipment to access these types of electricity from the natural environment.

Ensuring that solar and wind can provide sufficient energy has made an impact, as stated above, on the construction and electrical industry. Therefore, the two industries must incorporate renewable energy into their daily use during the construction process. In addition, renewable energy to create cleaner air quality around the construction sites and impact on the future as it will give the opportunity for the companies to invest in greener equipment and the reduction of greenhouse gases produced by the equipment that is being used.

B. New Approaches to Renewable Energy Growth in the United States

The United States' approaches have been very slow-moving to replace the non-renewable energies (Johnson, 2013). However, the European Union has been trying to advise the United States to impose the renewable energies that have been successful in their country. It has shown that the economic growth would be tremendous toward making the world a more accessible place to live and give everybody a chance at a better lifestyle. It will also create a phase-out of the non-renewable energy usage to a minimum, even though it will be beneficial to have the non-renewable energy as a secondary resource if the renewable energy cannot produce enough energy.

As we start getting into the early 2020s, there has been an increase in renewable energy used throughout the country in 2016. The numbers that have been shown for renewable energy usage show that 370.2 Terrawatt-hours is equivalent to 83.8 million tons of oil (Johnson, 2013). That number itself shows that we need to start investing in renewable energy to conserve the use of fossil fuels that have been in place for over 200 years, which that data has been provided from the year 1965 to 2016, which means that the United States should start investing in the use of renewable energy over non-renewable energy (Johnson, 2013). It will only increase the economic growth of the United States to invest in renewable energy because people are ready for a change in how we make energy.

Economic growth is the foremost priority for the countries that need to make the world a more sustainable place for future generations (Johnson, 2013). Investing in renewable energy will provide more income for families to have more time on their hands to spend less money on surviving the daily tasks. It will also include the decelerating carbon dioxide emissions, and an increase of renewable energy used within each household (Johnson, 2013). It will also start combating the use of volatile oil prices while decreasing the climate change acceleration worldwide (Johnson, 2013).

The new approaches will have some disadvantages towards how renewable energy will work with the economy's growth. Now, there is not enough battery capacity to store the energy created from solar and wind. It can also be unreliable with the location of each state, even though each renewable energy needs to have some sort of energy that the natural environment will provide each day (Johnson, 2013). It will also take up much space compared to power plants that will only take up a few acres, where renewable technology must take up more acres to give enough energy towards the power grid. It may not provide as much pollution as non-renewable energy, but it still gives pollution from the equipment being used, which will still create pollution to complete the renewable energy and may even pollute methane.

C. Promotion of Renewable Energy

Renewable energy has proven to be beneficial compared to non-renewable energy (Conserve Energy Future, 2020). Technology has given the world an advancement toward making everyone heard while also giving us new ways to replace non-renewable energy. The United States has decided to get a new policy to replace the older policies that allow non-renewable energies to fade into the past (Conserve Energy Future, 2020). It will also affect the new policies created to have a more sustainable future and create a greener world for the other underdeveloped countries.

The promotion of renewable energy has been in the works over the past few years. As stated before, however, it is time to let technology take over and allow the change to happen. It will be time for the United States to start making new policies to improve renewable energy over non-renewable energy. The United States will allow them to expand the economic growth for the country to make an impact toward making the world a healthier place, not just the earth, but human beings. It may also impact on the underdeveloped countries' decisions to expand into creating a better world for their own country.

Technological advancements have given us the ability to grow by reaching family and friends farther away to connect with just a screen in front of them (Conserve Energy Future, 2020). The world's advancements have come a long way, as each revolution has created a new way to conserve energy. First, wood was replaced by coal, coal was then replaced by oil, and now renewable energy is replacing oil to help make the world more livable for the future of

our society (Conserve Energy Future, 2020). However, it will take a more significant impact on the United States to make a new policy toward making people use renewable energy over fossil fuels, which we have seen an impact already with the new government wanting the change to preserve the world for the future generations.

The United States, as stated before, has been driving to create a new policy to replace the old style of living to complement the technological advancements that we are seeing today. For example, wind, solar, and biofuels have increased their usage over the 20th century and are now impacting the world today. This evidence has been gathered just over the United States, even though the European countries have been making their impact and continue eliminating greenhouse gases (Conserve Energy Future, 2020). Other countries are trying to eliminate greenhouse gases with their resources at their disposal, even with not having all the resources that developed countries have. It makes it easier for people to develop new ideas from just available materials to create a better world for the countries than their ancestors.

It will lead to effective policies that will create a more sustainable future with the renewable energy created today. It goes back to promoting the benefits of renewable energy that will provide more effectiveness than non-renewable energy. The new policies can use a feed-in tariff to continue to make an economic impact, while it may also help create an energy efficiency standard to promote the usage of renewable energy over non-renewable energy. It will also impact buildings with energy performance certification schemes that will make the companies achieve new standards for other companies to compete, creating more economic growth.

