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Hydropower Development and its Role in Sweden's Transition to Renewable Energy

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Abstract:- As a result of the greenhouse gas emissions from fossil fuels, which are causing climate change, many countries have decided to spend money in the commercial use of renewable energy sources. One particularly underutilized and under tapped renewable energy source is hydropower, which has enormous potential. The importance of increasing Sweden's hydro energy use, the difficulties it currently faces, and current research and development in Sweden will all be covered in this paper. This renewable resource will be essential in helping Sweden to fulfil its growing need for clean energy and will make it possible for the nation to greatly increase its supply of electricity to the grid in the years to come. This renewable resource will be essential in helping Sweden to fulfil its growing need for renewable energy and will make it possible for the country to greatly increase its supply of electricity to the grid in the years to come.

Keywords:- *Hydropower, Nuclear Energy, Energy Transition, Climate Change.*

I. INTRODUCTION

The global pursuit of sustainable energy solutions has become an urgent imperative as the devastating impacts of climate change continue to unfold. In this setting, hydropower facilities have become a key component of the renewable energy landscape, providing a dependable, clean, and environmentally benign method of generating electricity. In order to address the growing issues of energy security and environmental degradation, hydropower facilities have been important. They do this by harnessing the power of moving water.

The necessity to move toward sustainable and renewable energy sources is becoming more widely acknowledged as countries struggle with the effects of their overreliance on non-renewable energy. Hydropower stands out as a promising choice to support energy diversification and fight climate change because of its track record of efficiency and environmental advantages. This paper acknowledges that reducing reliance on nuclear power while increasing the utilization of hydropower can further enhance Sweden's energy infrastructure.

In 2022, hydropower, which generates an average of 4300 TWh per year and accounts for more than 18% of the world's electricity production. Between 2021 and 2030, the total hydroelectric capacity is anticipated to rise by 17%, or 230 GW [1]. Hydropower is a clean, renewable, and environment friendly form of energy. The 1100 GW global hydro capacity has grown at annual rate of roughly 3.5% over the last five years, with the majority of the growth occurring in Asia and Latin America. There are more than 1000 MW of planned hydroelectric power and about 160 GW now under construction [2]. Hydropower energy recorded economic benefits in 159 nations worldwide in 2016; In 2020, Hydropower became a technology that is widely used in 180 countries [3].

In Sweden's electrical market, hydropower is crucial. The necessity for a regulating source that can change its output within minutes rises as wind and solar energy production increases. The production of solar and wind energy is solely dependent on the weather and time of day [4]. Even Nuclear energy has its disadvantages. The fundamental fuel for nuclear energy, uranium, is non-renewable and finite. Long-term uranium resource accessibility and availability are a source of concern. Due to its capacity to control production, hydropower, which generates roughly 45% of all electricity, is considerably more important than that [5].

The electricity demand is comparatively high per person in Sweden because of the country's cold climate and electricity-intensive industries. In Sweden, 95% of the electricity generated is regarded as having minimal carbon dioxide emissions. The average carbon dioxide emissions in Sweden are 20 g CO2/kWh, those in the Nordic nations are around 100 g CO2/kWh, and the average emissions from the production of electricity in Europe are somewhere around 400 g CO2/kWh [4]. In 2022, electricity use in Sweden amounted to 137 TWh. Industry accounted for 34 percent, which corresponds to 46 TWh [6].

With 98 percent carbon-free power production and district heating accounting for 50 percent of all heating, Sweden has developed one of the most effective energy systems in the world during the past 100 years. About 71 TWh of energy was produced in 2021 by hydropower, 50,5 TWh by nuclear power, 27,5 TWh by wind energy, 15 TWh by combined heat and power, and just 1 TWh by solar energy [6].

