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Table of contents

OVERVIEW OF WIND ENERGY GENERATION IN GERMANY	1
ENERGY STORAGE TECHNOLOGIES	13
ENVIRONMENTAL IMPACT OF ENERGY SECTOR	29
RENEWABLE ENERGY INTEGRATION IN THE GRID	42
OVERVIEW OF SOLAR ENERGY IN BANGLADESH	51
GREEN HYDROGEN: THE FUTURE ENERGY	63

Keywords: Wind Energy; Turbines; Germany; Acceptance; Onshore; Offshore; India

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OVERVIEW OF WIND ENERGY GENERATION IN GERMANY

This paper provides an insight into the wind energy technologies in Germany and the policies implemented. Wind energy is being generated either onshore or offshore in various parts of the country. Following this, the people's acceptance is also required for this as it has direct and indirect effects. Even the environment has its effects on the wind affecting the produced power and vice versa. Lastly, a wide comparison is made between Germany and India in terms of their wind energy capacities, generation methods, utilities, and more. This paper signifies Germany's successful transition into the wind energy market and sets itself apart from its counterparts as a key player.

1. INTRODUCTION

The natural movement of air and other gases relative to the earth's surface is considered as wind. There are many different types of winds, ranging from local breezes produced by the heating of lands and lasting a few hours to global winds arising from the difference in solar energy absorption between the temperature zones on Earth to thunderstorms that can endure for tens of minutes. The two main causes of atmospheric circulation are the differential heating between the poles & the equator, and the rotation of the planet which is known as the Coriolis effect. Winds have various aspects: velocity, the density of the gas involved, and energy content. Winds are frequently described in

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terms of their intensity and the direction that they are blowing according to meteorology.

Westerly winds prevail in northwest Europe, and they get particularly strong during the winter. Summer westerlies, on the other hand, veer to the northwest and bring in cooler Arctic or subarctic air. The winter westerlies, which frequently originate from the southwest, bring in warm tropical air. Germany is located in the region of the mid-latitudes of western Europe with a temperate and wet environment. Between Sylt, an island in northern Germany, and the Zugspitze, Germany's highest peak, the annual mean temperature was 8.2°C from 1961 to 1990. Every year, the sun shines for around 1,544 hours. [1] Throughout the entire year, predominant westerly winds bring moist air masses in from the Atlantic. Winter winds are typically mild due to the ocean's influence, and summers are normally somewhat hot.

Nobody genuinely believed that wind energy could provide a significant portion of Germany's power generation even 15 years ago. But now, it is no longer a vision or an arcane. There are concrete plans for the future. The world leader in wind energy technology is Germany. It is the only nation that produces as much wind energy and has the most advanced technology in this field. The wind energy industry has expanded quickly in recent years. Even though just 13% of Germans oppose the expansion of renewable energy systems, according to an Emnid survey, this is a minority that we take seriously. Some individuals worry about the potential risks of wind energy. [2]

As we can see, Germany has great potential for wind energy generation and as we live in Germany, felt it is necessary to do a case study on the same. Hence, our paper includes chapters covering a wide range of topics structured in a chronological manner. Chapter 2 briefs about the operations and types of wind turbines in general. Chapter 3 explains the technologies present in Germany for wind energy. Chapter 4 discusses the public opinions about the implementation and utilization of wind energy and their acceptance. Chapter 5 compares the main milestones of wind energy generation between Germany and India. Chapter 6 finally gives a detailed conclusion considering all the above topics of this case study.

2. WIND TURBINES

A wind turbine is a device that converts the kinetic energy of wind into electrical energy. It involves the conversion of wind energy into the rotation of a turbine connected to the generator through the shaft and hence producing Electrical energy, and the critical parameters governing the efficiency of this conversion.

In order to reduce the usage of fossil fuels and lower energy costs, wind turbines are

being increasingly installed as a source of intermittent renewable energy in many countries. According to a study in 2009, wind energy had the "lowest greenhouse gas emissions, least water consumption, and most favorable social effects" compared to other energy sources.

2.1 HORIZONTAL AXIS WIND TURBINE

The most commonly used wind turbine is the horizontal axis type as shown in Fig.1. This turbine consists of four parts: Nacelle, Rotor, Tower & Control, and Foundation & Grid Connection. These turbines can produce power ranging from 10 kW to some MW. Wind velocity increases gradually with height, which makes horizontal axis wheels on towers more economical.



Fig. 1. Horizontal Axis Wind Turbines [3]

Another conventional and older type of horizontal axis turbine is the multi-blade wind turbine. Such windmills have a high starting torque which makes them suitable for driving water pumps. The number of rotations is low and they have high mechanical stability [4].

2.2 VERTICAL AXIS WIND TURBINE

Vertical axis turbines are of three main types: Savonius, Darrieus and H-Rotor. These types of wind turbines have a vertical axis construction. The main advantage of these turbines is that they are independent of wind direction. But they are noisier than

horizontal axis turbines.

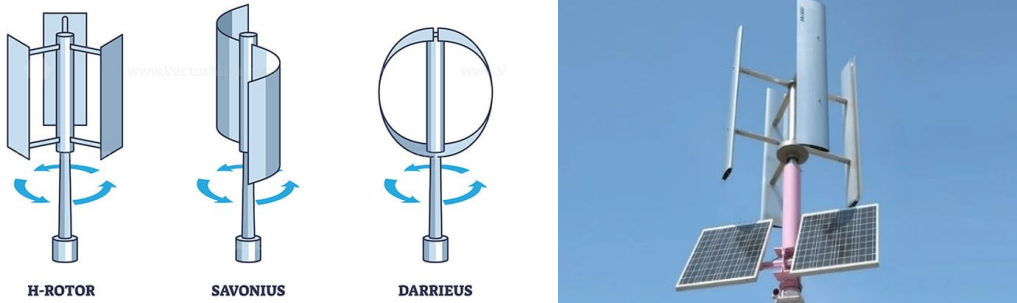


Fig. 2. Vertical Axis Wind Turbines [5]

The last type is known as an upstream power station or thermal tower. It can be considered as a hybrid between a wind turbine and a solar collector. The wind wheel is on top of a narrow high tower while the solar collector is present around the foot of the tower. Hence, it requires a lot of space and the tower has to be very high as we can see in Fig.2. [4]

3. TECHNOLOGIES IN GERMANY

According to the present statistics, wind energy on land accounts for more than 8% of the power supply in Germany. The percentage of electricity generated from renewable energy sources is said to increase to 60% by the year 2035. Hence, the development of renewable energies resulting in an economically feasible and environment-friendly energy supply in Germany with a high level of prosperity relies heavily on the utilization of wind energy as an important source [6].

Wind turbines generally use the wind's kinetic energy that is created by different air pressure conditions near the earth's surface. According to modern technologies, wind turbines use the buoyancy principle instead of the resistance principle. These turbines do not offer resistance to the wind, but instead, the wind flows across the rotor blades, creating a lift that causes the blades to rotate. Some countries use wind energy to drive pumps, while Germany utilizes wind turbines exclusively for electricity generation.

To expand wind energy usage in the country at a high level, some developments were made which include further expansion of suitable land locations for turbines; replacement of old & smaller systems with advanced and more powerful systems termed

repowering, and the gradual expansion of offshore wind energy.

3.1. ONSHORE TURBINES

Wind turbine installations in Germany started around the 1990s in very fewer numbers. But there is a gradual increase in these numbers from around 9000 turbines in the year 2000 to around 29,000 turbines in 2021. The rating capacity ranged from nearly 20 GW to 65 GW. Even though there is an expansion of offshore wind farms in the North and Baltic Seas, onshore wind energy will still play an important role, as it contributes the most cost-effective potential in renewable energy sources [6].

State and regional approval procedures control the wind energy usage on land with repowering playing a significant role in the future. With repowering, many old, smaller, low-power wind turbines are replaced with modern, more powerful turbines, especially in good wind potential locations. These new plants have a lot of advantages for the power supply and safe grid operations. One such onshore wind energy farm is in the town of Teltow in Brandenburg state as we can see in Fig. 3 below.



Fig. 3. Onshore Wind Energy Farm in Teltow, Brandenburg [7]

3.2. OFFSHORE TURBINES

In Germany's energy and environment policy, offshore wind energy serves as a crucial strategic pillar. The federal government intends to develop 6,500 MW of wind energy capacity in the German seas by 2020 and 15,000 MW by 2030. These expansion goals were adopted by the Renewable Energy Sources Act (EEG) reform in 2014. It also provides planning assurance for the industrialization of offshore wind energy by

limiting the expansion until 2030 [6].

The special circumstances in Germany pose great challenges to the implementation of offshore projects. Considering environmental protection policies and landscape on the North and Baltic Sea coasts, most of the offshore projects in German waters are planned and installed at a large distance from the shore which can be observed in Fig.4 and Fig.5.



Fig. 4. Offshore Wind Energy Farm in the North Sea [8] [9]



Fig. 5. Offshore Wind Energy Farm in Baltic Sea [10] [11]

Greater distances from the coast provide more difficult technological hurdles than would exist with offshore wind farms like those constructed in other European nations. This is true, for instance, of the grid connection, which is more technically challenging given the larger distance from the shore, or of funding, which is more challenging to obtain given these higher technical risks. However, unlike coastal projects, building and upkeep are also more difficult. As a result, issues such as the linkage of offshore wind farms to the German electrical grid and financing the projects are currently important obstacles for the sector. Utilizing the benefits of offshore wind energy for the German power supply as well as the opportunities that the new technology offers for the German economy and labour market requires an intensive exchange and coordination between all stakeholders and the overarching responsibility of various federal and state ministries [6].

4. WIND ENERGY ACCEPTANCE IN GERMANY

Wind energy acceptance has always been a hotly contested topic across the Western World, especially in Europe. The initial years of wind energy projects, albeit being a clean source of energy, were mostly met with skepticism and protests mainly from people who were forced to have wind turbines built close to their homes. But things have improved since the last couple of decades of renewable energy adoption. Today, renewable energy powers a major portion of the German economy, with thermal and nuclear power being slowly phased out by the government. Even still, there is a lot of emphasis given to how people view these projects as their opinions influence decision-makers and regulators and could mean disaster for wind energy developers if people look the other way for wind farms.

Studies show that there is a difference in the way people perceive wind energy in comparison to solar energy. Due to the negative effects of wind turbines such as visual impact and noise, wind parks are seen negatively by certain sections of the public in comparison to solar parks, which are overwhelmingly positive. There is also a difference in acceptance levels based on the type of wind farms in question. Two-thirds of correspondents view offshore wind farms as acceptable, but only 35% view onshore wind parks built within 500 m of their homes as acceptable [12].

The public view on wind energy acceptance can have an adverse effect on the financial investments made by private firms/individuals in wind energy projects. Various quantitative methodologies such as focus groups and choice experiments were used by Lienhoop in their research to get a clear picture of how the public assesses wind power projects. Results from these experiments show a mixed view on financial participation, assessing the risk factor of investment as well as the large amount of capital needed to become a shareholder as major concerns to locals. However, in terms of participation, most people are open and willing, more so in rural areas with regard to compensation. Reiterating the previous point on ownership and participation, if locals are given more opportunities in governance and shareholding of wind projects, acceptance is also likely to increase among the public. However, they are also looking for compensation due to the higher energy tariffs. Favourable policies also boost the probability of outside investment in wind energy, which is currently the case in Germany due to its position on green energy technologies [13].

Langer et al. have covered the non-technological challenges while implementing wind energy projects. They have extensively studied how factors such as public acceptance, the distance between wind turbines and residential areas, etc., affect wind farms' development by using statistical data analysis techniques. Studies indicate that the fear of infrasound has a negative impact on how the public views wind energy in

general. Contrary to popular belief, they have discovered that people with no previous experience with wind turbines are less likely to accept them compared to people who live close to wind farms. They have also uncovered an inverse correlation between the acceptance of wind projects with respect to income and age, which contradicts the studies done in older research projects. Surveys conducted also show that younger people are more open to discussion and participation and are more likely to accept wind projects [14].

To give an insight into the situation of wind energy acceptance in Germany, we have taken studies that compare Germany with other wind energy-producing nations such as France, Denmark, and India. Jobert et al. have used case studies based in France and Germany to establish the various factors responsible for the successful implementation of wind energy projects for their research paper. Although the overall opinion on wind energy is positive, there are several challenges such as acceptance, visual impact, land ownership, and monetary issues that have to be taken care of for the project to be a success. To assess the acceptance among the people, they conducted analyses on how various wind projects are being constructed, rather than conducting surveys among the public. They have uncovered that Germany provides more flexibility in the development of wind projects compared to France, where the government and the public are slightly pessimistic towards wind turbines. Local jurisdictions in Germany provide a privileged status to wind energy projects in comparison to the many difficulties faced in France in obtaining permits for their wind parks and other regulatory issues. In conclusion, their studies convey the importance of land ownership, utilization, trust, and participation as key metrics in the acceptance by the public and decision-makers in France and Germany [15].

Sovacool et al. have compared different wind energy markets, namely in Denmark and India. They have pointed out that Denmark, despite being a small country is a world leader in wind energy generation due to the Danish government's positive stance on renewable energy. Policies that favour wind energy such as taxes on fossil fuels, and CO₂ emissions as well as employment opportunities in the wind energy sector have helped the Danes establish themselves in the wind energy spectrum. India on the other hand has been able to triple its wind energy (in a 5-year period between 2005 and 2009) but on a per capita basis is extremely low when compared to Denmark. A lack of offshore wind farms despite having access to approximately 7,600 km of coastlines and 194 GW of potential offshore wind energy is quite noticeable. Reasons for low wind energy adoption in India include poor grid connectivity, lack of localized manufacturing units for wind turbines, voltage fluctuations, financing difficulties, and little to no community involvement in wind energy projects. The majority of the benefits given by the government towards wind energy adoption are completely utilized only by the wind energy producers and not much in the way of consumers and local communities [16].

5. COMPARISON OF WIND POWER GENERATION BETWEEN GERMANY AND INDIA

In order to visualize Germany's performance in the wind energy sector, we have compared the wind energy statistics of Germany with our home country, India.

India has an estimated wind power potential of 302 GW at 100 metres and 695.5 GW at 120 meters above ground level. In 2005, the installed wind capacity was roughly 6 GW but the figure has risen significantly to 42 GW as of September 2022, which makes India the fourth largest in the world in terms of installed wind capacity. This capacity is spread across the southern, western and northwestern states [17]. In comparison to previous years, the cost of power generated from wind has been decreasing rapidly. It currently sits at a rate of ₹2.77 (€Cent) per kWh, exclusive of subsidies [18]. India has a long coastline of about 7600 km surrounded by water on three sides and has good prospects of harnessing offshore wind energy. There is an estimated offshore wind energy potential of 70 GW, however, there are currently no offshore wind projects under construction or operation [19]. Currently, Indian lawmakers and economists believe that solar energy has been over-prioritized over wind energy, despite the massive potential of wind energy. They believe that wind energy should be considered an important driver for climate change mitigation and clean energy. The added socio-economic benefits from wind power generation and wind turbine manufacturing imply that wind energy has positively influenced the general public.

On the other hand, Germany is a pioneer in wind energy and has an installed capacity of 64 GW consisting of approximately 29,700 wind turbines as of August 2021, which ranks Germany third behind the United States and China, respectively. In contrast to India, Germany is making good use of its offshore wind potential with an installed capacity of 7.8 GW, despite possessing a much smaller coastline of about 2,400 km [20]. Reasons for this include a larger interest of the German public in renewable energy, particularly after the nuclear accident that took place in Japan in 2011 and hence larger investments in offshore wind energy development. However, there are challenges when it comes to grid integration with other energy sources and the need for further grid expansion, which is expensive and can take a lot of time in planning, development and construction. Despite the obstacles, the German government has set a target of achieving an installed offshore capacity target of 26 GW by 2030. Factors such as remuneration for wind energy utilization are much more favourable in Germany in comparison to India, where the wind sector is largely monopolized and in control by a few entities. Economic instruments such as feed-in tariffs and auction-based compensation help in increasing competition among wind energy producers and hence reduce the levelized cost of energy (LCOE), which currently ranges between 3.94 and 12.13 €Cent /kWh. The higher costs per kWh are for offshore due to the higher capital requirements and

operating costs [21]. To summarize, Germany is a world leader in wind power generation and continues to exert its influence on the wind energy field worldwide by expanding its operations in the form of projects and research.

6. CONCLUSION

In conclusion, the paper provides an overview of wind energy generation in Germany, highlighting the country's potential and advancements in the field. Germany has emerged as a global leader in wind energy technology and production. The country has experienced rapid growth in the wind energy industry, with plans for future expansion. Wind energy now plays a significant role in Germany's power generation and the percentage of electricity generated from renewable energy sources is expected to increase to 60% by 2035. Onshore wind turbines have seen a gradual increase in installations, with state and regional approval procedures and repowering playing important roles. Offshore wind energy is a strategic pillar in Germany's energy policy, with ambitious expansion goals set by the government. Public acceptance of wind energy has been a subject of debate, with concerns raised about visual impact, noise, and proximity to residential areas. While offshore wind farms generally receive higher acceptance, onshore wind parks built close to homes face more resistance. Factors such as financial participation, compensation, governance, and favorable policies influence public acceptance and investment in wind energy projects. The comparison between Germany and India showcases Germany as a world leader in wind power generation, while the latter has significant untapped wind power potential. However, India faces challenges such as poor grid connectivity, manufacturing limitations, financing difficulties, and limited community involvement in wind energy projects. From this comprehensive study, we can infer wind energy's ability to contribute to the creation of new jobs, increased environmental sustainability, stability in the German energy market, and increased independence from finite energy sources like coal, oil, and uranium. Germany's experience serves as a valuable case study for other countries aiming to transition from conventional fuels to renewable energies.

