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A Study on Bioenergy, Its Precise Nature, and Environmental Effects

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Abstract

Compared to conventional fossil fuels, bioenergy has several clear benefits, including that it can be regenerated indefinitely and produced in huge quantities; as a result, it plays a key role in helping the defense of energy security. However, the growth of bioenergy could create significant environmental changes, the exact nature of which is still unknown. Based on compiled and published data, the report provides a summary of the environmental problems caused by bioenergy production. According to research, as the field of bioenergy continues to advance, increased focus is placed on protecting the environment, and water issues (i.e., water quantity and quality) are the biggest concern among the factors affecting bioenergy production. However, soil erosion has received the least attention. While we acknowledge that bioenergy production can have a negative impact on the environment in terms of water quantity and quality, greenhouse gas emissions, biodiversity and soil organic carbon and soil erosion, the extent to which these negative impacts are felt varies. It depends on the types of biomasses used, the locations of the land and the management practices applied. Finding reasonable plantations, suitable bioenergy crop types and optimal management approaches can help the environment and the sustainable growth of bioenergy. In this area, China's bioenergy production has lagged and cannot keep up with the country's increasing energy consumption; however, although this type of energy has a negative impact on the environment, the country has enormous potential and demand for biomass-based energy, especially due to urbanisation . In conclusion, this article is expected to serve as a reference and guideline on what is being done in bioenergy focused countries and to encourage the development of more effective and environmentally sound guidelines to promote bioenergy production in these countries. ("Bioenergy production and environmental impacts | SpringerLink") ("Bioenergy production and environmental impacts | SpringerLink")

Keywords: *Bioenergy, Benefits of Bioenergy, Harms of Bioenergy, Environmental Effects of Bioenergy, Bioenergy, and Nature*

1. Introduction

Within this research, the primary focus was on previous research published during the reference period that included any of the study's key terms. (2000–2017). Since 2000, the number of articles on "bioenergy" has been steadily increasing; On the other hand, the number of studies on the environmental effects of bioenergy (such as water quantity and quality, greenhouse gas emissions , biodiversity and soil organic carbon and soil erosion) has been increasing with an exceptionally low growth rate since 2000. In the cumulative publications on the environmental impact of bioenergy production in 2017, "water quantity and quality" comes first (16%), followed by "greenhouse gas emissions" (6%), "biodiversity and soil organic carbon". This suggests that bioenergy production is more closely related to water resources and water pollution than other environmental impacts. In addition, there has been a consistent increase in the number of publications on environmental impacts; this implies a greater focus on environmental protection while advancing the development of bioenergy.

2. Changing Potential Water Consumption and Land Use of Bioenergy Crops

The potential water consumption of bioenergy crops and changing land use are the two main channels through which bioenergy production can affect the amount of water available. For example, the large-scale expansion of corn ethanol production (first generation biofuel) in the United States promoted by EISA in 2007 was predicted to create potential water stress at regional and local scales (Gasparatos et al. 2011; Hoekman et al. 2018; Zhou et al . ("Conceptual framework.docx - Conceptual framework: one. Visual...") ("Conceptual framework.docx - Conceptual framework: 1. Visual...") 2018; Zhou et al. others 2015). This is because corn needs more water than other crops (such as wheat and soybeans) due to the additional water consumed in every crop. At a regional scale, conversion of land use, primarily from native farmland or grassland to perennial grasses such as switchgrass and Miscanthus can have a significant and direct impact on hydrological processes such as evapotranspiration (ET), runoff, water yield.