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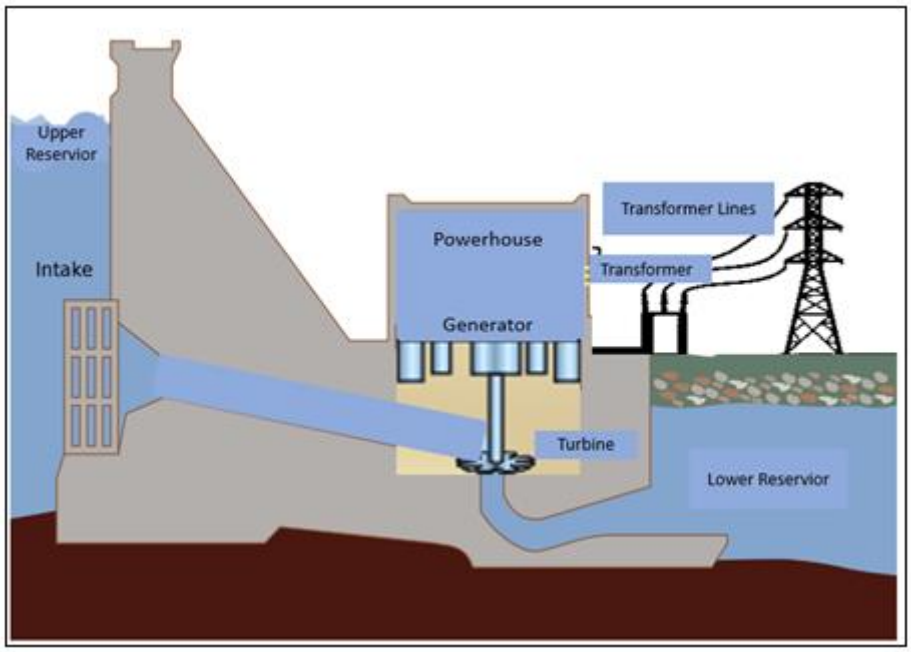

Fig. 1 Schematic diagram of Hydroelectric Plant

II. ADVANTAGES OF HYDRO ENERGY

- Hydropower uses a renewable resource that can be continuously replenished by nature, negating the need for fossil fuels.
- The power system has the ability to reduce carbon emissions due to the low greenhouse gas (GHG) emissions produced by fossil fuels like coal [7]. According to the Intergovernmental Panel on Climate Change's Report on Emissions Scenarios for 2011, the estimated cycle of GHG hydropower is 4 and 14g of [CO2.eq /kWh] [8].
- Hydroelectricity powers communities, industries, and urban areas, serving as a vital energy source. At present, approximately 9,000 operational projects exist, and in 2016, 159 nations worldwide claimed to derive advantages from hydroelectric power [3] [9].
- When climate dependent renewable sources like wind and solar aren't available, hydropower meets the demand. It also enhances the growth of these sources [10].
- Costs for primary energy generation are 2-4 times lower than in nuclear power plants due to low maintenance cost [10].
- Hydropower projects that serve multiple purposes, such as water conservation during dry seasons and controlled flood management, typically achieve the intended results when integrated with dams [11].
- Nuclear and thermal power plants have an efficiency coefficient of about 33%, while hydroelectric plants have a high efficiency coefficient of between 55% and 92% [12].
- Hydroelectric projects are known for their longevity, often exceeding 50 years of service. For instance, there are still operational hydro projects today that were built in the late 19th century, such as the one in Darjeeling, India, established in 1897 [13].
- The probability of extreme weather events like floods and droughts brought on by climate change is reduced by the storage infrastructure that a hydroelectric reservoir provides [14].
- The production of peak load energy from hydro allows for the best use to be made of base-load power from other less flexible electricity sources [15].
- When there is a surplus of electricity being produced, hydropower systems can be utilized to store it by pumping water uphill into reservoirs and releasing it when there is a spike in demand. This helps to stabilize the grid.
- Governments around the world are starting to set national goals for the provision of electricity from renewable sources and thus try to set-up the various Hydro energy policies in various countries as a result of concerns about climate change, an increase in energy consumption rates, international agreements to reduce GHG emissions, and thinking about the availability of hydropower.

