American Journal of Energy Research, 2023, Vol. 11, No. 3, 128-143
Available online at http://pubs.sciepub.com/ajer/11/3/4
Published by Science and Education Publishing
DOI:10.12691/ajer-11-3-4

The Role of Energy Storage in the Evolution of Renewable Energy and Its Effect on the Environment

Alec J. Ernst*, Isaac Ansah, Keyshon Bachus, Charles Kporxah, Olusegun S. Tomomewo

University of North Dakota, Grand Forks, USA
*Corresponding author: Alec J. Ernst, alec.ernst@ndus.edu

Received July 16, 2023; Revised August 17, 2023; Accepted August 24, 2023

Abstract Population increase, energy dependency and climate change are issues causing the world to rapidly focus on clean and renewable sources of energy. With a business-as-usual attitude, further consequences may ensue. Renewable energy will drive diversification of fuels and allow for energy infrastructures to become more independent from remote grids. Renewable energy is good for the planet and is virtually inexhaustible, unlike fossil fuels. Within the United States, numerous clean power projects have been set in place to support powering the electric grid with 100% clean energy by 2050. Constraints to this plan are that renewable energy is not available around the clock and has limited infrastructural investments for transmission, distribution etc. Energy storage can help to close the gap by efficient delivery of inflexible, baseload clean energy resources. Energy storage will be key to reliably delivering clean energy and understanding this role in the evolution of renewable energy and its effect on the environment has not been fully studied. This work investigates the role of energy storage in bridging the lapses between renewable energy production and climate change mitigation efforts. By using case studies, we showed the potential of energy storage in renewable energy curtailment efforts and reducing emissions associated with electric power generation. Legislation will play an important role in relaxing the market barriers to the deployment of renewable and storage systems. An overhaul of the bureaucratic structures in favor of renewable energy and its allied technologies such as energy storage systems, is required to allow a seamless transition into a new era in which clean energy dominates the share of the energy mix.

Keywords: *Renewable Energy, Energy Storage, Sustainability, Climate Change, Energy Systems, Fossil Fuels*

Cite This Article: Alec J. Ernst, Isaac Ansah, Keyshon Bachus, Charles Kporxah and Olusegun S. Tomomewo, "The Role of Energy Storage in the Evolution of Renewable Energy and Its Effect on the Environment." *American Journal of Energy Research*, vol. 11, no. 3 (2023): 128-143. doi: 10.12691/ajer-11-3-4.

1. Introduction

The energy sector is a primary driver of industrial and economic growth throughout the world. Without energy, most other sectors would not be able to operate in the same fashion as they currently do. Energy powers computers, cellular phones, transportation, and medical equipment, among other areas that we as humans rely on [1]. Developed and emerging nations need reliable energy to support social progress and to build a better quality of life. According to the U.S. Energy Information Administration (EIA), it is projected that world energy usage will increase up to 50% by the year 2050 from 2020, and in the United States more than 60% [2].

In order to increase energy production to meet the projected demand and do so in a responsible way that protects the environment, we must diversify our energy sources into new, alternative and renewable sources. We must also do so in an efficient way that allows for clean, reliable, low cost, and scalable solutions that can be implemented at scale. Business as usual approach is not feasible as pollutants from fossil fuels and other human causes move the earth's temperature into the danger zone [1,2].

Without action in the identified key areas, the world will likely face harsh consequences and nightmare scenarios [3]. Severe temperatures, wildfires and other extreme weather, as well as toxic air making it impossible to breathe without supporting devices. Wildlife and fish stock collapse, droughts and famine will also ensue. In order to make sound decisions on which direction we should take first, we must understand where our current energy comes from, how it is stored and what technologies are on the horizon.

Today, most of the energy in the world is produced from hydrocarbons, also known as fossil fuels. The most common types of hydrocarbons include natural gas, coal and oil. In the year 2021, fossil fuels supplied about 80 % of the world's energy [4]. When these fossil fuels are burned, a process known as combustion takes place. This reaction emits greenhouse gasses (GHG) in the form of carbon dioxide, methane, nitrous oxide and other harmful particulates. These gases trap the earth's outbound energy that would otherwise escape into space. This extreme warming energy causes intense weather events such as droughts and floods and hurricanes. Other changes include the altering of ecosystems and natural habitats as well as rising sea levels. Issues that directly affect humans are heat waves becoming more lethal, food supply shortages due to droughts and floods, and disease brought on through heat waves [5].

Billions of people rely on transportation daily to get around, contributing to 12 % of global emissions [4]. Buildings contribute to 17.5 % of emissions, as densely populated cities with numerous buildings consume up to 80 % of the world's energy needs. The second industry emitting the highest levels of pollution is the agriculture forestry and forestry land use sector. The world's population needs to eat and relies heavily on livestock. The methane from cows and other livestock contributes to almost 6 % of the total emissions. Considerations into how much land is needed to farm and how much area is cleared for grazing and cropland directly affect the amount of forestation available to capture carbon. There are significant opportunities in each of these areas to improve. These areas include both efficiency of production including storage for later use, efficiency of consumption, and renewable energy technology.

In the first sector, electric vehicles (EVs) could help shift away from fossil fuels use through utilizing solar energy as a renewable resource. In the second sector, high quality feed, manure management and livestock additives could help to reduce emissions from production, while consumption and self-sufficiency could be supplied by renewable technologies such as wind turbines, water pumping, biofuels and biomass [6]. These renewable resources are attractive as they are non-finite and can be found almost all around the world. As many sources of renewable energy are still in development and not fully monetized, it is important to continue research and development in conjunction with policy reform and regulations. Understanding the sources and ideal application for renewable energy will allow for energy dependence, reduced risk of energy security and reduced risk of adverse climate effects.

1.2. Objective and contribution

Identifying critical gaps in energy storage technology and advancements is essential in order to utilize these technologies to progress the energy grid and combat climate change. Because of the amount of scrutiny that has been placed on fossil generation, more focus is placed on renewables and energy storage. Energy storage has advanced substantially over the last decades but there are still many barriers and unanswered questions that will have to be addressed before it can fully be accepted as a viable solution to climate change and energy resilience [55]. The uncertainties around energy storage and its advancements will have to be answered by government officials, policy makers, and scientists, to close the many gaps that exist [20].

2. Literature Review

Innovative research and collaborations have been underway over the last decade in search for technologies that will support the energy transition and combat climate change. Energy storage has been a focal point as a potential mechanism to integrate more renewable energy onto the grid. Many energy leaders believe energy storage is a viable option that will accelerate the decarbonization efforts within the United States and across the globe. Though research and development are on the rise, an expedited development plan is needed to address the limitations associated with energy storage for commercial use. As we see the energy sector transform over the next decade, energy leaders, policy makers and governmental agencies are relying on further research and advancements with energy storage to support incorporating more renewable energy onto the grid and providing a resilient energy pool. As a near and long-term strategy, energy storage advancements will allow utilities, electric generation developers, and operators to increase the capacity of renewable energy usage by closing the gaps with energy storage technologies. The technology will allow for energy to be stored when the demands are low but when weather patterns are favorable for maximizing renewable energy generation. The energy can be later retrieved to the grid when demands are high and at the same time reduce the dependency on fossil fuel generation. Prior literature is considered and incorporated by reference as understanding the areas where further development is needed and is critical to academia in order to add new perspective, but also to support manufacturing energy storage products that will meet environmental, energy, and societal needs of the future. As we examine the work conducted by peer reviews related to energy storage technology, we noted areas that have been accomplished, data gaps, and identified those areas that will need additional development.

According to the current literature provided by Kebede, et al. (2022), energy storage suitability with many different applications is a gap that needs to be addressed. The writer emphasizes the fact that certain stationary energy storage apparatus is more compatible for specific renewable energy technologies. In addition, scale plays a major role in utilizing energy storage as a mechanism for supporting renewable energy systems. Kebede et al, also note that further studies related to the limitations and advancements for Lithium-ion batteries specifically power density, power capabilities, and lifespan need to be addressed, Kebede et al. (2022).

Hybrid energy storage is another option that utilities and generators may use to increase renewable energy sources. According to Schaefer, et al, Hybrid energy storage technology brings many advantages to generators that will support better capacity and power, Schaefer, et al. (2022). Utilizing multiple Energy storage sources allows larger utilities that have high energy demand to meet the consumer energy commitments at the scale and capacity required. The author indicated additional research is needed related to more elaborate sizing of energy storage hybrid systems related to different energy generation portfolios, Schaefer, et al. (2022).

Energy storage to scale and capacity has continued to be a gap that is of great concern. Per Sun, et al. (2022), shared energy storage for different energy bases may be an optional solution to providing higher scale, reliability and increasing renewables. Ultimately, it is an opportunity to reduce capital investment by sharing energy storage systems with multiple renewable energy bases, eliminating waste, and supporting resource conservation efforts, Sun, et al. (2022).

Extensive literature review indicates that further research should be conducted to evaluate the energy storage scales with different energy mixes and technology to assure products are developed that will allow generation to support large commercial energy pools around the globe. As many reviewers are focusing on energy storage as a solution, for supporting more renewables, there needs to be a shift to further evaluate the commercial usage of energy storage with a mix of technologies, energy demands, and diverse technology. From reviewing technology, many obstacles around the limitations associated with an energy system incapable of storing large amounts of energy during time with demands are not high. This continues to be a deterrent for many utilities that desire to use energy storage technology that will allow them to add more renewable energy to their portfolio. An examination of the scale and capacity of energy storage capabilities must be identified, and ongoing research will need to result in advancements to close the gaps in this area [19].