Nutrient pollution because of runoff and penetration into groundwater is one of the biggest concerns regarding the impact of growing bioenergy crops on the quality of the water supply. Nitrate is the most important contributor to food pollution. According to research by EPA (2011) maize has the highest fertilizer consumption and lowest nutrient utilization efficiency compared to other bioenergy crops. Therefore, increasing the number of plantings of maize or replacing it with maize continuously in a rotation system that includes soybeans will release significantly more nitrate to the waterways and lead to a reduction in the amount of nitrogen found in maize (Wu et al. 2014; Wu and Liu 2012) . However , there are important aspects to shifting land use from arable to perennial crops. Growing perennial grasses in basin size results in a reduction of 30-40% of total nitrogen loss compared to a standard cotton cropping scheme (Chen et al. 2017).

addition, growing perennial grasses requires almost minimal pesticide application, which is beneficial for improving water quality (Hoekman et al. 2018). Also, the previously mentioned water concerns can be controlled by selecting appropriate crop types and applying optimal management (such as harvest rate, irrigation, proper fertilization, and filter strip) (Qin et al. 2018; Wu et al. 2012). This shows that there is potential to strike a balance between bioenergy production and the conservation of water resources.

One of the most important targets to be followed while producing bioenergy is to reduce greenhouse gas emissions . Greenhouse gases (GHG), carbon dioxide (CO2) and nitrous oxide (N2O) are two key components due to the copious amounts of each and various production methods (Dunn et al. 2013; Qin et al. 2016). Numerous scientific studies have shown that the use of fossil fuels results in much higher levels of carbon dioxide (CO2) emissions than the direct use of biofuels . However, this theory has been refuted (Dunn et al. 2013; Fu et al. 2014; Wang et al. 2012). Liu et al. (2017) determined that the maximum possible switchgear production on marginal land could reduce emissions by the equivalent of twenty-nine million tons of CO2 per year if fossil fuel were to replace it. The model's findings also show that for transportation use in the United States, 40-85% of greenhouse gas emissions can be reduced by using ethanol compared to gasoline

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on a megajoule (MJ) energy basis ; however, the extent to which GHGs could be reduced varied depending on the raw material. There are also significant concerns about the indirect impact of bioenergy production on CO_2 emissions (Dunn et al. 2013; Searchinger et al. 2008). An example of this is the degradation of CO_2 emissions caused by changes in land use (Hill et al 2006; Sang and Zhu 2011). Harris et al. (2015) noted in a recent review of potential biofuel impacts that land transitions from arable crops to second generation bioenergy crops may result in a slight reduction in CO_2 emissions , whereas land conversion from native grasslands to first generation bioenergy crops and short rotation coppice (SRC) crops may result. ("Bioenergy production and environmental impacts | Geoscience Letters ...") ("Bioenergy production and environmental impacts | Geoscience Letters ...") These findings were found in the context of land transitions from arable crops to second-generation bioenergy crops. When considering how to reduce CO_2 emissions , it is essential and important to consider the many types of bioenergy products and the optimal management strategies for these products.

Another prominent greenhouse gas is nitrous oxide (N_2O), which has the potential to contribute to global warming 298 times more than carbon dioxide (CO_2). Agriculture is the primary sector responsible for producing this gas (Williams et al. 2010). Like CO_2 emissions , changes in land use are the main variables affecting N_2O emissions. For example, Harris et al. (2015) summarized that the effect of converting arable land to SRC, and perennial grasses resulted in an exceedingly small reduction of 0.2 t/ha for NO emissions, while the effect of converting grassland to SRC could result in a slight increase in N_2O emissions . . ("Bioenergy production and environmental impacts - JNKVV") This was the case when the two types of land conversion were compared. In addition, Liu et al. (2011) argued that using biomass produced on marginal lands for power generation could result in a beneficial environmental impact on national greenhouse gas emissions if it were to replace fossil fuel in the power generation process. On the other hand, the development of corn production, which is suppressed by the need for ethanol, may also accelerate N_2O emissions . Compared to growing other crops, maize needs much larger amounts of fertilizer, especially nitrogen fertilizer, which is the substrate of the soil denitrification process, and directly contributes to the increase in NO emissions . Therefore, making an informed decision about the type of

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bioenergy plant to be grown and where it will be planted is also extremely important to reduce N2O emissions .

