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Energy Transformation Development Strategies: Evaluation of Asset Conversion in the Regions

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Abstract: Manifestations of energy transformation are visible throughout the developed world. As the threat to the survival of humanity arises, the countries of the world are starting to take faster and more specific actions to transform the energy sector. One of the energy transformation strategies is the decentralized development of the energy system in the regions. This concept is especially relevant at this time, when centralized sources of energy production and supply are becoming the target of physical and cyber attacks. The purpose of this article is to form theoretical assumptions for the smooth implementation of the decentralization of the energy system. This article aims to remove obstacles to short-term energy transformation. The novelty of this article is related to emphasizing the role of biomass cogeneration in achieving energy system efficiency and greening. Mathematical modeling based on RSM is used in the article. The established factors of the market structure revealed that the efficiency of energy production is based on the use of cogeneration and the markets for raw materials and energy can be attributed to different types. The results of this study showed that the optimal combination of biomass cogeneration can ensure competitive energy production. This article is relevant because it offers transitional solutions until adequate hydrogen utilization and energy storage solutions are developed.

Keywords: energy transformation; cogeneration; renewable energy

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1. Introduction

Climate change, energy crises, military actions in the world, and unstable oil prices create enormous challenges for the world's nations. The need to use less fossil fuels opens opportunities for new or somewhat neglected green technologies. To reform the energy sector, it is necessary to have a clear and measured strategy. This allows for the identification of the potential of renewable resources in each space while finding sources of financing for the transformation. The use of renewable resources makes it possible to solve an actual problem of the developed world—as the population of cities grows, the economic vitality of regions drops significantly. By creating new energy production capacities in the regions, social exclusion is reduced and the main resources of the regions are better used—land areas, farms, and biomass sources. Nowadays, mankind is experiencing the third significant transformation that converts conventional fossil fuels to new energy. The future development will go along with the three major trends—resource type carbon reduction, production technology intensification, and utilization method diversification [1]. Based on these directions of transformation, the main investment decisions will be made, which will promote the progress of the energy system. Humanity is so far the least advanced in carbon collection and burial technologies; however, the development of other trends allows for tangible progress.

Recently, a process of the decentralization of energy production has been observed when large local power plants are abandoned. Instead, the focus is on solar or wind parks, modular biomass power plants, and the potential of using biogas. This is related to the changing energy sector—the increase in the number of generating consumers, the construction of efficient houses, and the increase in the number of wind and solar power plants. The year 2030 is predicted to be the turning point of new energy development in which the cost of new energy will drop to be able to compete with fossil energy; new energy will be promoted and applied on a large scale from 2030 to 2050 and the downward trend of carbon emissions will accelerate [1]. The idea of decentralization has been explored by global leaders in renewable energy but is now becoming a global trend. The promotion of decentralized power generation includes small-scale renewable energy systems, combined heat and power (CHP), and microgrids [2]. In addition, transformation solutions are complex and inseparable from each other. To increase the use of renewable energy resources, it is necessary to adapt the energy distribution networks. Although the concept of smart grid is not fundamentally new, its practical application is gaining momentum. Implementation of smart grid technologies could enhance grid flexibility and reliability. In addition, it encourages demand response programs to adjust energy consumption patterns based on supply and demand fluctuations [3]. The complexity of the transformation determines the fact that the process of transition to the use of renewable resources is complex and requires maximum involvement from politicians, businesses, and society.

Another trend is the development of energy storage technologies. As the energy production method changes, energy consumption solutions also change. Instead of continuous, polluting energy production, renewable but unstable energy is relied upon. The effect of instability is reduced by the activities of hydroaccumulation power plants and battery parks. Even more progress in energy storage solutions is expected soon. To address the global challenge of environmental pollution and the energy crisis, power devices, such as fuel cells, metal-air batteries, lithium-air batteries, lithium-ion batteries, lithium-sulfur batteries, and water electroliers; the electrochemical production of ammonia; supercapacitors; and photovoltaic devices are important energy conversion and storage technologies, which have caused widespread concern due to their merits regarding energy-efficient, eco-friendly, sustainable, and clean systems [4]. The development of energy storage solutions would improve the prospects for the use of renewable energy, especially in those countries where energy consumption is the highest, utilizing advanced energy storage systems, including batteries, pumped hydro storage, and thermal storage, to store excess energy and address intermittency issues [5]. The main obstacles to progress are the lack of infrastructure and the unwillingness to abandon old production and consumption habits. The lack of infrastructure can be compensated by rigorous planning. Energy storage technologies are combined with demand-side management. Reducing the need for energy storage requires contracts with consumers to adapt their consumption or production processes to surges in energy supply. The goals of all mentioned innovations are lower use of fossil fuels, more stable energy prices, and the ability to create innovations on a wider scale than is currently the case. The mentioned innovations can significantly contribute to the realization of these goals as they are focused on decarbonization and wider inclusion of regions in economic processes.

However, the presented transformation solutions are related to consistent long-term performance. As the pace of global warming continues to accelerate, there is a need to identify operational solutions that would be relevant in the short term. The use of these solutions would make it possible to accelerate the use of renewable resources while preparing for the essential stages of the transformation. The topic discussed in the article is important in that, currently, the focus is more on increasing the amount of energy production but not on the qualitative development of the energy system. Balanced energy consumption and the use of local resources would allow the acceleration of the scope of energy transformation. The main problem addressed in the article is how to deal with the challenges of short-term energy transformation. This is relevant for all stakeholders because, until hydrogen energy and electricity storage are developed, other stable green electricity generation solutions will be needed. In this case, refined solutions are proposed that allow the use of local biofuel for cogeneration purposes. Studies of individual energy sectors can help identify areas where a short-term transition to renewable energy is possible. The aim is to find a favorable energy transformation model that would create conditions for decentralized, sustainable, and profitable energy activities in the short term. The contribution of the article is to formulating the factors of the market structure that create conditions for the profitable use of local biomass and the decentralization of the energy system. This can be considered the novelty of the article. Another new aspect is the creation of an experimental model that allows for the assessment of optimal production volumes in terms of electricity price.

2. Literature Review

The global energy sector is characterized by an increasing use of synergistic effects and the interaction of different technologies. It becomes possible to produce different types of energy from one type of fuel, depending on the energy demand. As hydrogen technology expands, an even greater breakthrough in energy is possible, such as developing a hydrogen economy through green hydrogen production using renewable energy sources. Hydrogen is being explored as a clean fuel for various sectors, including transportation and industry [6]. This will increase the volume of electricity production. However, hydrogen energy is a long-term and extremely ambitious project with an uncertain financial payback period. Until hydrogen solutions become cost-effective, it is important to discover those opportunities that ensure the transition to green energy now. In addition, it is necessary to combine technological and tax aspects to achieve faster transformation. Previous studies have shown that the environmental tax and green technology are important drivers for improving energy efficiency and productivity and lowering energy intensity [7]. At the same time, there is agreement that regions are a favorable environment for energy transformation [8]. Fiscal aspects and political activity are important factors in the case of transformation as certain social risks are encountered, at least in the short term. In the case of another study, it is stated that achieving transformation from the economic and power structure based on non-renewable energy resources to one based on renewable energy resources is processed at the cost of diminishing economic activities [9]. Such a risk may arise if the energy transformation actions are carried out recklessly, without thinking about the possible social consequences (jobs eliminated, employee qualifications not changed, etc.). In the future, the situation will be the opposite. The contributions of RES to changes in the future employment levels are quite significant for the short to medium term while those coming from non-renewables are significantly smaller in comparison, partly because most of the jobs from non-renewable energy deployment are generated in countries outside the EU, particularly Asian countries [10]. One of the opportunities to create workplaces in renewable energy is the green supply chain. It can be another aspect of energetic transformation. The green supply chain plays an important role in promoting enterprise energy conservation and consumption reduction, optimizing energy consumption structure and other aspects [11]. The efficiency component is a particularly important part of the energy transformation. In addition, it is necessary to emphasize the aspect of promoting the improvement of energy efficiency, which is related to increasing the rationality of energy use in the places of its consumption, as well as limiting losses in the process of its transmission [12]. Public policies directed to improve environmental awareness should be directed first towards those regions where the exposure of the citizens to pollution is lower [13]. The European Union understood these risks—the European Green Deal sets out guidelines on how to make Europe the first climate-neutral continent by 2050 and provides the most comprehensive package of measures enabling Europe's inhabitants and businesses to benefit from a sustainable ecological transformation [14]. The abundance of renewable energy technologies encourages a review of the directions of transformation from a sustainability perspective. Previously applied solutions for the use of renewable resources today may not be compatible with the perspective of energy transformation. In previous studies, it was established that solar energy is the most appropriate and sustainable one, followed by biomass energy. Otherwise, hydro energy is the worst and least sustainable renewable energy resource [15]. The phenomenon of energy transformation originates primarily from an environmental perspective. To achieve a faster transformation, a focus on households has emerged as it is possible to test certain technologies and avoid the shock of changes. Commonly available technologies generating energy from renewable sources for households and enterprises solve problems associated with the systematic increase in energy demand and a limited amount of traditional energy sources, which are becoming increasingly expensive and cause significant environmental degradation. The problem of energy transformation is a key issue related to the possibility of the further development of world economies [16]. The inclusion of consumers in the energy system also includes the concept of producing consumers or, in other words, civil power engineering. In this case, residents' investments in independent energy production are encouraged. Civic power engineering is a vision in which the citizen becomes an entity and is not subject to the energy market and, additionally, has a virtual advisor in the form of smart grid and data processing technologies in a "digital cloud" [17]. In this case, it is necessary to strengthen the grid so that it can withstand sudden spikes in energy production. However, this does not eliminate the problems created by sudden changes. To avoid the shock of changes, two main directions are currently applied. Based on China's example, it is required to promote renewable energy and electricity through various effective policies, e.g., accelerating the "coal to electricity" and "coal to gas" projects [18]. However, the choice of gas as an intermediate fuel will only delay the prospects of energy transformation based on renewable resources. This article will look for possible perspectives that would allow the use of renewable sources in the interim period to ensure a stable energy supply and balancing functions of the energy system.