3. Renewable and Clean Energy Technology

Renewable energy is energy that is generated from natural resources that replenish continuously using non-finite resources [7,59,60]. Finite resources, or fossil fuels, will eventually be depleted as they take millions of years to form. Renewable energy sources are replenished much quicker, allowing for an increased energy source mix, thus minimizing dependency on any one source. There are many types of renewable energy as shown in Table 1.

Table 1: Types of Renewable Energy [8].

Type of Energy	Brief Description
Solar	Energy from the sun converted into thermal or electrical energy
Wind Energy	Kinetic energy created by air in motion, used to produce electricity.
Hydroelectric	Uses the power of moving water to generate electricity.
Ocean Energy	Renewable energy is derived from the sea. Wave, tidal, and ocean thermal.
Geothermal Energy	Heat energy is taken from within the Earth's core.
Biomass	Renewable organic material that comes from animals and plants.
Hydrogen	Excess renewable energy ran through tanks of water creating hydrolysis.

Renewable energy has both advantages and disadvantages that can be analyzed when determining which type fits a specific application. In Table 2, these advantages and disadvantages are listed.

As shown in Table 2, the advantages to renewable energy exceed the disadvantages. In example, solar energy is a renewable source, available around the world. Solar energy is environmentally friendly and can help to reduce carbon emissions as it is primarily a clean energy source. A disadvantage to solar energy, however, is that it is weather dependent. On cloudy or rainy days, the sun's energy output may not meet the energy demand from the panel. In this scenario, on days with high output that exceed the demand needed, solar panels can be paired with energy storage technology. This allows for the electricity to be captured during high production periods and discharged during low production periods, thus leveling out demand. Energy storage will play a key role in the evolution of renewable energy by improving efficiency and reducing waste of unused electricity [79].

Table 2. Advantages & Disadvantages of Renewable Energy [9].

Advantages	Disadvantages
They won't run out	High upfront costs
Low maintenance requirements	Intermittent, not always available
Environmental benefits	Limited storage capability
Lower energy security risk Creates new jobs. Cuts down on waste. Saves money	Geographic limitations Not always 100 % carbon free

4. Energy Storage

Energy storage is the capture of energy produced at one time for use later [10].

Energy storage is not a new concept. Batteries for instance, are a type of energy storage that has been used since the early 1800s. Energy storage is comparable to a refrigerator. In a refrigerator, food can be stored for days to weeks so that it does not have to be consumed immediately or discarded. In energy storage, electricity or energy can be consumed when demanded [11].

From these systems, energy storage can be broken down into short-term storage applications and long-term storage applications. Short-term applications typically store energy for a couple of hours while long-term applications store energy for days to weeks. Common short-term systems would be rooftop solar panels that hold energy for individual use. Other examples include batteries in EVs. Long-term energy storage harnesses a larger amount of utility scale energy from wind farms and solar arrays and allows for predictability and flexibility. Pumped hydropower is an example of long-term energy storage [21]. Energy storage has both benefits and concerns which will help to determine which type is best for the application [12].

Energy storage is important to maintain grid efficiency and demand fluctuation control. It must be designed and continuously improved in order to improve benefits to gain full adoption and standardization [20]. Energy storage can improve both fossil fuel applications and renewable energy applications. In fossil fuel applications, plant economics, reduced maintenance costs, the extension of fossil assets and efficiencies in environmental performance are all benefits that can be realized [13].

Energy storage will undoubtedly help to advance renewable energy systems by allowing energy to be pulled only when demanded, thus reducing loss and improving efficiency. Understanding the concerns highlighted today during the infancy of the renewable energy race will allow for future balance through energy storage. Reducing environmental impacts and climate change to 1.5 degrees or less by 2050 is outlined in the Paris agreement. Energy storage and renewable energy in harmony can support this by reducing negative effects and improving efficiency and flexibility [14]. This research aims to test the notion that energy storage devices can speed up efforts to mitigate climate change by boosting the proportion of renewable energy use and lowering energy curtailment. The validity of this hypothesis would be determined by reviewing the relevant literature and case studies.

5. Climate Change

Climate change is occurring at a rate ten times faster than any recorded point in the past 65 million years [15]. Climate change is a long-term increase or change in the Earth's average surface temperature or weather patterns. Earth's climate is in a continuous state of change. There have been times where the Earth has been both warmer and cooler than it is now. Current studies show that the Earth's climate is getting warmer and has increased about one degree Fahrenheit in the last 100 years [16]. Although this number may seem small, it can have big effects. Snow and ice caps melting, oceans rising, shifts in growing seasons, land degradation and an increase in extreme weather events [17,18].

6. Current State of Problem

As pressure to diversify the energy mix and decarbonize the grid remains a focal topic among energy leaders, energy storage technology and its capabilities are under extreme scrutiny. Understanding the strategy around how energy storage can add more renewables to the grid in addition to resilience is critical. Nevertheless, as more energy generating entities start to incorporate energy storage into their long-term decarbonization plans, consideration must be given to the advancements that must be made to utilize ESS to support the energy transition. [87] Cost, durability, efficiency, scale, intermittent and capacity appear to be gaps that need to be further addressed with extensive research. Energy storage technology can be a great mechanism for supporting renewable energy incorporation. The price of energy storage devices is one of their biggest problems. When compared to alternative energy storage methods, such as pumped hydroelectric storage, many energy storage technologies, such as batteries, are still relatively expensive. As a result, in some circumstances, it may be challenging to defend the expense of energy storage devices. After a given number of cycles, some energy storage devices may have to be replaced because of their short lifespan. Energy storage systems that are meant to run continuously may find this to be difficult. There is some energy lost throughout the process of storing and discharging due to some energy storage devices' partial efficiency. For energy storage systems that must store and release huge amounts of energy, this can be difficult. Renewable energy sources, like solar and wind, are intermittent, which means they don't always deliver a steady stream of electricity. Energy storage systems that rely on these sources may find this challenging since they need to be able to store extra energy when it is available and release it when it is needed.

Importantly, cost, durability, efficiency, scale, and intermittent of ESS must be confronted as major limiting factors for advancing the energy transition. Achieving many of the global initiatives such as Net Zero will be misfiring if research and collaborations don't solidify these technologies in a way that the energy transition can receive a maximum return on adding renewable energy to the grid. [88]

As a solution to energy decarbonization, utilities are looking to utilize energy storage to store energy from renewable energy when demand is not high. Consequently, the energy should be retrievable when demands are high, and the energy is needed to support reliability and resilience of the grid. Many limitations with renewable energy have been identified and energy storage may be one of the technologies that can be used to strengthen the reliability and usage of renewable energy. If research does not further the understanding of the scale and capacity issues with energy storage, we will not be able to fully capitalize from the usage of energy storage to support our problems with both climate and renewable energy developments. [88] Academia, policy makers, and manufacturers need to build synergies around developing literature as a roadmap that will further advance the development of energy storage and fast forward the storage technologies in a way that will support the global long term energy transition plans. Continuous advancements with energy storage will allow global efforts to increase more wind and solar on the grid and provide more confidence in energy storage technology as being a catalyst for speeding up the rate of decarbonization.

7. Identification of critical gaps in Energy storage systems

Identifying critical gaps in energy storage technology and advancements is essential in order to utilize these technologies to progress the energy grid and combat climate change. Because of the amount of scrutiny that has been placed on fossil generation, more focus is placed on renewables and energy storage. Energy storage has advanced substantially over the last decades but there are still many barriers and unanswered questions that will have to be addressed before it can fully be accepted as a viable solution to climate change and energy resilience [55]. The uncertainties around energy storage and its advancements will have to be answered by government officials, policy makers, and scientists, to close the many gaps that exist [20]. Areas of focus will need to engage dialogue around regulatory requirements, cost, reliability, safety, consumer approval, and waste disposal.

For years, the energy sector has been susceptible to excess amounts of regulatory burden, that has not only been costly to comply with but could have the potential to cease operations and result in reliability issues. In integrating energy storage into power generation, it will have its advantages but, policymakers will need to inform energy leaders and the public of how new regulations may affect these new technologies and their plant operations [69]. Most consumers think of energy storage to be utilized to support the limitations of renewable energy, which is far more environmentally friendlier than fossil fuel, but we still foresee additional regulations in the future that will add to the cost of doing business.

Additionally, we must address the issues around cost. As we assess the scale at which energy storage would need to be used to ensure energy reliability, historically, the price for energy storage at higher capacity was not practical. Over the years, the price for energy storage has decreased, but not the levels needed to leverage this technology. According to the World Energy Council, prices of energy storage are expected to fall by 70% over the next 15 years due to new technology and the amount of energy technology that is in development [21]. Nevertheless, excess cost analysts will need to consider governmental incentives to support the cost reductions needed to make this technology more accessible for not only the energy sector but for companies and consumers that want to utilize energy storage in conjunction with their renewables [20]. Energy storage should be seen as a viable option for not only large entities but for consumers and households that want to take advantage of storage saving and energy conservation opportunities. Over the last years, there have been some reductions in price around energy storage. However, as we look at the scale at which energy storage will need to be used to integrate more renewable energy and reliability, more cost reductions will be needed to incorporate this technology as a long-term strategy.

Next, reliability and safety education are the foundation for operating energy plants. Informative and consistent developments are needed related to these areas of concern. Safety for employees, communities, and for equipment commissioning and operation is imperative. The Occupational Health and Safety Administration (OSHA) has added a great deal of guidance specific to the energy sector and there is work to be done related to energy storage. Because this technology is gaining excessive attention, it is safe to assume there will be more studies in this area to provide energy to employees that are tasked with operating this type of equipment [22]. Also, as energy storage is used as one of the solutions with adding more renewables to the grid, reliability will have to be looked at in depth to ensure it is viable as a long-term solution. With so many parts of the world experiencing brown and blackout, analysis on the reliability that constructively outlines limitations on the reliability of energy storage that is resilient enough to store and discharge energy on demand when needed, must be addressed to ensure any foreseeable interruptions are addressed.