REFERENCES

- [1] Europe | History, Countries, Map, & Facts. Encyclopedia Britannica. Retrieved Nov 23, 2022, from <https://www.britannica.com/place/Europe/Climate>
- [2] Overview of wind energy in Germany. Retrieved Nov 23, 2022, from <https://web.archive.org/web/20070522084946/http://www.wind-energie.de/en/wind-energy-in-germany/overview/>
- [3] Agarwal, T. Horizontal Axis Wind Turbine: Construction, Types & Its Applications. ElProCus - Electronic Projects for Engineering Students. Retrieved Dec 28, 2022, from <https://www.elprocus.com/horizontal-axis-wind-turbine/>

- [4] Wagner, H.J., 2020. Introduction to wind energy systems. In EPJ Web of Conferences (Vol. 246, p. 00004). EDP Sciences.
- [5] Main components of a vertical axis wind turbine. (n.d.). ResearchGate. Retrieved Dec 28, 2022, from https://www.researchgate.net/figure/5-Main-components-of-a-horizontal-axis-wind-turbine_fig3_235340138
- [6] Bundesministerium für Wirtschaft und Klimaschutz. Retrieved Jan 5, 2023, from <https://www.erneuerbare-energien.de/EE/Navigation/DE/Technologien/technologien.html>
- [7] Fhm. Teltow Wind Park. Retrieved May 20, 2023, from <https://www.gettyimages.de/fotos/teltow-fl%C3%A4ming>
- [8] Halbjahr 2022 - Deutsche WindGuard. Retrieved May 20, 2023, from <https://www.windguard.de/id-1-halbjahr-2022.html>
- [9] Charlie Chesvick. Epic edge view on large offshore 8MW wind farm on the horizon in the North Sea. Retrieved May 20, 2023, from <https://www.gettyimages.de/fotos/nordsee-windpark>
- [10] Renewable Energy Germany offshore wind energy park at sea Baltic. Retrieved May 20, 2023, from <https://www.wind-energy-network.de/en/wind-farms-north-east-germany-offshore-projects.html>
- [11] Northland Power Inc. Wind farm in the Baltic Sea in cooperation with PKN Orlen. Retrieved May 20, 2023, from https://www.paih.gov.pl/20210428/northland_power_baltic
- [12] Sonnberger, M. and Ruddat, M., 2017. Local and socio-political acceptance of wind farms in Germany. *Technology in Society*, 51, pp.56-65.
- [13] Lienhoop, N., 2018. Acceptance of wind energy and the role of financial and procedural participation: An investigation with focus groups and choice experiments. *Energy Policy*, 118, pp.97-105.
- [14] Langer, K., Decker, T., Roosen, J. and Menrad, K., 2018. Factors influencing citizens' acceptance and non-acceptance of wind energy in Germany. *Journal of Cleaner Production*, 175, pp.133-144.
- [15] Jobert, A., Laborgne, P. and Mimler, S., 2007. Local acceptance of wind energy: Factors of success identified in French and German case studies. *Energy policy*, 35(5), pp.2751-2760.
- [16] Sovacool, B.K. and Ratan, P.L., 2012. Conceptualizing the acceptance of wind and solar electricity. *Renewable and Sustainable Energy Reviews*, 16(7), pp.5268-5279.
- [17] National Institute of Wind Energy. Retrieved May 10, 2023, from <https://niwe.res.in/>
- [18] Overview | Ministry of New and Renewable Energy, Government of India. Retrieved May 10, 2023, from <https://mnre.gov.in/wind/current-status/>
- [19] Offshore Wind | Ministry of New and Renewable Energy, Government of India. Retrieved May 12, 2023, from <https://mnre.gov.in/wind/offshore-wind/>
- [20] Renewable Energy Statistics 2021. (2021b, August 1). Retrieved May 23, 2023, from <https://www.irena.org/publications/2021/Aug/Renewable-energy-statistics-2021>
- [21] Levelized Cost of Electricity - Renewable Energy Technologies - Fraunhofer ISE. Fraunhofer Institute for Solar Energy Systems ISE. Retrieved May 23, 2023, from <https://www.ise.fraunhofer.de/en/publications/studies/cost-of-electricity.html>

Key words: Renewable energy, Energy storage technologies, Applications, Efficiency, Economics

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ENERGY STORAGE TECHNOLOGIES

The rapid expansion of renewable energy sources necessitates efficient and reliable energy storage technologies to mitigate their intermittent nature and support the transition towards a sustainable energy landscape. This research paper presents a comprehensive overview of energy storage technologies, encompassing various types, their underlying principles, and applications. Efficiency and economic considerations are integral to the analysis, as they play a vital role in the practical implementation and viability of energy storage technologies. The paper examines key energy storage technologies such as mechanical, chemical, electrochemical, electrical, thermal, and gas storages.

1. INTRODUCTION

The global energy landscape is undergoing significant transformations driven by several key factors, including the need for energy storage solutions, varying energy generation capacities, and the rising demand for renewable energy sources. These factors have implications for energy production, utilization rates, and overall energy demands across different regions of the world. One of the critical challenges faced in the energy sector is the efficient storage of energy. Energy storage technologies play a vital role in balancing the intermittency of renewable energy sources, such as solar and wind power. This means that the energy production potential differs depending on the chosen technology, impacting the overall energy mix and generation capabilities [1].

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The capacity for renewable energy sources, such as wind and solar power, has significantly increased worldwide. However, the share of renewable energy production does not yet match this capacity. This indicates that while there is immense potential for renewable energy, there is still a need to harness it effectively to achieve a sustainable and low-carbon future. Particularly in developing and emerging countries, the transition towards cleaner energy sources is gaining momentum. The primary energy utilization rate remains high, especially in industrialized countries. This highlights the importance of adopting energy-efficient practices and technologies to reduce the overall energy consumption and mitigate environmental impacts.

Over the past half-century, global final energy demand has consistently increased. This upward trend can be attributed to several factors, including population growth, urbanization, and economic development. As a result, there is a growing need for reliable and accessible energy solutions to meet the rising demands of various sectors, including residential, commercial, and industrial [2]. Furthermore, electricity demand is experiencing significant growth and is becoming increasingly important compared to traditional fossil fuels like coal, oil, and gas. The transition towards electric mobility, the electrification of industries, and the increasing reliance on electronic devices are contributing to this shift.

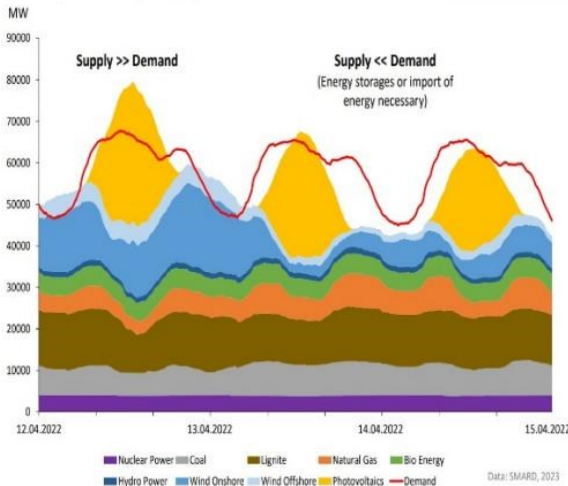


Fig. 1. Supply and Demand in real time [3]

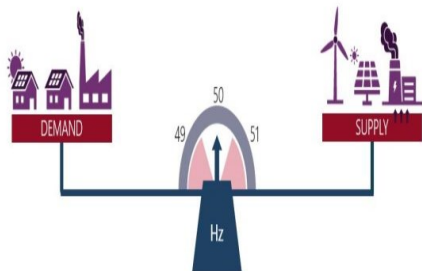


Fig. 2. Grid Stability [4]

The need for energy storage becomes crucial to ensure grid stability, manage peak loads, and support the integration of renewable energy sources into the power system. In the figure 1, real time supply and demand in Germany is shown and the excess power generation can also be seen. This excess energy if properly stored can be used during peak loads. The grid frequency should always be stable, balancing supply and demand, failing in which leads to problematic situations in the grid.

Considering the importance of continuous supply of energy, we want to share some insights about this topic. Chapter 2 gives an overview of all the different energy storage technologies available and their applications. Chapter 3 compares economic aspects, efficiencies, and charging / discharging duration of these technologies. In the Chapter 4 we will delve into the conclusions drawn from the research findings and discuss their implications in detail.

2. CLASSIFICATION OF ENERGY STORAGES

2.1. MECHANICAL ENERGY STORAGES

Mechanical energy storage is a technology rooted in classical mechanics, particularly the work of Isaac Newton, and is based on principles from the 18th and 19th centuries. The fundamental idea is to store energy in either kinetic or potential form, as well as pressure energy. By converting potential energy into kinetic energy and vice versa, mechanical energy storage systems can later convert this stored energy into electrical energy [5]. These systems utilize various mediums, including gaseous media like air, liquid media like water, and solid media such as rocks or natural forms. There are three primary types of mechanical energy storage systems that have gained global recognition:

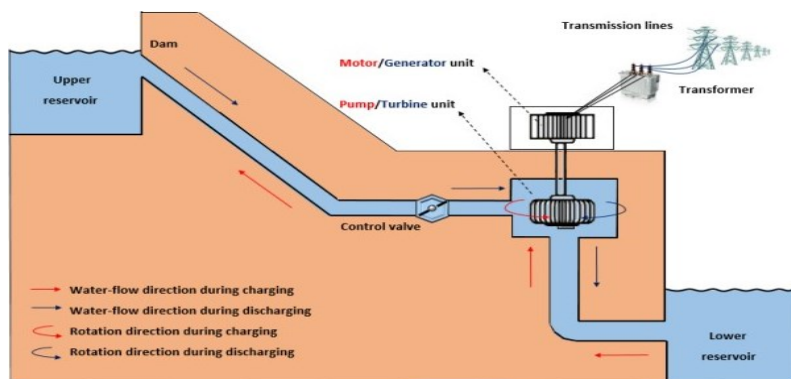


Fig. 3. Pumped Hydro Storage [6]

Pumped Hydro Storage (PHS) involves using excess electricity to pump water from a lower reservoir to a higher one. When electricity is needed, the water flows back down, passing through turbines to generate electrical power. PHS systems have the capability to provide multiple MW of power output using multiple motor/generator sets. They can

achieve high capacities, reaching up to multiple GWh, with energy-to-power coefficients of more than 10

Compressed Air Energy Storage (CAES) involves storing energy by compressing air and storing it in underground caverns or tanks. When electricity is required, the compressed air is released, driving a turbine to generate electricity. CAES power plants can deliver relatively high-power output over an extended duration and are well-suited for flexible operation and control energy delivery to meet varying energy demands. They have significant storage capacities and can achieve power outputs ranging from multiple hundreds of MW, making them suitable for large-scale energy requirements [7].

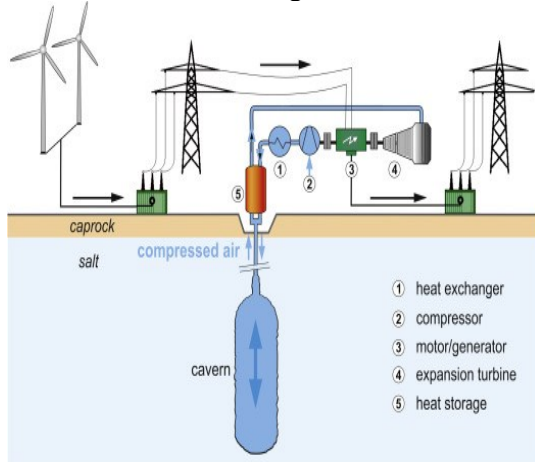


Fig. 4. Compressed Air Energy Storage [8]

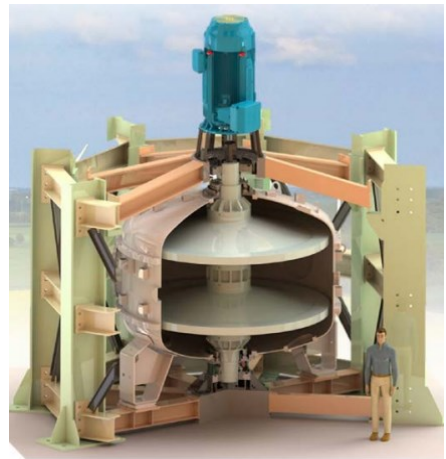


Fig. 5. Flywheel [9]

Flywheels store energy by spinning a massive rotor at high speeds. When energy is needed, the kinetic energy of the rotating flywheel is converted back into electrical energy using a generator. Flywheel systems are well-suited for short-term rapid energy absorption and release, making them suitable for applications requiring quick response times. They offer high power and energy densities, allowing for efficient energy storage in a compact system. However, they have relatively limited storage capacities, with energy-to-power coefficients of less than 0.01.

Mechanical energy storage systems, such as flywheels, can have a long cycle life. They can undergo a high number of cycles, often exceeding 100,000 cycles. This makes them suitable for repetitive energy storage applications, providing a durable and long-lasting solution. But this, may have relatively limited storage capacities. This means they may not be suitable for applications requiring long-duration energy storage or those with high energy demand over extended periods.

2.2. CHEMICAL ENERGY STORAGES

Chemical energy storage operates on the fundamental principle of absorbing sur-plus heat through an endothermic reaction, resulting in the storage of reaction products in separate entities. When the stored energy is needed, the discharge process involves an exothermic recombination of the reaction products, allowing the utilization of the released heat. Chemical storage is a vital and extensive category within energy storage, encompassing a wide range of technologies and applications. It is closely intertwined with electrical storage and often combined as electrochemical storage, particularly in the form of battery systems. Chemical energy storage provides a compelling compromise between relatively lower efficiencies, but higher capacities and power outputs compared to other storage methods. Its significance lies in enabling the long-term storage of energy generated from renewable sources, addressing the intermittency of renewable energy production. Chemical energy storage plays a critical role in our current energy supply, encompassing various solid, liquid, and gaseous forms such as wood, coal, mineral oil, natural gas, and hydrogen. These forms of energy storage are utilized for diverse purposes, including heating, electricity generation, and transportation. In the realm of transport and heat applications, chemical energy storage is particularly vital as it provides the combustibles and fuels necessary to power vehicles and meet heating demands [10].

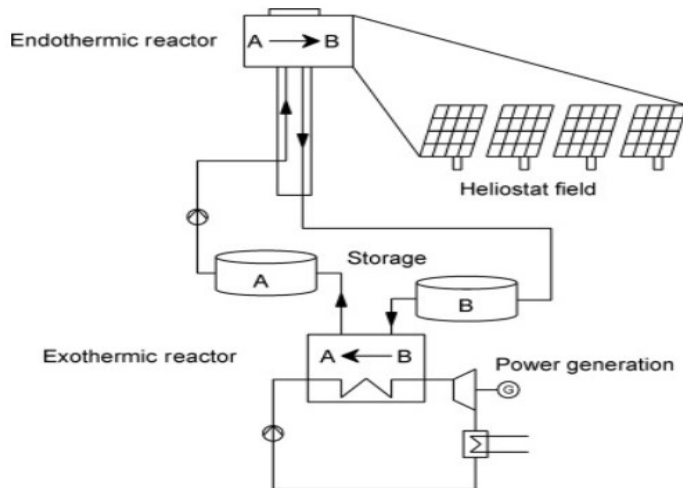


Fig.6. Chemical Energy Storages [11]

ADP-ATP system plays a vital role in cellular respiration, where ATP acts as an energy carrier. This system enables rapid and efficient energy transfer within cells, facilitating various biological processes. However, it has limited energy storage capacity

and relies on continuous regeneration, necessitating other energy sources like glucose.[12] Chemical Energy Storage Salt compounds, such as sodium-ion batteries, are utilized for stationary energy storage applications like grid-scale storage and renewable energy integration. Salt compounds offer advantages such as abundance and low cost, making them suitable for large-scale deployment. However, current salt-based energy storage technologies face challenges related to energy density and cycle life compared to alternative chemical storage options [13].

Thermal Energy Storage Boric acid is employed in chemical heat storage systems, utilizing reversible exothermic and endothermic reactions to store and release thermal energy. It exhibits a high heat capacity, enabling the storage of thermal energy for extended periods. This makes boric acid suitable for applications like heating and cooling systems [14]. However, precise control of temperature and reaction conditions is necessary, and scalability for large-scale applications may be limited.

Gaseous Energy Carriers Methane, a primary component of natural gas, finds broad applications in heating, electricity generation, and transportation. It offers advantages such as a high energy density, abundance, and an existing infrastructure for extraction, storage, and distribution. However, methane's contribution to climate change as a potent greenhouse gas and concerns regarding leakage during production and transportation need to be addressed.

2.3. ELECTROCHEMICAL ENERGY STORAGE

Electrochemical energy storage is a widely utilized technology that involves the conversion of electrical energy through chemical processes. Battery storage, the most common form of electrochemical energy storage, has found widespread applications in the energy supply system, ranging from small-scale to large-scale processes. While batteries offer average storage efficiency, their capacities and power outputs may be lower compared to other storage technologies. However, they are expected to play an increasingly important role in electromobility as the demand for electric vehicles rises. Ongoing research aims to enhance battery performance and energy density, making them more accessible and cost-effective for transportation and various sectors of the energy industry.

There are two main types of batteries namely primary and secondary. Primary batteries are non-rechargeable and involve non-reversible chemical reactions. They are commonly used in small-scale and portable applications where a one-time energy source is required. Once depleted, primary batteries cannot be recharged or reused, making them suitable for situations where long-term energy storage is not necessary. On the other hand, secondary batteries are rechargeable and involve mostly reversible chemical

reactions [15]. They can be charged and discharged multiple times, providing the advantage of permanent energy storage. Secondary batteries are commonly found in devices like laptops, smartphones, electric vehicles, and renewable energy systems, where the ability to recharge and reuse the battery is essential for sustained use. The development and improvement of secondary batteries have contributed to advancements in energy storage technology and the integration of renewable energy sources into the grid

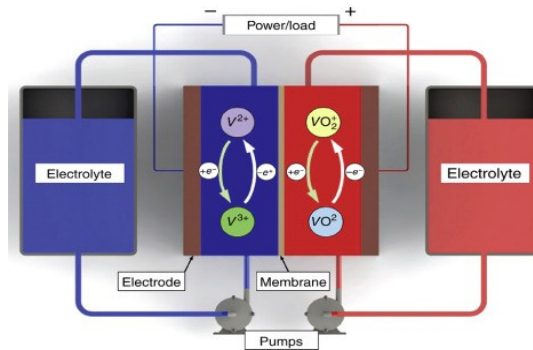


Fig. 7. Working Principle of Vanadium Redox Flow Battery [16]

Battery storages optimize supply requirements, compensate for load peaks, and act as buffer storage in industrial processes. They complement volatile generation plants and contribute to supply restoration after power failures. Battery storages find applications in electromobility, charging stations, and gas stations.

2.4. ELECTRICAL ENERGY STORAGE

Electrical energy storage systems are based on electrotechnical energy conversion principles using electric and magnetic fields. It is important to note that the term "energy storage" in common language often includes batteries, which is technically incorrect. The most common forms of electrical energy storage include direct storage in capacitors or coils, primarily used for short-term energy storage in power electronic applications. They excel in rapid charge and discharge capabilities but have lower energy output compared to other storage technologies [10].

Applications of electrical energy storage systems are diverse, including time-limited high-power outputs, power electronic devices, digital circuits, converters, defibrillators, engine start-ups, cyclic applications like hybrid vehicles and renewable energy systems, and smoothing circuits ensuring a stable and continuous power supply. These systems can undergo many cycles, often surpassing 100,000 cycles, making them suitable for

repetitive energy storage applications.

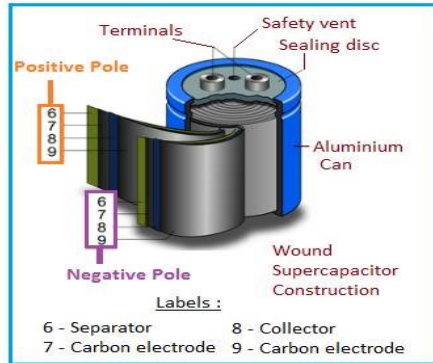


Fig. 8. Internal Construction of Wound Supercapacitor [17]

2.5. THERMAL ENERGY STORAGE

Thermal energy storage plays a crucial role in achieving a sustainable and efficient energy supply by addressing the heating and cooling needs of various sectors. The heat sector, accounting for around 50% of final energy consumption in Europe, highlights the significance of thermal energy storage. Additionally, the cooling sector is gaining increasing importance and is closely linked to the topic of heat. Sensible heat storage, latent heat storage, and thermochemical heat storage are the main technologies used in thermal energy storage, offering flexibility and efficiency.