2.1. Conversion Characteristics of Different Production Technologies

2.1.1. Electricity Production

The electricity generation process is traditionally carried out in high-power coal and gas power plants, as well as in nuclear power plants. In recent years, there has been an increase in energy production from wind or solar energy. It should be noted that electricity continues to be stably produced in biofuel cogeneration power plants and biogas power plants. The electricity sector plays a pivotal role in modern society, serving as the backbone of economic development and daily life. Over the years, this sector has witnessed transformative changes driven by technological advancements, environmental imperatives, and shifting energy policies [19]. To change the way electricity is produced to a more ecological one, a clear technological change is necessary. This is related to the choice of another fuel or a radical technological change. The decline of coal and the challenges facing nuclear power have reshaped the global power generation landscape. The rise of natural gas as a transitional fuel, coupled with the exploration of hydrogen as a clean energy carrier, further adds to the complexity of the sector [20]. In some countries, there is an attitude about the possibility of natural gas becoming an intermediate fuel for the final transformation. However, this approach is not correct. First, it is a fossil fuel and its use would only marginally reduce global pollution. Second, as in the case of oil, gas resources are concentrated in a dozen countries of the world, some of which are not characterized by clear political stability.

To properly utilize renewable energy resources for electricity production, it is necessary to solve the problem of unstable production. This can be completed in two ways. In the first case, it is necessary to expand the practice of demand-side management, when large electricity consumers adapt their ongoing production operations to the surges in electricity production. In the second case, it is necessary to expand energy storage capacities in hydroaccumulation power plants and battery parks. In the latter case, the efficiency of battery parks is still relatively low. The construction of hydroelectric power plants fundamentally changes the landscape and requires the destruction of natural biotopes. Dams may obstruct fish migration routes and lead to the degradation or loss of fish habitats, affecting local fish populations [21]. These actions are hardly compatible with today's environmental policy. While the sector undergoes positive transformations, it faces challenges, such as the intermittency of renewable sources, aging infrastructure, and evolving cybersecurity threats. The importance of energy security increases significantly in crisis situations [22]. Opportunities lie in addressing these challenges through innovation, policy support, and international collaboration [23]. The innovation element is inseparable from political will. With sufficient political support, the transformation of electricity generation can be accelerated. For the effective fulfillment of political will, it is necessary to consider expert knowledge related to the use of renewable energy technologies.

To find the most suitable short-term energy transformation methods, it is necessary to compare different production alternatives. Table 1 presents the main renewable energy solutions, compared according to essential characteristics. The technologies are fundamentally different and characterized by continuous technological progress. The presented technologies are universal and can be developed in various countries of the world. The table shows those solutions that are applied on a mass scale and use renewable energy resources. It does not include some types of production in which electricity is extracted as a by-product. Such a decision was made considering the possibility of supplying electricity to large residential areas; certain technological solutions would not allow this to be done.

Table 1. The most common renewables-based electricity generation alternatives.

Type	Onshore Wind Energy	Solar Energy	Offshore Wind Energy	Biomass Energy
Type of fuel	Local renewable	Local renewable	Local renewable	Local renewable
Product of energy	Electricity	Electricity/hot water	Electricity	Heat/electricity/biogas
Time of power plant construction, years	5–7	2–3	7–10	1–3 (conversion of fossil fuel power plants)
Efficiency of power plant, %	45	29	70	40 (part of electricity)
Price, mln. EUR/MW	2.5	0.8	3.5	0.5 (part of electricity)
Service time, years	25	25	30	25
The need for balancing	Necessary	Necessary	Requirable	Can be used for balancing

In the case of electricity, the transition towards renewable energy is fundamentally about changes in consumption. When using unstable energy sources (in the case of wind and solar), balancing solutions and production adapted to the energy supply are necessary. Biomass power plants can perform the balancing function themselves. This potential is not yet sufficiently exploited. The production of electricity is related to the process of heat production. Technology synergy exists not only in evaluating the use of fossil fuels but also in renewable energy technologies.

2.1.2. Heat Production

The heat production process is related to electricity production. The heat production sector encompasses a diverse range of processes and technologies that generate heat for various industrial, residential, and commercial applications. This sector plays a critical role in meeting energy demands and often intersects with broader energy systems. There are different production methods that have not changed over the past decades. The heat production sector is relatively carbonized, i.e., clear alternatives to fossil fuels are still lacking. One of the main reasons is the impact of direct combustion on the heat sector. The combustion of fossil fuels, including coal, oil, and natural gas, is a primary method for heat production. Combustion involves the exothermic reaction of fuel with oxygen, releasing thermal energy. While fossil fuel combustion is a major contributor to heat production, it raises environmental concerns due to greenhouse gas emissions and air pollutants [24]. Decoupling economic growth and GHG emissions will be one of the key challenges of the future [25]. Adequate solutions have not yet been developed that would allow the profitable use of wind and solar energy for heat production. One of the alternatives is the use of electric heat pumps. As for district heating systems, green heat can be produced from biomass or geothermal energy. In the case of biomass, it can be used in both urban and regional areas. Biomass power plants can be decentralized, adapting to heat demand in certain regions. The main advantage of using biomass is the locality of the fuel. Biomass resources are widely distributed in almost all countries of the world. In the case of geothermal energy, utilizing the Earth's natural heat, geothermal heat pumps extract warmth from the ground for heating applications [26]. Renewable heat technologies offer sustainable alternatives to fossil-fuel-based systems, reducing carbon footprints and dependence on finite resources. The infrastructure of the district heating sector can also be used to meet the demand for district cooling. It is similar to district heating but involves the distribution of chilled water for air conditioning [27]. District energy systems enhance efficiency and can integrate renewable and waste heat sources.

The heat production sector is a dynamic and multifaceted domain, involving various processes and technologies. As society seeks sustainable and efficient energy solutions, ongoing scientific research and innovation in heat production are essential for achieving environmental and energy goals. In the case of heat energy, synergies can be obtained when biomass cogeneration plants are built instead of coal- or gas-burning facilities. Combined heat and electricity production based on cogeneration technology is carried out in larger urban areas. In this case, next to the main product—thermal energy, a by-product—electricity is extracted. The conversion of pollution power plants complies with the principles of sustainable development as there is no need to build new foundations or pipelines or fundamentally change the terrain. In addition, the project is implemented much faster since it is not necessary to obtain building permits for new construction.

Analogously in the case of electricity, Table 2 presents alternative options for heat energy production. Heat production technology has not changed fundamentally for some time. However, important improvements have been made in recent decades in terms of operational efficiency and smooth power plant management. New technologies that have appeared allow the use of already produced types of energy by converting them into heat production. The technological development of heat production has been slower than that of electricity technology for reasons of demand—heat production is needed in countries with a climate characterized by cold autumns and winters. However, the production of centralized heat creates conditions in synergy with the supply of centralized coolness. This technological breakthrough creates conditions for the diffusion of these technologies on a wider scale.

Table 2. The most common renewables-based heat generation alternatives.

Type	Geothermal Energy	Electricity (Heat Pumps)	Biogas	Biomass Energy
Type of fuel	Local renewable	Local/imported renewable/ non-renewable	Local renewable	Local renewable
Product of energy	Heat/electricity	Heat	Heat/electricity/ biomethane	Heat/electricity/cool
Time of power plant construction, years	5–6	1–2	2–3	1–3 (conversion of fossil fuel power plants)
Efficiency of power plant, %	50 *	70	85 (part of heat)	105 (part of heat) **
Price, mln. EUR/MW	1	0.8	0.7 (part of heat)	0.3 (part of heat)
Service time, years	25	25	20	25

* Depending on the temperature of the geothermal water; ** If a condensing economizer is installed.

Due to less developed technological research, the dominant heat production technologies are related to the use of biological waste. They replace the coal- and gas-fired power plants that currently dominate. The use of biomass and biogas is competitive due to the construction time of the power plants and relatively lower costs per megawatt. The main advantage of such power plants is the ability to produce several types of energy at once or depending on the demand for different types of energy. However, due to the more convenient use of imported natural gas, this production method was somewhat forgotten.

Thermal energy production is characterized by flexibility and the ability to simultaneously produce several different types of energy. To use the possibilities of transformation, it is necessary to assess the perspective of gas consumption. Currently, the market is dominated by natural gas and petroleum gas; however, in the future, gas consumption will fundamentally change. It is noticeable that a large part of the scientific research and technological progress is directed specifically toward new-generation gas production technologies. In some cases, energy converted into gaseous form would allow the reduction of the overloads of the energy system, when a large amount of energy is produced at the same time.

2.1.3. Gas Production

Even today, natural gas is considered the least polluting fossil fuel. In some cases, it is proposed to include gas in energy transformation plans as an intermediate fuel in the transition to full decarbonization. This does not stop scientific and applied research—alternatives to natural gas have already been developed. The main strength of the alternatives is the ability to utilize existing gas transportation networks with certain technical adjustments.