Circular waste operations are essential for us to protect land, water, and the impact on climate from harmful pollutants that can be emitted from landfills as a result of waste disposal [28]. On a smaller mass scale, batteries have been recycled for reuse. Nevertheless, there has been very little development around large-scale disposal related to energy storage systems. As sectors adopt more energy storage, care and focus must be put on the environmental impact as it relates to end of life disposal. Many of the components of energy storage have the potential to be hazardous waste [23]. Due to how massive this apparatus can be, it is essential that recycling programs are developed to prevent these storage systems from being landfilled or increased amounts of hazardous waste from being generated. Also, cost is a major factor.

The amount of component parts and massive size of some of these energy systems can cost hundreds of thousands of dollars just to dispose of these systems at the end of life. These costs to the environment and financially, are alarming for the energy sector [23, 27]. The most prevalent batter for energy storage tends to be lithium-ion (Li-ion). It accounts for a large percentage of manufactured batteries used to scale for energy storage. Nevertheless, there appears to be only a small percentage of Li-ion batteries recycled. The mass number of components of these batteries is excessive and could cause environmental problems if not disposed of properly. Even landfilling these batteries can have a significant environmental impact that has the potential to contaminate soil, air and water. According to literature, Li-ion battery components are more difficult to separate in comparison to other batteries such as lead acid. However, additional studies are needed to provide concrete guidance to users on after life recycling options in order to reduce cost and waste disposal [27].

Last, aside from the energy sector entities, and companies adopting energy storage systems into their operations, consumer education and acceptance needs to be addressed. As countries adopt more renewables into their portfolio to reduce the risks of climate change, consumers need to be a part of the strategy and understand both the limitations and attributes that energy storage systems can bring to decarbonizing the economy [61]. Also, as we see more consumers adding renewals to their homes or even small businesses, some are now coupled with energy storage to be utilized as a backup during potential blackout and helping with savings. More awareness needs to be shifted to our consumers and educational tools to inform consumers of the energy challenges, opportunities, and the mechanism around renewals and energy system storage that can be used to combat climate change.

8. Renewable Energy Technology

The demand for energy to support socio-economic activities is growing amid concerns about climate change. Wind and solar power have shown promising leads as viable alternatives that could wean the world's over-reliance on fossil fuels. The push for renewable sources to address global warming comes with challenges that need to be overcome to increase their share in the energy mix.

There is enough evidence of growing renewable energy penetration into the energy mix, but the transition process may not be at a pace to meet the 1.5degC limit goal by 2050. The existing legal framework and socioeconomic barriers impede the transition from high to low-emission pathways. The push to increase renewable energy share in the energy mix has gained global attention as many countries adopt a united front through policy enactment to encourage renewable energy use. A handful of countries in the European Union have taken the lead in the research, development, and deployment with the sole aim of reducing global reliance on fossil fuels. Technology innovation is a critical means of accelerating the transition to renewable energy. Ultimately, renewable energy has emerged as a promising substitute to fossil sources amid growing concerns about the environmental consequences of GHG emissions.

The effort to mitigate the effects of climate change entails promoting the best use of clean energy and encouraging the global energy system to transition to electricity generation from low-carbon sources. Renewable sources such as wind and solar are forecasted to meet about half of the world's energy needs by 2050 [30]. EV demand will increase by 6% or approximately 2TWh of total electricity produced by 2040 [31]. However, limitations imposed by renewable sources, such as intermittent delivery from solar and wind sources, have paved the way for energy storage devices to be included in the mix of renewable energy technologies. Advances and deployment of energy storage devices with renewable energy sources have successfully addressed the downsides of deploying the latter. Energy storage improves the overall utilization of available green energy resources by smoothing fluctuations in power supply from such resources. Global energy demand is expected to rise by 56% between 2010 and 2040 [68]. The need for energy in the transportation sector is expected to grow further with the middle-class population in the United States [83]. Personal vehicles that use fossil fuel are expected to peak some years ahead before declining in favor of electric vehicles (EVs).

8.1. Energy Storage Technology

Electricity is primarily generated from traditional sources such as hydroelectric, fossil fuel-based technologies, nuclear, etc. Much more recently, other sources such as wind, solar, tidal power, and so on have been added to the spectrum of energy sources in increasing proportions as practical means of combating climate change by reducing GHG emissions. The fight against climate change has focused on the selective use of renewable electricity to power the grid. By optimizing resources from both renewable and traditional energy sources, energy storage systems can play a critical role in the overall grid system. They can be used at each stage of the supply chain, including generation, transmission, and distribution. Since the bulk of electric power is generated remotely, balancing power production with demand is crucial for energy management. Energy storage systems can also be viewed as the solution to address the intermittent and variable nature of renewable resources [66]. The latter serves as primary feed to storage systems to combat climate change and reduce GHG emissions. Energy storage systems are primarily deployed as just-in-time resources to address the specific energy needs of customers due to limited infrastructure investments.

The global population growth and income growth for the middle class in industrialized nations are fueling the demand for energy resources. Each energy source can only be forecasted to dominate the supply base reliably. Even though renewable sources have increased in shares, fossil fuel production continues to grow by tonnage, thanks to world population growth. Also, fossil fuels dominate the current energy infrastructure, such as gas pipelines, seaborne transportation, and delivery ports worldwide. Most energy grid systems must be configured to continuously take supply from renewable sources.

Energy storage systems can decarbonize the power sector by lowering global emissions. When configured to renewable sources, energy storage technology provides a carbon-free source of energy reserve and flexibility and reliability to the grid system. By upgrading existing energy infrastructures to accommodate supply from renewable energy sources, energy storage systems have promising potential to address infrastructural gap problems currently serving as impediments to renewable energy penetration efforts [65]. Aside from decarbonization, energy storage systems enable accumulation of the most value from renewable energy due to the former's ability to arbitrage wholesale prices during peak and non-peak seasons [30].

8.2. Battery Storage System Efficiency

The battery capacity, charging duration, and charging current are used to calculate battery efficiency [87]. This formula, which is applied by using the state of charge (SoC) and state of health (SoH) computations, may precisely predict the battery state. By using the battery efficiency to the open circuit voltage (OCV), the SoC may be precisely determined, reducing the initial inaccuracy of the Coulomb counting technique (CCM). The internal resistance of a battery rises during the charging and discharging process, while the constant current (CC) charging time decreases. The battery's CC charging time and battery efficiency can be used to forecast the SoH. When a battery is used, its efficiency declines. A battery's efficiency can only drop when it is in use because it is at its highest in the starting condition. Equation (1) describes a battery's efficiency. By deducting the battery loss from the 100% initial battery efficiency, one can express the efficiency of a battery. Loss can be computed using the charging and discharging powers, as stated in Equation (2), since the decrease in efficiency can be described as the rise in internal resistance. Ibat, R, and Vbat are the battery's internal resistance, charge-discharge current, and voltage, respectively.

$$\eta_{bat} = 100 - \eta_{loss} \tag{1}$$

$$\eta_{loss} = \frac{I_{bat}^2 \times R}{V_{bat} \times I_{bat}} \tag{2}$$

In this situation, Equation (3) can be used to express the battery's charge-discharge current. The quantity of charge (battery capacity) and the C-rates at which the battery has been charged or depleted over time can be used to compute the current during a battery's charge-discharge cycle. The battery's capacity is denoted by $Q_{bat,}$ and its charge-discharge cycle is measured by t. The electric charge equation is used in equation (3). The overall reduction in battery efficiency, shown in Equation (4), is given by Equations (2) and (3). To figure out a battery's internal resistance, apply equation (4). Given by Equation (5)

$$I_{bat} = \frac{Q_{bat}}{t} \tag{3}$$

$$\eta_{loss} = \frac{\left(\frac{Q_{bat}}{t}\right) \times R}{V_{bat}} \tag{4}$$

$$R = \frac{\eta_{loss} \times V_{bat} \times t}{Q_{bat}} \tag{5}$$

A battery protection system keeps an eye on the battery's condition and guards against overcharging and over-discharging, enhancing both its performance and safety. How well a BMS forecasts the SoC and SoH of the battery is used to measure its performance [88]. The SoC is tracked using CCM, with the value computed by integrating the current during the battery's charge-discharge cycle to the SoC's beginning value. However, because the current is added to the CCM's initial value, inaccuracies can build if the initial value is not known with precision. Equation (6) states the voltage as determined by Equation (5)'s use of the battery's open circuit voltage formula. Using the internal resistance discovered by solving Equation (5) and the battery's OCV, the condition of the battery can be predicted more precisely. Equation (7) illustrates the ultimate CCM. Applying the internal resistance value obtained from the battery efficiency equation to the standard CCM can increase the accuracy of the forecast of the battery condition. Cn is the battery's capacity, SoC(t) is the SoC at time t, SoC(t1) is the initial SoC, and Vocv is the battery voltage in the open state [89,90].

$$SoC(t-1) = V_{ocv} + \left(I_{bat} \times \frac{\eta_{loss} \times V_{bat} \times t}{Q_{bat}} \right) \tag{6}$$

$$SoC(t) = SoC(t-1) + \int_0^t \frac{I(t)}{C_n} dt \tag{7}$$

8.3. Related Benefits of Energy Storage Systems

The biggest reason for adopting energy storage systems is to help integrate renewable energy into the grid. The main counterargument for the effective deployment of renewable energy is the variable nature of their output. Incorporating a storage system enables renewable energy sources to align more effectively with electricity demand by making the latter more dispatchable. This means more renewable sources would be drawn onto the grid when readily needed to enhance grid resilience. By so doing, energy storage systems can increase the share of renewable sources to the grid, just like fossil sources but without emitting greenhouse gases into the atmosphere. Other reasons for using energy storage systems are the financial benefits of using backup power when the main supply becomes expensive. Energy storage systems can also provide grid resiliency by quicker response injection of energy on the grid as a contingency.

