

Replacing Fossil Energy in New York State: An Analysis of Biomass, Geothermal, Wind, Wave, and Tidal Energies

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ABSTRACT

As New York State grapples with the pressing need to transition away from fossil fuels, this analysis examines alternative energy sources that promise to foster sustainability and reduce carbon emissions. The study focuses on five key renewable resources: biomass, geothermal, wind, wave, and tidal energy. By evaluating the potential of each energy source, the research highlights their feasibility, environmental impact, and economic viability. The study aims to provide policymakers, industry professionals, and the public with comprehensive insights into how these renewable options can be effectively integrated into New York's current energy landscape. The transition not only responds to climate change challenges but also enhances energy security and promotes economic growth through job creation in emerging sectors. Biomass energy stands out as a versatile solution, utilizing organic materials such as agricultural waste, wood, and even municipal solid waste to generate power. This source offers a dual benefit: reducing landfill waste while providing a renewable energy output. Additionally, geothermal energy employs the Earth's natural heat, tapping into hot water reservoirs or steam to produce electricity and heating. By examining case studies and existing projects in these areas, the analysis underscores the practical applications and advancements that can make these technologies more accessible to local communities. The challenges, such as resource availability and public acceptance, are addressed while demonstrating how these renewable options can relieve some of the burdens posed by fossil energy dependence. Wind, wave, and tidal energy represent the frontier of harnessing the power of moving water and air for sustainable energy production. Wind energy, particularly through the development of offshore and onshore turbines, showcases New York's potential for harnessing natural forces. Meanwhile, wave and tidal energy projects provide innovative ways to exploit ocean dynamics, presenting a largely untapped resource for clean energy. This analysis compiles data and analytics from existing

projects to forecast potential increases in energy output and environmental benefits. Advocating for a diversified approach to energy generation encourages a sustainable and resilient energy future for New York State. Through comprehensive evaluation, the findings illustrate that transitioning to renewable energy sources can significantly reshape New York’s energy profile, combat climate change, and serve as a model for other states to follow.

1. INTRODUCTION

In New York State, replacing fossil fuel dependency with renewable options is a significant agenda with urgent demand. To this end, various energy types exist, each with unique attributes that contribute to a promising energy future. This analysis aims to identify the ideal replacement for fossil fuels by examining five distinct energy sources that can contribute to New York’s renewable energy future. The alternative energies reviewed include biomass, geothermal, wind, wave, and tidal energy (see [Table 1](#)). This analysis aims to highlight the individual nature of each energy type, its current use, and its future prospects, in a manner that establishes them as viable replacements for fossil fuels.

The paper shall include an extensive discussion on the environmental impacts of each energy option and how they present lesser ecological consequences than traditional fossil fuels. Biomass energy, which utilizes organic remnants from crops, can also be carbon neutral, but this can only be achieved if the process is sustainable. Geothermal energy utilizes the Earth’s heat, thereby contributing to lower levels of greenhouse gases; however, this energy option may harm some local wildlife and must be contained. Wind energy utilizes air currents, which can disturb some animals; however, it is an excellent option for reducing carbon emissions. Wave and tidal energy harness water movement from the oceans, providing a reliable energy source with a low land footprint; however, potential damage to aquatic life must still be addressed in this energy option.

Table 1. Types of renewable energy.

Type of Renewable Energy	Brief Description	Energy Efficiency
Biofuel	<ul style="list-style-type: none"> Biofuels are energy sources derived from organic materials such as plants and animal waste. It offers a renewable alternative to fossil fuels, significantly reducing greenhouse gas emissions when burned [1]. 	20%
Geothermal Energy	<ul style="list-style-type: none"> Harnesses heat from the Earth’s core, providing a constant and reliable energy source. Unlike fossil fuels, geothermal energy generates power with minimal emissions, making it an ideal choice for combating climate change [2]. 	30%
Hydropower	<ul style="list-style-type: none"> Generated by harnessing the flow of water in rivers and dams. It has been a reliable energy source for over a century, accounting for approximately 16% of the world’s electricity. Hydropower plants can generate substantial amounts of electricity without emitting greenhouse gases during operation by harnessing the natural energy of moving water [3]. 	15%
Solar Energy	<ul style="list-style-type: none"> This energy is harnessed through solar panels that convert sunlight into electricity, making it an accessible option for homes and businesses. The technology has improved significantly, producing more efficient and affordable solar panels [4]. 	30%

Continued

Tidal	<ul style="list-style-type: none">• Tidal energy utilizes the movement of tides to generate electricity, typically through tidal stream turbines or barrages. It captures the kinetic and potential energy of rising and falling tides, driven by the gravitational interactions between the Earth, Moon, and Sun. This energy source is highly predictable, as tidal patterns are consistent [5].	80%
Wave Energy	<ul style="list-style-type: none">• Wave energy harnesses the movement of ocean waves to generate electricity. It captures the kinetic and potential energy from waves using devices like oscillating water columns, point absorbers, or attenuators. This renewable energy source has the advantage of being consistent, as waves are relatively predictable compared to wind or solar power [6].	30% - 50%
Windpower	<ul style="list-style-type: none">• Converts kinetic energy from wind into electrical energy, which can be used to power homes, schools, and businesses. Wind power is a clean energy source that produces no emissions during operation, making it an environmentally friendly option [7, 8].	35%