One of the opportunities to replace natural gas is biomethane production. Biomethane, also known as renewable natural gas (RNG), is a type of biogas that is upgraded to a quality similar to fossil natural gas. It is produced through the anaerobic digestion or other biological processes of organic materials, such as agricultural residues, food waste, sewage, and energy crops. Biomethane is considered a sustainable and low-carbon energy source, contributing to efforts to reduce greenhouse gas emissions and promote the use of renewable energy [28]. Biogas produced from organic materials consists mainly of methane (CH_4) and carbon dioxide (CO_2), along with trace amounts of other gases. Biomethane is obtained by removing impurities and increasing the methane concentration to levels comparable to natural gas [29]. The impact of biomethane is clearly visible on livestock farms—they collect particularly polluting methane gas, which is then cleaned and burned. In this way, they do not enter the atmosphere and the process of raising animals becomes more ecological. New technologies allow this gas to be used as fuel for agricultural machinery. There are already mass-produced tractors that use this gas [30]. Initiatives have emerged in EU countries that supply purified biomethane to common main gas pipelines. Biomethane can be injected into natural gas pipelines, used as a vehicle fuel, or utilized for electricity generation. Its versatile applications make it a valuable renewable energy resource with potential benefits for reducing dependence on fossil fuels. This will partially improve the situation in the gas sector; however, the amount of animal waste is lower than the demand for gas. However, in countries where alternative fuels are used for heat or electricity production, biomethane can help minimize the need for natural gas.

The main likely alternative to natural gas and transport fuel is hydrogen. Currently, the possible cost price of hydrogen and the possible commercial price have already been calculated. In recent years, hydrogen has gained significant attention as a clean and versatile energy carrier with the potential to play a crucial role in the transition to a sustainable energy system. This is determined by the chemical properties of hydrogen—it can be extracted from water, the by-product is oxygen, and hydrogen itself is perhaps best suited for energy storage. Hydrogen can be produced through various methods, including steam methane reforming (SMR), electrolysis, and gasification of biomass. SMR is currently the most common method, using natural gas as a feedstock [31]. As the production of green hydrogen increased, the divide between black, gray, and blue types of hydrogen became apparent. It is widely accepted that the development of green hydrogen, where the gas is produced using renewable energy sources, is the goal. The most suitable for this is electricity obtained from wind farms, especially from the sea. This is due to the large amount of electricity generated. Hydrogen is then extracted by electrolysis, which is supplied to modified main gas pipelines. Hydrogen can store and deliver energy, making it an energy carrier. It can be used in fuel cells to produce electricity through an electrochemical reaction with oxygen and it can also be burned for heating and power generation [32]. In the case of the success of the development of hydrogen technologies, this would especially affect the transport sector, creating competition for electric cars.

Table 3 presents a comparison of the characteristics of biomethane and hydrogen. As these technologies are still largely in the development stage, some elements cannot be precisely defined. When developing gas technologies, preventive actions are important, primarily those changing the electricity and heat sectors. Significantly reduced gas demand for heat and electricity production will facilitate the transformation of the gas sector; however, progress in replacing natural gas in the long term is completely dependent on hydrogen production development.

Table 3. The most common renewables-based gas generation alternatives.

Type	Biomethane	Hydrogen
Type of fuel	Local renewable	Local renewable
Product of energy	Heat, gas for household needs, fuel for agriculture needs	Car fuel, gas for manufacturing
Time of power plant construction, years	2	?
Efficiency of power plant, %	65	?
Price, mln. EUR/MWh	136	20
Service time, years	20	?

While examining electricity, heat, and gas alternatives for the short term, it was decided upon to further analyze the use of biomass. Biomass can be considered a transition fuel due to the relatively high level of technological development and the possibility of producing all the mentioned types of energy from this fuel. Biomass technologies overlap with traditional heat and electricity generation technologies. In this way, cogeneration will be considered a transitional technology, allowing the production of several types of energy from one type of fuel. In addition, the use of biomass will ensure social inclusion in those regions that will have problems with the closure of coal plants.

2.2. The Importance of Biomass Cogeneration for Short-Term Transformation

The use of biomass for cogeneration has grown significantly in recent years. This is especially true for Eastern European countries that do not have their own natural gas resources. After realizing the availability of gas and the emergence of price instability, they turned to the use of local biomass. Biomass fully complies with the principles of sustainable development. In the case of incineration, wood waste or waste generated during production is used. Low-value plants that have no prospect of growing into large, environmentally valuable trees can also be used. In the case of biogas, only biological waste generated in the livestock or food processing sectors is used. Biomethane is extracted from them, avoiding the release of this extremely harmful gas into the atmosphere. Biomethane gas is significantly more harmful than carbon dioxide; therefore, biogas power plants will also be relevant in the long term.

Due to its age, the biomass energy sector includes both traditional and modern technologies. New biomass technologies include more efficient energy extraction technologies from lower-quality feedstock. However, traditional energy extraction by burning biomass still has a great influence today. Figure 1 shows that bioenergy includes different products and raw materials. Among the types of energy production presented, biofuel production is the least sustainable as it often still uses food-grade raw materials. Second-generation biofuels help to solve this problem but only partially. For this type of biofuel, palm oil is usually used, which is extracted in areas where especially valuable forests have been destroyed. Second-generation biofuels produced in EU countries are often labeled as palm oil free. As technology advances, a syngas breakthrough is possible, further facilitating the decarbonization of the transportation sector.

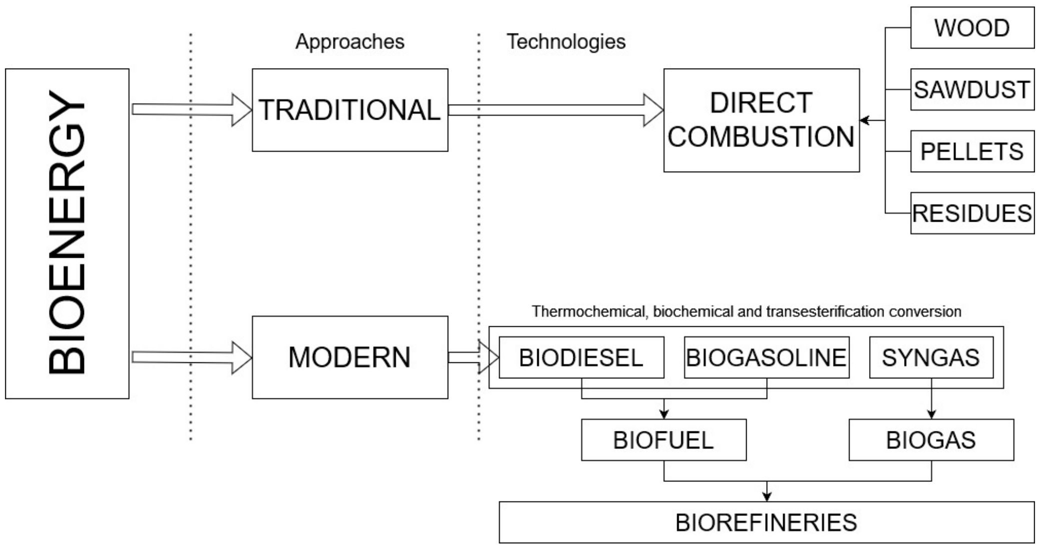

Figure 1. Typical roadmap of bioenergy production [33].

Traditional biomass-burning technologies are most efficiently used based on cogeneration technology. Because a large amount of heat is released during the production of electricity, biomass power plants are smaller than coal or gas power plants. This helps to decentralize the energy system—biomass cogeneration power plants are built near sources of heat consumption. In this way, the produced heat is used more efficiently and risks arising from power plant failures or external factors are reduced. By extracting two types of energy, available biofuels are used more efficiently and consumer needs are met more widely. Biomass cogeneration systems typically use organic materials derived from plants, animals, or waste as fuel to produce both electricity and thermal energy. Cogeneration, or combined heat and power (CHP), represents a paradigm shift in energy production, aimed at optimizing resource utilization and minimizing environmental impact. The cogeneration process is grounded in the second law of thermodynamics, emphasizing the significance of harnessing waste heat to enhance overall energy conversion efficiency. Notable references supporting this thermodynamic foundation include works by [34–36]. Biomass cogeneration utilizes biomass feedstocks, such as wood, agricultural residues, or organic waste, to produce electricity through a power generation system (usually a steam turbine or internal combustion engine). The waste heat generated during electricity production is then captured and used for heating or other industrial processes, maximizing the overall energy efficiency of the system.

Biomass cogeneration systems can use various technologies, including steam turbines, internal combustion engines, and gasification systems. These technologies can be adapted to different scales, from small-scale decentralized systems to large-scale power plants. In addition, it is necessary to emphasize that, in some cases, biomass can be burned in coal-fired power plants. This would avoid major investments in the short term until the coal plant is fully depreciated [37]. Biomass cogeneration is considered a renewable and sustainable energy option with potential environmental benefits. It can contribute to reducing greenhouse gas emissions, provide a reliable source of energy, and support local economies by utilizing locally available biomass resources [38]. From the perspective of sustainability, the use of worn-out power plant foundations or changing the mode of operation of a worn-out power plant significantly contribute to improving the quality of the environment. In addition, coal or gas power plants converted to biofuel cogeneration power plants will reduce the burden of administrative design and obtaining permits, save space for construction, and speed up project implementation.