9. Design

The approach to understanding the need for energy storage and renewable energy to create a cleaner and healthier environment starts with what has been done and what is being done. As shown within case study findings, and data analysis, it is imperative that we continue to study these issues. The goal is to transition to a world free of pollutants. This transition is far different from what is considered normal today. For renewable energy to transition without significant disruption, many things will have to change. These include improving global access to components and raw materials, reformation of policy both domestically and globally, shifting energy subsidies from fossil fuels to renewable energy, and increasing investments in renewables [73].

Technology deployment through renewable resources can help to move the needle to make that a reality, but it needs to be done with care. Currently, the world is shifting to EVs. However, many countries need the infrastructure or are adequately prepared. To successfully deploy, policy, technology, regulation, understanding of the need, and acceptance at the consumer level must all mesh together. Baseline data is in place; however, modeling showing the impact with or without action has yet to be fully defined. Studies in feasibility need to be conducted as well. Renewable energy technology today is still unstable, and energy storage still needs to be more efficient to transition completely. Each of these storage and renewable energy technologies has unique advantages and disadvantages that must be analyzed further during implementation.

Awareness of the disadvantages will allow for further improvements to overcome the obstacles when integrating into each system. Without proper design and implementation, negative impacts on our climate and our environment will ensue. Lithium-ion batteries are trending as a top pick for energy storage systems. They are gaining market share at an unprecedented rate and have many advantages over other sources. It must be understood, though, that there are limitations as well. These problems include supply chain issues for raw materials, trade policies, environmental impacts from mining materials, and end-of-life disposal regulations [74]. Reformed regulations and disposal methods will be needed to transfer to renewables, coupled with energy storage fully.

10. Procedure and Analysis

In support of our research objectives related to energy storage and its capabilities, limitations, and future review.

Reviewing the current work and development around energy storage, we carefully reviewed and cited the findings from the most recent and credible sources, including academic journals, case studies, industry developments, data modeling, etc. The literature review allowed us to determine the historical advancement of energy storage and what progress has been made to date. No direct data was collected as our source of data was primarily secondary, to use a large population to derive a conclusion that would also identify areas where additional research and development needed to be undertaken. In alignment with climate science and its timeline with goals of holding temperatures to 1.5 degrees C above pre-industrial times, we attempted to create a timeline that would show progression based on current data available through 2050 [25].

Our literature review starts with reviewing content related to the current state of renewable energy, its timeline for supporting energy transition, potential policy & legislation, and both limitations and optimizations with the current technology [24,29]. Next, we would focus on the advancements made with energy storage with efforts to identify gaps in technology. Our goal was also to understand how the current technology could be used at the commercial level to support a successful energy transition, support climate initiatives, and a healthy energy grid. Advanced scenario modeling was reviewed to allow us to understand how energy storage could contribute to the current energy portfolio and what upgrades and advancements would need to be made to achieve future energy forecasts. Assessing available data and literature on energy storage and renewable energy provided a clear understanding of the additional work required with both technologies. Last but not least, our final data and literature review consists of understanding the impact of energy storage and renewable energy on society, climate, and energy transition over the next two decades.

The long-term strategy the energy sector has deployed involves using both technologies. In conclusion, our findings should provide an overview of what additional advancements would have been made to use these technologies as a viable source as more and more fossil fuel generation is decommissioned. In addition, we sought to address how extensive new regulations would be on development and potentially affect the commissioning of energy storage, the cost for adoption, and whether advancements in technology will be able to accelerate at the same rate as policy and energy demands to meet both environmental and consumer needs. Notably, an extensive literature review was imperative, as our research contribution will allow the energy sector, consumers, governmental agencies, politicians, and academia to understand the challenges ahead better as we work to combat climate change and utilize the advancements in energy storage will bring.

As we advance energy storage, energy policy will be critical as the demand to reduce our GHG and achieve many of these global initiatives with reaching net zero by 2050 are focused on. Policy at both the governmental and international levels is essential to reducing the global dependency on fossil fuels and driving the electric grid to be more resilient and environmentally sensitive. Robust policy and regulations are rising and will catalyze accountability governance as we make history's most significant energy transition over the next two decades [25]. Many different countries around the globe are facing the difficult obstacles of developing strategies and timelines that will support decarbonization. Consequently, with more energy policy, the transition will be faster, and there needs to be synergies with neighboring countries to combat climate change effectively. As the energy section continues to feel the pressure of decarbonization, much focus has been put on energy storage. According to research, models have been developed using thermodynamics, indicating the energy storage limitations supporting the grid.

10.1. Roadmap

A hybrid approach should be considered in the interim that focuses on a step-by-step reduction of finite resources with a slow-paced increase in renewables. Figure 1 shows a deployment roadmap to combine energy storage with renewable energy technology. This roadmap's primary function is to improve the reliability and safety of the overall system and infrastructure while allowing for strategies for improvement to be identified and areas of concern to be reduced.

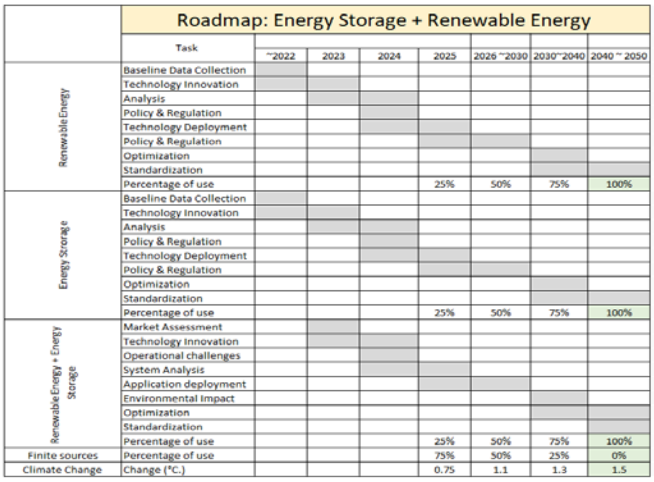

Figure 1. Proposed Roadmap: Energy Storage & Renewable Energy (Contributed by Author)

As displayed in Figure 1, our roadmap design follows a systematic approach to incorporating renewable energy technology with energy storage. This vessel will allow for renewables, ranging from wind and solar to biomass and geothermal, to couple with storage technologies such as batteries and pumped storage hydropower.

11. Case Studies

11.1. Case Study by Lawrence Berkeley National Laboratory

This study used EV charging technology in California to demonstrate its potential benefits to climate change mitigation efforts by researchers at Lawrence Berkeley National Laboratory (LBL) [58]. The researchers hypothesized that scheduling EV charging might help

California achieve its goals for integrating renewable power in a more affordable way than the state's 2010 mandate for installing grid energy storage [59]. California's system-wide balancing challenges were examined in the LBL case study. These problems are predicted to worsen through 2025 as additional renewable energy sources, particularly solar PV, are implemented. The "California Duck Curve" issue best describes this [60]. By adopting a policy regime to charge EVs in the middle of the day (when renewable solar generation is at its highest, as opposed to the evening or overnight), EVs could use the excess renewable electricity available at this time and help balance the grid while saving the cost of ramping up and down other electric generation.

V1G, which stands for "one-way" charging of EVs, is the name of this procedure. According to the LBL researchers, the technology for a one-way charging regime (i.e., grid-to-vehicle charging) is widely available. It may be implemented in California for about $150 million [61]. In the V1G alone scenario, down-ramping and up-ramping decreased by more than 2 GW/h by 2025. Vehicle-to-grid, or V2G, is a bi-directional charging system that uses the V1G mode to charge an electric vehicle's technologically advanced battery, then discharges any remaining energy to recharge the grid at times of high demand. Hence, more significant increases are seen when V1G and V2G vehicles are combined. Both down-ramping and up-ramping are significantly alleviated by almost 7GW/h, which is equivalent to averting the construction of 35 natural gas 600 MW facilities [62]. The LBL researchers estimate that such a strategy may save California between $12.8 billion and $15.4 billion in investments in stationary storage [63].

11.2. Case Study Utilizing En-Roads Simulation Software

An En-Road's simulation was conducted based on the Lawrence Berkeley National Laboratory study to ascertain the impact of the study's adopted policies on climate change. The three areas targeted by the policies included in the model are energy supply, transportation, and the building and industrial sectors. Taxation of coal facilities, which represents the shutting down of coal plants around the world, subsidies for renewable energy systems, subsidies for oil and gas plants, improvements in the energy efficiency of the transportation sector, incentives for electrification of the transportation sector, increase in population and economy and progress in the energy efficiency of buildings are all inputs for the model. Based on the adopted policies, the model's output indicated a 28.9 gigaton reduction in CO2 from the starting point. By the year 2100, this decrease in CO2 caused the earth's average temperature to drop by 0.5 °C, from 3.6 °C to 3.1 °C. The model's numerous inputs are depicted in Figure 2 below, along with the output chart.