D. Implications for Electrical Transformers in Solar Power Plants

Though solar power plants are becoming more prevalent in the United States, there is some concern about conserving the energy created from solar panels (2021). It may be beneficial to update the design of the transformer to know the data that shows energy usage and how much it is losing. It will also benefit from creating a design that will be harmonic to what energy is being used and how it is being produced to the power grid. Finally, it will help carry out a testing procedure to see harmonically consistent with the transformer and power grid.

The energy conservation produced from solar power plants starts with understanding how the transformer already works. It starts with how much energy will be lost before the corrections are made to use all the energy provided by the solar plants. The solar power plants will also benefit the companies to develop a better design to continue to use the data reviewed throughout the installation to the first year before any corrections need to occur. They have a basic understanding of how much it will lose, but it would be beneficial to make corrections toward the energy lost after running for over a year.

Creating a harmonic profile from the data that is being collected needs to start with the percentage of losses to have an equal correlation between the results gathered. It should also be updated with the power grid that is transferring the solar power to homes using the data to make sure they can conserve some energy to help create a better outcome to preserve the energy. However, we are still in the phase of finding out ways to keep the energy that is lost with alternative solutions that will give people power. Even if there is not enough energy being produced throughout the days, there is not enough natural energy. It may even be beneficial for solar power plants to invest in finding the best transformer that will create less energy loss. It will help with giving the most efficient energy to provide the whole power grid to complete a harmonic profile that the transformer is providing.

III. Financial Performance of Sustainable Power Producers

Renewable energy producers have increased productivity (Schabek, 2020). Renewable energy has been evident in all countries worldwide, especially in the United States. There has been a trend that the profitability of the renewable producers has shown an increase while being a decrease in the fossil fuel companies (Schabek, 2020). Fossil fuel producers have been promoted throughout the entire world by having an increase in production that will have a positive impact on the global market to help reduce fossil fuels. It will give more insight toward helping the world reduce climate change, primarily for developed countries; however, it will significantly impact the rest of the world that could come it with strategies that would help impact climate change.

A. When Will Fossil Fuel Reserves be Diminished?

It is expected that fossil fuels will continue to dominate at least 84 percent of the energy demand throughout the next ten years (Shafiee & Topal, 2009). It may have also been past the time when global oil production peaked and hit demand, with it having been the end of the fossil fuel era (Shafiee & Topal, 2009). Renewable energy needs to take a chance to help create a better society within the mind that the globe may have passed the era of fossil fuels. It has been shown that it has impacted on the developed countries that have waited until the last minute to start impacting climate change. It has also shown that world consumption has increased dramatically due to population growth but may start going down as the younger generations and technological advances have made an impact toward saving the world that they live and love.

B. Green Synthetic Fuels

Since there has been economic growth and population growth resulted in a rapid demand in energy increase to keep people living day to day (Rozzi et al., 2020). There have been new ways that could impact the usage of fossil fuels and the emission of greenhouse gases. That is called green synthetic fuel. Synthetic fuel would help start decarbonizing the energy system while boosting the energy that can convert to heat or electric power into the grid (Rozzi et al., 2020). Synthetic fuel could help create a chance to change the way people look at saving the world while also improving renewable energy that will be here at least by 2050 (Rozzi et al., 2020). It would allow people to use energy that would not create greenhouse gases and create a new way to investigate how we can save the world. Plus, it would give a chance to give a surplus of options to help the shortage of renewable energy shortage that could happen across the world.

C. Final-Stage Energy-Return-on-Investment for Fossil Fuels to Renewable Energy

The final energy stage seems to have more relevance towards society than the primary energy stage since it is closer to the end of energy services (Brockway et al., 2019). It has shown a decline during the final stages of fossil fuels and is closer to renewables than expected due to how new renewable energy resources have impacted the world (Brockway et al., 2019). In return, renewable energy may have a higher impact than fossil fuels when the final energy stage has been set. In addition, it may have been impacted how the world reacts toward allowing renewable energy to take full effect to reduce climate change and mitigate it entirely. It must be put into play as the years continue to fly by and the need to change how the world thinks to mitigate the impact of climate change.

IV. Energy Efficiency and Renewable Energy

With carbon-based fuels nearing their end, attention has been drawn toward making an impact on using renewable energy (Oró et al., 2015). With new renewables, wind, solar, Etc., it only accounts for three percent of the world's total usage. However, it proliferates (Oró, et al., 2015), which the transformation of the information technology will continue to improve their available capacities of energy to store for instances where the renewable energy cannot be produced, especially when days there might not be enough solar or wind to create the energy to continue powering the grid. Plus, it will be hard to know exactly what energy will be needed to power the grid using renewable energy until the technology makes a more significant impact, and improvements will be collected over the future.

A. Impact of Phasing out Fossil Fuel

To phase out fossil fuels, the socio-economy must allow the change to impact on the way they see it happening, even if that means trial and error before the century ends. Fossil fuels continue to drag financial resources away from impacting a sustainable future that the world is trying to achieve, along with making the income of fossil fuel producers to maintain political stability (Monasterolo & Raberto, 2019). If socioeconomics can contribute to phasing out fossil fuels and transitioning into low-carbon energy production, it would allow the world to rely more on renewable energy than fossil fuels that create greenhouse gases. It would also create more jobs towards greener technologies and investments that will allow renewable energy to impact on the world significantly as it would start making an impact on phasing out the investments of fossil fuels to energy and make it less profitable for the producers and consumers to rely on the energy that creates greenhouse gas (Monasterolo & Raberto, 2019). It would make the change across the countries and world to start making a better impact on the choices made to have a greener world.