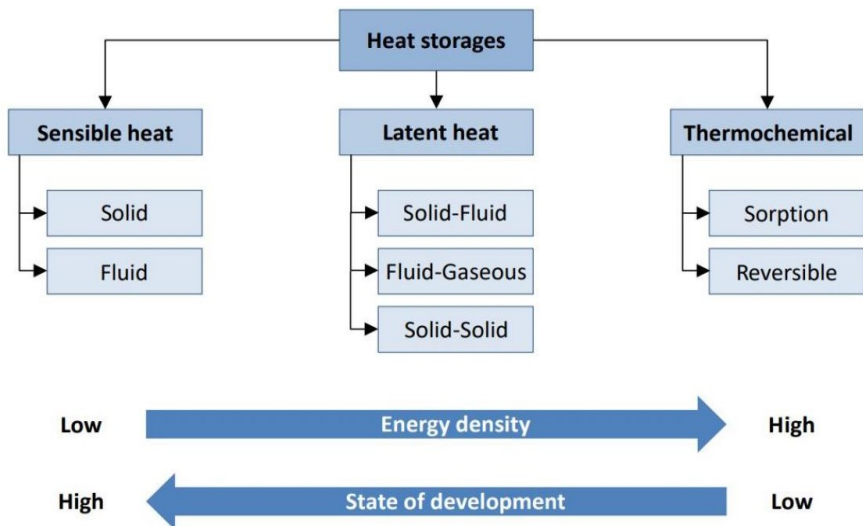


Fig. 9. Overview of Thermal Energy Storage [18]

These storage technologies are applied across different scales, from large central heat

storage tanks to small tanks for domestic hot water needs. Thermal energy storage enables seasonal storage, allowing heat to be stored in summer for use in winter, and helps in balancing energy demand between day and night. Current trends in thermal energy storage emphasize low-temperature systems with low flow temperatures, promoting energy efficiency and integration with renewable energy sources [19].

Sensible heat storage involves heating or cooling a substance, such as water or rocks, and storing the thermal energy in the temperature difference. The stored energy is released by transferring heat back to the desired application when needed. Latent heat storage involves the use of phase change materials (PCMs) that absorb or release thermal energy by changing their state (solid to liquid or liquid to gas) at a constant temperature. Thermochemical heat storage involves a chemical reaction that absorbs or releases heat. The storage material undergoes a reversible reaction, storing thermal energy during the endothermic reaction and releasing it during the exothermic reaction

2.6. GAS ENERGY STORAGE

Gas storage facilities play a central role in the energy supply system, both currently and in the future. With their high capacity, they serve as the largest energy storage method and are intricately connected to dedicated infrastructure, such as central gas grids and transcontinental pipelines. Two primary types of gas storages, namely cavern gas storages and aquifer storages, accommodate different scales of storage needs. These storage processes typically span long-term durations, boasting impressive efficiency levels exceeding 99%. Additionally, gas can be stored in its liquefied form, known as LNG, further expanding storage options. Power-to-gas technology stands out as a future-oriented approach, facilitating interconnections between various energy sectors, including electricity, heat, gas, and transportation [10]. Despite its significance, gas supply remains a highly politicized issue, not only within Europe but also in countries like Germany. Gaseous storage media, including air, fuel/gases (such as natural gas and propane), and hydrogen, offer distinct advantages and applications. Air is abundant but has lower energy density, suitable for Compressed Air Energy Storage (CAES). Fuel/gases have high energy density and established infrastructure but pose safety risks and carbon emissions. Hydrogen has high energy density and various applications but faces production costs and storage challenges.

Gas storage encompasses various types, each with its advantages and considerations. Cavern gas storage offers large-scale capacity and high efficiency but faces limited availability of suitable underground caverns and potential geological risks. Aquifer gas storage provides significant capacity with relatively lower construction costs, supporting seasonal variations in gas demand and enhancing energy system reliability. LNG enables long-distance transportation and efficient storage but requires specialized infrastructure and poses safety risks. Power-to-Gas technology converts excess electricity

into gaseous energy carriers like hydrogen or methane, facilitating energy sector integration and long-term storage, but it involves conversion losses and infrastructure requirements. These storage methods play critical roles in ensuring gas supply flexibility, supporting peak demand periods, and enhancing energy system resilience.

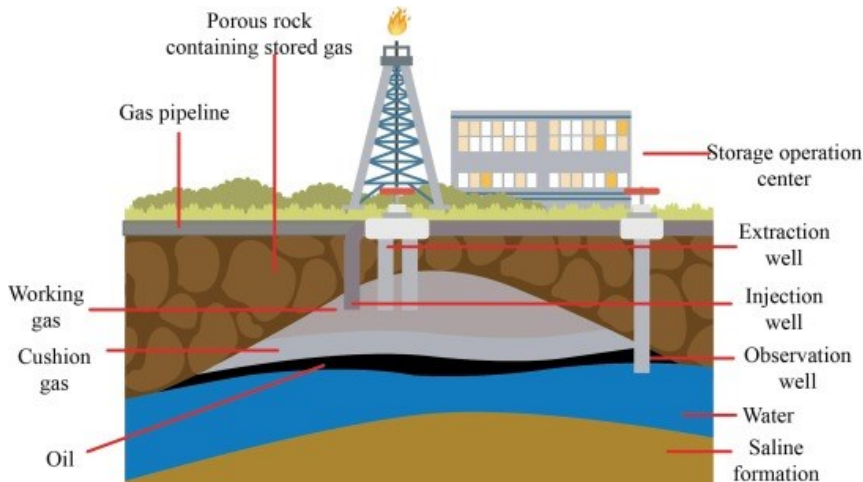


Fig. 10. Underground Gas Energy Storage [20]

2.7. HYDROGEN ENERGY STORAGE

Hydrogen is a versatile gas storage medium that offers a wide range of applications and plays a significant role in the energy landscape. It can be distinguished by its pure storage form, involving filling and withdrawal in tanks, or its utilization as a material in various process chains. As a long-term storage device, hydrogen provides flexibility in balancing fluctuating energy supply and demand.

The main characteristics of hydrogen process chains include comparatively low efficiencies but high power and energy outputs and capacities. This makes hydrogen suitable for applications requiring significant power output, such as fuel cells, pumps, and engines. It has also found increased use in mobile applications due to compression, condensation, and liquid storage techniques [21]. The demand for hydrogen is expected to rise sharply in the future, and there is a gradual transition from "gray" hydrogen, produced from fossil fuels, to "green" hydrogen, generated through renewable energy sources.

Hydrogen is a versatile element with various applications and distinct properties. It can be used directly as a material in industries like steel and chemicals. Additionally, it

serves as an energy storage medium, fuel for the mobility sector, and a source of energy and heat supply. Hydrogen exists as a gaseous form at ambient temperature, with a colorless and odorless appearance. It has a low density of 0.09 kg/m^3 and is the element with the lowest atomic mass. Under normal conditions on Earth, hydrogen exists as molecular hydrogen (H_2), rather than atomic hydrogen (H). However, at high temperatures, hydrogen becomes highly reactive.

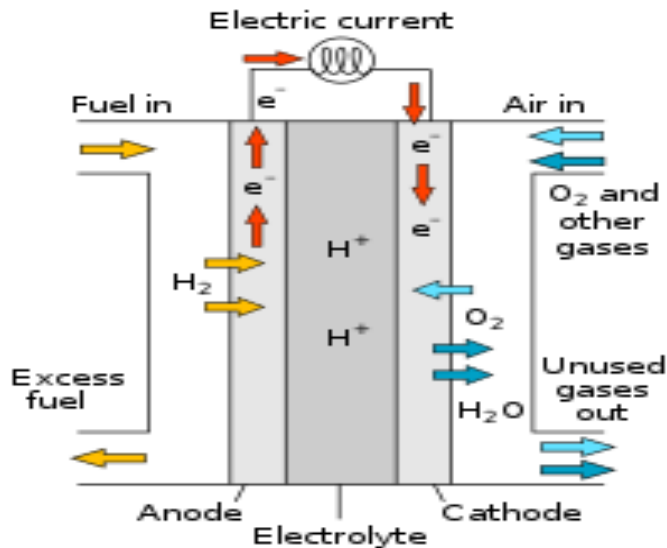


Fig. 11. Working of Hydrogen Fuel Cell [22]

One of the significant advantages of hydrogen is its high weight-related energy density, meaning it can store a large amount of energy per kilogram. It can be used as an energy carrier in various processes, including the use of hydrocarbons through oxidation, steam reforming of natural gas, water electrolysis, and methane pyrolysis from sources like biogas. These processes enable the production of hydrogen for different applications.

The applications of hydrogen are diverse and have significant potential. It can be directly utilized in industrial processes, serve as an energy storage medium for balancing supply and demand fluctuations, and be used as a fuel in the transportation sector, particularly for fuel cell vehicles. Hydrogen can also be employed for energy and heat supply in various sectors, contributing to decarbonization efforts and the transition to cleaner energy sources. Its high energy density makes it attractive for applications requiring a concentrated and efficient energy source.

3. COMPARISON OF DIFFERENT ASPECTS OF ENERGY STORAGES

3.1. EFFICIENCY

Mechanical energy storage systems, such as Pumped Hydro Storage (PHS) and Flywheel Energy Storage, offer high power and energy densities, quick starting times, controllable power output, and long lifespans. Pumped Hydro Storage (PHS) demonstrates an efficiency range of 70% to 85%, while Compressed Air Energy Storage (CAES) operates within a range of 50% to 75% efficiency. Flywheel Energy Storage shows higher efficiency, ranging from 85% to 95% [23].

Chemical storage includes Hydrogen Storage and Battery Storage. Hydrogen process chains generally have lower efficiencies but offer high power and energy outputs and capacities. Battery storages, on the other hand, exhibit average storage efficiency that can vary depending on the specific type of battery and operating conditions. Thermal storage, specifically Thermal Energy Storage, varies in efficiency depending on the specific technology employed, such as sensible heat storage or latent heat storage.

Electrical storage encompasses technologies like Supercapacitors, Capacitors, and Inductors, which all exhibit high efficiency with rapid charge and discharge capabilities. Electrical energy storage systems exhibit high efficiency, with energy losses during charging and discharging processes typically exceeding 95%. This efficiency ensures minimal waste and maximizes the useful energy output of the system. Within the realm of electrochemical storage, Battery Storage systems offer average efficiency that is influenced by factors such as the battery type, charge/discharge rates, and operating conditions. Lastly, in gas storage, the efficiency of Compressed Natural Gas (CNG) storage depends on compression and storage conditions.

Overall, the efficiency of storage technologies varies across different categories, reflecting the diverse nature of energy storage systems and their respective operational characteristics.

3.2. ECONOMIC ASPECTS

In terms of economic aspects, mechanical storage technologies present varying considerations. Pumped Hydro Storage (PHS) is often deemed economically viable due to its long operational lifespans and low operational costs. The economic feasibility of Compressed Air Energy Storage (CAES) relies on factors such as the geological conditions, infrastructure availability, and the scale of the system. Flywheel Energy Storage can be economically competitive for specific applications that require rapid response times and high-power output.

Chemical storage, particularly Hydrogen Storage, exhibits favourable economic aspects, especially with the increasing demand for "green" hydrogen produced from renewable energy sources. Battery Storage offers economic advantages through load management, peak shaving, and revenue potential from energy markets and power purchase agreements. Thermal storage, represented by Thermal Energy Storage, has economic viability influenced by factors such as the specific application, scale, and cost of the thermal storage technology. Within the realm of electrical storage, Supercapacitors, Capacitors, and Inductors can provide economic advantages due to their rapid charge and discharge capabilities and long cycle life.

Electrochemical Storage, mainly Battery Storage, offers economic benefits through cost savings, revenue potential, and decreasing unit prices with advancements in battery technology. In gas storage, the economic viability of Compressed Natural Gas (CNG) storage depends on factors such as the availability and price of natural gas, as well as infrastructure costs [24].

Overall, the economic considerations of energy storage technologies vary, with factors such as operational costs, revenue potential, technological advancements, and market conditions playing significant roles in determining their economic viability.

3.3. CHARGING AND DISCHARGING TIME

The charging and discharging times of various energy storage systems differ based on their specific characteristics. In mechanical storage, such as pumped hydro and compressed air, these times can range from minutes to hours. Flywheel energy storage, known for its rotational motion, offers rapid charging and discharging times typically in the range of seconds to minutes.

Chemical storage involves technologies like hydrogen storage and batteries. Charging and discharging times for hydrogen storage depend on factors such as capacity, compression/condensation, liquefaction infrastructure, and the intended application. They can span from minutes to hours. Battery storage, another form of chemical storage, is influenced by factors like battery capacity, charging infrastructure, and discharge rate. Charging and discharging times for batteries also vary, typically ranging from minutes to hours based on battery technology and application.

Thermal storage, which includes thermal energy storage systems, relies on specific technologies, such as the heat transfer medium and system design. Charging and discharging times for thermal storage can vary from minutes to hours, allowing for efficient storage and release of thermal energy [10].

Electrical storage options like supercapacitors, capacitors, and inductors offer very short charging and discharging times, typically in the range of seconds to minutes. Electrochemical storage, represented by batteries, also follows a similar pattern, with charging and discharging times depending on battery capacity, infrastructure, and discharge rate. These times can range from minutes to hours.

4.CONCLUSION

In conclusion, energy storage technologies are crucial for addressing the challenges of renewable energy integration, grid stability, and efficient energy management. This research paper explored various storage technologies, including mechanical, electrical, chemical, thermal, electrochemical, gas, and hydrogen storage. These technologies offer diverse solutions for different applications and have distinct advantages and limitations. Mechanical storage technologies like pumped hydro and compressed air excel in large-scale applications. Electrical storage, primarily batteries, finds widespread use in portable devices, electric vehicles, and grid-scale projects. Chemical storage, including hydrogen and advanced batteries, shows promise for high-energy density and long-duration applications. Thermal storage offers efficient heat energy management. Electrochemical technologies like fuel cells enable direct energy conversion. Gas and hydrogen storage solutions provide flexibility and scalability. Continued research is essential to enhance performance, efficiency, and cost-effectiveness, ensuring widespread adoption and a sustainable energy future.

REFERENCES

- [1] HUSSAIN, F., RAHMAN, M. M., SIVASENGARAN, A. N., & HASANUZZAMAN, M. (2020, January 1). *Energy storage technologies*. Elsevier ebooks. Retrieved on May 07, 2023, from <https://doi.org/10.1016/b978-0-12-814645-3.00006-7>
- [2] CAVA, F., KELLY, J. P., PEITZKE, W. R., BROWN, M. A., & SULLIVAN, S. (2016, January 1). *Advanced rail energy storage: green energy storage for green energy*. Elsevier ebooks. Retrieved on May 06, 2023, from <https://doi.org/10.1016/b978-0-12-803440-8.00004-x>
- [3] SMARD|2022. (n.d.). SMARD. Retrieved on May 07, 2023, from <https://www.smard.de/en/strommarkt-aktuell/2022>
- [4] Retrieved on May 07, 2023, from <https://aemo.com.au/learn/energy-explained/energy-101/energy-explained-frequency>

- [5] GYAMFI, S., ASUAMAH, E. Y., & GYABAAH, J. A. (2023, January 1). *Techno-economic challenges of pumped hydro energy storage*. Elsevier ebooks. Retrieved on May 11, 2023, from <https://doi.org/10.1016/b978-0-12-818853-8.00011-x>
- [6] P. NIKOLAIDIS, 2017 Retrieved on May 10, 2023, from <http://www.icomsociety.org/singapore2021/papers/470.pdf>
- [7] GUO, J., MA, R., & HUIYAN, Z. (2021B). Compressed air energy storage and future development. *Journal of physics: conference series*, 2108(1), 012037. Retrieved on May 15, 2023, From <https://doi.org/10.1088/1742-6596/2108/1/012037>
- [8] CAS- DONADEI, S., & SCHNEIDER, G. (2022, January 1). *Compressed air energy storage*. Elsevier eBooks. Retrieved on May 15, 2023, From <https://doi.org/10.1016/b978-0-12-824510-1.00034-9>
- [9] Retrieved on May 27, 2023, From <https://www.en-former.com/en/tu-dresden-builds-huge-flywheel-storage-system-for-wind-turbines/>
- [10] KRISTIAN PLATTA -Brandenburg Technical University, 2023
- [11] Retrieved on May 18, 2023, From <https://www.sciencedirect.com/topics/engineering/chemical-energy-storage>
- [12] NEUPANE, P., BHUJU, S., THAPA, N., & BHATTARAI, H. K. (2019). ATP Synthase: Structure, Function and Inhibition. *Biomolecular Concepts*, 10(1), 1–10. Retrieved on May 16, 2023, From <https://doi.org/10.1515/bmc-2019-0001>
- [13] Ellis, B. E., & Nazar, L. F. (2012). Sodium and sodium-ion energy storage batteries. *Current Opinion in Solid State & Materials Science*, 16(4), 168–177. Retrieved on May 17, 2023, From <https://doi.org/10.1016/j.cossms.2012.04.002>
- [14] Huber, C., Jahromy, S. S., Jordan, C., Schreiner, M., Harasek, M., Werner, A., & Winter, F. (2019). Boric Acid: A High Potential Candidate for Thermochemical Energy Storage. *Energies*, 12(6), 1086. Retrieved on May 20, 2023, From <https://doi.org/10.3390/en12061086>
- [15] Grover, J. (2022). Types of batteries: primary and secondary cell & uses. *Collegedunia*. Retrieved on May 23, 2023, From <https://collegedunia.com/exams/types-of-battery-physics-articleid-1434>
- [16] Doetsch, C., & Burfeind, J. (2016). Vanadium redox flow batteries. In *elsevier ebooks* (pp. 227–246). Retrieved on May 15, 2023, From <https://doi.org/10.1016/b978-0-12-803440-8.00012-9>
- [17] RF Wireless Vendors and Resources | RF Wireless World. (n.d.). Retrieved on May 25, 2023, From <https://www.rfwireless-world.com/terminology/advantages-and-disadvantages>
- [18] Retrieved on May 20, 2023, From <https://link.springer.com/book/10.1007/978-3-662-55504-0>
- [19] ZALBA, B., MARÍN, J., CABEZA, L. F., & MEHLING, H. (2003, February 1). *Review on thermal energy storage with phase change: materials, heat transfer analysis and applications*. Applied Thermal Engineering. Retrieved on May 28, 2023, From [https://doi.org/10.1016/s1359-4311\(02\)00192-8](https://doi.org/10.1016/s1359-4311(02)00192-8)
- [20] Retrieved on May 20, 2023, From <https://ars.els-cdn.com/content/image/1-s2.0-S0306261921002300-gr1.jpg>
- [21] BREEZE, P. (2018, May 18). *Power System Energy Storage Technologies*.
- [22] R.Dervisoglu May 2012, Retrieved on Dec 20, 2022, From https://en.wikipedia.org/wiki/File:Solid_oxide_fuel_cell_protonic.svg,
- [23] CHAKRABORTY, M. R., DAWN, S., SAHA, P. K., BASU, J. K., & USTUN, T. S. (2022, September 10). *A Comparative Review on Energy Storage Systems and Their Application in Deregulated Systems*. Batteries. Retrieved on May 10, 2023, From <https://doi.org/10.3390/batteries8090124>
- [24] SHARMA, R., KUMAR, H., KUMAR, G., SHARMA, S., ANEJA, R., SHARMA, A. K.,

KUMAR, R., & KUMAR, P. (2023, May 1). *Progress and challenges in electrochemical energy storage devices: Fabrication, electrode material, and economic aspects*. Chemical Engineering Journal Retrieved on May 29, 2023, From <https://doi.org/10.1016/j.cej.2023.143706>

Key words: Consumption, Energy Sources, Greenhouse gas, Renewable Sources, Energy Efficiency

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ENVIRONMENTAL IMPACT OF ENERGY SECTOR

This paper focuses exclusively on the impact of energy sector on the environment. From the perspective of sustainable development, energy usage and its significant environmental effects are explored, along with projected trends in energy use and related environmental problems. The most effective prospective solutions to the current environmental problems are highlighted as renewable energy technology and efficient energy consumption, along with some real-world examples. The use of energy, renewable energy, energy efficiency, the environment, and sustainable development are some of the topics that are looked at from both present and future angles. It is possible to draw the conclusion that the conclusions and suggestions made here will be useful to energy scientists, engineers, and decision-makers.