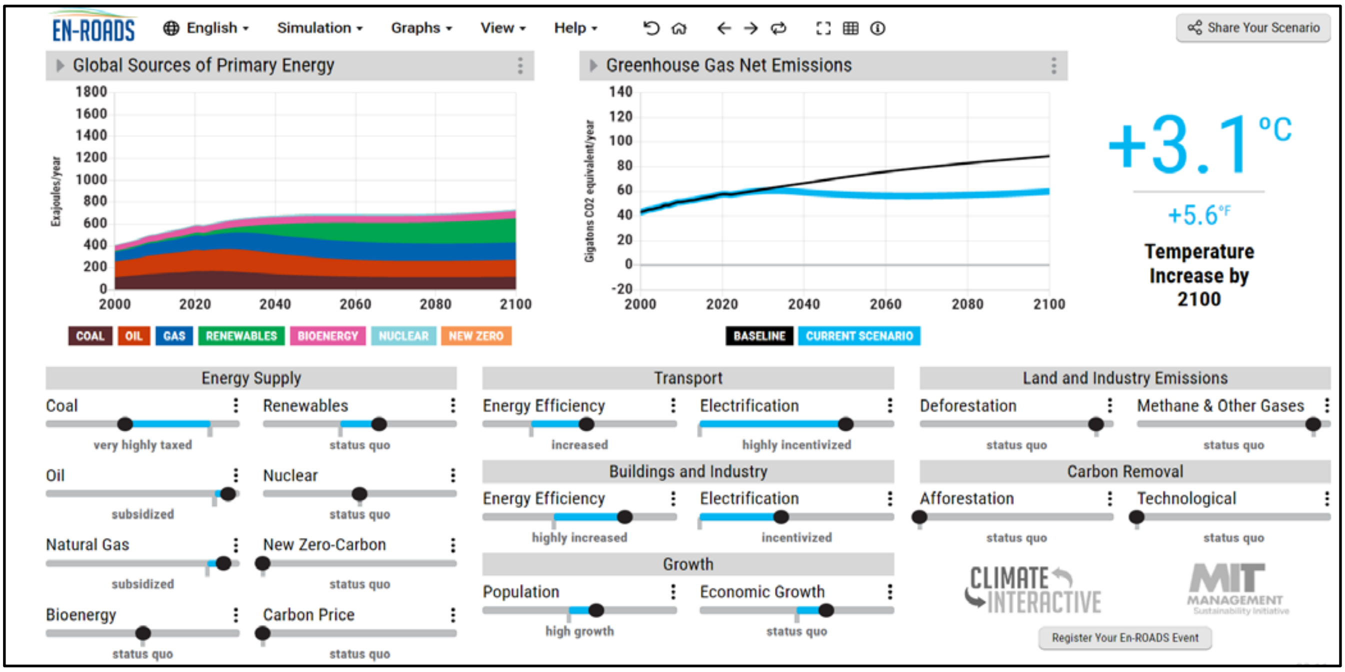

Figure 2. Model EN-Road's simulation for LBNL case study [51]

The interpretation outcomes lead to two key observation points, shown in Figure 2. The first argument is that, as evidenced by the difference between the baseline and anticipated GHG emissions, increasing transportation efficiency and electrification substantially impact limiting temperature increases. The second point is that improving building energy efficiency also significantly lowers the potential growth from the baseline value of 3.1 °C to 3.6 °C. Using systems like EN-Roads as catalysts for legislative and regulatory changes through a more thorough application study is possible. With positive legislative support in place, the V1G phase of the survey can be projected to highlight the significance of employing the right technology to enhance the share of renewable technology in the energy mix. Additionally, both V1G and V2G projections can demonstrate a decrease in our excessive reliance on fossil fuels through grid system optimization.

The transport industry contributes significantly to global warming and pollution through CO2 emissions. A practical strategy to hasten EV adoption in the transportation sector is business and government collaboration, as demonstrated by the Lawrence Berkeley National Laboratory case study. As observed in the V2G part of the study, the technological advancements to the battery-storage system have additional benefits beyond only serving as a power source for EVs. Potential benefits might be extended to domestic use. The simulation results are shown in Figure 2 strongly support combining technological efficiency, accelerated deployment, and supportive legislation to advance clean energy efforts. The expected hypothetical temperature drops of 3.1°C is due to the electrification of the transportation sector through the V1G segment of the case study, the electrification of the domestic segments of the building and industry sectors through the V2G segment of the study, and the dominance of renewables in the energy supply in both scenarios. These results provide compelling evidence for the need for supportive legislation. Although the simulation results are hypothetical, they indicate the potential impact of electrifying the transportation and domestic sectors. The results do not focus on how the input variables were manipulated to achieve these results.

11.3. Case Study by University of Michigan

This case study uses an excerpt from a study at the University of Michigan. This study shows how in the states of California and Texas, under various tax regimes, an energy storage system (ESS) can reduce carbon emissions and the use of renewable energy. According to the base scenario's minimum dispatch ability requirement of 7.0 GW, Figure 3 shows the total annual renewable curtailment in California for 2012 with and without access to energy storage, varying amounts of renewable capacity, and CO2-emission levies. Figure 4 presents the same information for the Electric Reliability Council of Texas (ERCOT) system under the base case 8.2-GW minimum-dispatch ability requirement. The studies in both states show that California has significantly higher rates of renewable energy curtailment than Texas. This is because California imports much more energy than Texas and produces much more energy from non-renewable sources (such as nuclear, geothermal, biomass, and hydropower facilities). Due to this increased stiffness, the California grid system finds it more difficult to absorb wind and solar energy. With increased carbon taxes, all energy storage technologies, except Li-ion batteries, become economically viable for this usage.

The study also found that energy storage in California is most useful when it can reduce the amount of renewable energy that must be curtailed and switch to fossil fuel-powered generating. This benefit increases with a greater carbon price due to the higher cost of fossil fuel-powered generation in the face of a tax. In contrast to a scenario with no renewable energy sources, several technologies (including PHS, CAES, VRB, and PSB batteries) can efficiently cut CO2 emissions by over 90%. Energy storage can thus be used to replace fossil fuel-based energy and reduce the need to limit the production of renewable energy sources. On the other hand, Texas' carbon tax, which may divert producing loads away from coal-fired units and toward natural gas-fired production, makes energy storage affordable, even without more renewable energy sources.

Figure 4 panels correspond to the different wind- and solar-penetration levels, which are indicated at the figure's left-hand side and bottom, respectively.

Figure 5 Renewable Curtailment & Emission Reduction in California (2010-2012) shows the effects of energy storage on reducing CO2 emissions and renewable energy in California. The outcomes in the picture are based on base-case 7.0 GW wind and solar penetration, a $200 per ton CO2 emissions tax, and penetration levels of 20 GW and 40 GW, respectively.

12. Findings and Results

We have confirmed that energy storage will play a crucial role in the transition to renewable energy through the review of literature, case studies, data review, and analysis. To successfully transition to renewables, it will be necessary to do so efficiently that builds public confidence. Renewable energy is essential for reducing air pollution and meeting the world's energy needs without harming the environment. To fully transition away from conventional sources, we must focus on the critical areas listed in Table 3.