A. Limitations of widespread use of hydropower

- The construction of hydropower plants is a lengthy process, typically spanning 10 to 20 years, in contrast to nuclear and thermal power plants, which can be built in a shorter timeframe of 3 to 4 years [12].
- To sustain their high efficiency levels, hydroelectric plants need to be situated in settings where there is little seasonality, ensuring a consistent flow of water without significant climatic fluctuations [16].
- The hydroelectric operation of dam projects can harm the local wildlife and aquatic ecosystems when dam gates are opened forcefully for flood control purposes, leading to the disruption and loss of wildlife and aquatic life within those ecosystems [17].

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- Reservoirs created by hydroelectric projects have the potential to inundate residential areas, valuable natural habitats, farmland, and historical sites. The necessary infrastructure for hydroelectric generation is often located in rural regions inhabited by economically disadvantaged populations, including indigenous communities, small-scale farmers, and peasants, who typically experience high levels of social marginalization and economic vulnerability [18].
- Hydroelectric projects demand a substantial budget for both construction and electrical equipment, along with the installation of transmission lines stretching from remote areas to urban centres [19].
- It involves splitting the river into two or three segments, disrupting the natural flow and irrigation, which can lead to a division of plant life both upstream and downstream. To address this, fish ramps, essentially elevators for fish to move upstream during the spawning season, are sometimes employed. However, this doesn't completely prevent the loss of many animals, which in turn disrupts the balance within ecosystems [20].

III. HYDROELECTRICITY IN EUROPE

Hydropower holds a vital place within Europe's energy sector due to its exceptional efficiency as a technology. It has a deep-rooted historical tradition in several European countries [21]. As the second most prominent source of renewable electricity, hydropower maintains its significance in today's energy landscape and contributed 32% of the EU's renewable electricity production and supplied 12% of the EU's total electricity [22]. Fig 2 shows the leading nations to produce hydroelectricity in Europe in 2021.

In 2021, Europe had an overall hydropower capacity of 255 GW, resulting in the generation of approximately 659 TWh of electricity from hydropower sources [23]. Fig 3 shows hydropower capacity across the European Countries.

Hydropower stands out as Europe's foremost renewable energy source, offering substantial potential to address the rising demand for green energy and increased energy consumption. Less known is the fact that Sweden possesses significant untapped hydropower resources [24] and is prepared to contribute to reducing reliance on non-renewable nuclear energy, which comes with its own set of limitations.

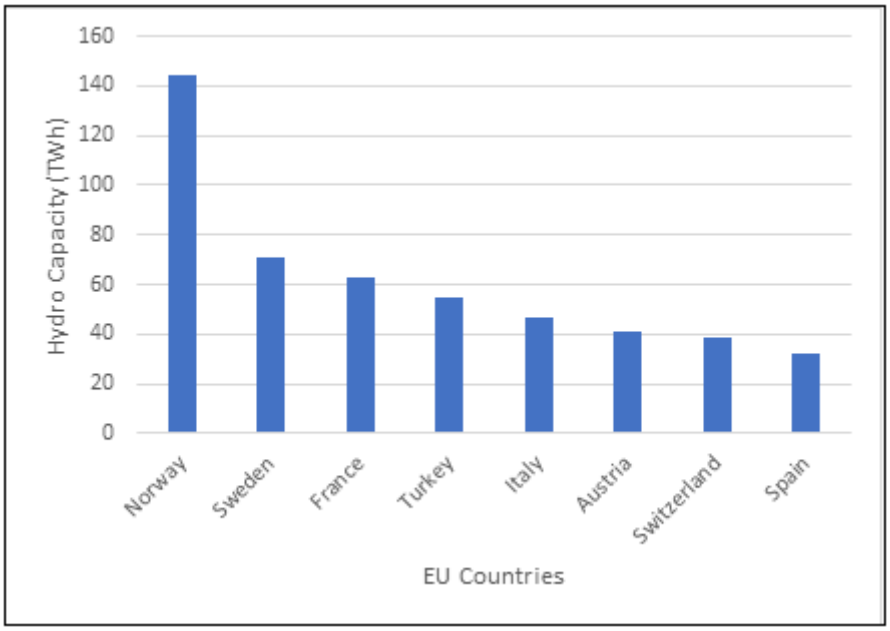

Fig. 2 The top nations for hydropower production in Europe in 2021 [25]