The new type of cogeneration power plant is characterized by a high level of efficiency. Currently, technologies are already being developed that would allow the production of efficient cogeneration power plants of lower power. This would expand the application of the technology in areas where electricity generation activities were not carried out before. As the need for balancing renewable energy grows, the importance of biomass cogeneration will continue to grow. The main technological progress of cogeneration is as follows:

- Prime Mover: Various prime movers, including gas turbines, steam turbines, reciprocating engines, and fuel cells, form the backbone of cogeneration systems. This is discussed in comprehensive studies by [39] on internal combustion engines;
- Heat Recovery Systems: Efficient heat recovery, a cornerstone of cogeneration, is facilitated by components such as heat exchangers and recuperators. Condensation economizers, which extract energy from hot smoke released into the atmosphere, are an integral part of cogeneration power plants [40];
- Control Systems: Advanced control systems play a pivotal role in optimizing the performance of cogeneration plants. Notable references include the work by [41] on feedback systems and control.

Technological progress in cogeneration creates clear operational advantages. Cogeneration technology has developed in the direction of using both biomass and biogas. In addition to the large amount of energy that can be produced, clean energy production that does not create a negative impact on the environment is ensured. The use of local organic resources prevents more harmful substances, such as methane, from entering the environment. The main advantages of biomass cogeneration are as follows:

- High Efficiency: cogeneration systems are lauded for their high overall efficiency, as documented in studies such as the review by [42] on efficiency improvements in CHP systems;
- Energy Cost Savings: economic benefits associated with cogeneration are supported by studies such as the analysis by [43] on the economic potential of CHP in the European Union;
- Environmental Benefits: cogeneration's positive environmental impact is corroborated by research, including the meta-analysis by [44] on the life cycle assessment of CHP technologies.

As evidenced by the referenced literature, cogeneration stands at the forefront of sustainable energy solutions. Biomass cogeneration provides a versatile and sustainable option for energy production, combining electricity generation with the utilization of waste heat for heating or industrial processes. It aligns with the principles of the circular economy and renewable energy, offering a potential solution for decentralized and distributed energy systems. Another important characteristic of energy from biomass concerns the peculiar factors of the market structure, involving many local businesses and public entities.

2.3. Characteristics of the Biomass Energy Sector

The impact of biomass utilization at different economic levels is significant. The development of the biomass energy business provides prerequisites for the use of local resources, the creation of new jobs, and the start of economic activity in rural areas. Due to the newness of the sector, it is not entirely clear what factors affect the performance of biomass utilization in cogeneration power plants. It is also not entirely clear what market relations unite the biomass processing and energy production markets. The entry of new business entities into the market and their ability to create added value significantly depend on the type of relationship. The scientific literature lacks information on how the value creation process takes place and which entities interact with each other to create a positive impact. It is from this interaction, based on local renewable biofuels, that potential directions of impact arise.

Another relevant shortcoming is that no attention is paid to the regional dimension. In the conducted theoretical or empirical studies emphasizing the benefits of using biomass in general, abstractness prevails and directions of positive effects are presented without verifying them. When assessing effects at the country level, one is limited to looking for certain correlations. In this case, the assessment is carried out only for one country or a group of countries; however, there is no uniform methodology that would allow comparing the countries with each other, considering the differences in their size, economic capacity, and opportunities to obtain fuel. Regional dynamics studies enable comparison of the regions of one country and individual countries. However, there is a notable lack of such studies evaluating the impact of biomass use. The main aspect, assessed from a regional perspective, is the conversion of some object (e.g., adaptation of a coal-burning power plant to biomass burning [45], etc.). Synergistic effects are ignored in this case.

Finally, impact assessment is limited to economic factors and excludes impacts on social well-being and environmental improvement. There is a lack of generalized assessment of the impact of the use of local resources. Nor has there been a criterion for assessing the impact of the use of biomass resources on the dynamics of changes in certain indicators. This is also related to the correlation between the use of local biomass and the change in social status. Research is conducted to assess the impacts created by energy production; however, the impacts created by the fuel preparation sector are ignored. It is in the latter sector that the prerequisites for the reduction of social inequality and the sustainable use of resources arise. This creates a positive economic impact; however, existing research does not address the question of how the economic, social, and environmental factors of renewable fuel production fit together and what impact they create together.

The systematization of the biomass energy sector is defined through the interaction of resource and product markets. The resource market includes biomass processing entities, biomass production owners, logistics, and transportation structures. The main goal of resource market participants is to supply biomass to power plants that use it and create value from biological raw materials that are considered waste [46]. Many market participants operate in the resource market as the aim is to decentralize biomass supply directions. All entities possessing biomass resources can participate in the market. Solid biomass, solid and liquid agricultural waste, and by-products obtained during environmental management are sold in the resource market. They are properly processed and fed to the incinerators. Many low-skilled people are employed in market activities and, in this way, the regional employment problem is solved. The activities are carried out in regional rural areas with abundant renewable biomass resources. The main direction of supply of prepared biomass is toward urban areas and industrial companies that need thermal energy, electricity, or biogas. Market operation phases are related to weather conditions and continuous energy demand. During the heat supply season, the demand for biomass increases and, in the warm period, biomass is used to meet the needs of industrial companies and domestic electricity and gas consumers.

Within the structure of the biomass energy sector, there is also a product market, which is the actual reason for the emergence of the resource market. This is due to the emergence of infrastructure using renewable biomass. For that purpose, it is necessary to create a supply chain that allows supplying the power plant. In the activity of the product market, four types of energy are obtained—electricity, heat, steam, and biogas. It is these types of energy that are realized as products of the product market. The product market realizes the potential created in the resource market—local biomass resources that are considered waste. The main objective of the product market participants is to meet the needs of urban types of areas and the needs of industrial enterprises in the supply of energy [47]. In the market for biomass energy products, energy is obtained using fuel processed in the resource market. The product market has signs of decentralization—it is dominated by medium-power power plants located near energy consumption points, distribution networks, and entities responsible for system maintenance. The activity is carried out in those areas that have developed energy distribution networks and demand for energy consumption. These can be urban settlements, industrial enterprises, or agricultural business systems. The market consists mainly of highly qualified workers who can manage complex energy systems. Depending on the conjuncture of the regional energy system, product market entities can work all year round or during periods of increased energy demand.

The use of biomass in energy is changing the structure of the entire economy. More efficiently used monetary funds are directed in different directions, enabling the positive impact to be multiplied in monetary terms. As fossil resource imports decline, cash remains in the country and helps create added value. It is created not only in an economic but also in a social and environmental environment. Internal circulation of money begins with the use of hitherto unused biological resources and their implementation requires both skilled and low-skilled workers. In the development of renewable, biomass-based energy, the progress of local production technologies is promoted, which helps to multiply the added value created within the country, as well as to expand the export of services [48]. Many new products are created using biomass—energy is extracted from biological waste and organic fertilizers and ash are obtained in intermediate production processes, which significantly increase agricultural production. The resulting synergistic effects allow us to state that the use of local biomass significantly boosts the country's economy in the regions and enables the creation of new business units in it, mobilizing human resources of various qualifications. By importing mineral resources from abroad, the flow of money is directed to foreign countries and the opportunity to create value domestically using available physical and human resources, as well as scientific and technical potential, is lost.

All the above statements define the structure of the biomass energy market as a general part of the energy system (Figure 2). The figure presents the main product lines of the system, changes in the market structure and their conditions, and influencing factors. The scheme highlights the complexity and multifaceted impact of the biomass sector on the economy. The primary products obtained in the factor market create market products and final products, such as fertilizers, wood products, and other products. The product market is dominated by energy products made using local waste. The products of this market include ash, which can be used for the formation of road relief, the laying of landfills, and other complementary activities. The figure shows that the market for factors of production consists of the resource market and the human resource market. These are the main ingredients that shape the performance of the biomass energy sector. However, there is another modification of production factors, which is related to the productive use of waste. This is how the main value (product) creation process takes place, where residual waste from the manufacturing process of end-use products is converted into energy. In this way, there is a transition to the derivative unit of the market structure—the product market. It consists of electricity and thermal energy, ash, biogas, and steam energy. Also included are other combustion products that may be extracted from the biomass processing process. They can be various resins or other by-products. In the product market, all energy products are quite identical, i.e., the form of their use or application differs but the current energy needs of consumers are met. Later, the structure of the biomass energy sector is examined through the section of the market conjuncture.