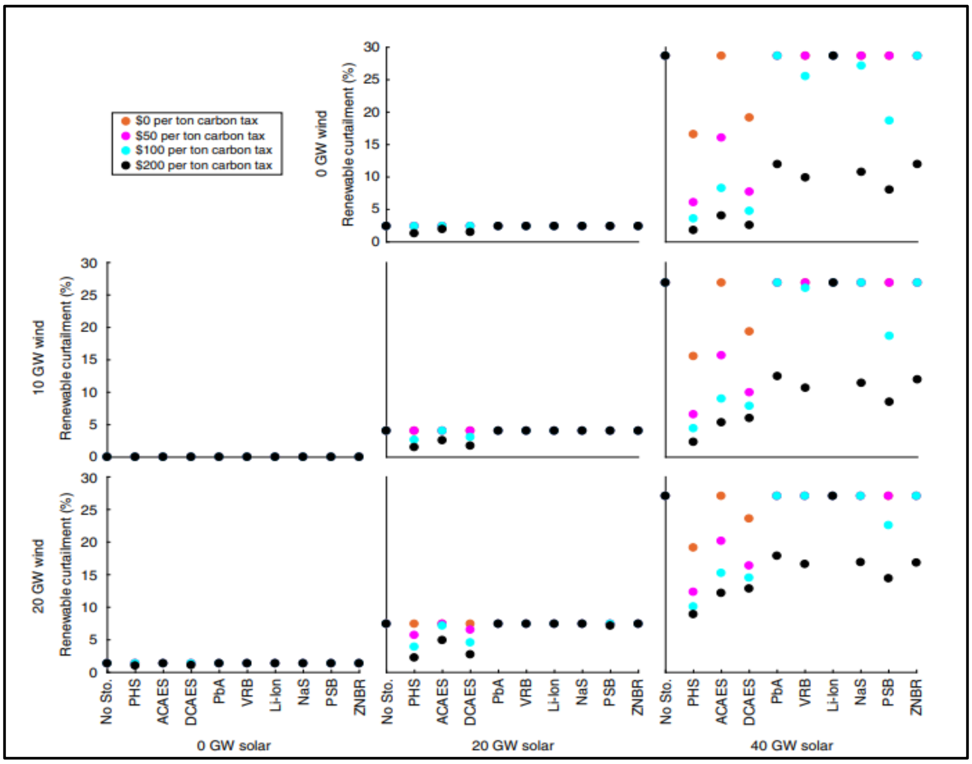

Figure 3. Renewable Curtailment in California, 2012

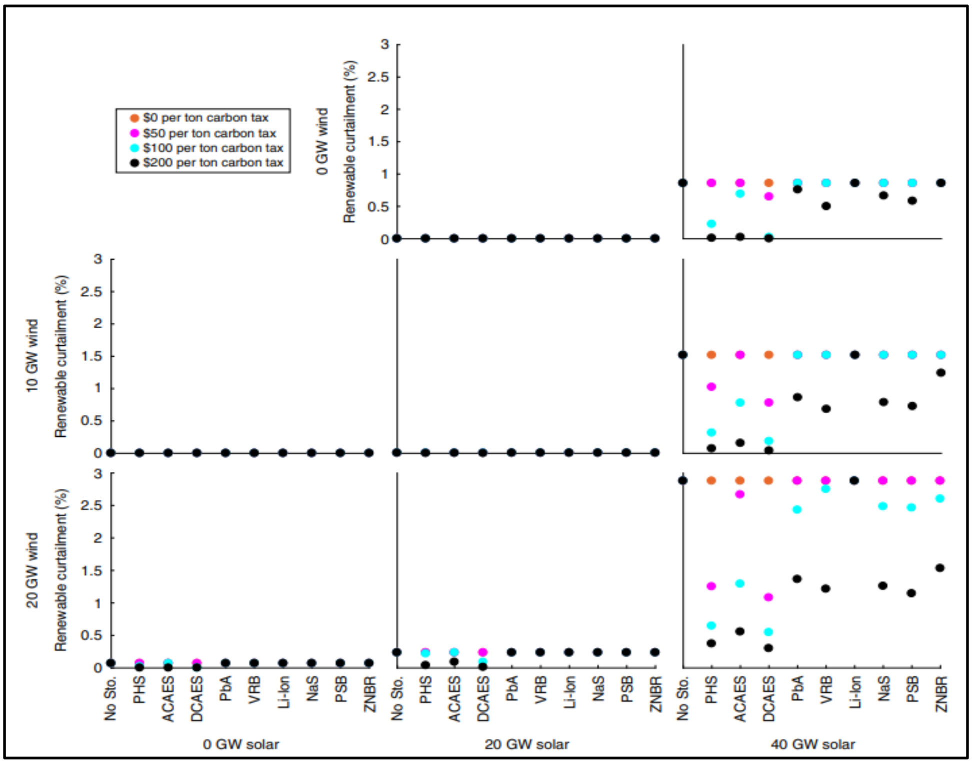

Figure 4. Renewable Curtailment in Texas, 2012.

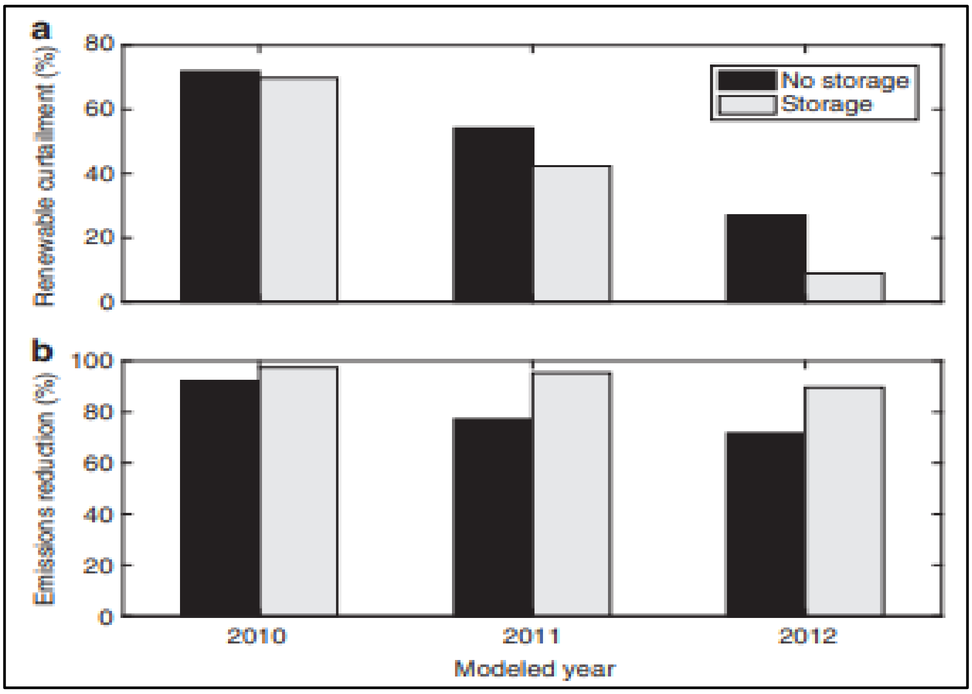

Figure 5. Renewable Curtailment & Emission Reduction in California (2010-2012)

Table 3. Energy Transition Focus Points

Area	Focused Efforts
Policy and Regulation	Tax incentives, environmental impact, sustainable development, technological development
Cost	Control to grow industry and economy
Reliability	Supports energy security.
Energy storage	System balance, levelized demand
Safety	Imperative to buy-in and success.
Education	Transparency with
Landfill & Disposition	Regulations for disposal and recycling

As indicated in Table 3, many factors should be considered when implementing renewable energy technologies, including return on investments [69]. This research paper aims to explore the role that renewable energy and energy storage will play in addressing climate change. In addition to cost, safety is also a critical factor in consumers' adoption of renewable energy. Energy storage is an essential component of renewable energy systems, as it helps to balance fluctuations in power generation and consumption. Increasing awareness of the benefits of renewable energy and energy storage is crucial as we move forward. There is a significant gap in understanding the impacts of relying on fossil fuels as the primary energy source. Renewable energy and energy storage can have a positive effect on the environment by utilizing natural, replenishable resources and improving efficiency using energy storage. Energy storage is essential for enabling the widespread adoption of renewable energy and ensuring its reliability.

12.1. Comparison with Previous Studies

As we look ahead from the current state of technology, data, and research, energy storage will be a part of the new energy portfolio that supports our climate initiatives and energy reliability. Nevertheless, our literature review and analysis of the most recent data paint a clear picture of what the focus needs to be going forward. Current research and development have found that many areas associated with energy storage need further advancements. According to the Department of Energy (DOE), which has conducted extensive research in this area, the energy storage lagging indicators are excessive. Many of the challenges around energy storage must be addressed for utilities, corporations, and lobbyists to endorse with the confidence that it will support not only the stability that is needed for a reliable energy grid but also as a critical solution to adding more renewable energy to the grid resulting in mitigating climate change. Because blackouts have been a persistent problem worldwide, if energy storage is to be used as a viable solution, research and development in the area must be fast-forwarded. Storage needs to be further analyzed and upgraded from some of the most recent data to allow it to be used at a large scale and be durable and compatible in support of long-term usage [26].

According to the review provided by the Department of Energy, areas that need additional focus are materials integrity to ensure power density and chemistry are resilient enough for the weather and power technologies enhancement that will provide a diversified performance for grids of different scales [26]. In addition, the DOE data and research also identified power electronics as an area that will need to be further developed, which will allow for better power supply reliability that will be vital as energy storage takes more of a presence [26]. Last, but not least, the DOA is also looking to undertake more research in grid analytics, policy, safety, and reliability testing [26]. These additional research areas will be imperative for energy storage to advance over the next decade. There are many unanswered questions, and as we get closer to 2030 with the expectation of halving our GHG emissions based on climate science goals, energy transition and energy storage technology will need to have any gaps closed and a clear path forward with the contribution it will make.

13. Conclusion and Recommendations

The global energy revolution is a moving target with many variables, such as technology changes, innovations, and research advancements, to support the efforts and timeline required to achieve Net Zero. Care and attention to our new and existing technologies, such as energy storage, must be addressed. We must understand the shortcomings and limitations of technology and identify viable solutions to facilitate energy transformation. On a vast scale, renewable green energy sources, such as wind and solar energy systems, can potentially supply all the world's energy needs, with significant benefits to climate - air quality, water quality, ecological systems, and energy security, at a reasonable cost. Also, these energy sources have been shown from this work to have significant potential to reduce greenhouse gases associated with the electric power sector. To accomplish this ambitious goal instead, it is estimated that the world needs about 4 - 5 million MW wind turbines, 90,000 300-MW solar PV plus CSP power plants, 1.9 billion 3 kW solar PV rooftop systems, and lesser amounts of geothermal, tidal, wave, and hydroelectric plants and devices.

To achieve the 2050 climate goal of 1.5degC global average temperature rise, it is required to expand significantly the transmission infrastructure to accommodate green energy sources. However, the intermittent of renewable energy resources is often cited as a significant barrier to their large-scale integration into the grid. Energy storage technology is undeniably the solution to the intermittent problem posed by renewable energy to address climate change issues. Energy storage will help address the pitfalls of supply and distribution while providing ancillary services to the electricity grid to ensure the reliability and stability of the power system.

The difficulties confronted by power companies regarding the supply and distribution of renewable energy could be alleviated in parts by adopting micro-grid systems. The technology can potentially accelerate the growing penetration of renewable energy and storage devices in distribution networks in a desirable way. To ensure sustainable development, the high cost of investment, access to financing, cycle efficiency of battery storage systems, and their safety, supply chain issues would need to be revamped [56]. Legislation is crucial in addressing the current market rules, which create barriers to promoting the share of renewable energy and storage systems. Consequently, as we develop long-term strategies to assure the energy transition progressives, advancing energy storage technologies capable of supporting grid resilience and reliability and reducing the dependency on fossil fuel generation will help global efforts achieve climate goals.

14. Further Research Needs

In conclusion, the key findings of this research demonstrate that renewable energy has the potential to support climate change mitigation efforts significantly. Despite infrastructure and regulatory barriers that have been in place in favor of fossil fuels, renewable energy can grow its proportion in the energy mix. Due to limitations associated with their ability to supply electricity compared to fossil fuel-based sources continuously, renewable energy sources such as solar and wind turbines are less desirable. Storage would enhance the advantages that come from using renewable energy sources. While long-term investments are being made to fill infrastructure gaps like dedicated grid systems, delivery and distribution outlets for renewable energy sources should include energy storage systems as a composite strategy to address short-term global warming mitigation efforts.

There are still obstacles, so further research and studies are required to enhance the technology. Coordinated efforts should be aligned with governmental policy and regulatory action to create adequate renewable energy infrastructure in the long term. Technology advancements in battery and charging systems can promote environmental aims and assist in fulfilling energy demand. Although EVs have become a focal point, some benefits extend beyond the auto industry, such as those to be derived in the HVAC industry.