1. INTRODUCTION

Energy is necessary for the improvement of social, economic and living conditions worldwide. It can take on a variety of forms [1], including mechanical, chemical, thermal, electrical, gravitational, nuclear, audible, motion, etc. Energy is defined as the capacity to do work. Depending on the use, energy can be magnified, converted, or stored. Energy sources include fissile (uranium, thorium, etc.), renewable (biomass, hydro, wind, solar, geothermal), and fossil (petroleum, coal, butane, natural gas, shale oil, etc.)

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Our economies and societies depend on the energy industry to function, but it is also one of the main sources of greenhouse gas emissions and environmental damage [3]. A sustainable future depends on minimizing the environmental effect of the energy industry since climate change poses serious challenges to our planet.

Through the adoption of cleaner technologies, renewable energy sources, and increased energy efficiency, the environmental impact of the energy sector has received increasing attention in recent years [4]. The many approaches to reaching this goal are examined in this paper, together with their implications for economics and public policy. By putting these solutions into practice, we can dramatically lessen the energy sector's negative environmental impacts, lessen the effects of climate change, and encourage a more sustainable future for everybody.

Examining methods to lessen the energy sector's negative environmental effects is the goal of this paper. The study will review earlier research on the effects of the energy sector on the environment and evaluate the efficacy of various mitigation measures. The study will also look at the consequences of these tactics for policy and the economy, as well as the obstacles and difficulties in putting them into practice. This paper's objective is to offer policymakers, business executives, and other stakeholders' ideas and suggestions for making the transition to more robust and sustainable energy systems.

In the upcoming sections of this paper, we will discuss about the primary energy consumption from various energy sources along with a data visualization of per capita energy consumption and year to year change of consumption in Germany and Poland. After that, we will describe the greenhouse gas emissions from energy sector and CO₂ gas emission as the most significant part of greenhouse emissions. These subsequently result in environmental pollution by having an adverse effect on climate change.

2. AN ANALYSIS ON ENERGY CONSUMPTION

The new millennium challenges for socio-economic upgradation and adoption of new lifestyles have caused a high demand for energy in developed and developing countries. Conventional sources for generating electricity are depleting and may become environmentally hazardous, leading to global warming. Renewable energy sources are being given preference as alternate and long-lasting sources of energy generation, as they are environmentally friendly and free from the danger of pollution and health hazards [5]. Global energy demand and resource consumption are projected to increase over the next several decades [6]. It is essential for energy consumption to be used in a productive manner for sustainable development due to rising petroleum prices and the limited lifetime of fossil fuels. Most of the global increase comes from developing countries for

energy and population [7].

Saving fuel is the most important measure for protecting the environment and climate, and development will be shaped by saving resources, decelerating fuel consumption, and supporting technical developments [8].

A chart representing the consumption of all the energy coming from various sources can provide an idea about how the world is behaving to control environmental pollution. From Fig.1 uses of renewable sources like modern biofuels, solar, wind, hydropower and other sources for the generation of energy have rapidly increased in the last 50 years [9]. While the use of other sources like oil, coal, nuclear energy has been diminishing in the past couple of decades. The reason is clear, environmental impact of these energy sources. This data represents the global primary energy consumption based on substitution method. The 'substitution method' corrects inefficiencies in fossil fuel and biomass conversion by replacing them with nuclear and renewable technologies.

Global primary energy consumption by source



Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.

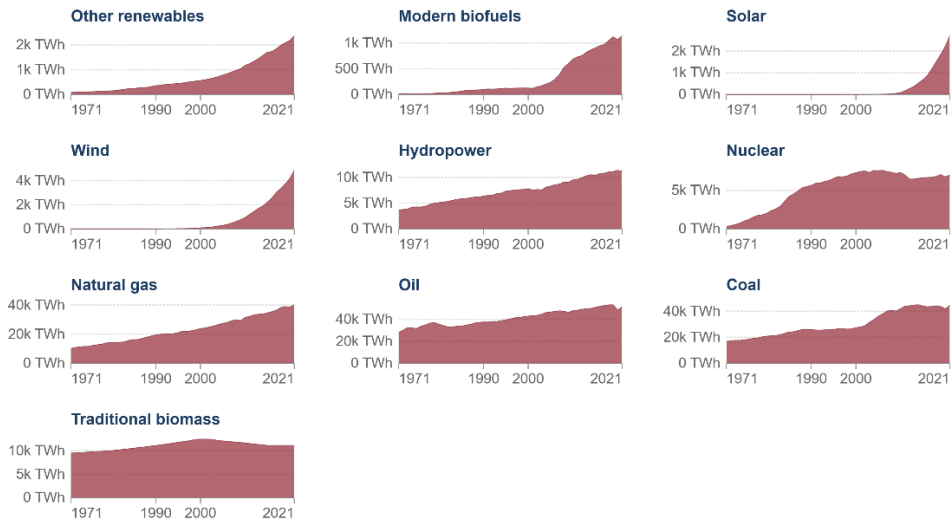


Fig. 1. Global primary energy consumption by source of energy[9]

Germany and Poland's primary energy usage is displayed on the interactive chart in Fig.2. It represents the overall energy used for transportation, heating, and electricity. The main energy used in this chart was obtained using the "substitution method," which means that nuclear and renewable energy technologies were transformed into their "primary input equivalents" if they had efficiency levels comparable to those of the conversion of fossil fuels [9].

Instead of using alternative energy units or million tonnes of oil equivalents, we have converted primary energy into terawatt-hours in order to maintain consistency.

For the last 50 years, the consumption of primary energy has been rising on a global scale. But not everywhere in the world is like this [9].

In many nations where earnings are rising swiftly and the population is expanding, energy consumption is rising. However, energy consumption is actually decreasing in many nations, especially richer nations that are attempting to increase energy efficiency. Positive figures show that a nation's energy consumption increased from the year before. Negative figures show that it used less energy than it did the year before [9], [10].

The interactive graph in Fig. 3 compares the global Year-on-Year change in primary energy consumption to the annual growth rates of energy consumption in Germany and Poland.

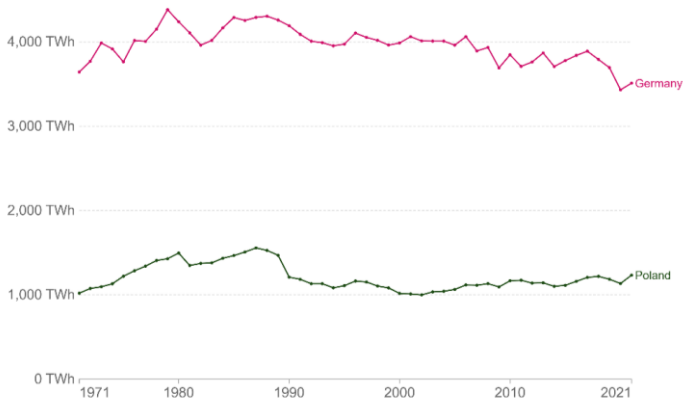


Fig. 2. Primary energy consumption in Germany and Poland [9]

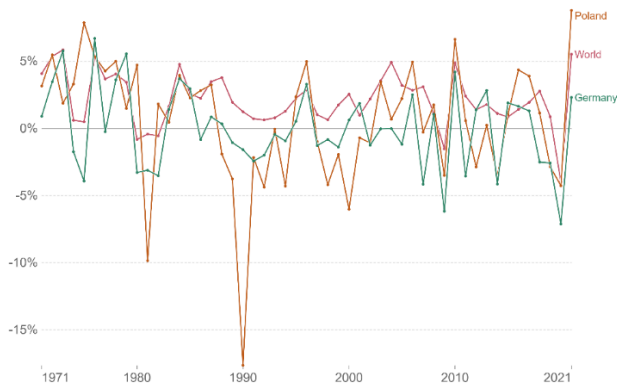


Fig. 3. Annual change in primary energy consumption [9]

3. ENVIRONMENTAL IMPACT OF ENERGY

Environmental issues cover a variety of pollutants, dangers, and ecosystem deterioration over ever-larger areas. In addition to global warming, issues with energy supply and use also affect other environmental issues such as air pollution, acid rain, ozone depletion, forest loss, and radioactive material emissions. If mankind is to have a bright energy future with little environmental impact, these challenges must be taken into account simultaneously. There is ample evidence to show that if humans continue to damage the environment, the future will suffer. Our paper will focus on the Greenhouse gas emission part as a factor of environmental impact from energy generation.

The IPCC (Inter-governmental Panel of Climate Change) states that CO₂, CH₄, halocarbons, and N₂O are the anthropogenic greenhouse gas (GHG) emissions contributing most obviously to global warming [11]. In this paper, we will mainly focus on CO₂ emissions from different fuel sources as the most important part greenhouse gas emissions, followed by a brief summary of Greenhouse gas emissions from energy sources.

3.1. CO₂ EMISSIONS

Understanding CO₂ emissions from Energy sector is an important issue that are the current world leaders are focusing right now. Identifying the primary sources of greenhouse gas emissions is essential for finding possibilities to reduce such emissions. More than 80% of all greenhouse gas emissions worldwide are carbon dioxide (CO₂), mostly from the burning of fossil fuels [12]. In 2010, the energy sector—which is defined to include fuels used to generate electricity and heat—contributed 41% of the world's CO₂ emissions (Fig.4).

The spatial distribution of energy use and CO₂ emissions closely resemble each other (Fig.4). In 2010, the two biggest energy consumers on the planet accounted for about half of all such emissions, while the top six polluting nations accounted for more than three-quarters. About 8% of the remaining energy-related CO₂ emissions were from other high-income nations, 15% from other middle-income nations, and only 0.5 % from all low-income nations countries combined [13]. How the country is acting with these number of emissions will be the concentrating factor in our paper, especially the action and remedies of measurement in Germany and Poland with respect to whole world.

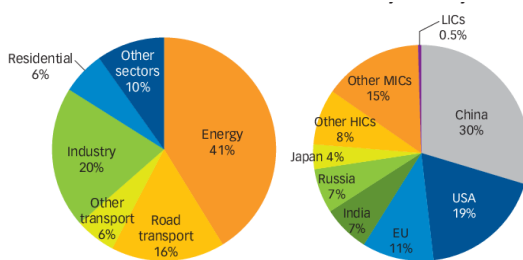


Fig. 4. Left: CO2 emissions by sector and Right: Energy-related CO2 emissions by country [13]

At present, the world is emitting roughly 50 billion tonnes of CO2 annually as a collective. Compared to 1990, when emissions were roughly 35 billion tonnes¹, this represents an increase of more than 40%. The rise in 2021's annual global emissions, from 33.3 GtCO₂ in 2020 to 34.9 GtCO₂, was 4.8%. Fig.5 shows the amount of CO2 produced each year in Germany and Poland. Where it can be seen that, around 650 million tonnes of CO₂ are emitted from Germany on contrary to the 350 million tonnes emitting from Poland [14]. These numbers are based on "production" or "territorial" emissions, such as those from the burning of fossil fuels or the production of cement within the nation's boundaries. The emissions from exchanged items (consumption-based emissions) are not considered in the chart. These numbers only consider CO2 emissions; they do not include all greenhouse gas emissions. Population density can have a significant impact on annual emissions.

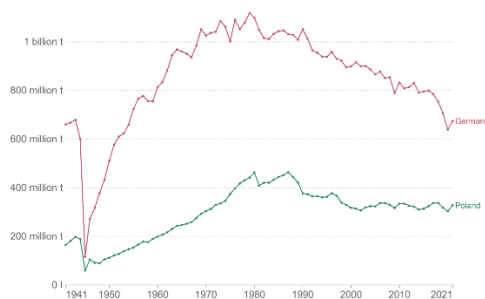


Fig. 5. Annual CO₂ emission Germany and Poland [14]

3.2. CO₂ EMISSIONS FROM DIFFERENT FUEL SOURCE

Coal, oil, gas, cement manufacturing, and gas flaring are just a few of the sources and fuel types that contribute to carbon dioxide (CO₂) emissions from the production of energy and materials. Currently, CO₂ emissions from coal, oil, and gas are distributed rather evenly. Fossil fuel combustion for electricity production and industrial manufacture of materials like cement account for the majority of CO₂ emissions. The breakdown

of annual CO₂ emissions by source—coal, oil, gas, cement manufacturing, or gas flaring—is displayed in the interactive chart on Fig.6. This breakdown varies as a country switch to or from a certain energy source and is significantly influenced by that country's energy mix.

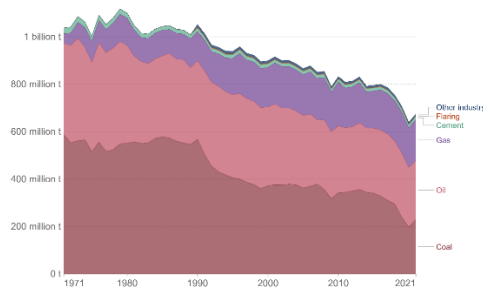


Fig. 6. CO₂ emission in Germany from different fuel source [14]

3.3. GREENHOUSE GAS EMISSIONS

The energy industry produces a sizable portion of the greenhouse gas emissions that cause climate change. Carbon dioxide (CO₂), the main greenhouse gas contributing to global warming, is released when fossil fuels like coal, oil, and natural gas are burned to produce energy. Methane (CH₄) and nitrous oxide (N₂O) are two more greenhouse gases that the energy industry is responsible for emitting. The carbon dioxide (CO₂) was highlighted in the graphics above. But there are more greenhouse gases besides CO₂. Other substances, such as methane and nitrous oxide, have up to this point also significantly contributed to global warming [15]. The first interactive graph (Fig.7) displays the greenhouse gas emissions by individuals. We have visualized the per capita GHG emissions from Germany and Poland with a variation from Total global GHG emissions. In the last 50 years, Germany has overcome its higher GHG emissions than Poland within the time span. Although the per capita emissions are still higher than that of global emissions. This is calculated using a metric called "carbon dioxide equivalents," which sums up all greenhouse gases. "Carbon dioxide equivalents" aim to account for the fact that not all units of a given gas, like tonnes, have the same warming effect. As a result, we multiply each gas' emissions by its "global warming potential" (GWP) value, which expresses how much warming one tonne of that gas would produce in comparison to one tonne of CO₂. In Fig. 8, a visualization is given from where these emissions come from: the contribution of each sector.

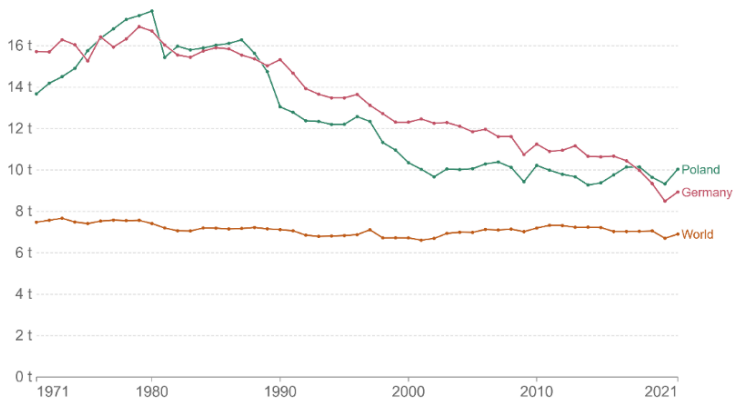


Fig. 7. Per capita GHG emissions [14], [16]

From the graph, it can be easily understandable that, Electricity and heat generation sources are the most responsible for higher GHG emissions throughout the world followed by transport sector, building sector and then Manufacturing & construction sector. Apart from CO₂, other greenhouse gases like methane and SO_x are given lesser importance in the Energy sector. As the emission of these gases are mainly from Agriculture sector and waste management sector [14].

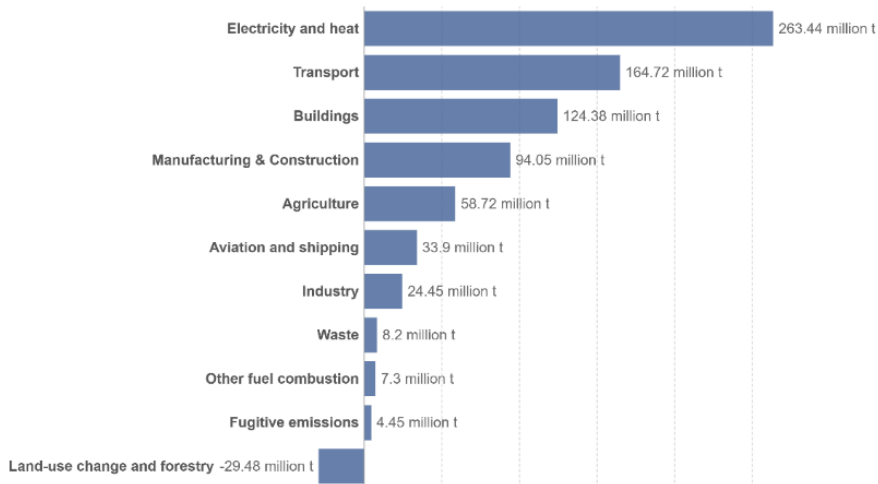


Fig. 8. GHG emissions by sector, Germany, 2019 [17]

4. CONTROL OF THE EMISSION

Controlling energy sector emissions is essential for combating climate change and lessening the effects of greenhouse gases. The following are some important tactics and techniques for reducing emissions from the energy sector:

Transition of energy: Moving away from fossil fuels and toward renewable energy sources like solar, wind, hydroelectricity, and geothermal power is one of the most efficient ways to reduce emissions. A large reduction in greenhouse gas emissions related to the production of electricity can be achieved by investing in infrastructure and technology for renewable energy [18].

Energy efficiency: Significant emission reductions can be achieved by increasing energy efficiency across all industries, including construction, transportation, and industrial processes. Energy-efficient products, procedures, and regulations can reduce energy use and, as a result, the emission of greenhouse gases.

Carbon capture, utilization, and storage (CCUS): Carbon dioxide emissions from factories and power plants are captured using carbon capture, utilization, and storage (CCUS) technology, which either store the emissions underground or use them in other processes [19]. Although it is still a developing technology, CCUS can assist in reducing emissions from industrial operations and power production that uses fossil fuels.

Phasing out coal: Coal is the most carbon-intensive fossil fuel; hence it must be phased out in favor of cleaner alternatives if emissions are to be reduced. This objective can be attained by switching from coal to natural gas, which emits fewer carbon emissions, and by increasing the use of renewable energy sources [20].