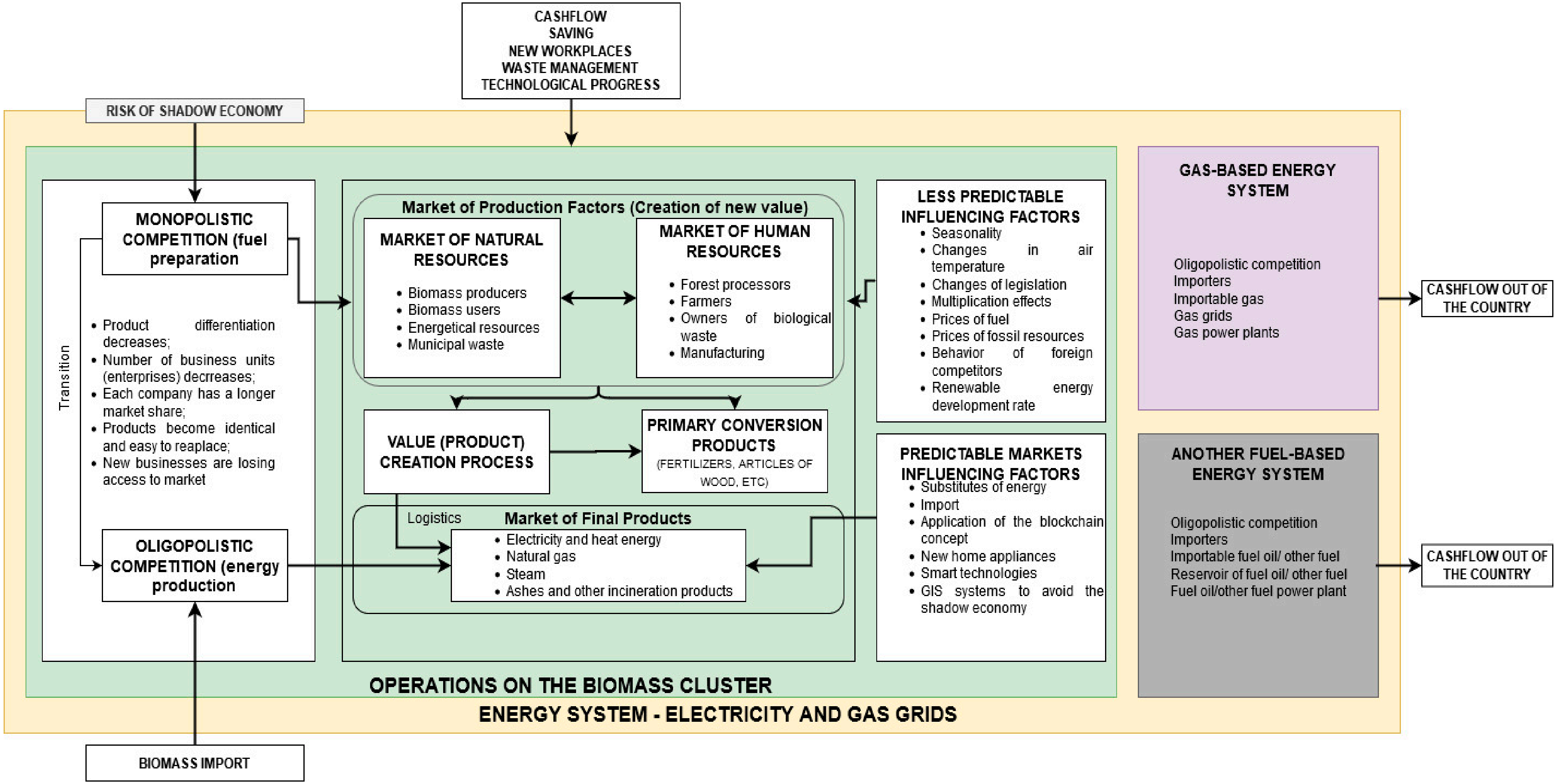

Figure 2. Decentralized regional biomass market structure.

3. Materials and Methods

The research uses the Design of Experiment (DOE) research method. Based on this method, experiments are conducted to determine the ability of one or another production method to compete in market conditions. This method allows the combination of relevant data groups into a single system, thus obtaining optimal results. Experimental designs are especially useful in addressing evaluation questions about the effectiveness and impact of programs. Emphasizing the use of comparative data as context for interpreting findings, experimental designs increase our confidence that observed outcomes are the result of a given program or innovation instead of a function of extraneous variables or events [49]. This method is suitable in the case where the aim is to discover new and relevant scientific results. The method can also be used when a certain prevention before decision-making is aimed at, since, with the help of the method, certain optimal interactions of phenomena can be found. This method aims to identify and understand causal relationships between variables. It involves careful experimental design to control potential confounding factors and ensure that data collection effectively answers the research questions and hypotheses. Designing experiments involves selecting factors and procedures and collecting and analyzing data to draw meaningful conclusions.

The experiment uses data from cogeneration power plants located in the Baltic states and includes data from currently prevailing renewable energy technologies based on biomass. Two indicators are selected as processing values:

- Thermal power of cogeneration biomass power plant;
- Electric power of cogeneration biomass power plant.

These indicators are interrelated and visible in the case of real biomass cogeneration plants. During the development of this type of power plant, heat and electricity power must be balanced. The selection is based on the case of the Baltic countries; therefore, since biomass cogeneration practices are widely applied in these countries, the latest and most relevant cogeneration technologies are also used. In addition, a clear sample of data increases the reliability of data sampling. The careful design of experiments is necessary to minimize the number of experiments that need to be carried out in the overall space of variables and parameters (the design space) [50]. Experimental data must be clearly argued, supported either by real examples or previous research [51].

The electricity price indicator is chosen as the dependent variable (Y). The characteristics of the electricity price are the most important in promoting the energy transformation in the short term. Since there is a lack of green electricity generation, biomass cogeneration could ensure stable electricity production. However, the cost of electricity production in power plants of different capacities is different. Electricity is considered a by-product of cogeneration so cost-effective maximization of its production is considered a technological challenge. Balancing the cogeneration power plant allows it to achieve the intended goals while obtaining profit from both heat and electricity production.

Response surface methodology (RSM) is used for the research, which allows the study of the relationships between explanatory variables and one or more response variables [52]. The RSM method is suitable for fitting a quadratic surface and it helps to optimize the process parameters with a minimum number of experiments, as well as to analyze the interaction between the parameters [53]. By combining mathematical and statistical instruments, RSM provides an opportunity to obtain relevant results on the larger application possibilities of biomass cogeneration. This leads to a better understanding of the phenomenon as this study uses practical data.

After the RSM-based analysis of biomass cogeneration factors, the optimal combination is determined from the obtained data, which allows us to achieve the best biomass cogeneration solution. The optimal combination is used to make investment decisions. Based on this, the optimal price of electricity is determined, at which point it could be possible to develop profitable biomass cogeneration capacities. The optimal combination is based on today's situation of power capacity and recorded energy sales prices.

4. Results and Discussion

4.1. Design of Experiment (DOE)

The initial stage of the research is related to the formation of a suitable data set for the experiment. Due to the specificity of this study, when it consists of two processing values (X1, X2) and one dependent variable (Y), thirteen data lines are involved in the experiment. Minitab version 21.4.2 software is used for the calculations. Table 4 provides detailed information about the initial phase of the experiment. The main parts of the experiment are heat power (TP) and electricity power (EP). Electricity price is determined based on concluded PPA contracts (average price of 2023), as well as long-term fixed electricity price transactions. Since there are two processing values in this experimental model, exactly thirteen tests are performed according to the experimental methodology. The prices of electricity produced with the help of biomass stabilized in 2022 when electricity prices rose significantly in Eastern Europe. This made it possible to form a sustainable business model where heat energy is sold to cities or factories and heat energy is transmitted through state-run transmission networks. The transfer of heat to consumers has allowed us to avoid the situation where excess heat is released into the environment in the name of electricity production. What is more, connected condensing economizers make it possible to further increase the efficiency of heat production. This justifies the expediency and neutral impact of electricity production on the environment.

Table 4. Experimental design.

Experiment Number	Processing Valuables		Electricity Price, EUR ct./kWh
	TP, MW	EP, MW	
Low level (−1)	20	4	
Medium level (0)	30	8	
High level (+1)	40	12	
1	0	0	11.5
2	1	−1	12
3	0	0	10
4	−1	1	8.5
5	−1	0	9
6	0	0	10.1
7	0	0	10.5
8	0	−1	10.8
9	0	0	9.8
10	1	1	7.9
11	0	1	8.6
12	−1	−1	9.7
13	1	0	9.6

Before performing analytical steps, it is necessary to study the main indicators of the model. Table 5 presents the main research coefficients, which show the basic diagnostics of the necessary coefficients. This will create conditions for validating the results of future studies.

Table 5. Research coefficients.

Term	Coef	SE Coef	T-Value	*p*-Value	VIF
Constant	0.49	0.247	41.48	0.000	
Heat	0.569	0.243	1.58	0.039	1.00
Electricity	0.474	0.243	5.14	0.001	1.00
Heat*Heat	−0.00643	0.358	−1.80	0.016	1.17
Electricity*Electricity	−0.0152	0.358	−0.68	0.019	1.17
Heat*Electricity	−0.01813	0.298	−2.44	0.045	1.00

One such coefficient is the coefficient of determination, which indicates the appropriateness of the model for further research. The information presented in Table 6 shows that both R-sq and adjusted R-sq indicators are extremely high. This allows us to make a preliminary conclusion that the model is built responsibly and will be based on the correct equation.

Table 6. Model summary.

S	R-sq	R-sq (adj)	R-sq (pred)
0.595360	99.19%	98.61%	96.72%

The next stage of the research is related to checking the adequacy of the analyzed data. In this case, the value of the coefficient of determination, which evaluates possible changes in the dependent variable, is evaluated. In this model, the value of the coefficient of determination reaches 99.19%. Next, an analysis of variance is carried out, which allows the model equation to be formed. Table 7 presents the main results of the analysis. This analysis is important in that it provides the indicators necessary to construct the model equation. In the presence of inappropriate indicators, the equation may not be accurate and may not give the required results.