Incorporating EV batteries in the grid-power management system is essential to effectively utilizing renewable energy resources. This negates the cost and burden of incorporating active energy storage systems to reduce fluctuations in renewable energy supply. "Parasitic demand" on the grid system from renewable energy sources could be minimized by instituting a policy regime that mandates EVs to charge their batteries promptly when solar energy is abundant in the day. This would ensure EVs are charged efficiently from the grid without interrupting the domestic power supply. For technologically enhanced EV batteries with a 2-way charging mode, electricity could be returned from the batteries for domestic consumption.

An overhaul of the bureaucratic and legislative structures favoring renewable energy is required to seamlessly transition into a new era in which clean energy dominates the share of the energy mix. The primary forces are coordinated activities in legal reform, global policy and regulation control, and technology advancement. Sanctions should be implemented following the adoption of these measures to emphasize their significance further. Without intervention, the planet will be more susceptible to unfavorable climatic circumstances, creating a toxic environment for future generations.

The production of EV batteries primarily relies on precious metals like cobalt and lithium. Few countries like China dominate the supply chain systems for manufacturing and delivery. Unexpected events like the Covid-19 pandemic have contributed to their production and downstream distribution system downturns. Producers in the sector have valid concerns about producing such precious metals in low-regulation regime countries in Africa. There is an urgent need for a global regulatory framework to enforce laws against child labor and weapon smuggling, which are primarily related to these countries.

References

[1] Gielen, Dolf. Boshell, Francisco. Deger, Saygin. Bazilian, Morgan D. Wagner, Nicholas. Gorini, Ricardo. (2019). The role of renewable energy in the global energy transformation. Energy Strategy Reviews. April 2019. 24(38-50) https://www.sciencedirect.com/science/article/pii/S2211467X19300082

[2] Kahan, Ari. (2019). EIA projects nearly 50% increase in world energy usage by 2050, led by growth in Asia. (24 Sept 2019). https://www.eia.gov/todayinenergy/detail.php?id=41433#

[3] Daley, Beth. (6 May 2021). Climate change: how bad could the future be if we do nothing? *The Conversation*. https://theconversation.com/climate-change-how-bad-could-the-future-be-if-we-do-nothing-159665

[4] Environmental and Energy Study Institute. (2022). Fossil Fuels. 22 July 2022. https://www.eesi.org/topics/fossil-fuels/description

[5] Ritchie, Hannah. (15 Dec 2021). A Global Breakdown of Greenhouse Gas Emissions by Sector. *Visual Capitalist.* http://www.visualcapitalist.com/cp/a-global-breakdown-of-greenhouse-gas-emissions-by-secotr/

[6] Fischer, James R., Finnel, Janine A., Lavoie, Brian D. (2006) Renewable Energy in Agriculture: Back to the Future?. *Choices*. https://www.choicesmagazine.org/2006-1/biofuels/2006-1-05.htm

[7] Ciolkosz, Daniel. (2009). What is Renewable Energy? *Penn State Extension*. https://extension.psu.edu/what-is-renewable-energy

[8] IGS Energy. (2022). 7 Types of Renewable Energy. https://www.igs.com/energy-resource-center/energy-101/types-of-renewable-energy

[9] Energysage (2022). Advantages and disadvantages of renewable energy. https://news.energysage.com/advantages-and-disadvantages-of-renewable-energy/

[10] Energy Storage. (15 Feb 2015) How it Works and Its Role in an Equitable Clean Energy Future. Union of Concerned Scientists. https://www.ucsusa.org/resources/how-energy-storage-works

[11] U.S. EPA. 22 Nov. 2021. Electricity Storage. Energy and the Environment. https://www.epa.gov/energy/electricity-storage

[12] Fractal. (2022). Energy Storage Utility Feasibility Study. Accessed: 18 June 2022. Retrieved from: https: //www.energystorageconsultants.com/energystoragefeasibility/

[13] National Energy Technology Laboratory. Energy Storage for Fossil Fuel Energy Systems. https://netl.doe.gov/carbon-management/crosscutting/energy-storage

[14] United States Climate Change. The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[15] Stanford University. (1 August 2013). Climate change occurring ten times faster than at any time in past 65 million years. ScienceDaily. https://www.sciencedaily.com/releases/2013/08/130801142420.htm

[16] Stillman, Dan. Green, JoCasta. (7 August 2017). What is Climate Change? *Nasa Knows*. https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-climate-change-k4.html

[17] Adler, Sami. (1 March 2021). How Much Would It Cost to End Climate Change?. *Global Giving*. https://www.globalgiving.org/learn/cost-to-end-climate-change/

[18] U.S. EIA. (13 December 2021). Gasoline - a petroleum product. *Gasoline explained*. https://www.eia.gov/energyexplained/gasoline/

[19] "Renewable energy transition: A case study of how international collaboration on Offshore Wind Technology Benefits American workers." (2021, July 30). Retrieved August 2, 2022, from https://energycentral.com/news/renewable-energy-transition-case-study-how-international-collaboration-offshore-wind-technology

[20] Ntavarinos, N., Davies, P., & Oterkus, E. (2019, September 30). Assessment of Energy Storage Technologies for case studies with increased renewable energy penetration. Retrieved August 2, 2022, from https://www.peertechzpublications.com/articles/ALO-4-107.php

[21] Energy Storage Grand Challenge Energy Storage Market Report. (n.d.). Retrieved August 3, 2022, fromhttps://www.energy.gov/sites/prod/files/2020/12/f81/Energy%20Storage%20Market%20Report%202020_0.pdf

[22] Delta Clean Energy / Industrial Intelligence Editor, & Delta Clean Energy / Industrial Intelligence Editor. (2022, January 20). Safety challenges in the design of Stationary Energy Storage Systems. Retrieved August 2, 2022, from https://blog.deltaww.com/en/energyinfrastructuresolutions-en/energy-storage/energy-storage-safety/

[23] Bandyk, M. (2020, May 26). Landfills emerge as promising battery storage sites to back up Renewable Energy. Retrieved August 2, 2022, from https://www.wastedive.com/news/landfills-promising-sites-battery-storage-solar-renewable-energy/577898/

[24] Case study: Feasibility analysis of renewable energy ... - UNLV libraries. (n.d.). Retrieved August 3, 2022, from https://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=1634&context=thesesdissertations

[25] Making the case for Energy Storage. (n.d.). Retrieved August 2, 2022, from https://www.burnsmcd.com/insightsnews/1898/white-papers/making-the-case-for-energy-storage

[26] Solving challenges in Energy Storage. (n.d.). Retrieved August 3, 2022, from https://www.energy.gov/sites/prod/files/2018/09/f55/2018-08-23_Spotlight%20on%20Energy%20Storage%20-%20Brochure%20and%20Success%20Stories_0.pdf

[27] Bandyk, M. (2020, May 26). Landfills emerge as promising battery storage sites to back up Renewable Energy. Retrieved August 2, 2022, from https://www.wastedive.com/news/landfills-promising-sites-battery-storage-solar-renewable-energy/577898/

[28] Mellor, J. (2019, December 21). Energy Storage Systems Face A Battery recycling and disposal crisis? Retrieved August 3, 2022, from https://energystorageforum.com/news/energy-storage/energy-storage-systems-facing-battery-recycling-disposal-crisis

[29] Sarah Vogelsong, V. (2021, January 20). Legislation aims to reduce barriers for energy storage projects. Retrieved August 6, 2022, from https://www.virginiamercury.com/2021/01/20/legislation-aims-to-reduce-barriers-for-energy-storage-projects/

[30] Mary Bates, *How Does a Battery Work?*, Massachusetts Institute of Technology—School of Engineering, May 1, 2012, https://engineering.mit.edu/engage/ask-an-engineer/how-does-a-battery-work/

[31] BNEF, Electric Vehicle Outlook. Available online: https://about.bnef.com/eletric-vehicle-outlook-2020/

[32] EIA, *Electricity Storage: Location, Location, Location … and Cost*, June 29, 2012, https://www.eia.gov/todayinenergy/detail.php?id=6910.

[33] CRS Report R42696, *Weather-Related Power Outages and Electric System Resiliency*, by Richard J. Campbell.

[34] Vella, Heidi, and Heidi Vella. "The True Cost of Energy Storage." *Power Technology*, 31 May 2016, https://www.power-technology.com/analysis/featurethe-true-cost-of-energy-storage-4872402/.

[35] U.S. Department of Energy, *The Potential Benefits of Distributed Generation and Rate-Related Issues That May Impede Their Expansion*, p. 42, February 2007, https://www.ferc.gov/legal/fed-sta/exp-study.pdf.

[36] EIA, *Annual Energy Outlook 2019 with Projections to 2050*, January 24, 2019, pp. 126-128. https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf.

[37] Sustainable Development Solutions Network and Institute for Sustainable Development and International Relations, Pathways to Deep Decarbonization, United Nations, July 8, 2014, http://unsdsn.org/wp-content/uploads/2014/07/DDPP_interim_2014_report.pdf.

[38] How Do Hydrogen Fuel Cell Vehicles Work?, March 14, 2018 https://www.ucsusa.org/clean-vehicles/electric-vehicles/how-do-hydrogen-fuel-cells-wor

[39] Marsh, J. (2021, August 20). Lithium Ion Battery Recycling: An overview: Energysage. Retrieved August 7, 2022, from https://news.energysage.com/lithium-ion-battery-recycling/#:~:text=Lithium-ion%20batteries%20aren%E2%80%99t%20quite%20as%20far%20along%20as,battery%20is%20shredded%20up%20into%20very%20small%20pieces.