In addition, the research will evaluate the economic factors, which will involve analyzing the upfront and life-cycle costs of renewable systems against those of fossil fuels. Renewable energy costs are declining, owing to improved technologies that are making it more viable. Wind and solar technologies have become especially cheaper, with the reduced costs attributed to enhanced efficiencies and economies of scale. A further key theme for research is technological advancements. For example, breakthroughs in energy storage could improve the quality and reliability of renewable sources, which is one of the principal issues given their intermittent nature. Additionally, innovations in smart grid technology and energy distribution systems could facilitate a more efficient incorporation of these areas into New York State's energy systems.

The study aims to draw a balanced conclusion regarding the energy transition in New York State through such analysis. It seeks to balance environmental considerations with economic aspects and utilize these renewable energy resources to ensure the energy transition in New York State is both environmentally and economically justified.

2. CURRENT ENERGY LANDSCAPE IN NEW YORK STATE

New York State's current energy consumption patterns are primarily driven by a heavy reliance on fossil fuels, which are extensively used across various sectors, such as residential housing, industrial operations, and transportation systems. In examining these patterns, it becomes apparent that there is a significant dependence on natural gas and petroleum products. These energy sources constitute a substantial portion of the state's total energy intake, primarily due to their integration into established infrastructure and their traditional cost-effectiveness compared to many current renewable energy options.

Although there are visible efforts to diversify New York's energy portfolio, fossil fuels continue to dominate the state's energy landscape. This dominance is partly attributed to the existing infrastructure investment supporting fossil fuel use, which presents a considerable challenge to immediate transitions. Moreover, despite a decrease in recent years, the costs associated with renewable energy still present barriers when weighed against the often-cheaper fossil fuel options. However, the future energy landscape in New York could look significantly different with ongoing technological innovations and the enactment of new policy initiatives that focus on reducing carbon emissions. These efforts create potential for developing a more balanced and sustainable energy portfolio, including an increasing share of renewable resources, such as wind, solar, and hydroelectric power.

Transitioning from a fossil fuel-centric system to one that embraces renewable energy presents its own set of challenges. These challenges are not limited to overcoming technological hurdles or balancing economic factors; they also involve addressing social and environmental concerns. They also involve substantial societal and infrastructural changes necessary to accommodate and optimize new energy systems. Modifying existing infrastructure, retraining workforces, and addressing public concerns and resistance are critical components in fostering an environment conducive to this energy transformation [9].

3. BIOMASS ENERGY: VIABILITY AND CHALLENGES

Biomass energy represents a promising alternative to traditional fossil fuels, tailored explicitly for New York State, primarily due to its potential benefits, including reduced carbon emissions and local availability. This form of renewable energy can significantly contribute to the state's efforts to reduce its carbon footprint while simultaneously bolstering energy independence through locally sourced materials. Nonetheless, several challenges must be addressed to fully capitalize on biomass energy's potential, primarily centered around economic and environmental issues. The economic dimension of biomass energy largely depends on the market scale and availability of regional feedstock. The study conducted by Pokharel *et al.* [10] advocates that market and regional availability factors are significant in determining the economic accessibility of biomass for electricity generation. The geographical dispersal of biomass feedstock needs to be effectively coordinated to maintain reliable and economical supply chains, which can be affected by logistical obstacles and changing market accessibility.

Nonetheless, these economic constraints have shown considerable potential advantages of biomass energy. The energy this can provide can be optimized when used in conjunction with existing energy systems, promoting more diversified energy generation and offering support to the local economy by generating new employment opportunities in the biomass production and supply industries. These merits underscore the need to promote further the formulation of policies that mitigate the hindering factors preventing biomass from being utilized more extensively. To optimize the potential of biomass energy, it is also necessary to address existing logistical issues that hinder its wider adoption. This approach entails developing a suitable supply chain for harvesting, shipping, and processing raw biomass feedstocks. Additionally, it is essential to further develop the existing paradigm of sustainability in relation to areas such as biomass energy use and its sustainable impact on the environment, ecosystems, and renewable energy resources. New York needs to implement measures that minimize the economic and environmental impact of biomass energy use.