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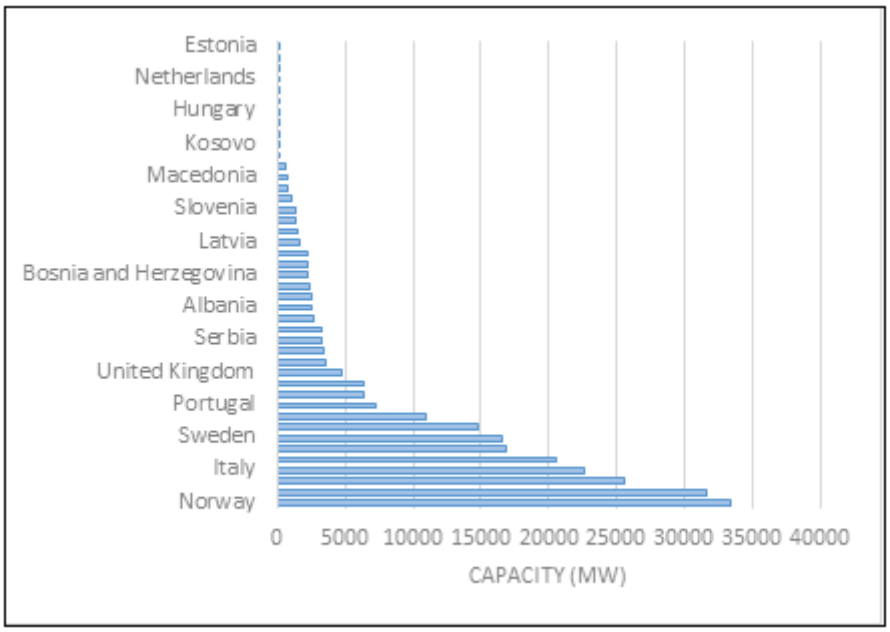

Fig. 3 Hydropower installed capacity (in megawatts, MW) across European countries in the year 2021 [23].

A. Sweden's Hydro energy overview

The government has made a strong commitment to developing renewable energy sources in order to reduce dependence on fossil fuels across all sectors. By 2040, Sweden hopes to have energy supply that is entirely reliant on renewable sources of energy. Expanding onshore wind energy will be the focus, with the intermittent nature of wind power being supplemented by the usage of hydro power facilities and improved cooperation with neighbouring countries [26].

In Sweden's current transition to a 100% renewable electricity system, hydropower is crucial. In Sweden, there are about 2,100 hydropower plants, which produce 67 TWh of electricity annually. 45% of the nation's total electrical generation comes from this source [27]. Most of Sweden's over 2,000 hydropower facilities are situated along the country's four primary rivers: Luleälv, Indalsälv, Umeälv, and Ångermanälv [26]. Table I shows the largest power plants and their respective installed capacities.

In Sweden, to be more specific, the northern areas of the country, which have an installed capacity of 16,300 MW, contribute 80% of the hydropower production. In this region, you can also find Harsprånget, Sweden's most substantial hydropower plant, which has a total capacity of 818 MW and annually generates over 2 TWh of electricity [24]. Electricity production in Sweden has predominantly been sourced from hydropower and nuclear power since the 1980s [28]. However, there has been a substantial rise in wind power generation over the last ten years. Fig 4 shows the total energy supply by source between the period 1980-2021.

Table I Largest Hydropower Plants in Sweden [29]

Serial No.	Hydropower plant name	Capacity (MW)	River
1	Harspranget	818	Lulleälven
2	Stornorrfors	599	Umeälven
3	Letsi	483	Lulleälven
4	Porjus	417	Lulleälven
5	Messaure	463	Lulleälven