Table 7. Analysis of variance.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Model	5	14.2711	2.8542	8.05	0.008
Linear	2	10.2567	5.1283	14.47	0.003
Heat	1	0.8817	0.8817	2.49	0.159
Electricity	1	9.3750	9.3750	26.45	0.001
Square	2	1.9120	0.9560	2.70	0.135
Heat*Heat	1	1.1423	1.1423	3.22	0.116
Electricity*Electricity	1	0.1632	0.1632	0.46	0.419
2-Way Interaction	1	2.1025	2.1025	5.93	0.045
Heat*Electricity	1	2.1025	2.1025	5.93	0.045
Error	7	2.4812	0.3545		
Lack-of-Fit	3	0.6532	0.2177	0.48	0.716
Pure Error	4	1.8280	0.4570		
Total	12	16.7523			

Table 6 shows that the analyzed model is appropriate—lack of fit > 0.05. This means that there is an adequacy between the proposed model and the experimental data [54]. This situation makes it possible to form a second-level equation, which is optimal for performing similar calculations. The equation of the model includes the determination of the relationships between the price of electricity and the energy released during cogeneration. Regression equation in uncoded units:

$$Y = 0.49 + 0.569TP + 0.474EP - 0.00643TP \times TP - 0.0152EP \times EP - 0.01813TP \times EP \quad (1)$$

The specified equation is related to graphically presented three-dimensional response surface plots. Constant values are selected to prepare Figure 3.

The next stage of this study is related to the determination of optimal parameters. Optimal parameters help answer the question of what combination of cogeneration power plants would ensure a competitive energy price. For this purpose, a contour plot is created, which includes thermal and electrical power, as well as the cost of electricity. The contour plot presented in Figure 4 shows the distribution of the relevant indicators. This contour plot shows that the interaction between heat and electricity power has a significant effect on electricity price. This is reflected in the shape of the ellipse visible in the graph. In this case, a clear influence of variables on the dependent variable can be seen when evaluating power differences. In future research, if the supply policy changes, one more component—cooling—could be included. For now, these studies are more at the concept level [55]; however, in the future, it will be necessary to evaluate the potential of combined cooling, heating, and power in cities.

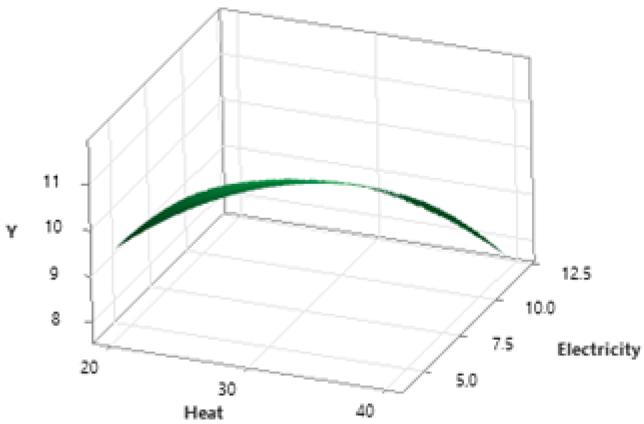

Figure 3. Combined effect of electricity (EP) and heat (TP) on electricity price (Y).

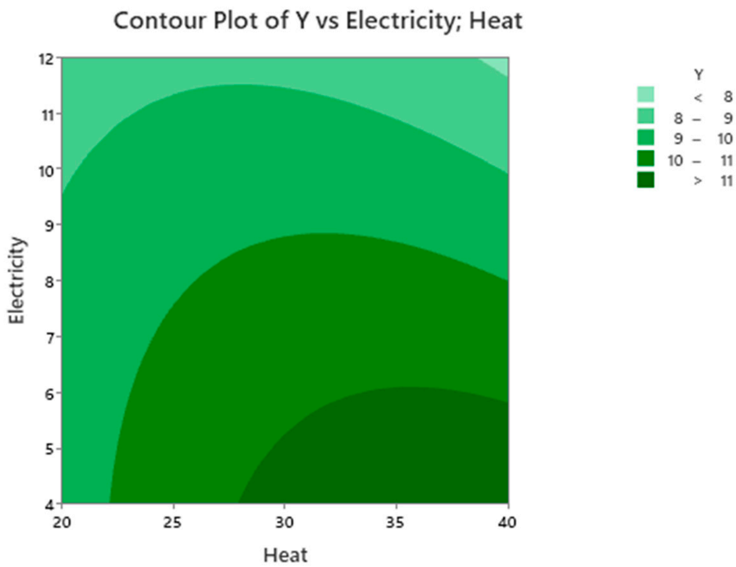

Figure 4. Contour plot of the effect of electricity (EP) and heat (TP) on electricity price (Y).

The data of the previously mentioned experiments are used to determine the optimal indicators. The results are presented in Figure 5. When determining the optimal parameters, large thermal and electric power plants work most efficiently. Thus, 40 MW of thermal power was selected, combining it with 12 MW of electrical power. This power is suitable for cities with a population of around 40,000 or large factories. A combined option is also possible, when such a power plant is developed by a factory, and the excess heat is transferred to the residents of a nearby city. This optimal combination results in a EUR 0.77773 ct. price per kWh of electricity.

The application of cogeneration technology is a suitable solution for the energy transformation of the intermediate period. This allows us to achieve a multi-directional positive effect. First, there is a transition to renewable energy based on the use of local raw materials. Secondly, by reorienting the energy system, the problems of using local waste, employing workers, and using polluting power plants are solved. In this case, the conversion of waste into energy is ensured and, in some cases, the use of fossil fuel power plants for the consumption of renewable energy resources. Third, when developing new power plants, they can be built near major consumption centers, thus decentralizing production capacity. The performed analysis shows that current examples of cogeneration can provide opportunities to evaluate optimal production indicators, thus confirming the necessity and profitability of sustainable, decentralized energy solutions.

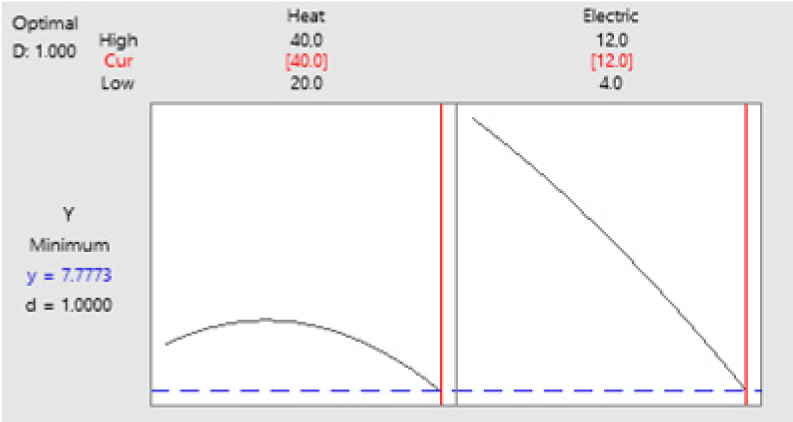

Figure 5. Optimal parameters of electricity (EP), heat (TP), and electricity price (Y).

4.2. Discussion

This article presents options for the development of energy transition in the medium term, with a particular preference for regions. This is an important development in the field of science as the current situation concerns national investments in grids, power plants, and infrastructure located in only a part of the regions. The role of the regional administrations themselves is limited to issuing permits, developing some small infrastructure, etc. With the expansion of wind and solar power generation, the role of the regions will be even more limited as the plants do not require a large amount of human resources to operate. Biomass energy would strengthen the regions in the medium term by attracting new investment in the necessary energy production capacity.

Biodiversity is another important aspect. Responsible biomass management can significantly improve the situation of biodiversity. The article assesses the use of unproductive wood that is not suitable for the timber industry or waste wood from timber industries for biomass production. An important aspect is that the plants evaluated in the experiment do not use stump wood and trees suitable for industry. This is particularly important in the context of the emphasis on biodiversity: stumps are left in the forests to promote regeneration and recyclable wood is not lost. This respects the principles of sustainable development and ensures that biomass is climate neutral. To ensure that biomass is derived from waste, it is necessary to ensure a certification mechanism that regulates not only the exploitation of biomass resources but also the amount of biomass that is left in forests for the development of biodiversity.

Key original research findings:

1. It highlights the need to find solutions for short-term energy transformation. The world's scientific and business communities are working hard to develop technologies that will enable the cost-effective substitution of fossil fuels. However, the state should not wait for these technologies and can already initiate some activities to transform the energy system. This article proposes the use of biomass as a renewable resource suitable both for energy production and for balancing the energy system in the interim period until large-scale energy production technologies are developed. This resource is suitable for decentralizing the energy system, empowering the regions, and, above all, expanding the green production portfolio;
2. A decentralized regional biomass market structure is in place. The structure brings together the main factors that are influenced by biomass deployment in each area. The framework assesses the regions of biofuel activity, the volumes of local fuels

they use, and the environment they are exposed to and identifies under-researched factors that can have a significant impact on the success of market players. Based on this framework, it is possible to identify value-adding regions, the volume of value generated in terms of increasing domestic biomass production and decreasing energy imports, and the direction of cash flows generated by the substitution of domestic production for imports. This structure demonstrates that the biomass sector is in line with the principles of sustainable development at all levels and that the production and supply processes are exclusive to companies in each region;

3. An experimental design has been developed to assess the cost-effectiveness of biomass utilization. Based on the Baltic states, CHP plants were selected to find the optimal mix of energy production. The paper emphasizes that the plants should be located in regional centers with high levels of thermal energy consumption. This allows more of the by-product—electricity—to be fed into the national grid. In addition, it highlights the potential prospect of balancing the energy system, thus enabling further improvements in plant profitability.

Comparing the article with previous studies, there is a clear divide. There is a focus on the growth of hydrogen technology without intermediate solutions. The use of hydrogen solutions is not only seen in centralized systems but also in decentralized systems [56]. Existing studies focus on long-term time frames for decarbonizing the energy system [57] but completely ignore the need for intermediate solutions to avoid irreversible climate change. Hydrogen is rightly seen as an energy storage solution that would allow large amounts of energy to be stored, transported, and, subsequently, used [58]. However, while cost-effective hydrogen production from renewable sources has not yet been developed, there is an urgent need for other solutions to produce more clean energy, which, in turn, will increase future hydrogen production.