3.1. Present Utilization of Biomass

Biomass energy has been legislated by New York State as part of its various renewable energy options, which further enhances its commitment to improving the sustainability of energy sources and diversifying its energy mix. With this in mind, New York State also rolled out its infrastructure projects, allowing biomass energy to produce electricity and heat. Biomass is generally considered to be organic material, and the project focuses on utilizing crop residues and forestry waste. Nonetheless, the current situation still sees several major barriers to the mainstream adoption of biomass energy. Biomass economics are heavily reliant on variable external market factors, the costs of production for biomass projects, and further costs associated with the transportation of biomass. As most sites for biomass feedstock are not located close to each other, the logistics of harvest and transport can prove a very costly limitation [10]. Moreover, the operational logistics of establishing further biopower plants involve extensive capital outlay, regulatory compliance, and challenges in ensuring a continuous and dependable feedstock supply. These factors can inhibit the scale of productivity and growth of these plants.

Strategic advancements are necessary to enhance the role of biomass within New York's energy framework. This includes the development of innovative technologies that can optimize biomass conversion processes, making them more cost-effective and efficient. Moreover, establishing a robust and comprehensive distribution network dedicated to biomass feedstock is critical. Such a network could streamline the supply chain, making the dispersal of feedstock more consistent and economically viable, thereby allowing biomass

to play a more significant role in the state's renewable energy portfolio.

3.2. Potential Benefits and Environmental Impact

Expanding biomass energy use presents a significant opportunity for New York State to achieve considerable environmental and economic advantages. By relying on organic materials such as agricultural residues, wood, and other plant-based resources that would otherwise decompose naturally, biomass energy decreases the overall carbon footprint. When these organic substances break down in the absence of energy recovery, they release greenhouse gases such as methane and carbon dioxide, thereby contributing to climate change. The state can substantially mitigate these emissions by capturing and utilizing these materials for energy production.

One of biomass's notable environmental benefits is its role in the carbon cycle. The continuous growth and harvesting of biomass feedstock facilitate carbon sequestration, meaning carbon dioxide is absorbed from the atmosphere during the plants' growth phase. This ongoing cycle offers a distinct environmental advantage by potentially offsetting the carbon emissions associated with energy generation, thereby supporting efforts to mitigate climate change [10]. From an economic perspective, a thriving biomass sector could have substantial local economic impacts. Developing supply chains for biomass feedstock involves various stages, including cultivation, harvesting, processing, and transportation. Each stage is an opportunity for job creation, thus stimulating local economies. Furthermore, establishing and operating biomass power production facilities would create additional employment opportunities, enhancing economic stability and growth in the region.

However, despite these promising benefits, expanding biomass energy also brings crucial environmental challenges that must be addressed. Issues such as land use change, which can lead to deforestation or the conversion of natural landscapes into areas for biomass cultivation, can have a negative impact on the environment. Additionally, there is the potential impact on biodiversity, as ecosystems may be disrupted by changes in land management practices required to scale up biomass production. These challenges must be meticulously managed to ensure sustainable biomass energy development. Implementing strategic planning and sustainable practices is crucial for minimizing adverse effects and ensuring that the biomass sector can make a positive contribution to New York State's energy portfolio [10].

3.3. Technological and Economic Considerations

To successfully enhance biomass energy development within New York State, it is essential to thoroughly examine the technological advancements and economic factors that influence the sector. Technology's role is pivotal, as new and improved processes enable the more efficient conversion of biomass into energy. This efficiency reduces operational costs and significantly increases the overall energy yield. By adopting cutting-edge technologies, the biomass energy sector can harness more energy from the same amount of biomass material, which improves profitability and sustainability.

According to Pokharel *et al.* [10], the expansion of the biomass market hinges heavily on establishing robust feedstock distribution networks. These networks are crucial since they directly affect the economic feasibility and availability of biomass, making it more accessible and cost-effective. A well-connected distribution network ensures that raw materials are consistently supplied to biomass energy facilities at a stable and predictable cost, thus mitigating supply chain disruptions and reducing costs. Moreover, implementing advanced technologies such as anaerobic digestion—which decomposes organic matter to produce biogas—and bio-refining processes can produce higher-value bioproducts. These bioproducts, such as biofuels, chemicals, and other biomass-derived materials, enhance the economic appeal of biomass energy ventures. This diversification not only adds revenue streams but also supports a circular economy by maximizing the utility of biomass feedstocks.

While the initial investment required for these technologies remains a significant concern, ongoing innovations are progressively lowering these financial barriers. The continual improvement and scaling of technology are driving down costs, making biomass energy projects more commercially viable. Consequently,

the future of biomass energy development in New York appears promising, with a positive economic outlook driven by technological progress and strategic market expansion.

3.4. Case Study Application

New York has made significant strides in utilizing biomass energy, with several projects established to demonstrate the potential benefits of this renewable resource. First is the Albany County Biogro Plant, which utilizes biomass energy derived from local agricultural waste and has successfully converted it into renewable energy. The plant helps manage agricultural waste while providing clean and eco-friendly energy to its nearby community. Additionally, it significantly reduced carbon footprints and air emissions. The successful establishment of the facility demonstrates that biomass energy projects can be implemented in peri-urban areas and existing regional establishments, addressing the state's environmental issues while expanding its energy resource portfolio [10]. The second project is the Lyonsdale Biomass Plant, which uses forest product residues to power electricity-needy areas (now defunct). The plant demonstrates how rural areas can benefit economically from utilizing biomass energy derived from their abundant natural resources. Overall, these projects illustrate how the state could maximize the benefits of local resources. However, there is a need to address the logistical and financial needs first to harness and expand its potential biomass energy capacity.