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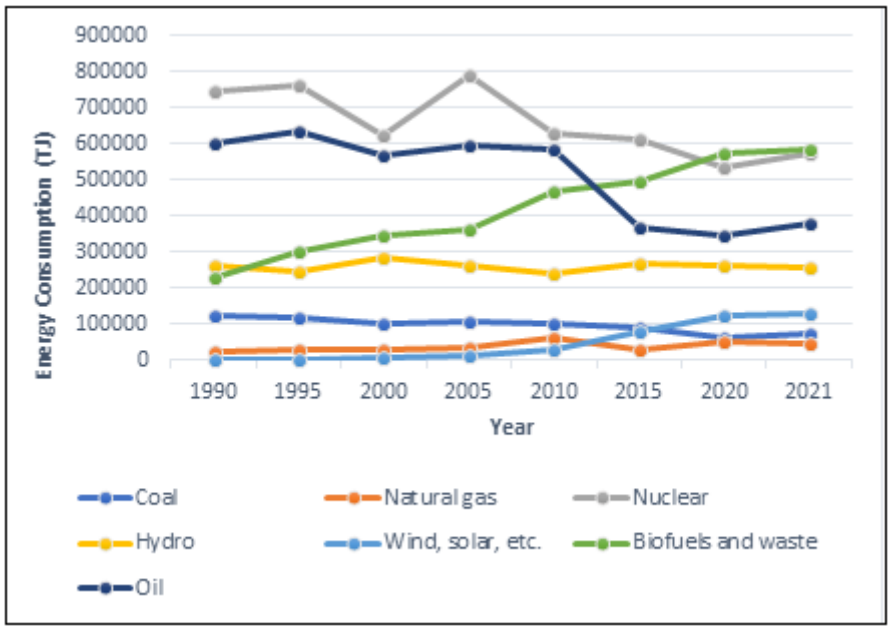

Fig. 4 Total energy supply (TES) by source [30]

➢ *Limitations of Nuclear Energy in Sweden:*

It is a common belief among Swedes that their nation has a reputation abroad for its clean, untarnished environment and its high technological and economic standards [31]. Nuclear energy has its own drawbacks in Sweden:

- Sweden's limited access to uranium deposits results in its dependence on imported nuclear fuel, creating a potential vulnerability in terms of supply security. Only 0.2% of the world's uranium resources are found in Sweden [32].
- In 2018, the Swedish government imposed a ban on the exploration and mining of uranium within the country, effectively cancelling any prospects of uranium production from the proposed mining activities [33].
- In Sweden, there exists a divergence of political stances and public attitudes toward nuclear energy. While some endorse its persistence as a low-carbon energy solution, others harbor concerns regarding safety, the management of nuclear waste, and the potential for accidents.
- The current share of nuclear energy in Sweden's electricity production, around 29.4 % [34], cannot be significantly increased to compensate for the decline in the use of fossil fuels . However, developing renewable sources such as hydropower, wind and solar has the potential to bring about more substantial changes in Sweden's electricity generation landscape.
- One of the primary challenges lies in the long-term handling of nuclear waste. Regardless of its source, this hazardous waste contains extremely poisonous chemicals like plutonium and uranium pellets. These highly toxic substances remain intensely radioactive for tens of thousands of years, posing threats to farmlands, fishing zones, freshwater reservoirs, and human health [35].

IV. CURRENT RESEARCH & DEVELOPMENT OF HYDROPOWER PLANTS IN SWEDEN

Over the next 20 years, Sweden intends to assess and modernize all of its hydropower production to meet current environmental standards. The initiatives aimed at mitigating the negative impact of hydropower on ecosystems and biodiversity will be of great importance before this evaluation. The goal is to minimize any disruptions to electricity generation. Flexible hydropower is a critical component in a growing energy system that relies increasingly on wind and solar power. Vattenfall, with its long-standing involvement in hydropower, continues to be a leader in Sweden's hydropower development [36].

Vattenfall plans to build four new hydropower projects with a possible capacity of a total of 720 MW, starting from 2026 and into the 2030s [37].