Ethical considerations are an additional aspect. The environmental impact of biomass has been extensively researched and biomass is recognized as a neutral fuel that produces no additional emissions. Combining biomass and hydrogen is even possible in industries such as steel production [59]. Biomass is recognized as a viable solution for boosting electricity generation in Europe [60]. This paper focuses on the fact that the use of biomass does not have a negative impact on biodiversity if biomass that is not suitable for recycling is used. However, there are still some ethical issues with hydrogen technologies [61]. There is still no clear regulation on how hydrogen should be extracted. From a sustainable perspective, wastewater should be used for hydrogen production. This is less cost effective than using fresh or sea water. However, these alternatives are less sustainable because of the salts released and the decreasing availability of fresh water. Until these ethical aspects are fully regulated, the production of green hydrogen cannot be considered fully environmentally neutral.

Another aspect is that the conversion of existing assets is hardly considered when expanding new production capacity. Currently, the option of burning biomass in coal-fired power plants in the short term has been mainly examined [62–64]. Unfortunately, other options for conversions are not analyzed, such as the use of foundations or walls of existing power plants to build biomass boilers or the use of condensing economizers where they do not exist. There is also virtually no mention of the possibility that biomass plants could replace coal and gas plants; they are currently used only for balancing. This paper highlights the cross-cutting effects of using biomass to enable the immediate decarbonization of electricity and heat systems.

Suggestions and policy implications:

- ➢ Biomass production standards being set;
- ➢ Intermediate steps in energy transformation being planned;
- ➢ Promotion of biomass use in regional centers (CHP) and the rest of the country (heat generation);
- ➢ Development of biogas to promote better use of waste.

5. Conclusions

Decarbonization of the energy sector will require significant financial investment and infrastructure changes. These processes will take place for decades to come; however, faster interim solutions are necessary to stop climate change. One of the intermediate solutions for electricity production and network balancing can be the use of biomass cogeneration. This would make it possible to use renewable local biofuel resources and old coal power plants and prepare for a new era of hydrogen use.

The biomass cogeneration sector is characterized by distinctive market structure factors involving a wide range of stakeholders. Due to the abundance of products made from biomass, suitable conditions are created to adapt to market changes and ensure the decarbonization of the energy sector. This is undertaken with the help of local renewable resources, human competencies, and technological potential. Energy production using biomass can be decentralized since cogeneration plants would be built near a source of high heat consumption. This would increase the security of the energy system in case of both physical and cyber attacks.

The need to deploy renewable energy became apparent in 2022 when fossil fuel prices were historically high. This highlighted the main problems, especially in Europe—dependence on fossil fuel prices, insufficient level of investment in renewable energy technologies, and slow decision-making. The production of green electricity ensures decentralization of the energy system, resistance to supply, and price shocks while strengthening the country's economy.

The design of the experiment method was used for the research, which allowed us to model the interaction of electricity, heat production, and electricity price. The results of this study showed that the optimal combination of cogeneration is associated with economies of scale—the larger the volume of heat production, the more electricity can be produced. This makes it possible to reduce the price of electricity and make it competitive. At the same time, there is an opportunity to receive income from balancing the energy system. The obtained optimal electricity price (EUR 0.77773) fully corresponds to the prevailing electricity prices in the stock exchanges, thus confirming the benefits of biomass cogeneration in the short term. A balanced biomass business model would avoid situations where investments are made in promising production technologies; however, their profitability is questionable in the short term. Changes in the price of electricity may be possible due to market conditions; however, the stability of fuel prices will ensure stable electricity prices. Countries with local renewable fuels have an opportunity not only to decarbonize electricity production but also to increase energy self-sufficiency. This will provide countries with geopolitical stability in a dynamic global environment. For countries on the path to decarbonization, it is necessary to rely on cogeneration solutions as this will allow solving the short-term problems associated with the movement of labor from the fossil fuel sector to renewable energy. When using biomass, it is necessary to rely on the established factors of the market structure as this will allow the development of local fuel preparation and energy production.

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References

1. Zou, C.; Xiong, B.; Xue, H.; Zheng, D.; Ge, Z.; Wang, Y.; Jiang, L.; Pan, S.; Wu, S. The role of new energy in carbon neutral. *Pet. Explor. Dev.* **2021**, *48*, 480–491. [CrossRef]
2. Lund, H.; Mathiesen, B.V. Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050. *Energy* **2009**, *34*, 524–531. [CrossRef]
3. Farhangi, H. The path of the smart grid. *IEEE Power Energy Mag.* **2010**, *8*, 18–28. [CrossRef]
4. Jing, H.; Zhu, P.; Zheng, X.; Zhang, Z.; Wang, D.; Li, Y. Theory-oriented screening and discovery of advanced energy transformation materials in electrocatalysis. *Adv. Powder Mater.* **2022**, *1*, 100013. [CrossRef]
5. Chu, S.; Majumdar, A. Opportunities and challenges for a sustainable energy future. *Nature* **2012**, *488*, 294–303. [CrossRef] [PubMed]
6. Harrison, K.W.; Remick, R.; Martin, G.D. *Hydrogen Production: Fundamentals and Case Study Summaries*; National Renewable Energy Laboratory (NREL): Essen, Germany, 2010.
7. Yasmeen, R.; Zhang, X.; Tao, R.; Shah, W.U.H. The impact of green technology, environmental tax and natural resources on energy efficiency and productivity: Perspective of OECD Rule of Law. *Energy Rep.* **2023**, *9*, 1308–1319. [CrossRef]
8. Igliński, B.; Kiełkowska, U.; Pietrzak, M.B.; Skrzatek, M.; Kumar, G.; Piechota, G. The regional energy transformation in the context of renewable energy sources potential. *Renew. Energy* **2023**, *218*, 119246. [CrossRef]
9. Güler, İ.; Atan, M.; Adalı, Z. The Effect of Economic Growth, Investment and Unemployment on Renewable Energy Transition: Evidence from OECD Countries. *Environ. Sci. Pollut. Res.* **2024**, 1–24. [CrossRef]
10. Bali Swain, R.; Karimu, A.; Gråd, E. Sustainable development, renewable energy transformation and employment impact in the EU. *Int. J. Sustain. Dev. World Ecol.* **2022**, *29*, 695–708. [CrossRef]
11. Xu, Y.; Liu, A.; Li, Z.; Li, J.; Xiong, J.; Fan, P. Review of Green Supply-Chain Management Diffusion in the Context of Energy Transformation. *Energies* **2023**, *16*, 686. [CrossRef]
12. Chomać-Pierzecka, E.; Sobczak, A.; Urbańczyk, E. RES market development and public awareness of the economic and environmental dimension of the energy transformation in Poland and Lithuania. *Energies* **2022**, *15*, 5461. [CrossRef]
13. Sánchez García, J.; Galdeano Gómez, E. What drives the preferences for cleaner energy? Parametrizing the elasticities of environmental quality demand for greenhouse gases. *Oeconomia Copernic.* **2023**, *14*, 449–482. [CrossRef]
14. Chudy-Laskowska, K.; Pisula, T. An Analysis of the Use of Energy from Conventional Fossil Fuels and Green Renewable Energy in the Context of the European Union's Planned Energy Transformation. *Energies* **2022**, *15*, 7369. [CrossRef]
15. Mohamed, M.; El-Saber, N. Toward Energy Transformation: Intelligent Decision-Making Model Based on Uncertainty Neutrosophic Theory. *Neutrosophic Syst. Appl.* **2023**, *9*, 13–23. [CrossRef]
16. Pietrzak, M.B.; Olczyk, M.; Kuc-Czarnecka, M.E. Assessment of the Feasibility of Energy Transformation Processes in European Union Member States. *Energies* **2022**, *15*, 661. [CrossRef]
17. Kiciński, J. Green energy transformation in Poland. *Bull. Pol. Acad. Sci. Tech. Sci.* **2021**, *69*, e136213. [CrossRef]
18. He, L.; Wang, B.; Xu, W.; Cui, Q.; Chen, H. Could China's long-term low-carbon energy transformation achieve the double dividend effect for the economy and environment? *Environ. Sci. Pollut. Res.* **2022**, *29*, 20128–20144. [CrossRef] [PubMed]
19. Hughes, T.P. *Networks of Power: Electrification in Western Society, 1880–1930*; JHU Press: Baltimore, MD, USA, 2011.
20. International Atomic Energy Agency. *Advances in Small Modular Reactor Technology Developments*; Advanced Reactors Information System (ARIS); IAEA: Vienna, Austria, 2022.
21. Fearnside, P.M. Impacts of Brazil's Madeira River Dams: Unlearned Lessons for Hydroelectric Development in Amazonia. *Environ. Sci. Policy* **2014**, *38*, 164–172. [CrossRef]
22. Jonek-Kowalska, I. Assessing the energy security of European countries in the resource and economic context. *Oeconomia Copernic.* **2022**, *13*, 301–334. [CrossRef]
23. U.S. Department of Energy. *Annual Energy Outlook*; U.S. Department of Energy: Washington, DC, USA, 2021.
24. Janssens-Maenhout, G.; Crippa, M.; Guizzardi, D.; Muntean, M.; Schaaf, E.; Dentener, F.; Bergamaschi, P.; Pagliari, V.; Olivier, J.G.; Peters, J.A.; et al. EDGAR v4. 3.2 Global Atlas of the three major Greenhouse Gas Emissions for the period 1970–2012. *Earth Syst. Sci. Data Discuss.* **2017**, *11*, 959–1002. [CrossRef]
25. Chovancová, J.; Tej, J. Decoupling economic growth from greenhouse gas emissions: The case of the energy sector in V4 countries. *Equilib. Q. J. Econ. Econ. Policy* **2020**, *15*, 235–251. [CrossRef]
26. Pavlov, G.K.; Olesen, B.W. Thermal energy storage—A review of concepts and systems for heating and cooling applications in buildings: Part 1—Seasonal storage in the ground. *HVAC R Res.* **2012**, *18*, 515–538. [CrossRef]
27. Dincer, I.; Rosen, M.A. *Thermal Energy Storage: Systems and Applications*; Wiley: Hoboken, NJ, USA, 2015.
28. Speece, R.E. *Anaerobic Biotechnology for Industrial Wastewaters*; Archae Press: Nashville, TN, USA, 1996.
29. Demirel, B.; Scherer, P. The roles of acetotrophic and hydrogenotrophic methanogens during anaerobic conversion of biomass to methane: A review. *Rev. Environ. Sci.* **2008**, *7*, 173–190. [CrossRef]
30. European Biogas Association (EBA). EBA's Vision for Renewable Gas in the Green Transition. Available online: https://www.europeanbiogas.eu/wp-content/uploads/2018/09/EBA-Vision-for-Renewable-Gas.pdf (accessed on 15 January 2024).
31. National Renewable Energy Laboratory (NREL). Hydrogen Production: Natural Gas Reforming. Available online: https://www.nrel.gov/hydrogen/proj_production_nat_gas_reforming.html (accessed on 15 January 2024).