3. Biodiversity and Organic Carbon

The level of biodiversity is an important indicator of the quality of both food production and ecosystem services (Qin et al. 2018). The original land use situation, the type of bioenergy production system, and the shape of the landscape all play a role in determining the impact of biofuel production on biodiversity (Correa et al. 2017; Immerzeel et al. 2014). Land use conversion is the most crucial factor affecting biological abundance through direct changes in land use conditions and production system depending on plant type and planting sites. Land use conversion occurs when the land is used for other than its intended purpose. For example, it has been determined that direct replacement of grasslands with various biofuel crops can lead to an increase in local productivity level and contribute to the preservation of ecosystem functions because of climate change (Correa et al. 2017; Sang and Zhu 2011). Additionally, several studies have concluded that growing Miscanthus has a significantly smaller negative impact on biodiversity compared to growing annual crops. This is primarily because perennial plantings offer stable habitats to support a variety of wildlife (Rowe et al. 2009; Werling et al. 2013). Also, growing energy crops in low-yielding or marginal areas can improve landscape design. In addition, improved management methods can reduce the risk of biodiversity loss in certain areas; however, this concept needs further research (Manning et al. 2015; Sang and Zhu 2011).

Elevated levels of soil organic carbon (SOC) are beneficial for soil water retention, soil biodiversity and crop production. Soil organic carbon is the most important indicator of soil quality. ("The Contribution of Some Soil and Crop Management Practice on Soil ...") ("The Contribution of Some Soil and Crop Management Practice on Soil ...") Bioenergy production has an impact on SOC through three main channels: residue removal, land use changes and tillage. In general, the practice of collecting residues from dead plants that are restored to originally cultivated fields can directly accelerate the loss of SOC due to low carbon input (Hoekman et al., 2018). On the other hand, loss of SOC can be regulated, at least to some extent, by adequate residue management, such as limited residue removal and extra organic matter inputs (such as fertilizer use) (Robertson et al. 2014; Sheehan et al. 2014; Wu et al. 2015).

Plant residue is the primary source used in biochar production. If crop residue is used in conjunction with adequate technology, it is possible to produce substantial amounts of biochar with currently available crop residue . Since it can not only collect SOC but also absorb inorganic carbon (i.e., CO2) present in the air (Li et al. 2017), biochar application can help improve air quality (for example, by reducing nitrogen oxides, methane and PM2.5 emissions). This could help improve the function of the carbon sink in the agricultural sector (Pourhashem et al. 2017). Management practice is the second factor contributing to SOC loss, in addition to soil degradation. For example, Drewniak et al. (2015) used a biogeochemical model to evaluate the effects of tillage methods on SOC and found that tillage can always cause SOC loss. This was discovered after simulating the effects of tillage techniques on SOC. Similarly, field trials have concluded that SOC levels can be significantly reduced by disturbance use (such as tillage procedures) (Cheng 2009; Ouyang et al. 2015; Warren Raffa et al. 2015). Additionally, land conversion is another crucial factor contributing to the change in SOC . The transition from arable to perennial grassland or the cultivation of bioenergy crops in marginally cultivated areas is often meant to imply bioenergy driven change in land use that has beneficial effects on carbon sequestration. Growing miscanthus in arable land will result in carbon sequestration ranging from 0.42 to 3.8 Mg C/ha per year, according to the findings of a recent analysis (McCalmont et al., 2017a). An organic aggregate with electronegativity is known that can absorb CO2 from the air and be beneficial both to the carbon pool of agricultural soil and to the maintenance of air quality (e.g., reduction in nitrogen oxides, methane and PM2.5).

Biochar application is important for increasing the organic carbon in the soil due to the electronegativity of this organic aggregate (Pourhashem et al. 2017). When generating bioenergy, considering biodiversity and carbon sequestration, it is vital to identify the most suitable regions, the most adaptable plant species, and the most appropriate management strategies.