Transportation electrification: Switching to electric vehicles (EVs) from fossil fuel-powered vehicles can cut emissions in the transportation sector by a significant amount. The acceptance of EVs, the development of a charging infrastructure, and the encouragement of cleaner transportation options can all help reduce emissions [21].

Policy measures: To encourage emission reductions in the energy sector, governments can enact policies like carbon pricing (via carbon taxes or cap-and-trade systems), renewable energy standards, and energy efficiency rules. Investment in low-carbon technologies can be stimulated and measures to decrease emissions can be supported by clear and stable policy frameworks.

Cooperation: International collaboration is necessary to address emissions from the energy industry. Collaboration between nations is encouraged by international agreements like the Paris Agreement to curb global warming and ameliorate climate change.

In our segment, we will only elaborately discuss about the Carbon and energy efficiency as a control factor of emission.

4.1. ENERGY EFFICIENCY: INTENSITY GRAPH

Since energy contributes so much to CO₂, lowering energy use will surely aid in

lowering emissions. However, some energy use is necessary for a healthy population and improving living standards. Therefore, it can be helpful to track energy intensity as a metric. The quantity of energy used per unit of gross domestic product is measured as energy intensity. It accurately gauges how successfully a nation uses energy to generate a certain level of economic production. It requires less energy per unit of GDP when the energy intensity is lower.

One key indicator of whether nations are cutting emissions is energy intensity, which is depicted in the graph above (Fig.9). The chart indicates the energy intensity of Germany and Poland along with the whole world. The quantity of energy unit per GDP is lower in Germany than Poland, even than the average in whole world. Although, the chart suggests that, Poland has successfully lowered their energy intensity by more than half in the last 50 years.

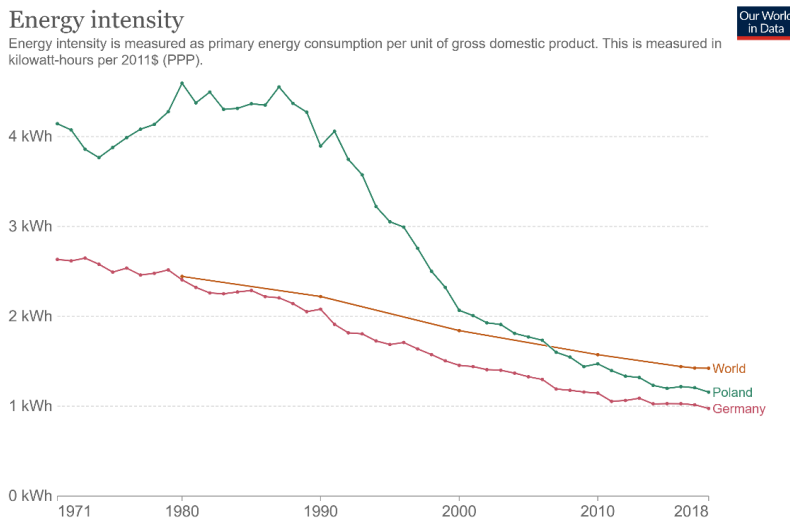


Fig. 9. Energy consumption per GDP [14], [22]

4.2. CARBON EFFICIENCY: INTENSITY GRAPH

The carbon intensity, or the quantity of CO₂ emitted per unit of energy, is the other crucial component in this equation. By using less energy and/or using energy with fewer carbon emissions, we can lower emissions. The graph from Fig. 10 displays carbon intensity, which is the amount of carbon dioxide (CO₂) released per kilogram of oil equivalent consumed.

The carbon intensity differs countries to countries due to several factors, like economic structure, infrastructure and technologies, geographic factors, policies and regulations, etc. The chart indicates that, Germany has lower carbon intensity of energy production than average global amount and that of Poland. The above-mentioned reasons

can be playing vital roles in this case.

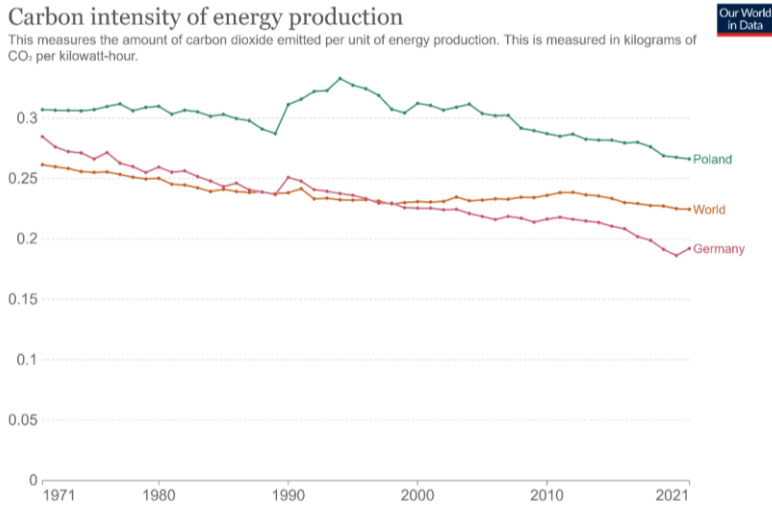


Fig. 10. Carbon intensity of energy production [14], [22]

5. CONCLUSION

The energy sector plays a crucial role in powering our modern world, but it also has a significant environmental impact. The burning of fossil fuels to generate energy is the largest source of greenhouse gas emissions, which contribute to climate change, air pollution, and other environmental problems [15]. These negative impacts have serious consequences for both human and environmental health. Many evaluations of economic, energy, and environmental policies depend on estimates of future energy usage. This essay focused on energy consumption and the effect on the environment, especially on Greenhouse gas emissions.

The attention on energy use has resulted from the rise in energy prices. We must look for aberrant and unusual spikes or declines in consumption, identify and assess methods for conservation, and consider the effects of energy usage on the environment [23]. From analysis of previous data from various sources, it is observed that Germany and Poland are trying hard to get their best in controlling the emission, but it is still not enough. Long-term planning is necessary when investing in renewable energy technologies. Only when costs are spread out across the project's operational lifetime can

renewable energy rival fossil fuels. Making greater use of renewable energy sources and technology is one way to combat the coming energy crisis.

REFERENCES

- [1] S. Bilgen, 'Structure and environmental impact of global energy consumption', *Renew. Sustain. Energy Rev.*, vol. 38, pp. 890–902, 2014, doi: <https://doi.org/10.1016/j.rser.2014.07.004>.
- [2] D. Delgado, G. Heffter, and M. Minakshi, 'Hydrogen generation', *Altern. Energ. Updat. Prog.*, pp. 141–161, 2013.
- [3] B. H. Jørgensen and H. Holttinen, 'IEA Wind TCP Annual Report 2021', IEA, 2022.
- [4] E. Bianco and H. Blanco, 'Green hydrogen: a guide to policy making', 2020.
- [5] Z. A. Nayyar, N. A. Zaigham, and A. Qadeer, 'Assessment of present conventional and non-conventional energy scenario of Pakistan', *Renew. Sustain. Energy Rev.*, vol. 31, pp. 543–553, 2014, doi: <https://doi.org/10.1016/j.rser.2013.12.049>.
- [6] G. E. Peake, *US energy: overview of the trends, statistics, supply and consumption*. Nova Science Publishers, 2010.
- [7] S. Lawrence, Q. Liu, and V. M. Yakovenko, 'Global Inequality in Energy Consumption from 1980 to 2010', *Entropy*, vol. 15, no. 12, pp. 5565–5579, 2013, doi: 10.3390/e15125565.
- [8] M. Palocz-Andresen, *Decreasing fuel consumption and exhaust gas emissions in transportation: sensing, control and reduction of emissions*. Springer Science & Business Media, 2012.
- [9] H. Ritchie, M. Roser, and P. Rosado, 'Energy', *Our World Data*, 2022.
- [10] L. Lyu and L. Fang, 'A Study on EC Translation of BP Statistical Review of World Energy 2022 from the Perspective of Schema Theory', *J. Linguist. Commun. Stud.*, vol. 2, no. 1, pp. 10–14, 2023.
- [11] J. T. S. Pedersen, D. van Vuuren, J. Gupta, F. D. Santos, J. Edmonds, and R. Swart, 'IPCC emission scenarios: How did critiques affect their quality and relevance 1990–2022?', *Glob. Environ. Change*, vol. 75, p. 102538, 2022.
- [12] T. Van de Graaf, 'International energy agency', in *Handbook of governance and security*, Edward Elgar Publishing, 2014, pp. 489–503.
- [13] V. Foster and D. Bedrosyan, 'Understanding CO2 emissions from the global energy sector', 2014.
- [14] H. Ritchie, M. Roser, and P. Rosado, 'CO₂ and Greenhouse Gas Emissions', *Our World Data*, 2020.
- [15] R. Dones, T. Heck, and S. Hirschberg, 'Greenhouse gas emissions from energy systems: comparison and overview', 2004.
- [16] M. W. Jones *et al.*, 'National contributions to climate change due to historical emissions of carbon dioxide, methane, and nitrous oxide since 1850', *Sci. Data*, vol. 10, no. 1, p. 155, 2023.
- [17] C. WRI, 'Climate analysis indicators tool: WRI's climate data explorer', *World Resour. Inst. Publ.*, 2014.
- [18] K. Hansen, B. V. Mathiesen, and I. R. Skov, 'Full energy system transition towards 100% renewable energy in Germany in 2050', *Renew. Sustain. Energy Rev.*, vol. 102, pp. 1–13, 2019.
- [19] J. F. D. Tapia, J.-Y. Lee, R. E. Ooi, D. C. Foo, and R. R. Tan, 'A review of optimization and decision-making models for the planning of CO₂ capture, utilization and storage (CCUS) systems', *Sustain. Prod. Consum.*, vol. 13, pp. 1–15, 2018.
- [20] B. Gałgóczi, 'Phasing out coal—a just transition approach', *ETUI Res. Pap.-Work. Pap.*, 2019.
- [21] H. Lund and E. Münster, 'Integrated transportation and energy sector CO₂ emission control strategies', *Transp. Policy*, vol. 13, no. 5, pp. 426–433, 2006.

- [22] N. Palma and J. Reis, 'The Maddison Project', 2017.
- [23] M. Jefferson, 'Accelerating the transition to sustainable energy systems', *Energy Policy*, vol. 36, no. 11, pp. 4116–4125, 2008.

Key words: Renewable Energy, Renewables in Germany, Hydro Power, Wind and PV Plants

Antonello LORUSSO ¹

RENEWABLE ENERGY INTEGRATION IN THE GRID

The objective of this research is to deepen the knowledge in the field of renewable energy integration in the grid, which refers to the process of incorporating renewable energy sources, such as solar, wind, and hydropower, into the existing energy infrastructure. This involves optimizing the operation and management of the grid to accommodate the variability of renewable energy resources and ensure a reliable and stable power supply.

Renewable energy sources are inherently variable, as they depend on weather conditions, time of day, and other factors. As a result, integrating them into the grid requires careful planning and management to ensure that energy supply matches demand at all times.

1. INTRODUCTION

In contemporary society, addressing climate change and safeguarding the planet have become critical issues, driving the need for new developments and changes in human activities. As part of the European Green Deal, the Commission proposed a target in September 2020, aimed at reducing greenhouse gas emissions, including emissions and removals, to at least 55% of 1990 levels by 2030 on a European scale [2]. The implementation of renewable energy sources is leading to the rapid growth of the world energy system, primarily due to the increasing use of renewable energy sources such as solar panels and wind turbines. These sources are becoming more common and are expected to continue to rise in popularity. However, since they produce electricity, the primary impact is on the electrical grid. Solar and wind are unpredictable energy sources, which can create additional stress on the existing electrical grid. Additionally, renewable sources are widely distributed, and integrating them into the grid requires a reconfiguration of the grid infrastructure to support their high penetration [1]. Since there are many renewable energy sources available, this paper focused on the most popular in Germany and the next part of the article is structured as follow: in Chapter 2.

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the “Development and Grid Distribution of Renewable in Germany”, in Chapter 3. the “Renewable Sources Most Used”, which has been subdivided in 3.1. for the “Hydro Power”, 3.2. for the “Wind Energy” and last one 3.3. for the "Photovoltaics”.

2. DEVELOPMENT AND GRID DISTRIBUTION OF RENEWABLES IN GERMANY

Germany is aiming to shift towards renewable energy sources and reach a minimum of 80% share in the energy supply by 2050. To achieve this, the integration of renewable energies into the power supply system is crucial in order to replace traditional energy sources. Such a transition requires a fundamental transformation of the energy supply system. One of the main challenges of the energy transition is to ensure a reliable, environmentally friendly, and economically efficient power supply. In 2015, renewable energy accounted for 30% of gross electricity production, but this figure varies throughout the year. At times, the share of fluctuating renewable energies like wind and solar can reach over 60%. Germany's grid development plan indicates that by 2024, approximately 140 GW of renewable energy capacity will likely be installed, even though annual energy consumption ranges between only 40 and 80 GW. This means that renewable energies will be able to meet or exceed the current electricity demand in the future [7]. The country has seen significant growth in installed capacity for photovoltaics, wind energy, and biomass since the implementation of feed-in tariffs in 1990, reaching a capacity of 92 GW by the end of 2015, as we can notice in Fig. 1 [3].

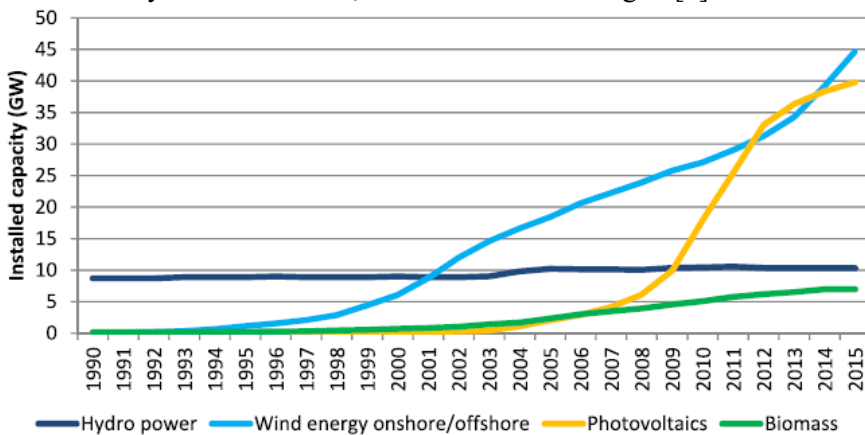


Fig. 1 Installed capacity in Germany from 1990 until 2015 [4]

A notable feature of this expansion is its decentralized nature, with a total capacity of 85 GW connected to the distribution grid. More than half of this capacity, 44 GW, is installed in the medium-voltage grid, while 24 GW and 17 GW are connected to the low

and high-voltage grids, respectively [4].

3. RENEWABLE SOURCES MOST USED IN GERMANY

3.1. HYDRO POWER

Hydropower has the potential to play a critical role in the energy transition by offering balancing and system services to the grid, which can aid in the integration of variable renewables. The supply of energy from renewable sources is variable, and inverter-based resources cannot meet the requirements for maintaining grid voltage or frequency. Hydropower's balancing and system services can help to address this issue and facilitate the integration of renewables. In fact, in Germany hydro storage is currently the predominant technology used for accumulating large reserves of electrical energy, as depicted in Table 1 [5]. Hydropower plants can be categorized into two types based on their installed capacity: small hydro (below 1 MW) and large hydro (above 1 MW). In Germany, the majority of large hydroelectric power stations are run-of-river power stations, accounting for 80% of the total, while the remaining 20% are pumped storage power stations [7].

With the increasing need for storage and grid support services, Pumped Hydro Storage presents itself as a natural large-scale energy storage solution. It provides a wide range of services, including reactive power support, frequency control, synchronous or virtual inertia, and black-start capabilities. Moreover, the high inertia of rotating machines in hydropower can stabilize the grid in case of disturbances, which in turn helps to regulate grid frequency. This makes it possible for low-inertia renewable energies such as wind and solar to enter the grid and allows their power to be transmitted over long distances. This type of plants is a type of energy storage system that involves two reservoirs connected by a system of pipes and pumps. When there is excess energy available, water is pumped from the lower reservoir to the higher one. Later, when the energy is needed, the water flows back down through turbines, generating electricity, making it a repeatable process, with an efficiency above 80%.

In traditional fixed-speed pumped storage plants, power output can only be adjusted while the plant is generating electricity. However, newer variable speed technology allows for power regulation over a wider range, both while generating and pumping, providing greater flexibility to support grid stability.

Hydro storage technology can act as a catalyst for the transition and modernization of power generation, thanks not only to its grid stabilization capabilities, but also from the storage perspective [6].

Plant project	State ^a	Head (m)	Capacity (MW)	Costs (€M)
Vianden M 11	(Lux.)	280	200	155
Ruhr spoil tip	NW	50–100	15/200 ^b	n.a.
Blautal (Ulm)	BW	170	60	60
Waldeck 2 plus	HE	360	300	250
Schweich (Trier)	RP	200	300	300–400
Forbach	BW	320–360	200	250
Riedl	BY	350	300	350
Atdorf	BW	600	1400	1200
Heimbach	RP	500	400–600	500–700
Simmerath	NW	240	640	700
Nethe (Höxter)	NW	220	390	500+
Schmalwasser	TH	200–300	400	500+

Table 1. Characteristics of Hydropower plants in Germany [5]

3.2. WIND ENERGY

The success of renewable energies owes a significant part to wind energy, which has been harnessed by humans for centuries. However, with recent advancements in technology and experience, we have been able to more effectively and consistently tap into its vast potential. Wind energy harnesses power from a renewable source, with minimal greenhouse gas emissions and waste. Additionally, research suggests that wind energy is less vulnerable to fluctuations in weather patterns and climate change [7]. Wind energy is the second strongest renewable energy source in terms of installed capacity after hydropower. It has the potential to generate a significant amount of energy compared to other renewable energy technologies. It was responsible for the highest contribution among green energy sources, generating over 25% of Germany's total electricity in 2020. The number of installed wind turbines in the country increased threefold from 2000 to 2020, reaching 31,109 by the end of the year. As a result of favorable wind conditions, most wind farms are situated in the northern part of the country, with Lower Saxony having the largest share of installed turbines at 6,352 [8].

Wind turbines capture the energy of wind by utilizing differences in air pressure near the surface of the Earth. Instead of resistance, modern turbines employ the principle of buoyancy. They don't resist the wind, but rather, as wind passes over their blades, the lift generated causes them to rotate.

In Germany, wind turbines are solely utilized for generating electricity connected to the

grid, in contrast to other parts of the world where wind energy is used for pumping [7]. The coastal region of the North Sea offers ideal conditions for establishing wind farms due to the consistent wind patterns. In terms of wind energy production across Germany, Lower Saxony leads the way with the largest number of wind farms and a total installed capacity of 10,582 MW, as depicted in Fig. 2.



Fig. 2 Distribution of wind power plants in Germany [7]

The technology and cost efficiency of wind energy have undergone significant progress since the Renewable Energy Act was introduced in 2000. This is demonstrated by the shift from monetary subsidies through feed-in tariffs to open market tendering processes in 2017. Onshore wind energy technology is already able to compete with conventional power plants in terms of costs. Wind power generation is considered to be the most cost-competitive option when compared to other renewable energy sources. In terms of economics, wind energy has reached a mature technological stage and is rapidly advancing as a cost-effective source of electricity. Moreover, as numerous wind turbines have reached the end of their operational lifespan in 2020, the so-called “repowering” is a feasible solution to sustain wind power efficiency, replacing old, smaller plants with modern, more powerful ones [8].