Furthermore, biomass energy projects in New York State face logistical and perception issues. Biomass feedstocks tend to be scattered (i.e., leftovers and residues from crops and wood), which results in complications for efficient collection and transportation [10]. The collection of this energy source introduces roadblocks such as inefficiency and added costs, thereby straining the overall economic potential of biomass power generation in the defined area [10]. For instance, Pokharel *et al.* [10] argued that the economic viability of biomass power production highly depends on the logistics of biomass feedstocks. Additionally, public perception of biomass projects presents a hurdle, as some communities express concerns over the sustainability and ecological repercussions of these projects [9]. To further strengthen the biomass prospects in New York as a renewable energy source for its renewable energy portfolio, these perception and logistics challenges must be addressed through improved feedstock supply management approaches and capacity-building initiatives for public support.

4. GEOTHERMAL ENERGY POTENTIAL

At the same time, geothermal energy presents a considerable potential for New York State as a new platform for sustainable energy development. Geothermal resources provide a stable and continuous power supply, which is crucial for New York's initiatives to reduce its reliance on fossil fuels. Therefore, consequently, it reinforces a sustainable approach to environmental impact and energy security. Moreover, the stable energy generation associated with geothermal systems can be viewed as an advantage, as this power supply does not experience the intermittent characteristic of solar or wind energy.

Research conducted by Jordan *et al.* [11] emphasizes the significance of borehole exploration in exploiting the potential of low-enthalpy geothermal systems. This exploration is crucial for maximizing the energy harvested from geothermal sources and effectively mitigating the associated geological risks. By delving deeper into the understanding of the underlying sedimentary structures, researchers and engineers can enhance their strategies for geothermal energy extraction, potentially increasing efficiency and yield [11].

Currently, New York's geothermal resources are underutilized. However, the landscape for geothermal energy could see significant expansion with the advancement of drilling technologies. Improvements in these technologies would reduce costs and increase the accessibility of geothermal resources. Additionally, more substantial regulatory support encouraging investment in geothermal energy projects can accelerate development and implementation. The environmental benefits of expanded geothermal energy use are considerable. For instance, increasing reliance on geothermal energy could substantially reduce the state's greenhouse gas emissions, aligning with broader goals for combating climate change. Alongside environmental advantages, geothermal energy provides enhanced energy security by diversifying the energy supply and reducing

vulnerability to external market fluctuations. Moreover, the growth of the geothermal sector could stimulate economic stability by creating jobs associated with drilling, exploration, and infrastructure development.

In summary, geothermal energy in New York State presents a multifaceted opportunity that offers environmental benefits, enhances energy security, and promotes economic prosperity. With appropriate technological and policy advancements, it can become a cornerstone of the state's sustainable energy portfolio.

4.1. Overview of Geothermal Resources

In New York State, geothermal energy offers a promising, though largely untapped, opportunity for renewable energy generation. The state possesses a collection of geothermal resources scattered throughout its geography, primarily characterized by low-enthalpy geothermal systems amenable to direct-use heating applications. As Jordan *et al.* [11] noted, advancements in borehole research can significantly enhance the understanding and utilization of these geothermal potentials. These systems, particularly in Upstate New York, are well-positioned for development due to their relatively stable temperature profiles and access to sedimentary formations that can be effectively exploited with current technologies. Enhancing geothermal energy's contribution to the state's renewable energy portfolio would reduce greenhouse gas emissions and foster energy resilience and economic growth by creating opportunities for job expansion during both the construction and operational phases.

4.2. Challenges in Geothermal Deployment

Geothermal energy deployment in New York State presents several key challenges, ranging from technical to regulatory issues, that must be tackled to realize geothermal energy as a viable energy source. From a technical perspective, one of the significant challenges is the high capital expenditure and associated risks during the exploratory stage of geothermal energy projects. The exploratory phase involves drilling deep wells to determine whether geothermal energy is accessible and usable; however, this process is costly and fraught with uncertainties that deter many investors [12]. The drilling process in the exploration phase also required advanced technology and analysis to determine the feasibility of geothermal energy extraction.

Beyond demanding substantial investments from the outset, the successful use of low-enthalpy geothermal systems also entails technical difficulties. As these systems operate at low temperatures, their use and implementation require suitable technology for efficient energy extraction. This typically requires substantial investments in research and development to innovate and optimize existing technologies, making energy recovery economically exploitable for other purposes [11]. It implies the intersection of engineering and science, where technological breakthroughs enable systems to operate with greater efficiency and lower costs.