[40] Improving power system modeling: A tool to link capacity ... - NREL. (n.d.). Retrieved August 7, 2022, from https://www.nrel.gov/docs/fy16osti/64905.pdf

[41] Climate change and batteries: The search for future Power Storage Solutions. (n.d.). Retrieved August 7, 2022, from https://royalsociety.org/-/media/policy/projects/climate-change-science-solutions/climate-science-solutions-batteries.pdf

[42] Case study 1: Alaska, U.S., Island/off-grid frequency response - irena. (n.d.). Retrieved August 7, 2022, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_Battery_Storage_case_studies_2015.pdf?la=en&hash=9F36F343000EAC1763B685F18B9CD61311463A6E

[43] Economic Analysis case studies of Battery Energy Storage with Sam - NREL. (n.d.). Retrieved August 7, 2022, from https://www.nrel.gov/docs/fy16osti/64987.pdf

[44] New EU regulatory framework for batteries - european Parliament. (n.d.). Retrieved August 7, 2022, from https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf

[45] Emerging hazards of battery energy storage system fires. (n.d.). Retrieved August 7, 2022, from https://www.fema.gov/case-study/emerging-hazards-battery-energy-storage-system-fires

[46] District Energy in cities Paris case study overview. (n.d.). Retrieved August 7, 2022, from http://www.districtenergyinitiative.org/sites/default/files/publications/paris-case-study-290520171142.pdf

[47] Case study: Co-optimising a municipally owned battery storage site in Britain. (2021, August 09). Retrieved August 7, 2022, from https://www.energy-storage.news/case-study-co-optimising-a-municipally-owned-battery-storage-site-in-britain/

[48] Climate change related impacts in the San Diego region by 2050. (n.d.). Retrieved August 7, 2022, from https://www.sandiego.gov/sites/default/files/legacy/environmental-services/pdf/sustainable/2050climate.pdf

[49] (n.d.). Retrieved August 7, 2022, from https://answers.microsoft.com/en-us/windows/forum/all/cusersusernamedocumentsfile-folder-name/3c43589c-b582-433b-99ea-cfe3e1b2a270

[50] Guney, M. S., & Tepe, Y. (2017). Classification and assessment of energy storage systems. Renewable and Sustainable Energy Reviews, 75, 1187-1197, from https://www.sciencedirect.com/science/article/pii/S1364032116308218?casa_token=BKN2ZFgscTsAAAAA:PZHAQLADOnqYFyLMxiUzqHzQyPkU5uLyu-CX6_mRQsN8as0YgG8iUgp0wjwagtolipvVhdd_

[51] En-Roads.https://en-roads.climateinteractive.org/scenario.html?v=22.8.0&p16=-0.01&p47=3.1&p50=3.1&p53=44&p55=48

[52] Cook, J., Nuccitelli, D., Green, S. A., Richardson, M., Winkler, B., Painting, R., Way, R., Jacobs, P. and Skuce, A. (2013) 'Quantifying the consensus on anthropogenic global warming in the scientific literature', Environmental Research Letters. IOP Publishing, 8(2), p. 024024. doi: 10.1088/1748-9326/8/2/024024.

[53] Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., MD, M., Bilir, T. E., Chatterjee, M., KL, E., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandea, P. R. and White, L. L. (eds) (2014) Climate Change 2014: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[54] Giddens, A. (2011) The Politics of Climate Change. Second Edition. Cambridge, UK and Malden, USA: Polity Press.

[55] Global Carbon Project (2014) Carbon budget and trends 2014. Global Carbon Project. doi: www.globalcarbonproject.org/carbonbudget.

[56] Grin, J., Rotmans, J. and Schot, J. (2010) Transitions to Sustainable Development. New York: Routledge.

[57] Hackmann, H. and St Clair, A. (2012) Transformative cornerstones of social science research for global change. International Social Science Council. doi: http://www.worldsocialscience.org/documents/transformative-cornerstones.pdf.

[58] Bhattari, Utsav. Maraseni, Tek. Apan, Armando. 10 August 2022. Assay of renewable energy transition: A systematic literature review. Science of the Total Environment. Vol 833. http://www.sciencedirect.com/science/article/abs/pii/S0048969722022525

[59] Energy Information Administration. (2004). Annual energy outlook 2004: with projections to 2025. Available online: http://www.eia.doe.gov/oiaf/aeo/.

[60] Lund, J.W. (2005). The United States of America country update. Proceedings of the World Geothermal Congress 2005, Antalya, Turkey. April 24-29. Available online: http://geoheat.oit.edu/pdf/tp121.pdf.

[61] California Public Utilities Commission, "Assembly Bill 2514 Decision," 3 September 2013. [Online]. Available: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M078/K912/78912194.PDF.

[62] D. Shimogawa, "Hawaii Electric to use energy storage project developed by California startup," Pacific Business News, 11 September 2014. [Online]. Available: http://www.bizjournals.com/pacific/blog/morning_call/2014/09/hawaiian-electric-to-useenergy-storage-project.html

[63] N. DiOrio, A. Dobos, S. Janzou, A. Nelson and B. Lundstrom, "Technoeconomic Modeling of Battery Energy Storage in SAM," National Renewable Energy Laboratory, Golden, 2015.

[64] D. Linden and T. Reddy, Linden's Handbook of Batteries - 4th Edition, New York : McGraw Hill, 2011.

[65] Outback Power, "Energy Cell RE," [Online]. Available: http://www.outbackpower.com/outback-products/energy-storage/item/energycellre?category_id=442. [Accessed 17 August 2015]

[66] DSIRE, "California Solar Initiatives - PV Incentives," 18 June 2015. [Online]. Available: http://programs.dsireusa.org/system/program/detail/2362. [Accessed 17 August 2015].

[67] Knoxville Utilities Board, "Electric Rate Schedules," [Online]. Available: http://tinyurl.com/nte9t36. [Accessed 24 August 2015]

[68] Breaking barriers in deployment of renewable energy https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6351575/#bib4

[69] W. Short, D. J. Packey and T. Holt, "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies," National Renewable Energy Laboratory, Golden, 1995.

[70] National Service Center for Environmental Publications (NSCEP) https://https://www.epa.gov/nscep

[71] 2017 National Emissions Inventory (NEI) Data https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

[72] De Sisternes, F. J., Jenkins, J. D., & Botterud, A. (2016). The value of energy storage in decarbonizing the electricity sector. Applied Energy, 175, 368-379.

[73] Richard and Zulfikar Yurnaidi. Energy Storage: Unlocking the Full Potential of Renewable Energy

[74] Mayyas, Ahmad. Steward, Darlene. Mann, Margaret. The Case for Recycling: Overview and Challenges in the Material Supply Chain

for Automotive Li-ion Batteries. National Renewable Energy Laboratory. https://docs.google.com/document/d/105pdconl2Hnu_vE-gsGxPYrx62yABGQc/edit

[75] Zablocki, Alexandra. (2019) Fact Sheet | Energy Storage: Environmental and Energy Study Institute. https://www.eesi.org/papers/view/energy-storage-2019

[76] Energy storage is key to unlocking renewable renewable power's full potential. https://accept.aseanenergy.org/energy-storage-unlocking-the-full-potential-of-RE#:~:text=Energy%20Storage%3A%20Key%20to%20Unlock%20the%20Full%20Potential,gaps%20caused%20by%20intermittency%20issues%20of%20renewable%20energy.

[77] Sterner, Michael. & Stadler, Ingo (2019) Handbook of Energy Storage: Demand, Technologies, Integration. (2nd Ed.). Springer Berlin, Heidelberg. 113

[78] NRDC,(2015),TheParisAgreementonClimateChange. https://www.nrdc.org/sites/default/files/paris-climate-agreement-IB.pdf

[79] U.S. Department of Energy. Solar Energy Technologies Program. (2003). Solar energy technology program - multiyear technical plan 2004-2007 and beyond. August 29(draft), DOE/GO-102003-1775.

[80] Richard J. Campbell. Electricity Storage: Applications, Issues, and Technologies http://www.everycrsreport.com/reports/R45980.html

[81] Maryam Arbabzadeh1 , Ramteen Sioshansi2, Jeremiah X. Johnson3 & Gregory A. Keoleian The role of energy storage in deep decarbonization of electricity production The role of energy storage in deep decarbonization of electricity production | Nature Communications

[82] US Energy Information Administratoin. 5 July 2022. Fossil Fuels Were Once Again the Dominant Energy Source in the U.S. 2021. Retrieved from: https://https://inspectioneering.com/news/2022-07-05/10195/fossil-fuels-were-once-again-the-dominant-energy-source-in-the-us-in-2021

[83] US Energy Information Administration. Dec 2022. Total Energy - Monthly Energy Review. Retrieved from: http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

[84] Richard J. Campbell (2019). Electricity Storage: Applications, Issues, and Technologies (A Congressional Research Service publication).

[85] Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators [Docket Nos. RM16-23-000; AD16-20-000; Order No. 841].

[86] Climate Action Tracker. Nov 2022. Addressing Global Warming. Retrieved from: https:////climateactiontracker.org/global/temperatures/

[87] Lee et al. Battery Management System Algorithm for Energy Storage Systems Considering Battery Efficiency

[88] Xiong, R.; Li, L.; Tian, J. Towards a smarter battery management system: A critical review on battery state of health monitoring methods. J. Power Sour. 2018, 405, 18–29

[89] Movassagh, K.; Raihan, A.; Balasingam, B.; Pattipati, K. A Critical Look at Coulomb Counting Approach for State of Charge Estimation in Batteries. Energies 2021, 14, 4074.

[90] Lu, L.; Han, X.; Li, J.; Hua, J.; Ouyang, M. A review on the key issues for lithium-ion battery management in electric vehicles. J. Power Sources 2013, 226, 272–288.