3.3. PHOTOVOLTAICS

Germany is a leading country in the world when it comes to the development and integration of renewable energy, particularly in the field of PV systems. It is possible to notice that particularly well by looking at Fig. 3, where “Added PV Capacity” (A) measures the incremental increase in PV installations within 2000 and 2020, while “Cumulative PV Capacity” (B) represents the total accumulated PV capacity over time [10]. As of the end of 2015, Germany had an installed photovoltaic capacity of around 40 GW (as represented in Fig. 1), with more than half of the expansion taking place in the country's low-voltage grids, which amounted to a total of 22 GW. These numbers made this one of the fastest growing renewable energy technologies in the country. The majority of this capacity comes from rooftop systems installed on residential or commercial buildings, with 90% of them having an installed capacity of under 30 kW. Therefore, the growth of PV systems at the low-voltage level is primarily occurring through small-scale systems, which is a unique aspect of Germany's energy transition [9]. Solar cells are devices that convert sunlight into electricity by utilizing a semiconductor, typically made of silicon. When photons strike the semiconductor layers, it creates free charges, allowing electrons to flow as an electrical current through a conductor. This direct current can power electrical devices or be stored in batteries. If it's converted to alternating current, it can be fed into the public power grid. Essentially, solar cells enable the direct conversion of sunlight to electricity [7]. The proliferation of PV plants primarily occurs by integrating small-scale systems into low-voltage grids. This is mainly due to the structure of the Renewable Energy Sources Act and the technological features of PVs. Small PV systems are almost as efficient as large-scale ones.

Noteworthy is that the number of photovoltaic installations is higher in the South of Germany than the northern part; causing the overload of operating equipment, that leads, consequently, to the grid expansion.

In the traditional grid system, local distribution transformers were utilized to connect the medium voltage and low-voltage grids. These transformers usually had an output of 100 to 630 kVA and were primarily designed for consumer grids. However, with the increased installation of PV systems, it happened that the amount of generated energy exceeds the demand for electricity. To address this, one approach is to create a new low-voltage grid by dividing the existing local grid and powering the separated subsection with an extra local distribution transformer.

On the other hand, in the event that current carrying capacity is not sufficient, the lines were distributed in parallel. As probably expected, the cross-section of the cables used must be increased (up to 300mm²) to overcome this issue.

Modify the structure of the grid can be advantageous for incorporating more photovoltaic capacity into low-voltage grids. For instance, if the grid has a ring topology, connecting the two power lines at the switching station can turn the grid into a closed ring, which results in less resistance and voltage drop in the grid. Therefore, voltage-related

issues that require grid expansion can be temporarily prevented. Moreover, for grid lines that can be supplied by two local substations, an optimization measure can be implemented. If the amount of reverse flow at one local distribution transformer is significantly higher than at the other, a pair of switches in the system can be activated to transfer some of the grid feed-in to the second local distribution transformer.

By utilizing improved grid planning techniques, it becomes possible to make more precise forecasts about the impact of distributed PV systems, thereby reducing the requirement for unnecessary safety measures and enhancing the operational efficiency of the grid. Typically, conventional methods of grid expansion are utilized and new technologies are gradually integrated after conducting successful pilot projects [9].

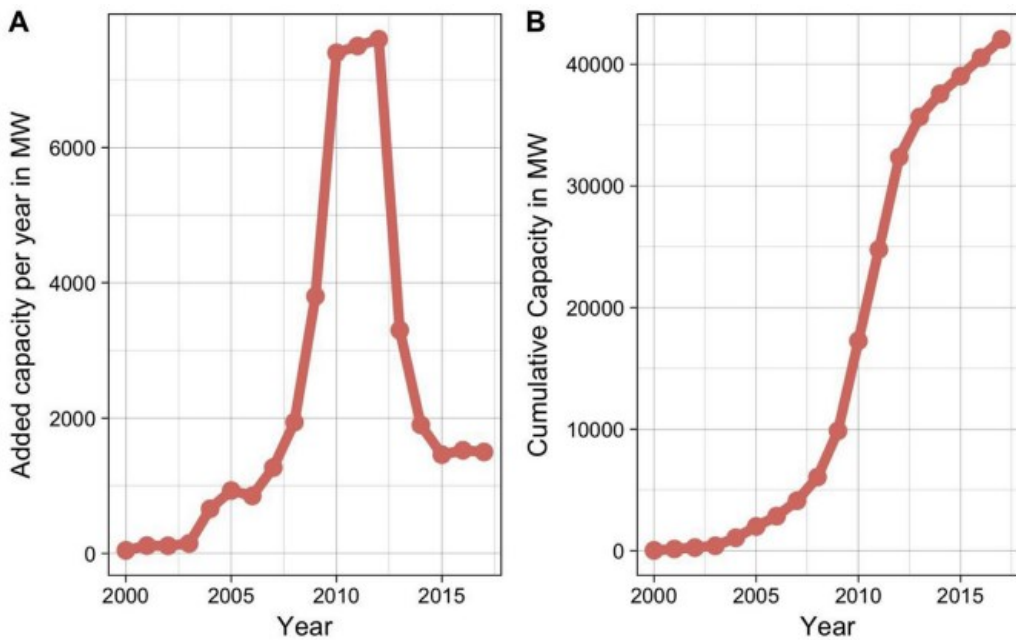


Fig. 3 Added and Cumulative PV [10]

4. CONCLUSION

This study highlighted the importance of careful planning and management in accommodating the variability of renewable energy resources to ensure a reliable and stable power supply. The inherent variability of renewable sources, influenced by factors such as weather conditions and time of day, necessitates robust grid optimization strategies. Germany's commitment to transitioning towards renewable energy sources was

emphasized and the country has witnessed significant growth in installed capacity for photovoltaics, wind energy and improvements regarding hydro power plants. The study emphasized the need for grid reconfiguration and the incorporation of additional local distribution transformers to address the surplus energy generated by photovoltaic installations. In the context of integrating variable renewable energies on a large scale, the intermittent nature of their production and their uneven geographical distribution pose challenges to the stability of the power system. As a result, there is a need for additional flexibility measures to ensure grid stability. These measures include demand response, energy storage, and the potential curtailment of variable renewable energies. However, it is important to note that these options have limitations in terms of their power and energy capacities and relying solely on them may not be sufficient to prevent congestion within the transmission grid. To optimize the integration of renewable energy, improved grid planning methods were identified as crucial, allowing for more accurate forecasts and reducing the need for unnecessary safety measures. Traditional grid expansion techniques were acknowledged, with the gradual introduction of new technologies following successful pilot projects. The German experience demonstrates the availability of various initial optimization techniques within the grid to enhance its hosting capacity. However, there are alternative measures that have been discussed in the literature but have not yet been widely implemented and this is primarily due to their current cost-effectiveness ratio, which presents challenges in justifying their adoption. In the end, this research has provided valuable insights into renewable energy integration in the grid, shedding light on the challenges, opportunities, and strategies involved. The findings contribute to the ongoing efforts to transition towards a sustainable energy future, emphasizing the importance of efficient grid management and optimized planning for the successful incorporation of renewable energy sources.

REFERENCES

- [1] DARIO PELOSI, ARIANNA BALDINELLI, GIOVANNI CINTI, DANA-ALEXANDRA CIUPAGEANU, ANDREA OTTAVIANO, FRANCESCA SANTORI, FEDERICO CARERE, LINDA BARELLI, *Battery-hydrogen vs. flywheel-battery hybrid storage systems for renewable energy integration in mini-grid: A techno-economic comparison*, In: *Journal of Energy Storage* 63 (2023) 106968, Elsevier
- [2] GIULIO RAIMONDI, GIUSEPPE SPAZZAFUMO, *Exploring Renewable Energy Communities integration through a hydrogen Power-to-Power system in Italy*, In: *Renewable Energy* 206 (2023) 710–721, Elsevier
- [3] A. WHITEMAN, T. RINKE, J. ESPARRAGO, S. ELSAYED, *Renewable capacity statistics*, IRENA 2016
- [4] BENJAMIN BAYER, ADELA MARIAN, *Innovative measures for integrating renewable energy in the German medium-voltage grids*, In: *Energy Reports* 6 (2020) 336–342, Elsevier
- [5] BJARNE STEFFEN, *Prospects for pumped-hydro storage in Germany*, In: *Energy Policy* 45 (2012)

- 420–429, Elsevier
- [6] R. ANSORENA RUIZ, L.H. DE VILDER, E.B. PRASASTI, M. AOUAD, A. DE LUCA, B. GEISSELER, K. TERHEIDEN, S. SCANU, A. MICCOLI, V. ROEBER, M. MARENCE, R. MOLL, J.D. BRICKER, N. GOSEBERG, *Low-head pumped hydro storage: A review on civil structure designs, legal and environmental aspects to make its realization feasible in seawater*, In: *Renewable and Sustainable Energy Reviews* 160 (2022) 112281, Elsevier
- [7] BUNDESMINISTERIUM FÜR WIRTSCHAFT UND KLIMASCHUTZ, <https://www.erneuerbare-energien.de/EE/Navigation/DE/Technologien/technologien.html>, *Informationsportal Erneubare Energien*
- [8] THERESA KIUNKE, NATALIA GEMIGNANI, PEDRO MALHEIRO, THOMAS BRUDERMANN, *Key factors influencing onshore wind energy development: A case study from the German North Sea region*, In: *Energy Policy* 165 (2022) 112962, Elsevier
- [9] BENJAMIN BAYER, PATRICK MATSCHOSS, HEIKO THOMAS, ADELA MARIAN, *The German experience with integrating photovoltaic systems into the low-voltage grids*, In: *Renewable Energy* 119 (2018) 129-141, Elsevier
- [10] LUCIA BAUR, MAURICIO URIONA M., *Diffusion of photovoltaic technology in Germany: A sustainable success or an illusion driven by guaranteed feed-in tariffs?*, In: *Energy* 150 (2018) 289-298, Elsevier

Key words: Geographical Solar Potentiality, Solar Home System, Solar Street Light, Solar Park, Solar Charging Station, Solar Irrigation, Obstacles of Solar Energy overcome of these obstacles, comparison

Md Shahadat HOSEN ¹

OVERVIEW OF SOLAR ENERGY IN BANGLADESH

For any country, socio-economic development depends on having a secure, affordable and reliable energy supply that is low cost. Bangladesh is a developing country that has been struggling with energy crisis for a long time. Now Bangladesh is trying to shift to renewable energy sources from its traditional fossil fuel sources. By 2030, the government of Bangladesh aims to generate 20 percent of its total energy from renewable sources. Solar energy is the most abundant renewable source in Bangladesh [1]. Bangladesh is blessed with solar energy potential. This research paper explores the current situation of solar energy, the existing solar energy technologies, the possible solutions to the challenges faced by the government of Bangladesh in producing solar energy, and the comparison of solar energy production with developed countries.

1. INTRODUCTION

Modern civilization relies heavily on energy as a vital tool for its survival. Most people around the world use fossil fuels such as oil, coal and natural gas to meet their energy needs. However, these fuels are not renewable and will run out sooner or later. Therefore, it is urgent to find alternative sources of energy. Bangladesh is a developing country that faces a growing demand for energy in various sectors. However, its natural gas reserves are very limited. Petro-Bangla (Nov 17,2017) reported that the remaining gas reserve is about 13 trillion cubic feet, which will be depleted in 10-12 years [2]. Among the renewable energy sources, solar energy has more potential than wind energy, biomass energy and hydropower energy in Bangladesh. According to the current status, the total installed capacity of renewable energy is 1171.29 MW, of which 937.3 MW come from solar energy [3].

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Renewable Energy Installed Capacity: **1171.29 MW**

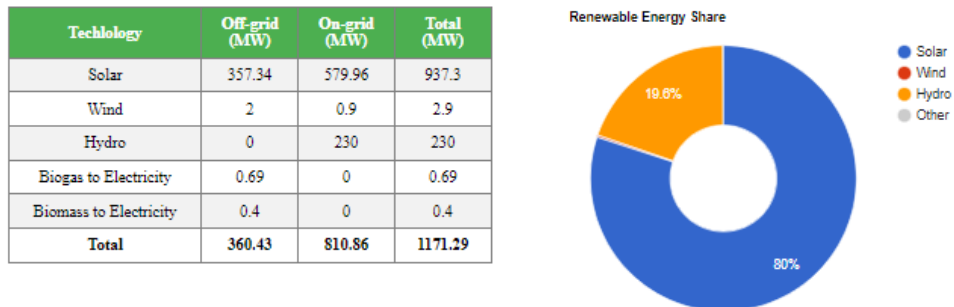


Fig. 1. Present RE energy status in Bangladesh [3]

Bangladesh government has taken many steps to improve solar energy in Bangladesh. These project can be classified in two ways a) Small projects b) Solar large projects. Solar park, Rooftop solar except NEM, Net Metering Rooftop Solar, Solar Irrigation, Solar Micro grid, Solar Nano grid, Solar Charging Station, Solar Drinking water project are including of large project and Solar Home System, Solar Street Light and Solar Water Heater are including of small projects [3].

2. GEOGRAPHICAL OPPORTUNITIES OF SOLAR ENERGY IN BANGLADESH

Geographically Bangladesh has high potentiality for Solar Energy. Geographically Bangladesh is located in between 20.30° and 20.38° north latitude. This is a good location having a total area $149E+11$ m² these decent over the land for approximately 300 days per year. March to April is the best time for maximum solar radiation and December to January occurs minimum solar radiation. Average 7 to 10 hours are daily sunlight hours in Bangladesh. Sometimes due to cloud, rainfall and fog may reduce approximately 54% of sunlight. So, these big amount of solar energy has a high potential which can be used to meet the energy demand in Bangladesh [4].

3. SOLAR ENERGY GENERATION PROJECTS IN BANGLADESH

Bangladesh has different types of solar energy projects. We can have classified them as a) Solar small projects and b) Solar large projects [3].

3.1 SOLAR SMALL PROJECTS IN BANGLADESH

Solar Home System, Solar Street Light and Solar Water Heater are considered as

Small Solar projects in Bangladesh [3]. These small solar projects are also off-grid solar projects in Bangladesh. Bangladesh has the largest off-grid solar power program in the world, which offers experiences and lessons for other countries to expand access to clean and affordable electricity. By harnessing solar power, the program enabled 20 million (12%) Bangladeshis to access electricity [5].

3.1.1 SOLAR HOME SYSTEM IN BANGLADESH

Solar home systems (SHS) have played a transformative role in Bangladesh's rural electrification. These off-grid solar solutions provide clean and reliable electricity to households, particularly in remote areas where grid connectivity is limited. SHS in Bangladesh typically consist of a solar panel, battery, and inverter, enabling households to power lights, fans, mobile charging, and small appliances. This decentralized approach has significantly improved energy access and contributed to sustainable development in rural communities.

3.1.1.1 INITIATIVE OF SOLAR HOME SYSTEM IN BANGLADESH

The solar home system (SHS) initiative launched in January 2003 and was facilitated by the government own Development Company Limited (IDCOL). The goal was to “fulfil basic electricity requirement of the off-grid rural people of Bangladesh [5].

IDCOL was set up in 1997 to finance the development of medium- large-scale infrastructure and renewable energy project in Bangladesh. By June 2003, IDCOL’s international partner, such as the world bank and International Development Association (IDA) had joined forces to support the SHS initiative via the first Rural Electrification and Renewable Energy Development Project (RERED). Initial funding from world bank was extended several times over the years via RERED [5].

The implementation of the Solar Home System (SHS) project in Bangladesh in Bangladesh involves partnering with selected local organizations, who serve as the primary promoters of the initiative. These partner organizations (POs) are responsible for identifying private customers, providing loans, installing the solar home systems as well as ensuring after sales services. Meanwhile, the infrastructure Development Company Limited (IDCOL) provides grants and soft loans to support the project implementation

and offer technical assistance. The POs offer soft loans to financially disadvantaged families in Bangladesh to install SHS in their homes, with a low down payment for a period of three years. Through these approach, the SHS project has successfully expanded access to electricity in rural and remote areas, improving the quality of life for millions of people while promoting sustainable and clean energy.

3.1.1.2 DEVELOPMENT OF BANGLADESH SOLAR HOME SYSTEM

Bangladesh is a riverine country. It is almost impossible to connect the grid system to the riverside houses in Bangladesh. Solar home system is the most popular system in remote and hard to reach area in Bangladesh. Bangladesh government has successfully implemented affordable off- grid solar energy solutions through a public private partnership. Bangladesh has the largest off-grid solar power program in Bangladesh, which offers experiences and lessons for others countries to expand access to clean and affordable electricity. By Harnessing solar power, the program enabled more than 20 million Bangladeshis to access electricity [5]. Now Bangladesh has installed 356.86 MW off-grid electricity among them 263.59 MW comes from solar home system. Almost 6037689 home system are installed in Bangladesh [3].

Solar Home System | Number of System: 6037689

All Organization		All Sub-Organization/Office/Program		Search
SL.	Technology Name	Number	Capacity	Agency
1	Solar Home System	15250	0.83 MWp	BREE
2	Solar Home System	97	0.104 MWp	PGCB
3	Solar Home System	13952	0.907 MWp	NESCO
4	Solar Home System	4494162	187.12 MWp	IDCOL
5	Solar Home System	400	0.2 MWp	GIZ
6	Solar Home System	1513619	71.25 MWp	McDMR
7	Solar Home System	1	0.02 MWp	B-R PowerGen
8	Solar Home System	200	3.15 MWp	RDGD
9	Solar Home System	1	0.003 MWp	BRRI
10	Solar Home System	7	0.009 MWp	BARI

Fig.2. Present Solar Home System status in Bangladesh [3]

3.1.1.2 SOLAR STREET LIGHT PROJECT IN BANGLADESH

Solar street lights are being used as an alternative to conventional street lighting in Bangladesh. The country has made significant progress in adopting solar street lights in urban areas, which helps to reduce energy consumption and reliance on non-renewable energy sources. Now in Bangladesh has almost 297691 street light off-grid system and produce 17.10 mw electricity [3].

Solar Street Light | Number of System: 297691

All Organization		All Sub-Organization/Office/Program		Search
SL.	Technology Name	Number	Capacity	Agency
1	Solar Street Light	800	0.36 MWp	BPDB
2	Solar Street Light	830	0.038 MWp	NESCO
3	Solar Street Light	263	0.005 MWp	MoCHTA
4	Solar Street Light	295798	16.7 MWp	MoDMR

Fig.3. Present Solar Street Light projects status in Bangladesh [3]

3.2 LARGE SOLAR PROJECTS IN BANGLADESH

Including large-scale solar projects, solar parks, rooftop solar systems (excluding NEM), net metering rooftop solar, solar irrigation, solar micro grids, solar Nano grids, solar charging stations, and solar drinking water projects are among the various solar energy initiatives in place [3].