4. Soil Erosion

Soil erosion is a major concern in bioenergy production as it reduces the quality of the soil and the resulting productivity of both natural and agro-ecosystems. This is because soil erosion is a quite common and fundamental problem. The increase in the amount of land used to grow maize, clearing of residue and conversion of land use are the three main contributing factors to soil erosion. As a result of the increased demand for ethanol, more land is set aside for growing maize, which has slightly looser planting spacing than other crops. This can have major detrimental effects on soil retention. It was predicted that if maize cultivation increased in these lands, the benefits of conservation measures on soil retention would be further diminished. On the other hand, it has been estimated that cultivating existing maize crops with appropriate tillage practices will also reduce soil erosion (Hoekman et al. 2018). Since crop residue allowed to remain on the soil surface can function as a buffer against the erosive forces of wind and water (Blanco- Canqui and Wortmann 2017), the collection of crop residues can increase the risk of soil erosion as it provides less physical protection. for the soil surface (EPA 2011; Lal 2005). This can result in the loss of both nutrients and SOC . According to Cibin et al. (2016), however, soil erosion caused by high residue removal can be mitigated with appropriate management options. These management options include direct introduction of organic matter as well as other preventive measures. Additionally, changing land use can worsen erosion or protect soil from it. For example, converting forests to perennial bioenergy crops may increase the risk of soil and water loss (Liu et al. 2012), whereas converting grain crops to perennial grasses can have positive effects on soil and water retention. (“Bioenergy production and environmental impacts | Geoscience Letters ...”) (“Bioenergy production and environmental impacts | Geoscience Letters ...”) These effects can be attributed to the fact that perennials produce more sod than annuals (Cooney et al. 2017). In addition, perennial grasses, particularly switchgear, have the potential to reduce the amount of sediment carried by streamflow and the amount of soil eroded, as well as increase the amount of water used and the amount of water absorbed by the soil. This shows that perennial plants are advantageous in terms of soil and water saving compared to traditional crops grown in these areas (Brown et al. two thousand; Cooney et al. 2017). Considering this, the cultivation of perennial grasses, especially on sloping arable land or areas prone to erosion, has greater potential than ethanol production from maize.

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5. Analysis of the Impacts of Bioenergy Production on the Environment Throughout the Entire Life Cycle

Life cycle assessment, also known as LCA, is a widely used method to measure the environmental impacts associated with all phases of a product's life, from the extraction of raw materials to its processing, distribution, use and end. -Your life. This method goes from the cradle to the grave (Pennington et al. 2004). Life cycle assessment (LCA) has been widely used to analyze the pros and cons of bioenergy production for the environmental environment in various parts of the world (Boschiero et al. 2016; Cherubini and Stromman 2011; Dias et al. 2017; Homagain et al., al. et al. 2015). According to Fazio and Monti (2011), who studied the environmental effects of growing perennial energy crops from the cradle to the grave , significant greenhouse gas emissions of up to 5 Mg/ha fossil-C can be reduced using perennial crops. Additionally, perennial herbs can be beneficial in reducing N2O emissions, which can result in emissions that are about 40-50% lower than those produced by fossil fuels. Despite harmful effects on the surrounding environment, Life Cycle Assessment, Schmidt et al. (2015) show that growing perennial grasses on marginal lands and using them for heat and power generation can result in significant reductions in greenhouse gas emissions . In the case of Miscanthus , these reductions can reach 13 t CO2 equivalent per hectare per year.

Qin et al. (2018) researched that switching from fossil fuels to biofuels in China could also greatly reduce the country's overall air pollution levels (for example, particulate matter). In addition, life cycle assessment (LCA) studies have shown that bioenergy production from agricultural residues has positive effects on the environment (Guerrero and Muoz 2018; Soam et al. 2017; Tonini et al. 2016). Soam et al. (2017), the traditional method of generating electricity in India produces lower amounts of greenhouse gas emissions than electricity generation from rice straw . According to the findings of Tonini et al.(2016), biofuel production from agricultural residues that does not involve a change in land use is a potential alternative for reducing emissions from a life-cycle perspective . According to research conducted by Parajuli et al. (2017), planting willow and alfalfa for use as feedstock for bioenergy has the potential to result in the sequestration of larger amounts

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of soil organic carbon, which will lead to a smaller carbon footprint. The cultivation of bioenergy crops (e.g., Miscanthus) has also been recognized as an effective CO2 sink in the UK (Mcccalmont et al. 2017b). This suggests that bioenergy production could be a good option to sequester more carbon in the soil. Overall, one conclusion that can be drawn from the talk so far is that bioenergy production can be advantageous not only for reducing greenhouse gas emissions , but also for SOC sequestration. However, there are only a few reports based on LCA regarding other environmental concerns such as water depletion and water quality dynamics throughout the life cycle of bioenergy plants. This is because the impacts of bioenergy production on such issues vary depending on the type of biomass, the land resource and the management practices used. A life cycle assessment (LCA) should be used in further research to determine the extent to which bioenergy production is harmful to the natural environment.