B. Hybrid Renewable Energy Systems

The most significant concern towards fossil fuel is the harmful gases surrounding the area that we are living in for a while, creating a more significant concern on how we can reduce the greenhouse gases produced from it (Goel & Sharma, 2017). Which has created different countries to create a new way to fight the battle of generating cleaner ways to generate cleaner energy and green energy (Goel & Sharma, 2017). These impacts to create a greener world have made some dramatic changes in how we should start investing in greener practices that would allow us to use the energy to reduce greenhouse gases and carbon dioxide emissions into the air we need to breathe and live. Which should be implemented on what type of renewable resources are acceptable for the countries or states to use in the region that they are in, along with making a more significant focus on having rural electricity being used to help start making a more significant impact on the usage of larger cities to implement the way we use renewable energies.

C. Replacing Fossil Fuels With Renewable Energy: Utopia or Valid Option

The development of energy demand and renewable energy usage could be more problematic for underdeveloped countries to make the impact toward a greener world a little more complicated, as they are still trying to make their way into a developed country with older equipment that developed countries have designed (Lemm et al., 2020). Though they are still trying to grow as a country, it may be more difficult for the country to allow the change to happen locally. It would be necessary to have the local strategies be considered with the resources at their disposal and make a quantitative basis on how they should use not only natural resources but also prioritize technology and conversations that are needed to use by the energy supply (Lemm et al., 2020). It would have to take the people in the region to decide how they want

to limit energy usage during the times when energy cannot be easily accessed.

D. Solar-Wind Hybrid Renewable Energy

Electricity demand continues to increase day by day, but it would not be enough for non-renewable energy sources alone and where renewable energy can impact the electricity demand (Khare et al., 2016). With the usage of renewable energy increasing tremendously over the past few decades, it will continue to increase newer technology that can continue to increase the electricity demand and be more fascinating to solve the usage of renewable energy (Khare et al., 2016). Renewable energy is where the site of a location for renewable energy needs to be in consideration of making an impact toward the community that it is going to impact, which would bring in different ideas and current options that would allow the local communities and surrounding areas to make a move toward a greener society. In addition, it would allow the other areas to better understand what is needed to be used to help create more electricity and exceed the demand that continues to increase day by day.

E. Renewable and Non-Renewable Energy Consumption From G7 Countries

With non-renewable energy consumption higher in the G7 countries, the only relationship that is targeted is economic growth (Tugcu et al., 2012). That would be needed to continue to grow the countries into a larger and more developed country that the underdeveloped countries are trying to achieve. However, it may change for the G7 countries to start creating a more significant impact on using renewable energy to continue to grow the economic growth they want to see without using non-renewable energy (Tugcu et al., 2012). Economic growth, non-renewable energy, and renewable would allow the G7 countries to start making an impact on a change that would allow them to continue making energy consumption from natural resources and allow economic growth to continue.

V. Conclusion

This review has examined the multifaceted transition toward renewable energy integration within the construction industry and the broader energy landscape, with particular attention to the United States in comparison to global leaders such as the European Union. The synthesis of literature underscores that the shift from fossil fuels to renewable energy sources—solar, wind, geothermal, hydro, and hybrid systems—is not merely an environmental necessity but a fundamental imperative for achieving long-term sustainability and economic resilience.

Several critical themes emerge from this analysis. Technologically, the integration of renewable energy into construction practices requires significant advancements, particularly in grid infrastructure, energy storage, and the redesign of electrical transformers to harmonize with variable power inputs from sources like solar. Economically, evidence indicates a growing financial viability for renewable energy producers, with profitability trends favoring sustainable power over fossil fuels. However, challenges remain, including high upfront costs, intermittency issues, and the need for improved battery capacity. From a policy perspective, the review highlights that effective, forward-looking policies—such as feed-in tariffs, energy performance standards, and ambitious decarbonization goals—are essential to accelerate adoption. The United States can draw valuable lessons from the European Union's more cohesive and accelerated policy frameworks.

Persistent barriers, including socioeconomic dependencies on fossil fuels, grid limitations, and the unequal distribution of renewable resources across regions, continue to slow progress. Moreover, the transition demands a holistic approach that considers not only technological innovation but also the socioeconomic implications of phasing out fossil fuels, including workforce transitions and energy equity.

Ultimately, this review affirms that the integration of renewable energy into construction and energy systems is a complex but achievable goal. Success will require coordinated efforts across technology development, policy innovation, economic investment, and societal acceptance. As the United States and other developed nations move forward, the path to a sustainable built environment will depend on their collective ability to embrace a new energy revolution—one that replaces outdated fossil fuel paradigms with resilient, renewable, and equitable energy systems for future generations.

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