32. U.S. Department of Energy (DOE). Hydrogen Basics. Available online: https://www.energy.gov/eere/fuelcells/hydrogen-basics (accessed on 15 January 2024).
33. Rashidi, N.A.; Chai, Y.H.; Yusup, S. Biomass energy in Malaysia: Current scenario, policies, and implementation challenges. *Bioenergy Res.* **2022**, *15*, 1371–1386. [CrossRef] [PubMed]
34. Cengel, Y.A.; Boles, M.A. *Thermodynamics: An Engineering Approach*; McGraw-Hill Education: New York, NY, USA, 2014.
35. Gimelli, A.; Luongo, A. Thermodynamic and experimental analysis of a biomass steam power plant: Critical issues and their possible solutions with CCGT systems. *Energy Procedia* **2014**, *45*, 227–236. [CrossRef]
36. Santos, V.O.; Queiroz, L.S.; Araujo, R.O.; Ribeiro, F.C.; Guimarães, M.N.; da Costa, C.E.; Chaar, J.S.; de Souza, L.K. Pyrolysis of acai seed biomass: Kinetics and thermodynamic parameters using thermogravimetric analysis. *Bioresour. Technol. Rep.* **2020**, *12*, 100553. [CrossRef]
37. Yang, W.; Pudasainee, D.; Gupta, R.; Li, W.; Wang, B.; Sun, L. An overview of inorganic particulate matter emission from coal/biomass/MSW combustion: Sampling and measurement, formation, distribution, inorganic composition and influencing factors. *Fuel Process. Technol.* **2021**, *213*, 106657. [CrossRef]
38. Hiloidhari, M.; Sharno, M.A.; Baruah, D.C.; Bezbaruah, A.N. Green and sustainable biomass supply chain for environmental, social and economic benefits. *Biomass Bioenergy* **2023**, *175*, 106893. [CrossRef]
39. Heywood, J.B. *Internal Combustion Engine Fundamentals*; McGraw-Hill Education: New York, NY, USA, 2014.
40. Xu, Q.; Wu, J.; Guo, Z.; Xue, X.; Li, X. Analysis of optimal intermediate temperature and injection pressure for refrigerant injection heat pump systems with economiser. *Appl. Therm. Eng.* **2022**, *210*, 118361. [CrossRef]
41. Åström, K.J.; Murray, R.M. *Feedback Systems: An Introduction for Scientists and Engineers*; Princeton University Press: Princeton, NJ, USA, 2010.
42. Karki, S.; Kulkarni, M.; Mann, M.D.; Salehfar, H. Efficiency improvements through combined heat and power for on-site distributed generation technologies. *Cogener. Distrib. Gener. J.* **2007**, *22*, 19–34. [CrossRef]
43. Bauen, A. *The Economic Potential of CHP in the European Union*; International Energy Agency (IEA): Paris, France, 2010.
44. Valente, A.; Iribarren, D.; Dufour, J. Life cycle assessment of hydrogen energy systems: A review of methodological choices. *Int. J. Life Cycle Assess.* **2017**, *22*, 346–363. [CrossRef]
45. Toklu, E. Biomass energy potential and utilization in Turkey. *Renew. Energy* **2017**, *107*, 235–244. [CrossRef]
46. Popp, J.; Kovács, S.; Oláh, J.; Divéki, Z.; Balázs, E. Bioeconomy: Biomass and biomass-based energy supply and demand. *New Biotechnol.* **2021**, *60*, 76–84. [CrossRef] [PubMed]
47. Favero, A.; Daigneault, A.; Sohngen, B.; Baker, J. A system-wide assessment of forest biomass production, markets, and carbon. *GCB Bioenergy* **2023**, *15*, 154–165. [CrossRef]
48. Zetterholm, J.; Bryngemark, E.; Ahlström, J.; Söderholm, P.; Harvey, S.; Wetterlund, E. Economic evaluation of large-scale biorefinery deployment: A framework integrating dynamic biomass market and techno-economic models. *Sustainability* **2020**, *12*, 7126. [CrossRef]
49. Gribbons, B.; Herman, J. True and quasi-experimental designs. *Pract. Assess. Res. Eval.* **2019**, *5*, 14.
50. Anderson, V.L.; McLean, R.A. *Design of Experiments: A Realistic Approach*; CRC Press: Boca Raton, FL, USA, 2018.
51. Wen, C.; Zhang, Y.; Wang, C.; Xue, D.; Bai, Y.; Antonov, S.; Dai, L.; Lookman, T.; Su, Y. Machine learning assisted design of high entropy alloys with desired property. *Acta Mater.* **2019**, *170*, 109–117. [CrossRef]
52. Karimifard, S.; Moghaddam, M.R.A. Application of response surface methodology in physicochemical removal of dyes from wastewater: A critical review. *Sci. Total Environ.* **2018**, *640*, 772–797. [CrossRef]
53. Behera, S.K.; Meena, H.; Chakraborty, S.; Meikap, B.C. Application of response surface methodology (RSM) for optimization of leaching parameters for ash reduction from low-grade coal. *Int. J. Min. Sci. Technol.* **2018**, *28*, 621–629. [CrossRef]
54. Chelladurai, S.J.S.; Murugan, K.; Ray, A.P.; Upadhyaya, M.; Narasimharaj, V.; Gnanasekaran, S. Optimization of process parameters using response surface methodology: A review. *Mater. Today Proc.* **2021**, *37*, 1301–1304. [CrossRef]
55. Tataraki, K.; Giannini, E.; Kavvadias, K.; Maroulis, Z. Cogeneration economics for greenhouses in Europe. *Energies* **2020**, *13*, 3373. [CrossRef]
56. Ozturk, M.; Dincer, I. Life cycle assessment of hydrogen-based electricity generation in place of conventional fuels for residential buildings. *Int. J. Hydrogen Energy* **2020**, *45*, 26536–26544. [CrossRef]
57. Lux, B.; Pfluger, B. A supply curve of electricity-based hydrogen in a decarbonized European energy system in 2050. *Appl. Energy* **2020**, *269*, 115011. [CrossRef]
58. Mayyas, A.; Wei, M.; Levis, G. Hydrogen as a long-term, large-scale energy storage solution when coupled with renewable energy sources or grids with dynamic electricity pricing schemes. *Int. J. Hydrogen Energy* **2020**, *45*, 16311–16325. [CrossRef]
59. Swennenhuis, F.; de Gooyert, V.; de Coninck, H. Towards a CO_2-neutral steel industry: Justice aspects of CO_2 capture and storage, biomass-and green hydrogen-based emission reductions. *Energy Res. Soc. Sci.* **2022**, *88*, 102598. [CrossRef]
60. Rehfeldt, M.; Worrell, E.; Eichhammer, W.; Fleiter, T. A review of the emission reduction potential of fuel switch towards biomass and electricity in European basic materials industry until 2030. *Renew. Sustain. Energy Rev.* **2020**, *120*, 109672. [CrossRef]
61. Häußermann, J.J.; Maier, M.J.; Kirsch, T.C.; Kaiser, S.; Schraudner, M. Social acceptance of green hydrogen in Germany: Building trust through responsible innovation. *Energy Sustain. Soc.* **2023**, *13*, 22. [CrossRef]
62. Mann, M.; Spath, P. A life cycle assessment of biomass cofiring in a coal-fired power plant. *Clean. Prod. Process.* **2001**, *3*, 81–91. [CrossRef]

63. Sahu, S.G.; Chakraborty, N.; Sarkar, P. Coal–biomass co-combustion: An overview. *Renew. Sustain. Energy Rev.* **2014**, *39*, 575–586. [CrossRef]
64. Yan, Y.; Yang, C.; Peng, L.; Li, R.; Bai, H. Emission characteristics of volatile organic compounds from coal-, coal gangue-, and biomass-fired power plants in China. *Atmos. Environ.* **2016**, *143*, 261–269. [CrossRef]