6. Bioenergy Potential and Environmental Impacts in China

Home to a fifth of the world's population, China is also a rapidly expanding economic entity experiencing rising levels of energy consumption. Bioenergy generation to replace traditional fossil fuels to reduce carbon emissions and protect our home on earth is a major concern and urgent concern for China as well as the rest of the world. In fact, China has substantial untapped potential for bioenergy production. "China is one of the largest agricultural countries in the world." (“Balancing straw returning and chemical fertilizers in China: Role of ...”) (“Balancing straw returning and chemical fertilizers in China: Role of ...”) It has about 130 million hectares (Mha) of agricultural land producing more than six hundred million tons (Mt) of crop residue. These crop residues have the potential to be used as a feedstock for biofuel production (Jiang et al. 2012; Liu et al. et al. 2012 ; Sang and Zhu 2011). However, according to Sang and Zhu (2011), about two hundred million metric tons of crop residues were incinerated with a low conversion efficiency, and more than one hundred million metric tons were directly burned in the field. This resulted in the release of additional carbon that was already stored in the system, which indisputably contributes to air pollution. If more agricultural residues were used with better efficiency, the amount of bioenergy produced would be much greater and the amount of energy

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consumed would be more acceptable. The application of biochar produced using residue is important for increasing organic carbon, as it is an organic aggregate with electronegativity that can absorb CO_2 from the air and benefit both the carbon sink of the agricultural soil and the preservation of air quality . soil . In addition , biochar application is important for increasing the organic carbon in the soil (Pourhashem et al. 2017). For this reason, it is especially important to create more effective methods to make the best use of agricultural waste. Cultivation of bioenergy crops can take advantage of China's large arable land, which either has low productivity or is located on the slopes (Fu et al. 2014; Lu et al. 2014; Sang and Zhu 2011). According to the estimation of Sang and Zhu (2011) China has more than one hundred million hectares of land that can be used for growing bioenergy crops. These crops have the capacity to produce one billion tons of biofuel feedstock if all of China's degraded land is converted to miscanthus . In addition, China has many plant species and genetic resources, especially for miscanthus . In conclusion, China has significant potential to develop suitable bioenergy crop types to strike a balance between bioenergy production and environmental protection. Due to the gap in bioenergy development and the falling rate of renewable energy consumption, more effective policies to promote bioenergy production are urgently needed compared to the efforts of the United States and the European Union. to protect energy security and mitigate the effects of climate change. In China and other developing countries and other countries around the world, the primary goal of scientific research should be to derive additional knowledge and the best possible management to drive bioenergy development and environmental protection.

As a result of its ability to support global climate change goals as well as broader environmental, social, economic, and sustainable goals, bioenergy is a potential source for renewable and low-carbon energy systems that can capture atmospheric carbon while also providing ample space. There is scientific evidence showing the advantages of using bioenergy, but results are often variable and subject to uncertainty. In addition, it is essential to consider the various non-carbon sustainable aspects of bioenergy systems. If we consider bioenergy solely as a component of the energy sector, we cannot guarantee such things as sustainable biomass production and supply, clean uses with minimal adverse health effects, and energy vectors that are both fair and economical. Context, specific and long-term methods are needed to ensure that bioenergy provides

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the necessary comprehensive emission reductions. These techniques are crucial for understanding the synergies and trade-offs that exist between bioenergy-related agricultural and forestry systems . Evaluating the impacts of bioenergy on the environment and wider sustainable impacts should consider complete supply chains as well as direct and indirect stakeholders, their drivers, benefits, and challenges. With these, we need to examine and evaluate bioenergy and its implications in the context of the system of which it is a part, as well as its immediate and broader implications for the environment, the economy and society.