In Sweden, collaborative development initiatives involving universities, research institutions, and industry partners are actively underway. These projects centre around hydropower technology, environmental consequences, and policy frameworks, with the goal of leveraging collective knowledge and fostering innovation in this domain:

- Scientists are actively engaged in the development of innovative technologies geared towards facilitating the smoother migration of fish through hydropower installations. This endeavour encompasses the study of fish behaviour, the design of fish-friendly turbines, and the implementation of effective fish passage systems, all aimed at mitigating the ecological impact of hydropower plants [38].
- Luleå University of Technology, in partnership with the business sector, public authorities, and six other universities, is embarking on research efforts centered around sustainable, safe, and efficient hydropower. The primary focus of this research is to contribute to the development of a sustainable energy system and to

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improve the ecological conditions of regulated river ecosystems [39].

- Pumped-storage facilities hold significant importance in stabilizing the electrical grid and storing energy. Current research is dedicated to refining their efficiency and operational capabilities, with a specific emphasis on improving performance and their ability to integrate effectively with variable renewable energy sources [40].
- In urban settings, there are active developments aimed at investigating the viability of implementing small-scale hydropower systems. These projects centre on the utilization of the existing water infrastructure to generate energy in an eco-friendly and locally focused manner [41].
- Uniper's commitment to advancing battery systems for hydropower continues as they aim to swiftly assist the electricity grid in case of unexpected disruptions. They are in the process of installing two additional systems at the Bodum and Fjällsjö power plants located in Jämtland, Sweden, with a total capacity of approximately 12 Megawatts (MW) [42].
- Fortum has recently activated the batteries at the Forshuvud hydropower plant near Borlänge and Dalälven in Dalarna, Sweden, as previously announced. This represents the first instance of utilizing batteries within the power grid to support hydropower operations and enhance regulation power. The facility has been furnished with a significant quantity of lithium-ion batteries, offering a total storage capacity of 6.2 MWh and a maximum power output of 5 MW [43].
- With the growing presence of intermittent renewable energy sources like wind and solar, hydropower presents a valuable solution for enhancing grid flexibility and effectively managing the balance between energy supply and demand.

The collaborative research and development initiatives highlights Sweden's commitment to finding an appropriate balance between the advantages of hydropower and the imperative of addressing environmental and social concerns. These activities are directed towards ensuring the sustainable progression of hydropower projects, thereby encouraging the nation's energy security and advancing its renewable energy objectives, all while mitigating any detrimental effects on ecosystems and communities.

V. CONCLUSION

This paper provides a condensed overview of hydropower and its research directions in Sweden, emphasizing how development of hydropower can diminish reliance on nuclear energy and other non-renewable resources, ultimately aligning with Sweden's target of achieving a fully renewable energy supply of 100%. Hydropower technology is recognized as one of the most well-established technologies among various renewable energy sources, representing a sustainable and renewable energy source. It accounts for roughly 45% of Sweden's total electricity production and constitutes over 80% of all renewable electricity generation in the year 2021.

Hydropower plays a crucial role in Sweden's energy landscape and its potential to address the challenges posed by climate change and energy security. As the world confronts the pressing need for sustainable energy sources, hydropower emerges as a dependable, renewable, and environmentally friendly alternative.

Sweden, endowed with substantial hydropower capacity, possesses the opportunity to further tap into this valuable resource for a transition toward a cleaner and more sustainable energy system. The nation's dedication to diminishing reliance on fossil fuels and achieving a fully renewable energy supply by 2040 underscores the pivotal role of hydropower in this transition.

However, this paper has also highlighted specific constraints and challenges linked to the extensive utilization of hydropower, including the lengthy construction timelines, potential ecological impacts, and the requirement for substantial financial investments. Proficient handling of these challenges is crucial to ensure that the development of hydropower aligns with environmental and societal considerations.

Sweden's continuous endeavours in research and development, encompassing inventive technologies for facilitating fish migration, promoting sustainable hydropower practices, and integrating small-scale hydropower systems, signify the nation's commitment to advancing hydropower technology while mitigating its environmental impact.

Overall, hydropower holds a bright and promising future in Sweden and globally, offering a sustainable and efficient means of electricity generation while contributing to the global campaign against climate change. As Sweden persists in its investments for the modernization and expansion of its hydropower infrastructure, it can serve as an exemplar for other nations aiming to embrace renewable energy sources and decrease their dependence on fossil fuels.

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