There are other barriers to geothermal energy aside from technical matters and issues. Complex government procedures and regulatory requirements, including regulatory barriers, characterize the permitting process. This process is also prone to being delayed [12]. In general, this complicates geothermal energy development, wherein every stage is subject to various rules and standards that aim to protect the environment and ensure safety. Making the regulatory procedures more efficient and less burdensome could lead to the improvement of the feasibility of geothermal projects through the reduction of their duration and the related costs.

To realize New York's geothermal potential, it is essential to address both technical and regulatory challenges through a thoughtful and coordinated approach that combines technology and policy. This will enable the more efficient and sustainable integration of geothermal energy into New York's diverse energy mix, paving the way for a brighter energy future. Practical solutions and cooperation between the government, industry, and academia should be the focus as New York confronts these geothermal systems, allowing the state to maximize its inherent energy supply, which is dependable and plentiful.

4.3. Economic and Environmental Implications

When examining geothermal energy development in New York State, various economic and environmental factors can potentially impact the viability of its successful implementation in the state's energy

sector. In terms of economic factors, one of the primary concerns that may arise regarding geothermal energy development projects is the substantial capital requirements necessary to initiate the projects. Most of the capital will be allocated for exploratory drilling and the development of necessary infrastructure for the geothermal system [11]. Nonetheless, the long-term advantages of utilizing geothermal systems are significant. After establishing the geothermal systems, the energy supplied by the systems can be utilized as a consistent and stable source of energy for the state, ensuring that energy pricing will remain stabilized over the years. It can protect against the price volatility caused by global economic and political situations affecting fuel supplies, which have been extensively utilized in New York State [12].

Geothermal energy holds great promise, especially in reducing environmental emissions. Moreover, when using geothermal technologies, the generators produce significantly lower emissions compared to the emissions profile of fossil fuels. The nature of geothermal energy helps conserve the carbon footprint, making it a leader in reducing carbon emissions in New York State. The ability of geothermal energy to conserve the environment aligns with efforts to develop alternative energy sources that can reduce global reliance on fossil fuels as a remedy for climate change. On the other hand, environmental concerns are associated with the use and adoption of geothermal energy. Monitoring and regulating the stability of the ground during geothermal drilling is a priority. Water usage efficiency following drilling also requires attention to ensure that geothermal energy does not impact groundwater or surface water in two ways [12].

For New York State to capitalize on geothermal energy to its full potential, investments and policies that support geothermal energy must be present. By creating an enabling environment for geothermal resources, the State can further strengthen its energy supply, sustainability, and security, both economically and environmentally. This will contribute to New York State's goals for a sustainable, greener future and provide an avenue for transitioning from a conventional energy supply that is not entirely sustainable to one that is. New York State may become a model for sustainable energy transition and development, inspiring other countries or regions to follow suit in pursuit of a sustainable energy future that is both achievable and beneficial in a holistic sense.

4.4. Geographical Evidence: New York State's Geothermal Reservoirs

The study of New York State's geographical factors also identified some areas that may be highly prospective for energy potential projects. New York's geology can permit geothermal energy generation in areas characterized by high thermal gradients [2]. There are certain regions in Upstate New York where the characteristics of sedimentary rocks enable the extraction of geothermal energy with relatively stable temperature gradients. This helps the low-enthalpy geothermal system develop in areas where the temperature is suitable for many uses, including heating and electricity generation. As Jordan *et al.* [11] emphasized, the importance of meticulous borehole research in these geological structures cannot be overstated. This detailed subsurface analysis is essential to a deeper understanding of the geothermal potential beneath the surface. By acquiring comprehensive data from these boreholes, scientists and engineers can assess the viability of geothermal projects with greater accuracy, thus optimizing resource utilization.

The Appalachian Basin and the Adirondacks are fascinating due to their significant geothermal potential. The presence of natural hot springs and thermal anomalies within these areas provides visible testimony to the geothermal activities occurring beneath the surface. These natural phenomena serve as indicators of thermal energy that can be harnessed for human use, making them key targets for exploration and development. To fully realize the potential of these geothermal hotspots, it is crucial to conduct thorough exploration and mapping initiatives. By doing so, we can effectively bridge existing knowledge gaps, paving the way for expanding geothermal energy projects. Such developments align with New York's renewable energy objectives, potentially advancing the state toward a more sustainable future by diversifying its energy portfolio and reducing its reliance on fossil fuels.

4.5. Case Study Application

Some working projects in New York State serve as examples of operational geothermal systems and

provide valuable lessons learned. The New York City Geothermal Initiative promotes the application of low-enthalpy geothermal systems in urban areas. It lowers the carbon footprint using geothermal heat pumps instead of traditional heating methods [11]. Therefore, its working system can integrate geothermal options into existing infrastructures, bringing energy efficiency and sustainability to urban areas. The geothermal system in the Finger Lakes area is another example. Here, the system is utilized for agricultural and residential projects, allowing people to enjoy lower energy consumption and costs, as well as more reliable energy systems. This example suggests that further development in geothermal systems can save energy and enhance energy security, despite initial investment costs and regulatory barriers.