7. Using Bioenergy for Power Generation

Bioenergy is by far the largest supplier of renewable energy to the transportation and heating industries and contributes a sizable portion of the renewable power used to generate electricity. In the same year, bioenergy provided about five hundred Tw of electricity. While annual capacity additions have been stable at around 5-7 GW per year between 2010 and 2016, bioenergy only plays a significant role in the power generation portfolios of a select few countries around the world. Therefore, in 2016, around 90 percent of the total capacity was in just twenty-six countries. This indicates that bioenergy use is increasing, but in many cases is not expanding aggressively to a wider variety of countries, despite the availability of biomass resources .

As time passes, Asia is expected to replace Europe as the largest market for the distribution of bioenergy electricity. This is due to several factors, including the increase in energy demand, availability of low-cost sources for biomass waste and residue, and long-term targets in developing countries such as China, India, and Thailand.

One of the major challenges faced by bioenergy in the power generation sector is the prohibitive cost of electricity generation and the limited scope of reducing these costs due to the overall maturity of the technology applied. This is one of the biggest challenges facing bioenergy. Traditional power plant methods, such as the direct combustion of solid fuels or the use of gaseous products of biomass in gas turbines or gas engines, serve as primary inspiration for the development of these technologies. Even when combined with heat generation in most cases,

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electricity generation from biomass still has little potential to improve project economy or technology.

Since the beginning of human history, numerous methods and technologies have been used to prepare food and heat indoor spaces using biomass in many ways. At this point in time, biomass has turned into an energy source that is expected to be an environmentally friendly and sustainable economic model. For bioenergy to continue to have a sustainable future, the demand and supply mismatch at low prices must be minimized by farmers as much as possible. A comprehensive understanding of bioenergy dynamics requires familiarity with the bioenergy market in addition to other renewable energy sources, several types of bioenergy, conversion methods and by-products of these conversion technologies. The term "biofuel" refers to all the various fuel types (liquid, solid and gas) that can be produced from biomass by various methods. Gaseous and liquid forms of biofuels created through pyrolysis, fermentation , gasification, or transesterification are used in industrial processing and transportation, respectively.

Solar energy makes the largest contribution to the energy content of biomass. In the presence of light, plants use carbon dioxide in the air and water in the soil to produce glucose and oxygen. This process requires the presence of both carbon dioxide and water. Photosynthesis is the name given to the process by which glucose is produced by plants in the presence of sunlight. Photosynthesis cannot take place when there is insufficient light.

Glucose, which has the chemical formula 6H12O6, is a carbohydrate that can turn into cellulose and starch in plants, and when combined with nitrogen, it can turn into protein and other molecules. The other by-product is oxygen, which is released into the atmosphere and used for breathing by living organisms such as plants and animals.

It is important to note that the meaning of several words depends on biomass. The Energy and Environmental Research Establishment (EERE) defines biomass as "an energy source derived from organic materials". The Food and Agriculture Organization of the United Nations (FAO) defines biomass as "a substance of biological origin that is located in geological formations and does not contain fossilized material". The term "recent biological material and animal waste" is how the term biomass is defined in the first chapter of this book.

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Modified definitions of these terms are often used in the derivation of certain terms. For example, the chapter on wood energy defines wood bioenergy as "energy derived from the direct or indirect conversion of biomass from trees and woody shrubs". This definition is often used in the process of deriving certain terms. Similarly, descriptions of alternative bioenergy possibilities can be developed from first, second and third generation biofuels.

The meaning of a phrase may differ depending on the source of the information used. It is especially important to consider the context of use. Below is a list of the most important words defined by various organizations and experts.

But as natural gas, solar and wind power prices continued to fall, the planning process for power systems had to adapt to accommodate these new realities. Solar and wind power currently have the lowest leveled energy cost of any energy source in two-thirds of the world and will have the lowest in every region of the world by 2030 (Bloomberg New Energy Finance, 2019).). NextEra Energy is one of the largest energy companies in the United States. NextEra in 2019 The Energy CEO stated that combining solar and wind power with energy storage would be more cost-effective than coal, oil, or nuclear power, and that it would be "massively disruptive for the traditional fleet" (Roslund , 2019).). It is no longer necessary to have electricity at base load, which is rarely turned off , but instead to have flexible and dispatchable power as needed. This is because intermittent renewable energy sources make up a growing portion of power.