3.2.1 SOLAR PARK

Bangladesh is actively seeking to harness solar energy to address its increasing energy needs. To this end, the country has initiated various projects, including the establishment of solar parks. Currently, there are ten solar parks operating in Bangladesh, generating a total of approximately 453.4 MW of electricity that is being supplied to the national grid. Moreover, seven additional solar parks are currently under construction, with a combined capacity of 351.49 MW [3], expected to be completed within the next

3-4 years. The country has also planned for 31 more solar parks with a total capacity of 1600 MW within 2030, that are currently in the planning stages. These solar park projects are parts of Bangladeshi's broader goal to generate 10% of its electricity from renewable energy sources by 2021 and to generated 20% of its electricity from renewable sources by 2030 [1].

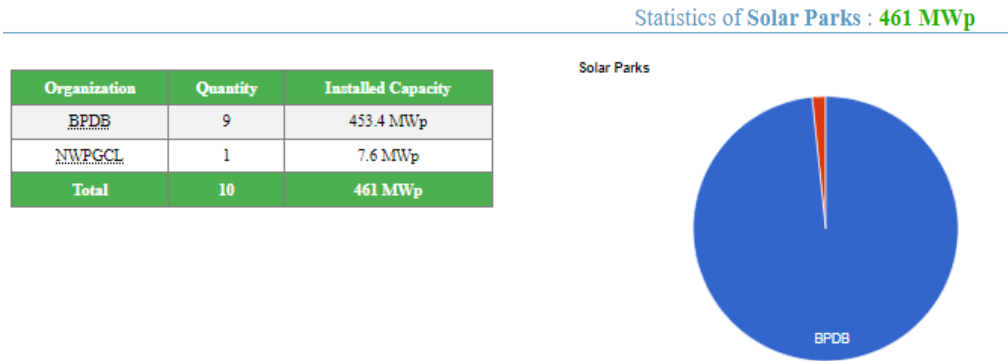


Fig.3. Present Solar Park projects status in Bangladesh [3]

3.2.2 SOLAR IRRIGATION IN BANGLADESH

Bangladesh is a country that relies heavily on agriculture for its food security and economic development. However, irrigation is a major challenge for farmers, especially in the dry season, when groundwater levels are low and diesel pumps are expensive and polluting. To address this challenge, the government of Bangladesh, with the support of various partners, has initiated a solar irrigation project that aims to promote the use of solar-powered irrigation pumps (SIPs) as a clean, renewable and cost-effective alternative to diesel pumps.

The solar irrigation project has several benefits for farmers, the environment and the society. SIPs can reduce greenhouse gas emissions, save foreign exchange on diesel imports, improve water management practices, increase crop yields and incomes, and create employment opportunities. SIPs can also enhance the resilience of farmers to climate change impacts, such as droughts and floods, by providing reliable and timely irrigation.

The solar irrigation project started in 2010 under the initiative of Infrastructure Development Company Limited (IDCOL), a government-owned financial institution. In Bangladesh, the majority of irrigation pumps, approximately 1.34 million or 83%, are currently powered by diesel, while around 0.27 million pumps (16%) rely on grid electricity [6]. These pumps collectively consume a significant amount of resources, utilizing approximately 900 million liters of diesel and 700 MW of electricity per year. However, the installation of solar irrigation pumps presents an effective solution to reduce dependence on fossil fuels and grid electricity. Recognizing this potential, the Infrastructure Development Company Limited (IDCOL) has set a target to install 50,000 solar irrigation pumps by 2025. As of October 2019, IDCOL has successfully installed 1,630 solar irrigation pumps, with 1,323 pumps already operational, boasting a capacity of 32 MW. The remaining pumps are expected to become operational in the near future, further contributing to the transition towards sustainable and renewable energy sources in the agricultural sector. Following table is the solar irrigation present status.

Statistics of Solar Irrigation Pumps : 51.45 MWp

Organization	Quantity	Installed Capacity
IDCOL	1523	42.08 MWp
BMDA	792	4.37 MWp
BADC	197	2.55 MWp
BREE	220	1.98 MWp
RDA	25	292.08 kWp
BARD	9	99 kWp
BARI	37	51 kWp
BRRJ	9	25.68 kWp
Total	2812	51.45 MWp

Solar Irrigation Pumps

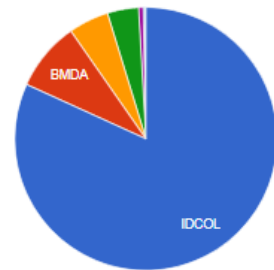


Fig.4. Present Solar Irrigation projects status in Bangladesh [3]

The solar irrigation project is an example of how solar energy can revolutionize irrigation in Bangladesh and contribute to sustainable agricultural development. The project has received positive feedback from farmers and stakeholders, who have reported improved water availability, reduced costs, increased profits, and better environmental conditions. The project also has potential for scaling up and replication in other regions and countries with similar challenges and opportunities.

3.2.3 NET METERING ROOFTOP SOLAR SYSTEM IN BANGLADESH

Solar net metering system is a mechanism that allows customers to generate electricity from solar panels installed on their rooftops and feed the excess electricity to the grid. This way, they can reduce their electricity bills and contribute to the national renewable energy target. Bangladesh has introduced the net metering guideline in 2018 and amended it in 2019 to promote rooftop solar systems. According to the Bangladesh Electricity Department, the net metering system has already increased the solar electricity generation by 67.231 MW, with 1837 clients connected to the grid system [3].

Statistics of Installed Net Metering System: 1837

Utility Name	Installed Capacity	Quantity
BPDB	16.296 MW _p	390
BREB	42.247 MW _p	349
DPDC	3.057 MW _p	322
DESCO	2.611 MW _p	418
WZPDCL	1.258 MW _p	285
NESCO	1.763 MW _p	73
TOTAL	67.231 MW _p	1837

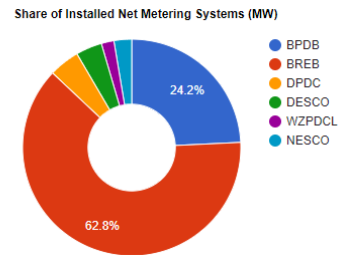


Fig.5. Present Solar Irrigation projects status in Bangladesh [3]

The net metering system has several benefits, such as reducing transmission and distribution losses, enhancing grid stability, creating green jobs, and saving fossil fuels. However, there are also some challenges, such as technical standards, metering and billing issues, grid integration, and awareness among customers. To overcome these challenges, the government and other stakeholders need to work together to provide proper instrumental support, financial incentives, capacity building, and public awareness for the net metering

3.2.4 SOLAR CHARGING STATION IN BANGLADESH

One of the applications of solar energy is to power electric vehicles, such as easy bikes and auto-rickshaws, which are popular modes of transport in Bangladesh. Solar charging stations (SCS) are facilities that use solar panels to generate electricity and store it in batteries for charging electric vehicles. Several SCS have been installed in different locations in Bangladesh, such as Keranigonj, Chittagong and Sylhet, with capacities ranging from 20 kW to 21 kW [3]. These SCS can charge 20-22 electric vehicles at a time and reduce the dependence on fossil fuels and grid electricity [7]. SCS are also being designed for electric cars, which are expected to increase in demand in the future. Following table is the solar charging station present status.

Statistics of Solar Charging Station : 0.28 MWp

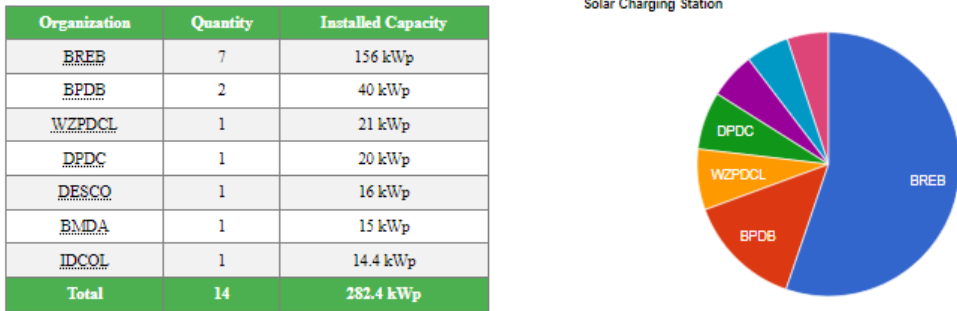


Fig.6. Present Solar Charging Station status in Bangladesh [3]

4. OBSTACLES OF SOLAR ENERGY IN BANGLADESH

There is not enough information about the viability, risk, and return of solar projects for private investors. The credit ratings for such projects are also low compared to other countries. Bangladesh has a high population density and a scarcity of land for large-scale solar projects. The land acquisition process is also complex and time-consuming. Bangladesh does not have a clear and consistent policy framework for promoting solar energy. The regulatory and institutional arrangements are also weak and fragmented. There is a lack of coordination among different ministries, agencies, and stakeholders. Education, training, and research: Bangladesh lacks skilled manpower and technical expertise for developing and maintaining solar systems. There is also a need for more education, training, and research on solar energy to improve its efficiency and affordability.

5. OVERCOME THE OBOSTACLES OF SOLAR ENERGY IN BANGLADEAH

To overcome obstacles to solar energy adoption in Bangladesh, several measures can be implemented. Here are some solutions- The government can offer financial incentives, tax breaks, and subsidies for solar energy installations. They can also establish favorable policies and regulations that encourage renewable energy development. The government and private sector can invest in building solar infrastructure, including solar

parks, rooftop solar installations, and mini-grids. This would enhance the availability and accessibility of solar energy. Educating the public about the benefits of solar energy and raising awareness of its potential can help overcome misconceptions and resistance. This can be done through campaigns, workshops, and educational programs. Providing accessible financing options such as low-interest loans or installment plans can make solar energy systems more affordable for households and businesses. Encouraging collaboration between government agencies, private sector entities, non-governmental organizations (NGOs), and international organizations can leverage expertise, resources, and funding to accelerate solar energy adoption.

6. COMPARISON OF SOLAR ENERGY GENERATION BETWEEN BANGLADESH AND GERMANY

Solar energy is a crucial renewable energy source that is adopted differently across countries due to various geographical, economical, and technical factors. Now, I will compare the geographical, economical, and technical aspects of solar energy generation in Bangladesh and Germany.

6.1 GEOGRAPHICAL

Bangladesh, located near the equator, enjoys a higher solar irradiance level throughout the year, making it an ideal location for solar energy generation [1]. In contrast, Germany, situated at higher latitudes, receives lower solar irradiance [10]. However, Germany has been able to overcome this limitation through advanced solar technologies and efficient systems, allowing it to become a global leader in solar energy generation.

6.2 ECONOMICAL

Germany has made significant investments in solar energy, resulting in a mature and highly competitive solar industry. The country has implemented favorable policies, feed-in tariffs, and subsidies that have encouraged widespread adoption of solar energy [5,11]. In Bangladesh, although solar energy has gained traction, economic challenges such as high upfront costs and limited financing options hinder its broader

implementation. However, the declining costs of solar technologies globally present opportunities for cost-effective solar energy solutions in both countries.

6.3 TECHNICAL

Germany possesses advanced technical expertise in solar energy, along with a well-established grid infrastructure that facilitates efficient integration and distribution of solar power. The country has implemented smart grid systems and net-metering policies, enabling seamless integration of solar energy into the national grid [11]. Bangladesh faces challenges in terms of grid infrastructure, particularly in rural areas. However, the decentralized approach, including off-grid solar solutions such as home systems and mini-grids, has been successful in providing electricity to remote areas.

7. CONCLUSION

Solar energy generation in Bangladesh has witnessed significant growth and has the potential to play a vital role in the country's energy transition. Government policies, initiatives, and the success of the SHS program have contributed to expanding electricity access and reducing carbon emissions. The Bangladeshi government, in collaboration with organizations such as IDCOL (Infrastructure Development Company Limited) and BPDP (Bangladesh Power Development Board), has initiated several initiatives to harness solar energy for electricity generation. Through these efforts, over 6.3 million solar home systems (SHSs) with a combined capacity of 263.59 MW have been installed by IDCOL and various private organizations. Additionally, BPDP has taken significant strides in establishing solar parks and solar PV power plants. Furthermore, multiple research teams from different universities and research organizations are actively engaged in enhancing existing renewable technologies, supported by the financing scheme provided by IDCOL. These collective endeavors highlight the government's commitment to expanding the utilization of solar radiation as a sustainable energy source in Bangladesh. Overcoming challenges such as financing, grid infrastructure, and technical capacity will be essential for the sustained growth of solar energy generation in Bangladesh. With continued commitment and strategic investments, solar energy can contribute significantly to the country's sustainable development goals.

REFERENCES

- [1] S. ADNAN, Hajee Mohammad Danesh Science and Technology university, Prospect and utilization of Solar Energy in Bangladesh, https://www.academia.edu/43388088/Prospects_and_Utilization_of_Solar_Energy_in_Bangladesh
- [2] Prospect of Gas Reserves in Bangladesh | 2017-11-17. Available at <https://www.daily-sun.com>.
- [3] SREDA, National Database of Renewable Energy | 2023-05-30. Available at <http://www.renewableenergy.gov.bd>
- [4] Rahamat Ullah Tanvir, Muhammad Rubayat Bin Shahadat, ManojGhosh, Mohammed Khan,” Prospects and Utilization of RenewableEnergy in Bangladesh: A Review Article.” International Journal ofScientific & Engineering Research, Volume 8, Issue 4, April-2017
- [5] Center for public impact, The Solar Home System in Bangladesh, <https://www.centreforpublicimpact.org/case-study/solar-home-systems-bangladesh>
- [6] Sazzad Hossain, Mohammad Maksudur Rahman (2021) Solar Energy Prospects in Bangladesh: Target and Current Status. Energy and Power Engineering 13(08):322-332. https://www.researchgate.net/publication/353844520_Solar_Energy_Prospects_in_Bangladesh_Target_and_Current_Status
- [7] The Dhaka Turbine, First Solar Powered Easy Bike Charging Station opens Today | 2016-01-2021 Available at: <https://archive.dhakatribune.com/uncategorized/2016/01/21/first-solar-powered-easy-bike-charging-station-opens-today>
- [8] Bangladesh Power Development Board(BPDB), Government of Bangladesh, <https://www.adb.org/sites/default/files/project-documents/37113-013-ban-rpab-03.pdf>
- [9] Renewable Energy Act (EEG), <https://wiki.energytransition.org/the-book/policies-for-clean-energy/renewable-energy-act-eeeg/>
- [10] Solar power in Germany- output, business and perspectives, <https://www.cleanenergywire.org/factsheets/solar-power-germany-output-business-perspectives>
- [11] Federal Ministry for Economic Affairs and climate-Action,https://www.bmwk.de/Redaktion/EN/Textsammlungen/Energy/funding-for-the-expansion-of-renewable-energy-sources.html?cms_artId=8f87b95f-b53a-4a05-9a83-2fd5258fd031

Abhishek ADHIKARI ¹

GREEN HYDROGEN: THE FUTURE ENERGY

The transition to a sustainable and decarbonized energy system is an urgent global priority, and green hydrogen has emerged as a potential solution. We explore the concept of green hydrogen as a critical element for a cleaner and more sustainable energy landscape of the future. Green hydrogen refers to hydrogen produced through electrolysis using renewable energy sources such as solar and wind. By using renewable energy to produce hydrogen, the process becomes carbon-free, helping to reduce greenhouse gas emissions. This summary highlights the potential of green hydrogen as an energy carrier and discusses its application in various sectors such as transportation, industry, and power generation. It also addresses the challenges associated with scaling up green hydrogen production, such as cost, infrastructure development, and technological advancement.

1. INTRODUCTION

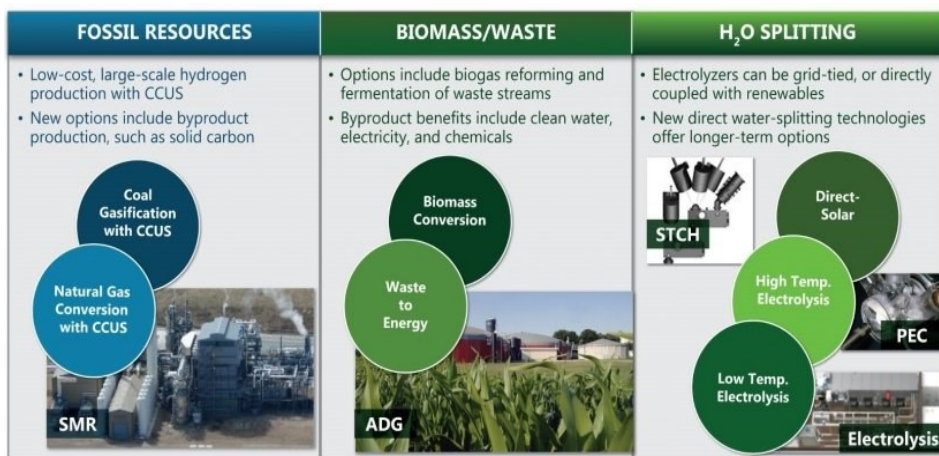
The simplest element on earth is hydrogen. It consists of only one proton and one electron and is an energy carrier, not an energy source. It contains a lot of energy, more than natural gas or fossil oil by mass. It is a clean, flexible energy carrier and is always combined with other elements. Hydrogen can be produced in a variety of ways. One method of producing this carbon-free fuel is by splitting water into hydrogen and oxygen using renewable resources. This is known as green hydrogen.

The urgency to tackle climate change and reduce greenhouse gas emissions has fueled the global search for sustainable and carbon-free energy solutions. In this quest, green hydrogen has emerged as a frontrunner and holds immense potential to revolutionize the energy landscape. Green hydrogen refers to hydrogen produced by electrolysis and

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fueled by renewable energy sources such as solar and wind. Unlike conventional hydrogen production methods that rely on fossil fuels, green hydrogen production is carbon-free, making it a critical pillar for a clean and sustainable future energy system. This introduction provides the basis for discussing the concept of green hydrogen and its transformative role in shaping the energy sector.

Hydrogen is a versatile energy carrier that can help address several critical energy problems. Hydrogen can be produced from almost any energy resource. However, the current use of hydrogen in oil refining and chemical production is largely met by hydrogen from fossil fuels, which is associated with significant CO₂ emissions.



(Fig.1): - The Pathway of H₂ production [7]

*CCUS: carbon capture, utilization, and storage; *SMR: steam methane reforming; *ADG: anaerobic digester gas; *STCH: solar thermochemical hydrogen; *PEC: photoelectrochemical

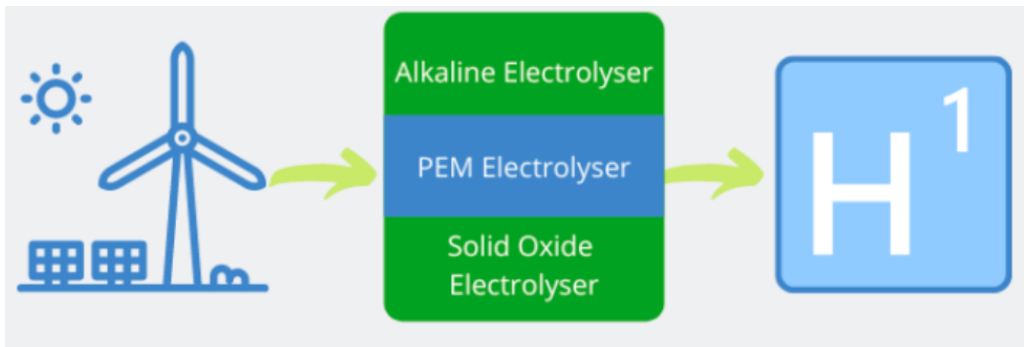
2.HYDROGEN PRODUCTION

Hydrogen can be produced through low-carbon pathways using diverse, domestic resources, including fossil fuels, such as natural gas and coal, coupled with carbon capture and storage, through splitting of water using nuclear energy and renewable energy sources, such as wind, solar, geothermal, and hydro-electric power and from biomass through biological processes (Fig.1) The pathway of H₂ production can be roughly divided into several processes. This path of H₂ (Fig.1) shows that there are different types of H₂, for example blue H₂ and green H₂. Blue hydrogen is produced from natural gas, where the emissions are captured using carbon capture and storage.