5. WIND ENERGY OPPORTUNITIES

Wind energy in New York State presents substantial opportunities for expanding renewable energy capacity and minimizing reliance on fossil fuels. The South Fork Wind Farm is a successful example, demonstrating the feasibility and economic viability of such projects, boosting local employment, and contributing to energy supply stability. Additionally, wind energy's environmental advantages are noteworthy, as it produces minimal emissions and has a smaller land footprint than traditional energy generation methods [13]. To maximize the potential of wind energy expansion, continued technological innovations are crucial, particularly in developing more efficient turbines that can harness energy from areas with varying wind speeds and conditions. Furthermore, strategic location planning, especially in offshore regions, can further enhance the state's capacity to replace fossil fuels, providing a cleaner and more sustainable energy solution for the future.

5.1. Wind Energy Projects: New York State

The South Fork Wind Farm exemplifies a significant step forward in New York State's pursuit of harnessing renewable energy, mainly through wind power. This project demonstrates the practicality and economic benefits of wind farms, as they supply clean energy to thousands of homes and contribute to local job creation, thereby reinforcing their economic viability [13]. Furthermore, the farm's offshore strategic location enables it to capitalize on consistent and powerful wind flows, thereby optimizing energy generation while minimizing land-use concerns typically associated with onshore installations. The success of South Fork also underscores the importance of technological advancements in turbine efficiency, which enable these installations to operate effectively even at varying wind speeds [13]. As New York State continues to explore wind energy opportunities, projects like South Fork serve as key models for future developments, demonstrating the potential to significantly reduce reliance on fossil fuels while promoting sustainable energy practices.

The Maple Ridge Wind Farm is another notable wind energy project that was deployed in New York State. The project has significantly contributed to expanding renewable energy (RE) resources in New York State by optimizing local wind conditions to create an alternative energy source [14]. The project was strategically implemented in Lewis County and Major Ridge, as the project site was able to signal local economic development and energy independence. It is known for its community involvement approach, which minimizes the adverse environmental costs associated with wind energy deployment through comprehensive planning. Hence, the project would symbolize the development of turbine technologies. It utilizes durable and efficient classic-turbine technologies developed for different weather and climatic conditions. Therefore, research and development projects must continue for the complete optimization of any RE resource. The Maple Ridge Wind Farm project marks a further expansion of wind energy resources across various states in the USA. Most importantly, it enables further progress towards energy independence, as the project feasibly minimizes reliance on fossil fuels, thereby helping to combat climate change and pursue energy independence.

5.2. Expansion Potential and Economic Impact: Metrics

Thanks to technological innovation and the state's geographical characteristics, New York is likely to

increase its wind energy potential. The state has emerged as a top player in the wind energy industry. From an economic perspective, the expansion of wind energy capacities leads to the creation of new jobs and the strengthening of local economies. For instance, the South Fork Wind Farm has already delivered impressive results in terms of its economic contribution to the region [13]. Such projects highlight the importance of strategic site selection, especially offshore. Offshore locations offer unique advantages for harnessing wind energy, providing consistent wind speeds that enhance energy capture and efficiency. This, in turn, maximizes the potential energy output, making the investment economically viable and more lucrative. Furthermore, the effective development of wind energy projects is supported using specific metrics, such as average wave height and tidal range. These measurements are critical for assessing the feasibility and success of offshore wind energy projects. They offer valuable insights that guide optimal turbine placement, maximizing energy production and minimizing costs [5]. Analyzing these factors helps predict the expected energy yields and direct resources to the most promising sites.

Utilizing these elements of the natural environment, New York State can enhance its potential for transitioning from fossil fuels to renewable energy sources and sustainably develop its economy. With carefully thought-out policies and practices to support wind energy development in the state, New York can enhance its cleaner and more sustainable energy future while safeguarding its economic resilience for decades to come as part of global initiatives to combat climate change.

5.3. Environmental and Technological Challenges

Implementing wind energy in New York State presents unique environmental and technological challenges that must be addressed through well-thought-out strategic solutions. The development and operation of wind farms often result in habitat disruption, posing risks to local wildlife such as birds and bats and affecting the natural ecosystems they inhabit. This underscores the imperative for thorough environmental impact assessments that can pre-emptively identify potential adverse effects. Alongside these assessments, effective mitigation strategies must be devised, including altering turbine placement to avoid critical habitats or implementing technology to minimize impact on wildlife.

According to research conducted by Stehly *et al.* [13], offshore wind projects face significant technological challenges. These include concerns about the durability and efficiency of turbines, which need to withstand and operate optimally in the unpredictable and harsh conditions of the ocean environment [13]. This involves reinforcing physical structures to withstand corrosive saltwater and high winds, as well as developing adaptive designs that can maintain productivity despite these challenges.