In a grid that significantly reduces carbon emissions , flexibility will be needed over a wide period, from minutes to seasons. There are numerous software and hardware solutions as well as management approaches for networks to meet a wide variety of flexibility requirements. These include demand-side measures (using prices to change the timing of demand from industrial and residential customers), flexible sources of electrical power sources (such as gas and hydro), electricity storage (batteries, pumped hydro , compressed air), storage chemical bonds (hydrogen production and synthetic fuels; Pierpont , Nelson, Goggins , and Posner , 2017) and improved integration of power grid areas (Schaber , Steinke , Mühlich , and Hamache) to provide greater flexibility.

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The falling price of batteries means that as early as 2030, battery storage will be cheaper than a new combined cycle gas turbine to enable intraday energy transitions in environments where flexibility is required in brief time periods (minutes to hours). This is because the cost of batteries has decreased (Polymeneas , Tai and Wagner, 2018). However, given the longer timeframes, it seems uncertain that for at least the next few decades, pairing intermittent renewable energy sources with storage will be the most cost-effective way to provide resilience. At high penetrations of solar and storage, it becomes difficult to replace the remaining natural gas or other 'firm' generation capacity with solar and storage without significantly overbuilding solar or adding very long-term storage. This is because high solar and storage penetrations require significant overbuilding of solar capacity (Davis et al., 2018). For example, Ming , Olson , DeMoor , Jiang and Schlag (2019) conclude that although emissions from the electricity sector have decreased by 90-95%, 17-35 GW of natural gas capacity will still be required by 2050. This was the case even though the number of days this capacity was used decreased significantly. In their deep decarbonisation studies for California , Ming, Olson, DeMoor , Jiang , and Schlag used California as an example. While this technology is not yet the most cost-effective way to produce hydrogen, several studies have found that "renewable hydrogen" (hydrogen produced from variable renewable sources via electrolysis) can provide an economically viable source of long-term storage (Davis et al., 2018).

Therefore, rather than replacing 'base load' power generation, bioenergy will, by mid-century, compete with other forms of energy to deliver robust electricity that can be used for load balancing throughout the day and during changeover. Bioenergy is unlikely to form a large component of this energy mix due to many varied factors.

First, because of the cheap price of natural gas in some countries, such as the United States, natural gas infrastructure is more widespread and expanding at a much faster rate than bioenergy infrastructure. In areas where the necessary infrastructure is already available, the option that will provide the lowest total cost for the company's electricity will be the use of natural gas power plants that are in operation, albeit with a lower capacity factor. Their emissions will be low since they will only be online for short periods at a time . It is also highly likely that these plants will benefit from CCS or hydrogen by the middle of this century. The United States currently offers

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tax credits to power plants that can capture and store carbon dioxide, and investments in modern technologies that can capture carbon dioxide are increasing.

8. Conclusion

Biofuels that require copious amounts of land are likely not to be the most desirable source of bioenergy used for firm power. Instead, an increase in the use of biogas, a low-carbon fuel that can be created from manure, municipal garbage, and sewage, is expected. For example, biogas was responsible for 17.2% of Germany's renewable fuel-based electricity generation in 2016, which was only a marginally smaller share of PVs (Liebetrau, Denysenko and Gromke , 2017) . On the other hand, by 2050, large baseload power plants, such as those that no longer use wood pellets as a fuel source, would not be able to meet the flexibility requirements of the future electrical grid due to the challenges of scaling up to meet energy output. The economic incentive for affordable distributed power will increase significantly as the energy market becomes increasingly saturated with intermittent renewables. This is because the market has become more saturated. While diverse types of bioenergy are part of the solution to meet this demand, demand-side responses of such bioenergies will need to compete with a wide variety of other potential solutions such as battery storage, hydropower, concentrated solar power. This scenario would have little in common with the traditional view of substituting baseload coal for baseload bioenergy, assuming that the former is the cheapest low- emissions fuel. More research is needed in the literature on this subject .

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