The primary demand for hydrogen today is for petroleum refining and ammonia production. However, hydrogen can be used across multiple sectors to enable zero or near-zero emissions in other chemical and industrial processes, integrated clean energy systems, and transportation. Emerging hydrogen markets within these sectors include data centers, ports, steel manufacturing, and medium- and heavy-duty trucks.

2.1. H₂ PRODUCTION THROUGH ELEKTROLYSIS

Electrolysis is a most promising option for green hydrogen production from renewable resources. Electrolysis is the process of splitting water into hydrogen and oxygen using electricity. This reaction takes place in a device called an electrolyzer. Electrolyzers range in size from small, appliance-sized devices that are well suited for small-scale distributed hydrogen production to large, more centralized production facilities that could be directly connected to renewable energy or other forms of electricity generation without greenhouse gas emissions. The Fig.1a illustrates that there are three types of water electrolysis technologies.



(Fig.1a): Water electrolysis processes [10]

Alkaline Electrolyser

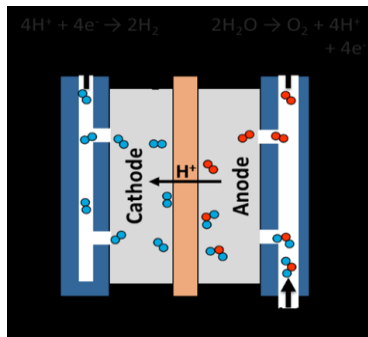
Alkaline water electrolysis is one of the simplest methods of hydrogen production, although it is a relatively expensive technology. This technology is very clean and produces hydrogen gas with a purity of over 99.989%.[10] Proton Electrolyte Membrane Electrolysers.

Solid Oxide Electrolyser (SOE)

SOE is the least developed electrolysis technology. It is not yet widely commercialized, but lab-scale systems have been developed and demonstrated, and individual companies are currently trying to bring this technology to market.

Proton Elektrolyte Membrane Electrolyzers

- Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons).



(Fig .2): - Diagram of (PEM) electrolysis reactions [8]

Proton exchange membrane (PEM) electrolyzers are a promising technology for hydrogen production, especially for applications requiring high purity hydrogen. PEM electrolyzers use a solid polymer electrolyte membrane to separate the anode and cathode chambers and produce hydrogen and oxygen through the electrochemical reaction of water.

- Anode Reaction: $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$ (1)
- Cathode Reaction: $4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2$ (2)

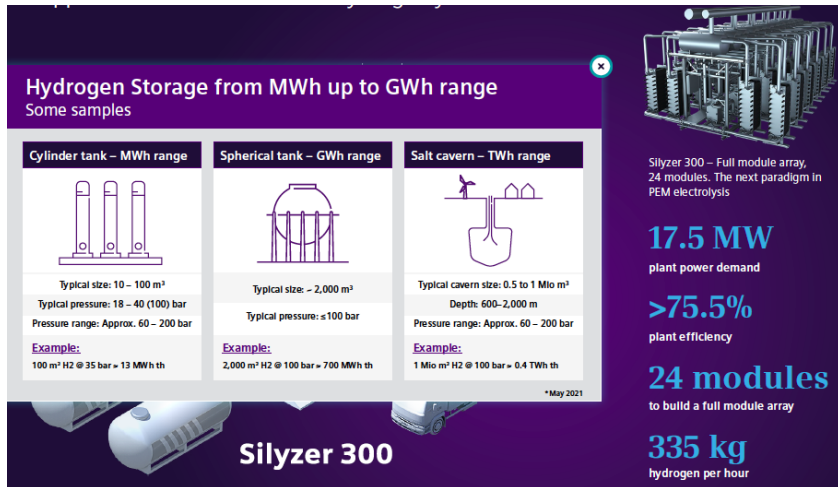
The latest generation of PEM electrolyzers can achieve up to 80% efficiency, which is higher than other electrolyzer technologies such as alkaline electrolyzers. The efficiency of PEM electrolyzers is largely due to the low cell voltage required for operation, which reduces the energy required for hydrogen production.

In addition, PEM electrolyzers have a fast response time, allowing them to ramp up or ramp down production quickly as demand changes or renewable energy sources such as wind or solar power become available. This flexibility makes PEM electrolyzers suitable for integration with renewable energy sources to produce green hydrogen.

3. TECHNOLOGY OF SIEMENS FOR H₂ PRODUCTIONS

There are many other technologies that can be made for H₂. Because PEM electrolysis technology and its best-known representative, the Silyzer, are relatively young technologies, further improvements in efficiency and a reduction in investment costs can be expected. Significant increases in production capacities over the next ten years will also lead to further progress and savings. Having successfully launched the Silyzer 300, the next step will be a PEM model in the 100+ megawatt range.

Silyzer 300: - Large industrial application Silyzer 300 is the latest and the most powerful product line in the double-digit megawatt class in Siemens' PEM electrolysis portfolio. The next paradigm in PEM electrolysis



(Fig.3): - Performance of Silyzer 300 [4]

- Fast start-up and shutdown
- High Gas purity
- No hazardous chemicals
- Power factor compensation (optional)
- No permanent operating personnel required

Advanced control systems can optimize electrolyzer operation for maximum efficiency. The Silyzer 300 uses an advanced control system that monitors and adjusts operating parameters in real time to ensure optimal efficiency.

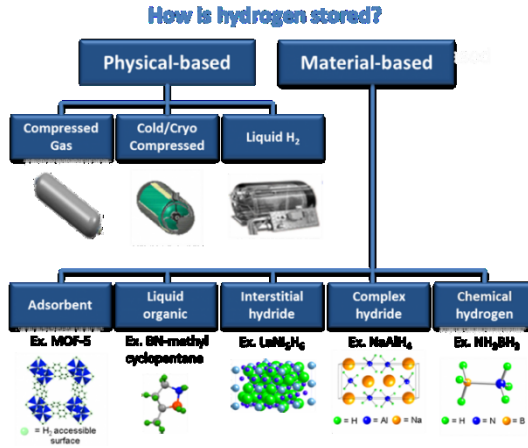
4.H₂ ENERGY STORAGE

Hydrogen as a core energy carrier will play an important role in achieving net-zero CO₂ emissions in the future for those sectors in industry, mobility and energy that cannot be decarbonized through electrification.

Strategic chemical energy storage (Fig.4) in the form of hydrogen (gaseous or liquid) has the potential to store energy over long periods of time and can be scaled up without

site constraints. It can be used as an energy carrier, stored and delivered to where it is needed. There is no high self-discharge or power degradation with the storage system.

Among all fuels, hydrogen has the highest energy per mass, but its low density at ambient temperature results in low energy per unit volume.

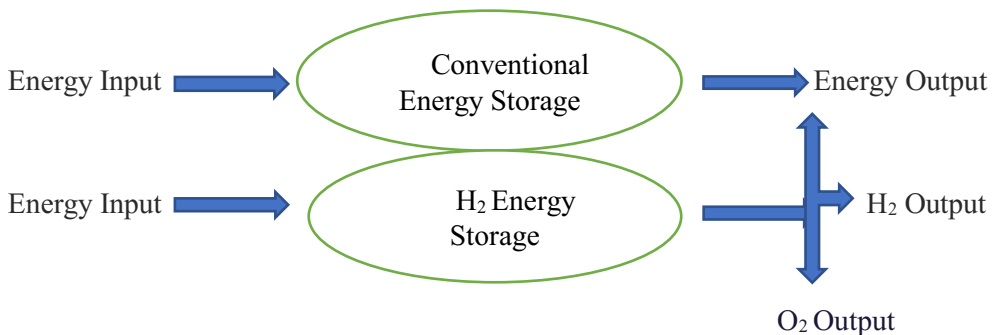


(Fig.4): - Storage of H₂ on a physical and chemical basis [11]

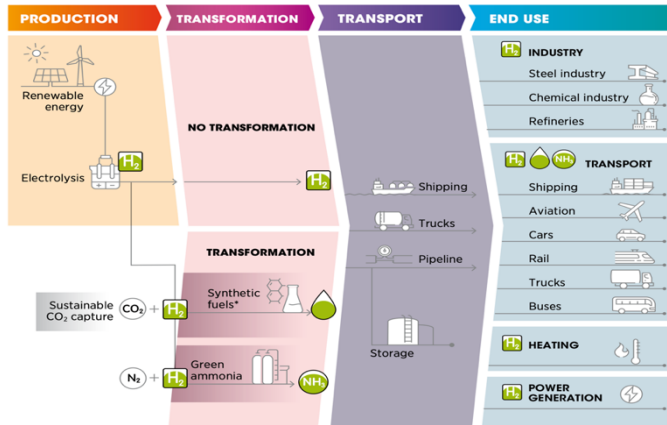
“The first Energy Earth shot, launched June 7, 2021: -Hydrogen Shot seeks to reduce the cost of clean hydrogen by 80% to **\$1 per 1 kilogram in 1 decade** ("1 1 1").”

5. COMP. BETWEEN TWO EST AND HEST

In general, energy storage technologies are compared in terms of their lifetime, efficiency, energy density, power density and technological maturity.



(Fig .5): - A simple diagram to distinguish between two storage concepts.

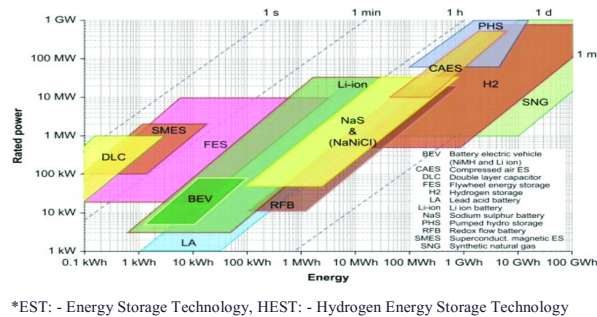


(Fig 6).: - Comparison of different energy storage technologies in terms of rated power, storable energy and discharge time.[3]

Fig.6 shows that the choice of energy storage technology depends on the application and performance requirements. Lithium-ion batteries are well suited for applications that require high power and relatively short discharge times. Pumped storage power plants are better suited for applications that require high power and longer discharge times. Flywheel energy storage is better suited for applications that require high power and short discharge times. Thermal energy storage is better suited for applications that require lower power and longer discharge times. The storable energy of each technology should also be considered when selecting the appropriate technology for a particular application.

6.APPLICATIONS OF GREEN H₂

Although hydrogen is often referred to as the environmentally friendly fuel of the future, especially for use in fuel cell electric vehicles, hydrogen can be used for much more than zero-emission cars. From increasing the flexibility of the power grid to greening agriculture, hydrogen could play an important role in a clean and resilient energy system.



(Fig.7): production, conversion and end use of green hydrogen throughout the energy system image
*IRENA [2]

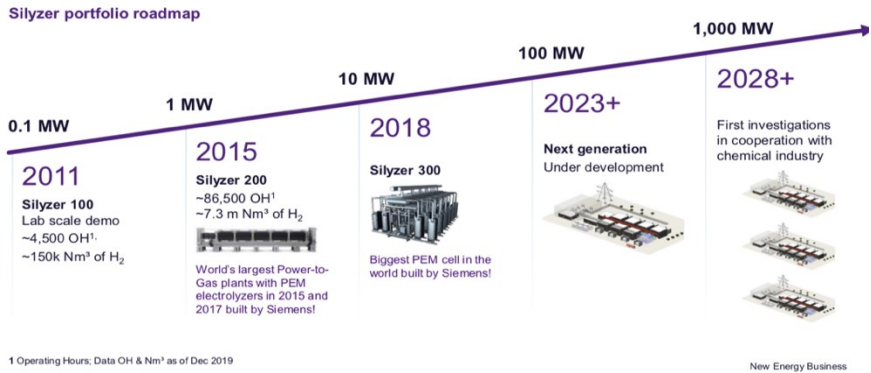
Fig. 7. illustrate its versatility and that green hydrogen can be used in different sectors. It plays a key role in the global energy transition, contributing to the diversification of energy sources worldwide and driving economic and technological innovation. Its exceptional properties make it a powerful enabler for the energy transition, benefiting both the energy system and end-use applications such as chemicals, transportation and heat generation. In energy-intensive industries such as steel production, it can directly replace gray hydrogen and other substances.

7. FUTURE PLAN OF SIEMENS (H₂)

Siemens commissions one of the largest green hydrogen production plants in Germany.

At the Wunsiedel Energy Park, up to 1,350 tons of green hydrogen can now be produced annually from renewable solar and wind power. The hydrogen is produced using an electrolyzer - with a total output of 8.75 megawatts - from Siemens Energy's latest and most powerful product line. The "Silyzer 300" is based on proton exchange membrane (PEM) technology, which is ideally suited for operation with renewable energies. The hydrogen will be used primarily in the region's industrial and commercial enterprises, but also in road transport. With this amount of hydrogen, 400 hydrogen-powered 40-ton trucks - with a regional range of 150 kilometers per day - could drive for an entire year without emitting CO₂. By using the hydrogen produced in Wunsiedel and thus replacing fossil fuels, annual CO₂ emissions can be reduced by up to 13,500

tons.




(Fig.8): - Silyzer Portfolio roadmap for H₂ Productions [5]

The roadmap begins with intensive research and development efforts to improve the performance and efficiency of Silyzer technologies. This includes further development of catalyst materials; optimization of system designs and improvement of overall process economics.

7.1 H2 FUTURE PROJECT

H2FUTURE is a European flagship project for the production of green hydrogen from electricity generated from renewable energy sources. With the coordination of the energy supplier VERBUND, the steel manufacturer VOESTALPINE and SIEMENS ENERGY, a manufacturer of Proton Exchange Membrane electrolyzers (PEM electrolyzers), a large-scale 6 MW (PEM) electrolysis plant is being installed and operated at the VOESTALPINE linz steelworks in Austria. Fig.9 shows the projects, their challenges, use cases and their solutions.[12]



H₂FUTURE
A European Flagship project for generation and use of green hydrogen

SIEMENS ENERGY

Project

- Partner: VERBUND (coordination), voestalpine, Austrian Power Grid (APG), TNO, K1-MET
- Country: Austria
- Installed: 2019
- Product: Silyzer 300

Use cases

- Hydrogen for the steel making process
- Supply grid services

Challenge

- Potential for "breakthrough" steelmaking technologies which replace carbon by green hydrogen as basis for further upscaling to industrial dimensions
- Installation and integration into an existing coke oven gas pipeline at the steel plant
- High electrolysis system efficiency of 80%



Solutions

- Operation of a 12-module array Silyzer 300
- Highly dynamic power consumption – enabling grid services
- State-of-the-art process control technology based on SIMATIC PCS 7

6 MW
Power demand based on Silyzer 300

1,200 Nm³
of green hydrogen per hour

2021-03-19

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735503. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovative programme and Hydrogen Europe and NERGHY

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(Fig.9): Project H₂FUTURE [5]

8. CONCLUSION

Hydrogen energy is considered to be the future of energy. There is an urgent need for global decarbonization of all energy systems to mitigate global warming. Renewable energies will play a pivotal role in providing a green energy supply through sector coupling.

Europe has alternative sources of gas for power generation, such as nuclear power plants. However, certain disasters have prompted Europe to reconsider the use of nuclear power plants for electricity generation. Let's take Germany as an example. In 2021, nuclear power generated by six power plants accounted for 13.3% of Germany's electricity supply. However, by the end of 2021, three power plants will be shut down, and the remaining three are scheduled for decommissioning by the end of 2022, in accordance with the 2011 nuclear phase-out plan. In fact, one of the plants has already been shut down as of mid-April 2023. While nuclear power is a viable option, it carries the risk of major disasters like Chernobyl and Fukushima. Therefore, the energy sector needs to explore alternative options and innovative trends to address this crisis and improve energy storage. The energy storage in hydrogen is a technically credible option

for grid-wide storage and is already being tested in pilot projects. Because of its low efficiency, it may be overlooked despite its potential advantages such as high energy density and low self-discharge.

The Siemens Company has numerous future projects. For instance, their Silyzer 300 is considered the leading model for hydrogen production. Hydrogen energy storage has emerged as a promising solution to tackle the challenges posed by intermittent renewable energy sources and facilitate the transition to a low-carbon energy system. With its high energy density, low environmental impact, and wide range of applications, hydrogen has the potential to play an important role in meeting the energy needs of the future. The development of advanced hydrogen storage technologies such as electrolysis and fuel cells has made it possible to produce, store and use hydrogen efficiently and cost-effectively.

Overall, hydrogen energy storage offers a promising solution to the challenges of transitioning to a low-carbon energy system. With continued innovation and investment, hydrogen has the potential to become a key component for a sustainable energy future.

REFERENCES

- [1] Ali, D. (2019). Hydrogen Energy Storage. In IntechOpen eBooks. <https://doi.org/10.5772/intechopen.88902>
- [2] 4 technologies driving the green hydrogen revolution. (2022, May 20). World Economic Forum. <https://www.weforum.org/agenda/2021/06/4-technologies-accelerating-green-hydrogen-revolution>
- [3] Figure 9. comparison of different energy storage technologies in relation to (2023, May 07). Re-search Gate. https://www.researchgate.net/figure/Comparison-of-different-energy-storage-technologies-in-terms-of-rated-power-storable_fig3_312483419
- [4] Hydrogen for Energy. (2023, May 02). siemens-energy.com Global Website. <https://www.siemens-energy.com/global/en/priorities/future-technologies/hydrogen.html>
- [5] Hydrogen for Energy. (2023, May 01). <https://www.siemens-energy.com/global/en/priorities/future-technologies/hydrogen.html>
- [6] Hydrogen for Energy. (2023, April 29). siemens-energy.com Global Website. <https://www.siemens-energy.com/global/en/priorities/future-technologies/hydrogen.html>
- [7] Hydrogen production. (2023, April 28). Energy.gov. <https://www.energy.gov/eere/fuelcells/hydrogen-production>
- [8] Hydrogen production: electrolysis. (2023, April 29). Energy.gov. <https://www.energy.gov/eere/fuel-cells/hydrogen-production-electrolysis>
- [9] Siemens Energy starts production of hydrogen electrolysis in Berlin (2023, May 04).

<https://press.siemens-energy.com/global/en/pressrelease/siemens-energy-start-production-hydrogen-electrolyzers-berlin>

[10] Jadhav, A. (2022). Water electrolysis: the most promising method for green hydrogen production. Solar Edition. <https://solaredition.com/water-electrolysis-the-most-promising-method-for-green-hydrogen-production/>

[11] Hydrogen Storage. (2023, May 07). Energy.gov. <https://www.energy.gov/eere/fuelcells/hydrogen-storage>

[12] User, S. (2023, May 08). H2FUTURE PROJECT - Home Page. <https://www.h2future-proj>