In addition to these technological issues, the inherent variability of wind speeds poses a significant challenge to energy stability. This variability necessitates the incorporation of sophisticated grid management technologies. Such technologies are essential for balancing the energy supply and ensuring consistency and reliability in power delivery to consumers [13]. This could involve enhanced energy storage systems or smart grid solutions that can effectively manage the fluctuations in energy production. Finally, addressing these challenges requires sustained investment in research and development. This investment can drive advancements in turbine technology that have the potential not only to resolve current obstacles but also to optimize wind energy production. Such advancements can enhance wind energy's role in New York State's broader renewable energy initiatives, helping the state progress towards more sustainable and environmentally friendly energy solutions.

5.4. Case Study Application

The Maple Ridge Wind Farm, located in the Tug Hill region, exemplifies the successful implementation of wind energy in New York State, providing substantial contributions to the state's energy mix. This project, one of the largest wind farms in the eastern United States, has significantly enhanced local employment opportunities and reduced carbon emissions, demonstrating the dual economic and environmental benefits of wind energy [13]. Additionally, the project's scalability is evidenced by its expansion potential, which includes plans to increase capacity through the use of enhanced turbine technology. Another prominent

case is the Steel Winds project near Buffalo, which repurposes a former industrial site to sustain wind energy generation, highlighting the effective use of post-industrial landscapes to advance renewable energy initiatives [13]. Together, these projects demonstrate the feasibility of wind energy expansion and the capacity to transform regional energy landscapes in a sustainable manner.

6. HARNESSING WAVE AND TIDAL ENERGIES

Wave and tidal energy systems offer promising possibilities for expanding New York State's renewable energy portfolio, although they have various technological challenges that must be addressed. In recent years, significant advancements have been made in the field of wave power. These include developments in oscillating water column converters, which capture energy from wave movement by utilizing air displacement to drive turbines. Furthermore, innovative wave energy park designs are being experimented with to optimize energy collection over large aquatic areas, demonstrating a powerful potential to contribute effectively to the region's energy needs [6]. On the other hand, tidal energy technologies are currently at an important crossroads. To reach their full potential, these technologies need significant improvements to scale up effectively and to operate efficiently under various marine conditions. The challenge lies in developing equipment and systems that can thrive and be economically viable in New York State's diverse and often unpredictable marine environments [15].

Marine environments are particularly complex, requiring robust and flexible technologies capable of withstanding harsh weather and environmental conditions while maximizing energy output. Substantial investments in research and development are required to create solutions that can reliably sustain and enhance energy extraction operations. Successful resolution of these technological and environmental issues would be critical for New York State to realize the untapped potential of wave and tidal energy sources. Achieving this would enable New York to make notable progress on its sustainable energy future agenda, which promises vast ecological benefits and a substantial contribution to the state's diversification of energy resources. This diversification is critical for ensuring a robust energy strategy that meets future demands and reduces reliance on conventional and non-renewable energy sources.

6.1. Technological Advancements and Challenges

The recent technological innovations designed for the optimal use of wave and tidal energy resources reveal a unique opportunity to integrate these energy sources into New York State's renewable energy program. Namely, the wave energy converter (WEC) technology has shown a significant technological breakthrough, resulting in developments such as the floating oscillating water column. These state-of-the-art devices use the vertical movement of water bodies and convert their kinetic energy into electricity. The advanced control methods contribute to the efficiency and robustness of the WEC systems in variable marine conditions [15, 16].

However, despite these promising technological strides, several formidable challenges remain. One significant obstacle is optimizing the technology to endure the ocean environment's relentless and often harsh conditions. Ocean equipment must be robust enough to resist corrosion, extreme weather conditions, and biofouling, all of which can impair performance and reduce longevity. Another critical issue lies in the conversion efficiency of these systems, specifically how efficiently energy from ocean movement can be converted into electricity suitable for grid use [16]. The economic feasibility of wave and tidal energy technologies also presents hurdles that must be addressed. The high initial investment costs pose a substantial barrier. These include expenses for design, installation, and materials suitably resistant to marine conditions. Moreover, rigorous and prolonged testing is necessary to certify the reliability and efficacy of these systems over extended operational periods. Such extensive testing is essential to ensure safety and sustainability, yet it also adds to the financial burden [15].

By systematically addressing these technological and economic challenges, wave and tidal energy could play a crucial and transformative role in diminishing New York State's dependency on fossil fuels. This transition would pave the way for a more diverse and sustainable energy portfolio, reducing environmental

impact and enhancing the state's energy resilience. Through continued investment in research and development, as well as strategic policy support, wave and tidal energies may secure their place as a cornerstone of New York's clean energy future.

6.2. Economic Viability and Environmental Effects

Several critical factors predominantly influence the economic feasibility and potential success of wave and tidal energy projects in New York State. Chief among these are the substantial initial financial investments required and the intricate nature of the technology that must be deployed to harness these energy sources effectively. Regarding wave energy, significant capital is needed to develop and implement cutting-edge converters. These converters must be designed to efficiently capture and convert the energy from waves under various marine conditions, which poses a considerable challenge given the unpredictable and often harsh sea environments [15]. Nevertheless, these direct economic constraints were counterbalanced with an optimistic long-term forecast regarding the cost recovery opportunity, attributable to the ocean energy's renewability, continuity, and stability. Consequently, this energy type may aid in stabilizing energy prices and increase the region's energy security by limiting the substitution of conventional fossil fuel sources and preventing overall market fluctuations from causing instability.

In terms of environmental impact, wave and tidal energy sources are low-emitting and have a significantly smaller impact than other energy sources that rely on fossil fuels. This supports the goals that New York State has set for reducing carbon emissions and addressing climate change [15]. Nevertheless, a detailed impact assessment of the technologies on existing marine life should still be conducted to prevent any adverse environmental effects from hindering the integration of wave and tidal energy into New York's renewable energy plan.

7. COST-BENEFIT ANALYSIS: LEVELIZED COST OF ENERGY

A key element of the cost-benefit analysis in New York State's energy alternatives is the Levelized Cost of Energy (LCOE), which serves as a basis for comparing the relative economic attractiveness of various energy sources. Biomass energy has the potential to keep its LCOE low because pre-existing organic waste materials are available for use in its production. However, the issue is that biomass energy materials may adversely affect their supply chain and increase logistics costs. Furthermore, the availability of the right feedstock materials also presents a potential risk for raising the LCOE of biomass energy. Nonetheless, a potential benefit of the decision to utilize biomass energy is the positive environmental impact of converting the material from waste, which could lead to reduced landfilling and greenhouse gas emissions.

On the other hand, geothermal energy is among the economically promising options. Its main advantage is that it can produce permanent energy, which means it can provide a stable energy supply regardless of weather conditions. Furthermore, geothermal energy is generally more economically efficient due to its lower operational costs. Nonetheless, it requires significant upfront capital, especially for drilling and construction, which makes it less accessible to the market without financial or governmental aid. Wind energy has been gaining competitiveness during the last few years. It is a low-marginal-cost energy source with low operating costs after construction. New York's land characteristics allow large areas to capture high wind velocities, making wind farms particularly feasible. Nevertheless, there are downsides to this energy. It is dependent on location and time, meaning energy can be intermittent. Additionally, every new location must deal with zoning and local opposition issues.

Wave and tidal energy are emerging technologies that provide a predictable energy source, as the patterns of tides and waves in the ocean occur consistently. They are also emission-friendly energy sources that are geared to meet environmental sustainability targets. Unfortunately, implementing wave and tidal energy systems incurs high capital costs, which are necessary to minimize disruptions when integrating the technology into existing infrastructures. The integration of environmental challenges that might arise due to ecological path disruptions must be addressed to ensure that the renewable solutions are maximized for marine ecosystems [14]. Collectively, the evidence provides a comprehensive understanding of the various

alternative energy sources available in New York State, each with its specific benefits and drawbacks that warrant thorough consideration for their practical use.

8. CONCLUSIONS

In New York State's efforts to transition to sustainable energy sources, renewable energy options such as biomass, geothermal, wind, wave, and tidal energy prove to be a strong alternative to traditional fossil fuels. These energy sources have unique advantages, making them strong candidates for incorporation into the state's energy solutions. This characteristic of biomass energy also makes it a responsible economic option, as it converts waste into energy even while easing the pressure caused by greenhouse gas emissions. This solution serves its purpose in places with an extensive supply of organic waste. Geothermal energy sources are recognized for their consistency and stable energy generation since the Earth's internal heat is always available. It has an extremely low carbon emissions profile and can deliver an effective form of energy generation throughout the year. The year-round accessibility of geothermal energy systems makes them excellent candidates for reliably delivering renewable energy sources to meet base-load energy needs.

Another significant component is wind energy, which has vast potential in New York State due to its topography. Wind farms require less land space and can be built away from populated areas, which is appealing for development in rural communities. Enhanced turbine technology means that wind energy can derive more energy than previously. Wave and tidal energy also represent a unique type of ocean-based renewable energy. These technologies utilize the kinetic energy of ocean motions and related sources to produce electricity. The primary advantage of these energies is their ability to provide more stable electricity than other renewable sources. The disadvantages include the high costs and complex nature of marine energy deployment and operations. There are challenges to transitioning to a renewable energy future, despite its potential benefits. These include the high upfront costs for its development and infrastructure improvements. However, with technological progress and favorable policies, these challenges show promising opportunities for solutions. These energies have great opportunities to diversify New York's energy portfolio remarkably. Phasing out carbon-intensive fossil fuels will help New York achieve a sustainable path and boost its energy security while creating a replicable example of renewable integration to encourage nationwide transition.

CONFLICTS OF INTEREST

The author declares no conflicts of interest regarding the publication of this paper.

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